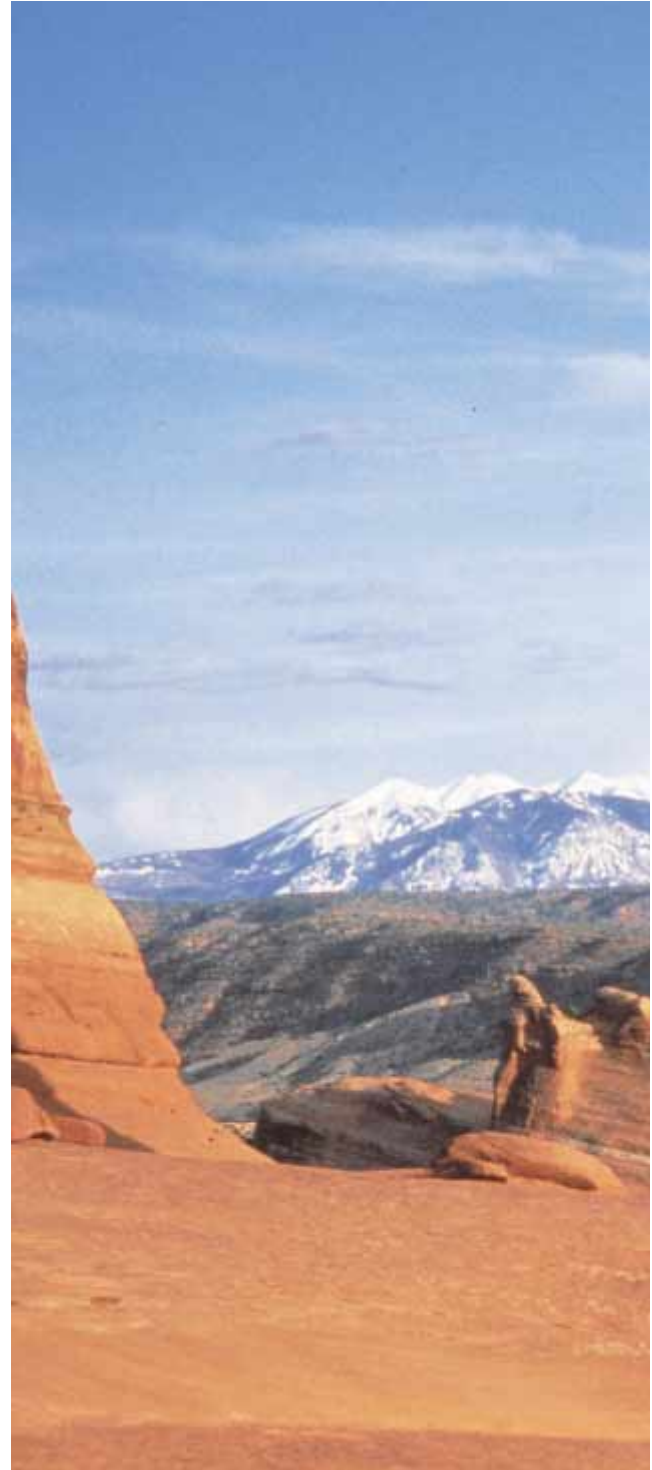


Weathering and Soil

Early in Earth history, between 4.5 and 3.5 billion years ago, swarms of meteorites crashed into all of the planets and their moons. Today, the craters created by these impacts are abundant on the Moon but are completely gone from the Earth's surface. Why has the Moon retained its craters, and why have the craters vanished from the Earth?

Tectonic activity such as mountain building and volcanic eruptions has continually renewed the Earth's surface over geologic time. In addition, Earth has an atmosphere and water, which decompose and erode bedrock. The combination of tectonic activity, weathering, and erosion has eliminated all traces of early meteorite impacts from the Earth's surface. In contrast, the smaller Moon has lost most of its heat, so tectonic activity is nonexistent. In addition, the Moon has no atmosphere or water to weather and erode its surface. As a result, the lunar surface is covered with meteorite craters, many of which are billions of years old.



Delicate Arch, in Utah, formed as sandstone weathered and eroded.





Figure 6-1 This boulder weathered in place.

► 6.1 WEATHERING

Weathering is the decomposition and disintegration of rocks and minerals at the Earth's surface. Weathering itself involves little or no movement of the decomposed rocks and minerals. This material accumulates where it forms and overlies unweathered bedrock (Fig. 6-1).

Erosion is the removal of weathered rocks and minerals by moving water, wind, glaciers, and gravity. After a rock fragment has been eroded from its place of origin, it may be transported large distances by those same agents: flowing water, wind, ice, and gravity. When the

wind or water slows down and loses energy or, in the case of glaciers, when the ice melts, transport stops and sediment is deposited. These four processes—weathering, erosion, transportation, and deposition—work together to modify the Earth's surface (Fig. 6-2).

MECHANICAL AND CHEMICAL WEATHERING

The environment at the Earth's surface is corrosive to most materials. An iron tool left outside will rust. Even stone is vulnerable to corrosion. As a result, ancient stone cities have fallen to ruin. Over longer periods of time, rock outcrops and entire mountain ranges wear away. Weathering occurs by both mechanical and chemical processes. **Mechanical weathering** reduces solid rock to rubble but does not alter the chemical composition of rocks and minerals. In contrast, **chemical weathering** occurs when air and water chemically react with rock to alter its composition and mineral content. These chemical changes are analogous to rusting in that the final products differ both physically and chemically from the starting material.

► 6.2 MECHANICAL WEATHERING

Mechanical weathering breaks large rocks into smaller ones but does not alter the rock's chemical nature or its minerals. Think of grinding a rock in a crusher; the fragments are no different from the parent rock, except that they are smaller.

Five major processes cause mechanical weathering: pressure-release fracturing, frost wedging, abrasion, organic activity, and thermal expansion and contraction. Two additional processes—salt cracking and hydrolysis expansion—result from combinations of mechanical and chemical processes.

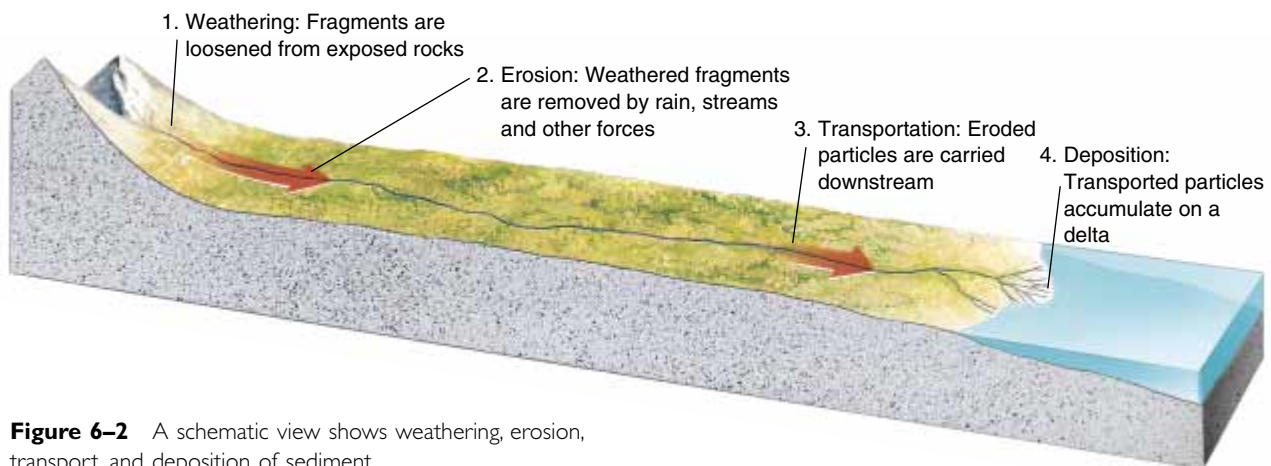


Figure 6-2 A schematic view shows weathering, erosion, transport, and deposition of sediment.

PRESSURE-RELEASE FRACTURING

Many igneous and metamorphic rocks form deep below the Earth's surface. Imagine, for example, that a granitic pluton solidifies from magma at a depth of 15 kilometers. At that depth, the pressure from the weight of overlying rock is about 5000 times that at the Earth's surface. Over millennia, tectonic forces may raise the pluton to form a mountain range. The overlying rock erodes away as the pluton rises and the pressure on the buried rock decreases. As the pressure diminishes, the rock expands, but because the rock is now cool and brittle, it fractures as it expands. This process is called **pressure-release fracturing**. Many igneous and metamorphic rocks that formed at depth, but now lie at the Earth's surface, have been fractured in this manner (Fig. 6–3).

FROST WEDGING

Water expands when it freezes. If water accumulates in a crack and then freezes, its expansion pushes the rock apart in a process called **frost wedging**. In a temperate climate, water may freeze at night and thaw during the day. Ice cements the rock together temporarily, but when it melts, the rock fragments may tumble from a steep cliff. If you hike or climb in mountains when the daily freeze–thaw cycle occurs, be careful; rockfall due to frost wedging is common. Experienced climbers travel in the early morning when the water is still frozen and ice holds the rock together.

Large piles of loose angular rocks, called **talus slopes**, lie beneath many cliffs (Fig. 6–4). These rocks fell from the cliffs mainly as a result of frost wedging.

ABRASION

Many rocks along a stream or beach are rounded and smooth. They have been shaped by collisions with other rocks as they tumbled downstream and with silt and sand carried by moving water. As particles collide, their sharp edges and corners wear away. The mechanical wearing and grinding of rock surfaces by friction and impact is called **abrasion** (Fig. 6–5). Note that pure water itself is not abrasive; the collisions among rock, sand, and silt cause the weathering.

Wind also hurls sand and other small particles against rocks, often sandblasting unusual and beautiful landforms (Fig. 6–6). Glaciers (discussed in Chapter 17) also cause much abrasion as they drag particles ranging in size from clay to boulders across bedrock. In this case, both the rock fragments embedded in the ice and the bedrock beneath are abraded.

ORGANIC ACTIVITY

If soil collects in a crack in solid rock, a seed may fall there and sprout. The roots work their way down into the crack, expand, and may eventually push the rock apart (Fig. 6–7). City dwellers often see the results of organic activity in sidewalks, where tree roots push from underneath, raising the concrete and frequently cracking it.

THERMAL EXPANSION AND CONTRACTION

Rocks at the Earth's surface are exposed to daily and yearly cycles of heating and cooling. They expand when they are heated and contract when they cool. When tem-



Figure 6–3 Pressure-release fracturing contributed to the formation of these cracks in a granite cliff in Tuolumne Meadows, California.

perature changes rapidly, the surface of a rock heats or cools faster than its interior and, as a result, the surface expands or contracts faster than the interior. The resulting forces may fracture the rock.

In mountains or deserts at mid-latitudes, temperature may fluctuate from -5°C to $+25^{\circ}\text{C}$ during a spring day. Is this 30° difference sufficient to fracture rocks?

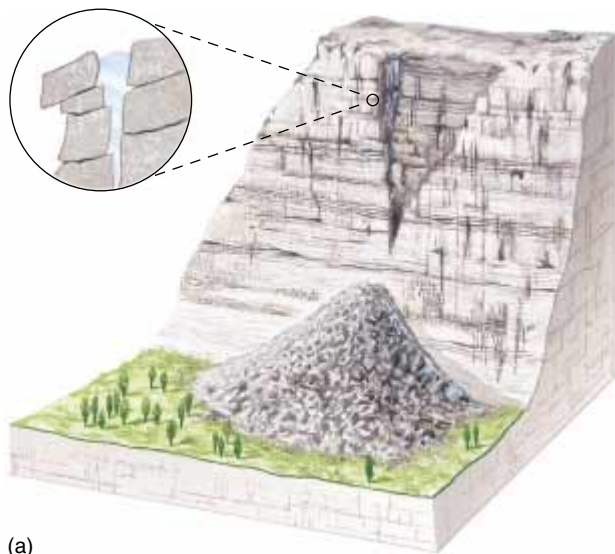


Figure 6-4 (a) Frost wedging dislodges rocks from cliffs and creates talus slopes. (b) Frost wedging has produced this talus cone in Valley of the Ten Peaks, Canadian Rockies.



Figure 6-5 Abrasion rounded these rocks in a streambed in Yellowstone National Park, Wyoming.

The answer is uncertain. In one laboratory experiment, scientists heated and cooled granite repeatedly by more than 100°C and they did not observe any fracturing. These results imply that normal temperature changes might not be an important cause of mechanical weathering. However, the rocks used in the experiment were small and the experiment was carried out over a brief period of time. Perhaps thermal expansion and contraction are more significant in large outcrops. Or perhaps daily heating-cooling cycles repeated over hundreds of thousands of years may promote fracturing.

In contrast to a small atmospheric temperature fluctuation, fire heats rock by hundreds of degrees. If you line a campfire with granite stones, the rocks commonly break as you cook your dinner. In a similar manner,



Figure 6-6 Wind abrasion selectively eroded the base of this rock in Lago Poopo, Bolivia, because windblown sand moves mostly near the ground surface.



Figure 6-7 As this tree grew from a crack in bedrock, its roots forced the crack to widen.

forest fires or brush fires occur commonly in many ecosystems and are an important agent of mechanical weathering.

► 6.3 CHEMICAL WEATHERING

Rock is durable over a single human lifetime. Return to your childhood haunts and you will see that the rock outcrops in woodlands or parks have not changed. Over

longer expanses of geologic time, however, rocks decompose chemically at the Earth's surface.

The most important processes of chemical weathering are dissolution, hydrolysis, and oxidation. Water, carbon dioxide, acids and bases, and oxygen are common substances that cause these processes to decompose rocks.

DISSOLUTION

If you put a crystal of halite (rock salt) in water, it dissolves and the ions disperse to form a solution. Halite dissolves so rapidly and completely that this mineral is rare in moist environments.

A small proportion of water molecules spontaneously dissociate (break apart) to form an equal number of hydrogen ions (H^+) and hydroxyl ions (OH^-).¹ Many common chemicals dissociate in water to increase either the hydrogen or the hydroxyl ion concentration. For example, HCl (hydrochloric acid) dissociates to release H^+ and Cl^- ions. The H^+ ions increase the hydrogen ion concentration and the solution becomes acid. In a similar manner, $NaOH$ dissociates to increase the hydroxyl ion concentration and the solution becomes a base. Hydrogen and hydroxyl ions are chemically reactive and therefore acids and bases are much more corrosive than pure water.

To understand how acids and bases dissolve minerals, think of an atom on the surface of a crystal. It is held in place because it is attracted to the other atoms in the

¹Hydrogen ions react instantaneously and completely with water, H_2O , to form the hydronium ion, H_3O^+ , but for the sake of simplicity, we will consider the hydrogen ion, H^+ , as an independent entity.

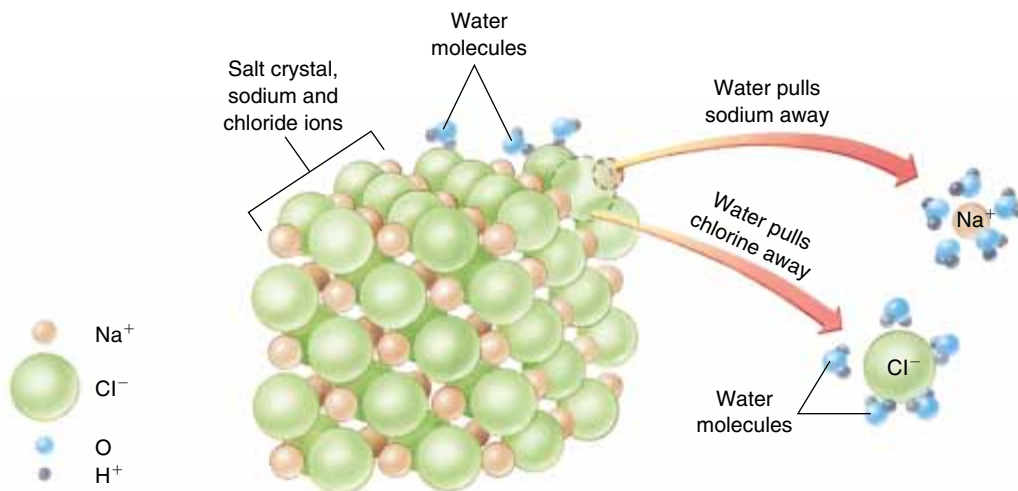
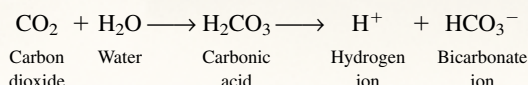


Figure 6-8 Halite dissolves in water because the attractions between the water molecules and the sodium and chloride ions are greater than the strength of the chemical bonds in the crystal.

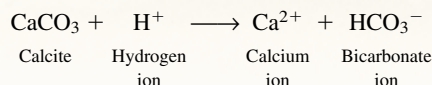
F O C U S O N

REPRESENTATIVE REACTIONS IN
CHEMICAL WEATHERING**Dissolution of Calcite**

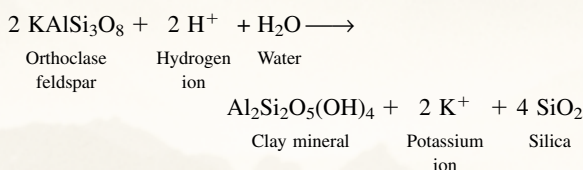
Calcite, the mineral that comprises limestone and marble, weathers in natural environments in a three-step process. In the first two steps, water reacts with carbon dioxide in the air to produce carbonic acid, which dissociates to release hydrogen ions:



In the third step, calcite dissolves in the carbonic acid solution.

**Hydrolysis**

An example of a reaction in which feldspar hydrolyzes to clay is as follows:



crystal by electrical forces. At the same time, electrical attractions to the outside environment pull the atom away from the crystal. The result is like a tug-of-war. If the bonds between the atom and the crystal are stronger than the attraction of the atom to its outside environment, then the crystal remains intact. If outside attractions are stronger, they pull the atom away from the crystal and the mineral dissolves (Fig. 6–8). Acids and bases are generally more effective at dissolving minerals than pure water because they provide more electrically charged hydrogen and hydroxyl ions to pull atoms out of crystals. For example, limestone is made of the mineral calcite (CaCO_3). Calcite barely dissolves in pure water but is quite soluble in acid. If you place a drop of strong acid on limestone, bubbles of carbon dioxide gas rise from the surface as the calcite dissolves.

Water found in nature is never pure. Atmospheric carbon dioxide dissolves in raindrops and reacts to form a weak acid called carbonic acid. As a result, even the purest rainwater, which falls in the Arctic or on remote mountains, is slightly acidic. As shown in the “Focus On” box “Representative Reactions in Chemical Weathering,” this acidic rainwater dissolves limestone. Industrial pollution can make rain even more acidic. Limestone outcrops commonly show signs of intense chemical weathering as a result of natural and polluted rain.

In addition, when water flows through the ground, it dissolves ions from soil and bedrock. In some instances, these ions render the water acidic; in other cases the water becomes basic. Flowing water carries the dissolved ions away from the site of weathering. Weathering by so-

lution produces spectacular caverns in limestone (Fig. 6–9). This topic is discussed further in Chapter 15.

Most solution reactions are reversible. A reversible reaction can proceed in either direction if conditions change. For example, calcite dissolves readily in acid to form a solution. If a base is added to the solution, solid calcite will precipitate again.

HYDROLYSIS

During dissolution, a mineral dissolves but does not otherwise react chemically with the solution. However, during **hydrolysis**, water reacts with a mineral to form a new mineral with the water incorporated into its crystal structure. Many common minerals weather by hydrolysis. For example, feldspar, the most abundant mineral in the Earth’s crust, weathers by hydrolysis to form clay. As feldspar converts to clay, flowing water carries off soluble cations such as potassium. The water combines with the less soluble ions to form clay minerals (see the “Focus On” box “Representative Reactions”).

Quartz is the only rock-forming silicate mineral that does not weather to form clay. Quartz resists weathering because it is pure silica, SiO_2 , and does not contain any of the more soluble cations. When granite weathers, the feldspar and other minerals react to form clay but the unaltered quartz grains fall free from the rock. Some granites have been so deeply weathered by hydrolysis that mineral grains can be pried out with a fingernail to depths of several meters (Fig. 6–10). The rock looks like granite but has the consistency of sand.



Figure 6-9 Stalactites and stalagmites in a limestone cavern. (Courtesy Scott Resources/Hubbard Scientific)

Because quartz is so tough and resistant to weathering, it is the primary component of sand. Much of it is transported to the sea coast, where it concentrates on beaches and eventually forms sandstone.

OXIDATION

Many elements react with atmospheric oxygen, O_2 . Iron rusts when it reacts with water and oxygen. Rusting is one example of a more general process called **oxidation**.² Oxidation reactions are so common in nature that pure metals are rare in the Earth's crust, and most metallic elements exist in nature as compounds. Only a few metals, such as gold, silver, copper, and platinum commonly occur in their pure states.

Recall from Chapter 3 that iron is abundant in many minerals, including olivine, pyroxene, and amphibole. If the iron in such a mineral oxidizes, the mineral decomposes. Many metallic elements, such as iron, copper, lead, and zinc, occur as sulfide minerals in ore deposits. When metallic sulfides oxidize, the sulfur reacts to form sulfuric acid, a strong acid. For example, pyrite (FeS_2) oxidizes to form sulfuric acid and iron oxide. The sulfuric acid washes into streams and ground water, where it may harm aquatic organisms. Thus, many natural ore deposits generate sulfuric acid when they weather. The

²Oxidation is properly defined as the loss of electrons from a compound or element during a chemical reaction. In the weathering of common minerals, this usually occurs when the mineral reacts with molecular oxygen.

same reaction may be accelerated when ore is dug up and exposed at a mine site. This problem is discussed further in Chapter 19.

▶ 6.4 CHEMICAL AND MECHANICAL WEATHERING OPERATING TOGETHER

Chemical and mechanical weathering work together, often on the same rock at the same time. Chemical processes generally act only on the surface of a solid object, so the reaction speeds up if the surface area increases. Think of a burning log; the fire starts on the outside and works its way toward the interior. A split log burns faster because the surface area is greater. Mechanical processes crack rocks, thereby exposing more surface area for chemical agents to work on (Fig. 6-11).

After mechanical processes fracture a rock, water and air seep into the fractures and initiate chemical weathering. Figure 6-12a shows that chemical weathering attacks a rock face from only one direction but attacks an edge from two sides and a corner from three sides. As a result of the multidirectional attack, the corners and edges weather most rapidly; the faces, attacked from only one direction, weather more slowly. Over time, the corners and edges become rounded in a process called **spheroidal weathering** (Fig. 6-12b). It is common to see rounded boulders still lying where they formed by this process.

SALT CRACKING

In environments where ground water is salty, salt water seeps into cracks in bedrock. When the water evaporates,



Figure 6-10 Coarse grains of quartz and feldspar accumulate directly over weathered granite. The lens cap in the middle illustrates scale.

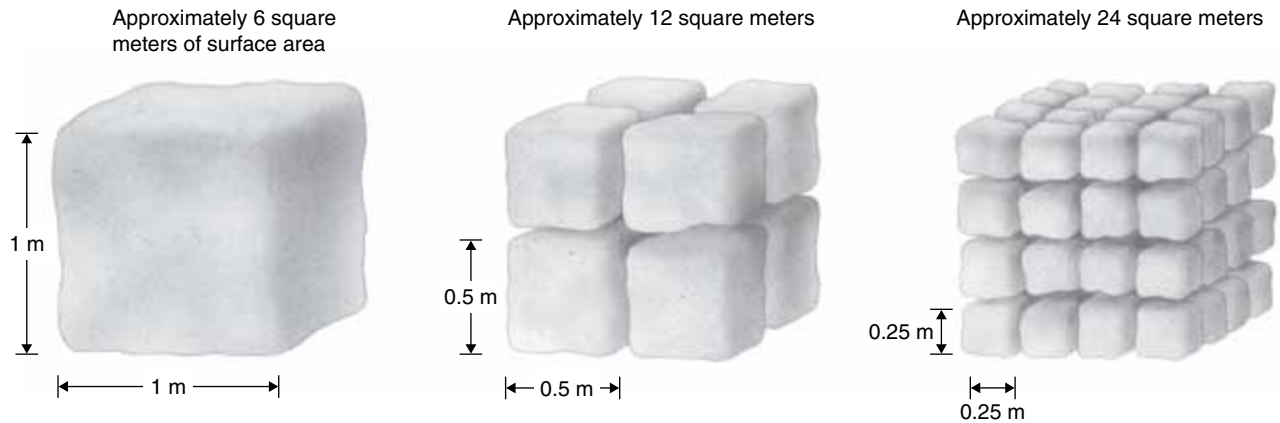


Figure 6-11 When rocks are broken apart by mechanical weathering, more surface is available for chemical weathering.

the dissolved salts crystallize. The growing crystals exert tremendous forces, enough to widen a crack and fracture a rock, a process called **salt cracking**. Thus, a mechanical process such as thermal expansion or pressure release may initially fracture bedrock. Then salt water migrates into the crack, and salt precipitates (a chemical process). Finally, the expanding salt crystals mechanically push the rock apart.

Many sea cliffs show pits and depressions caused by salt cracking because spray from the breaking waves brings the salt to the rock. Salt cracking is also common in deserts, where surface and underground water often contain dissolved salts (Fig. 6-13).

EXFOLIATION

Granite commonly fractures by **exfoliation**, a process in which large plates or shells split away like the layers of an onion (Fig. 6-14). The plates may be only 10 or 20 centimeters thick near the surface, but they thicken with depth. Because exfoliation fractures are usually absent below a depth of 50 to 100 meters, they seem to be a result of exposure of the granite at the Earth's surface.

Exfoliation is frequently explained as a form of pressure-release fracturing. However, many geologists suggest that hydrolysis may contribute to exfoliation. During hydrolysis, feldspars and other silicate minerals react to form clay. As a result of the addition of water, clays have

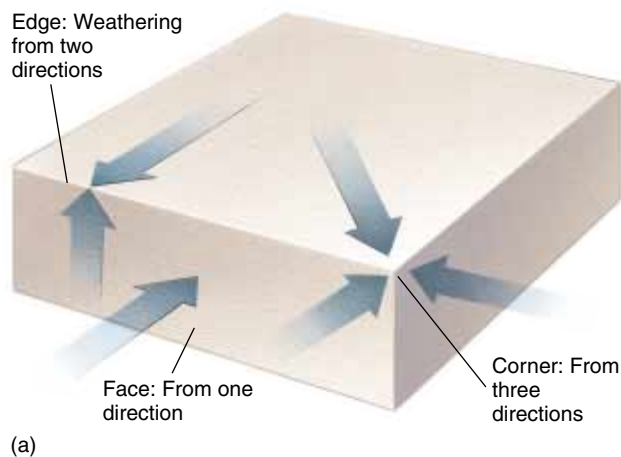


Figure 6-12 (a) More surface area is available for chemical attack on the corners and edges of a cube than on a face. Therefore, corners and edges are rounded during weathering. (b) Both mechanical and chemical processes have weathered this boulder; along old fractures.



(b)



Figure 6-13 Salt cracking formed this depression in sandstone in Cedar Mesa, Utah. The white patches are salt crystals.

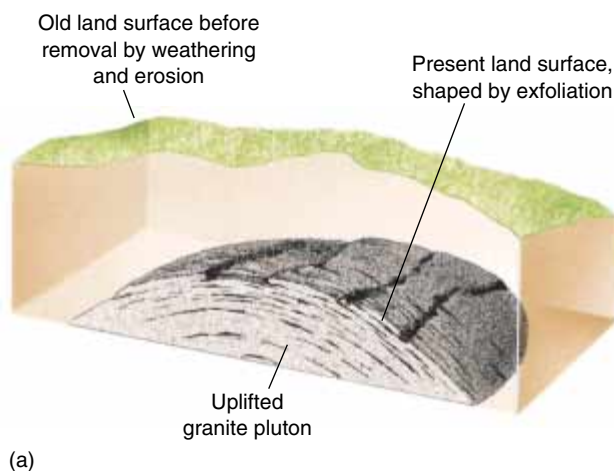
a greater volume than that of the original minerals. Thus, a chemical reaction (hydrolysis) forms clay, and the mechanical expansion of the clay contributes to the exfoliation fractures.

► 6.5 SOIL

Mechanical weathering produces both large rock fragments and small particles such as sand and silt. Chemical weathering forms clay and dissolved ions. Some of these weathering products accumulate on the Earth over bedrock. This material is called **regolith**. Soil scientists define **soil** as upper layers of regolith that support plant growth.

Soil commonly consists of sand, silt, clay, and organic material. Clay particles are so small and pack so tightly that water does not flow through them readily. In fact, even gases have trouble passing through clay-rich soils, so plants growing in clay soils suffer from lack of oxygen. In contrast, water and oxygen travel easily through loosely packed sandy soils. The most fertile soils contain a mixture of sand, clay, and silt as well as generous amounts of organic matter. Such a mixture is called **loam**.

If you walk through a forest or prairie, you can find bits of leaves, stems, and flowers on the soil surface. This material is called **litter** (Fig. 6-15). When litter decomposes sufficiently that you can no longer determine the origin of individual pieces, it becomes **humus**.



(a)

Figure 6-14 (a) Formation of an exfoliation dome. The exfoliation slabs are only a few centimeters to a few meters thick. (b) Exfoliation has fractured this granite in Pinkham Notch, New Hampshire.



(b)

Humus is an essential component of most fertile soils. If you pour a small amount of water into soil rich in humus, the soil absorbs most of the water. Humus retains so much moisture that humus-rich soil swells after a rain and shrinks during dry spells. This alternate shrinking and swelling loosens the soil, allowing roots to grow into it easily. A rich layer of humus also insulates the soil from excessive heat and cold and reduces water loss by evaporation. Humus also retains nutrients in soil and makes them available to plants.

In intensive agriculture, farmers commonly plow the soil and leave it exposed for weeks or months. Humus oxidizes in air and degrades. Running water frequently dissolves soil nutrients and carries them away. Farmers replace the lost nutrients with chemical fertilizers but frequently do not replenish humus. As a result, much of the natural ability of soil to conserve and regulate water and nutrients is lost. When rainwater flows over the surface, it carries soil particles, excess fertilizer, and pesticide residues, polluting streams and ground water.

SOIL PROFILES

A typical mature soil consists of several layers called **soil horizons**. The uppermost layer is called the **O horizon**, named for its **O**rganic component. This layer consists mostly of litter and humus with a small proportion of minerals (Fig. 6–16). The next layer down, called the **A horizon**, is a mixture of humus, sand, silt, and clay. The combined O and A horizons are called **topsoil**. A kilogram of average fertile topsoil contains about 30 percent by weight organic matter, including approximately 2 trillion bacteria, 400 million fungi, 50 million algae, 30 million protozoa, and thousands of larger organisms such as insects, worms, nematodes, and mites.



Figure 6–15 Litter is organic matter that has fallen to the ground and started to decompose but still retains its original form and shape.

The third layer, the **B horizon** or subsoil, is a transitional zone between topsoil and weathered parent rock below. Roots and other organic material occur in the B horizon, but the total amount of organic matter is low. The lowest layer, called the **C horizon**, consists of partially weathered rock that grades into unweathered parent rock. This zone contains little organic matter.

When rainwater falls on soil, it sinks into the O and A horizons, weathering minerals and carrying dissolved ions to lower levels. This downward movement of dissolved ions is called **leaching**. The A horizon is sandy because water also carries clay downward but leaves the sand behind. Because materials are removed from the A horizon, it is called the **zone of leaching**.

Dissolved ions and clay carried downward from the A horizon accumulate in the B horizon, which is called the **zone of accumulation**. This layer retains moisture because of its high clay content. Although moisture retention may be beneficial, if too much clay accumulates, the B horizon creates a dense, waterlogged soil.

► 6.6 SOIL-FORMING FACTORS

Why are some soils rich and others poor, some sandy and others loamy? Six factors control soil characteristics: parent rock, climate, rates of plant growth and decay, slope angle and aspect, time, and transport.

PARENT ROCK

The texture and composition of a soil depends partly on its parent rock. For example, when granite decomposes, the feldspar converts to clay and the rock releases quartz as sand grains. If the clay leaches into the B horizon, a sandy soil forms. In contrast, because basalt contains no quartz, soil formed from basalt is likely to be rich in clay and contain only small amounts of sand. Nutrient abundance also depends in part on the parent rock. For example, a pure quartz sandstone contains no nutrients, and soil formed on it must get its nutrients from outside sources.

CLIMATE

Temperature and rainfall affect soil formation. Rain seeps downward through soil, but several other factors pull the water back upward. Roots suck soil water toward the surface, and water near the surface evaporates. In addition, water is electrically attracted to soil particles. If the pore size between particles is small enough, **capillary action** draws water upward.

During a rainstorm, water seeps through the A horizon, dissolving soluble ions such as calcium, magnesium, potassium, and sodium. In arid and semiarid

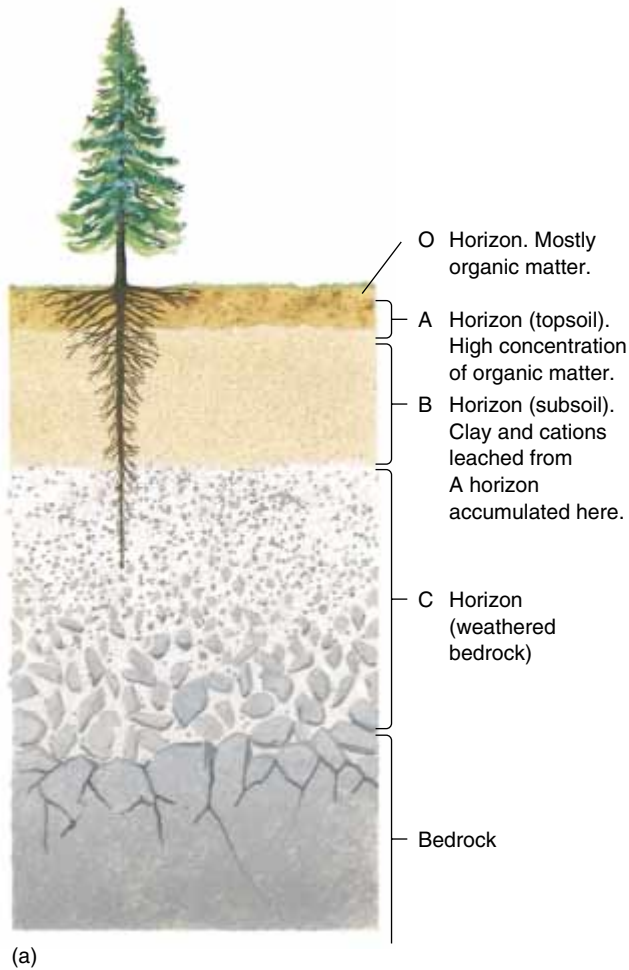


Figure 6-16 (a) Schematic soil profile showing typical soil horizons. (b) Soil horizons are often easily distinguished by color and texture. The dark upper layer is the A horizon; the whiter lower layer is the B horizon. (Soil Conservation Service)

regions, when the water reaches the B horizon, capillary action and plant roots then draw it back up toward the surface, where it evaporates or is incorporated into plant tissue. After the water escapes, many of its dissolved ions precipitate in the B horizon, encrusting the soil with salts. A soil of this type is a **pedocal** (Fig. 6-17a). This process often deposits enough calcium carbonate to form a hard cement called **caliche** in the soil. In the Imperial Valley in California, for example, irrigation water contains high concentrations of calcium carbonate. A thick continuous layer of caliche forms in the soil as the water evaporates. To continue growing crops, farmers must then rip this layer apart with heavy machinery.

Because nutrients concentrate when water evaporates, many pedocal are fertile if irrigation water is available. However, salts often concentrate so much that they become toxic to plants (Fig. 6-18). As mentioned previously, all streams contain small concentrations of dissolved salts. If arid or semiarid soils are intensively irrigated, salts can accumulate until plants cannot grow. This process is called **salinization**. Some historians argue that salinization destroyed croplands and thereby

contributed to the decline of many ancient civilizations, such as the Babylonian Empire.

In a wet climate, water seeping down through the soil leaches soluble ions from both the A and B horizons. The less soluble elements, such as aluminum, iron, and some silicon, remain behind, accumulating in the B horizon to form a soil type called a **pedalfer** (Fig. 6-17b). The subsoil in a pedalfer is commonly rich in clay, which is mostly aluminum and silicon, and has the reddish color of iron oxide.

In regions of very high rainfall, such as a tropical rainforest, so much water seeps through the soil that it leaches away nearly all the soluble cations. Only very insoluble aluminum and iron minerals remain (Fig. 6-17c). Soil of this type is called a **laterite**. Laterites are often colored rust-red by iron oxide (Fig. 6-19). A highly aluminous laterite, called **bauxite**, is the world's main type of aluminum ore.

The second important component of climate, average annual temperature, affects soil formation in two ways. First, chemical reactions proceed more rapidly in warm temperatures than in cooler conditions, so chemi-

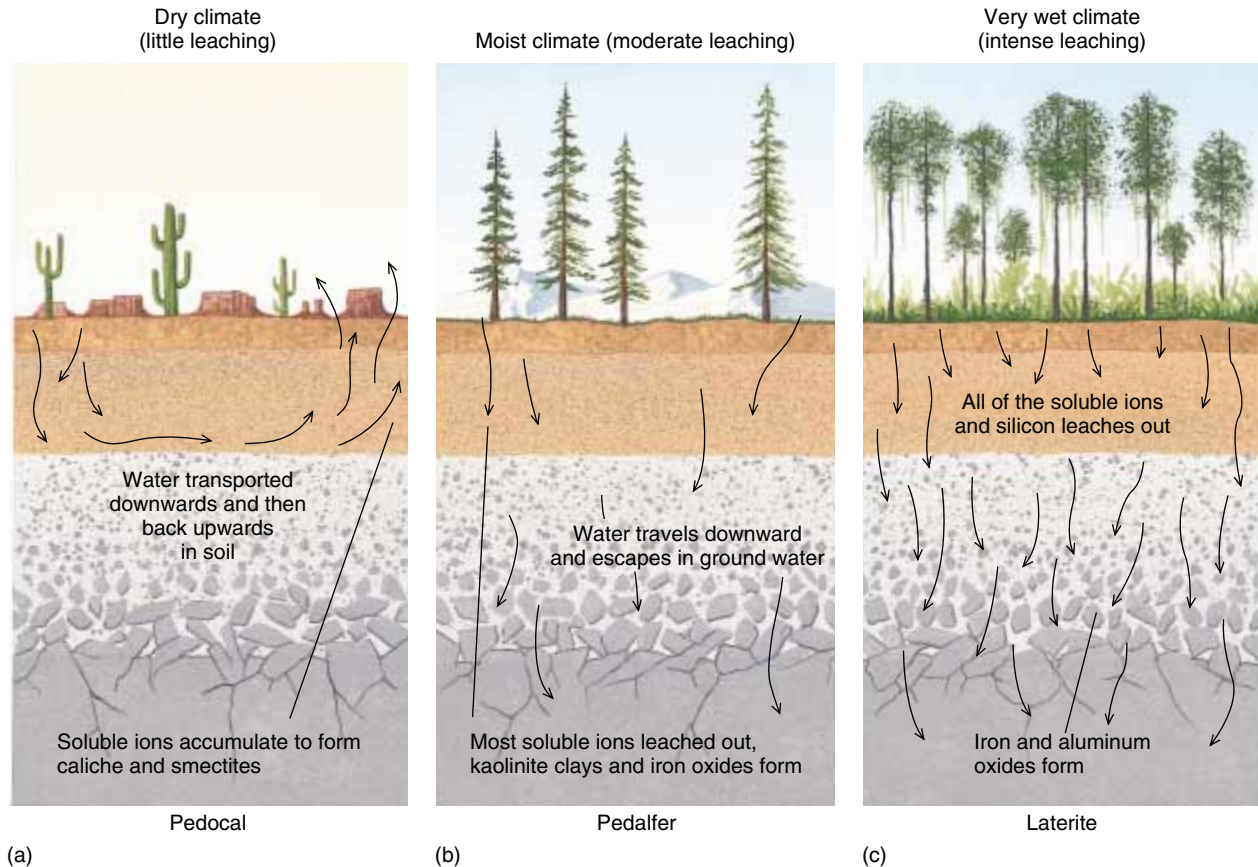


Figure 6-17 The formation of pedocals, pedalferes, and laterites.

cal weathering is faster in warmer climates than in cold ones. Second, plant growth and decay are temperature dependent as discussed below.

RATES OF GROWTH AND DECAY OF ORGANIC MATERIAL

In the tropics, plants grow and decay rapidly all year long. When leaves and stems decay, the nutrients are quickly absorbed by the growing plants. As a result, little humus accumulates and few nutrients are stored in the soil (Fig. 6-20a). The Arctic, on the other hand, is so cold that plant growth and decay are slow. Therefore, litter and humus form slowly and Arctic soils contain little organic matter (Fig. 6-20b).

The most fertile soils are those of prairies and forests in temperate latitudes. There, large amounts of plant litter drop to the ground in the autumn, but decay is slow during the cold winter months. During the spring and summer, litter decomposes and releases nutrients into the soil. However, in a temperate region, plant growth is not fast enough to remove all the nutrients during the grow-

ing season. As a result, thick layers of humus accumulate and soil contains abundant nutrients.

SLOPE ASPECT AND STEEPNESS

Aspect is the orientation of a slope with respect to the Sun. In the semiarid American West, thick soils and dense forests cover the cool, shady north slopes of hills, but thin soils and grass dominate hot, dry southern exposures. The reason for this difference is that in the Northern Hemisphere more water evaporates from the hot, sunny southern slopes. Therefore, fewer plants grow, weathering occurs slowly, and soil development is retarded. The moister northern slopes weather more deeply to form thicker soils.

In general, hillsides have thin soils and valleys are covered by thicker soil, because soil erodes from hills and accumulates in valleys. When hilly regions were first settled and farmed, people naturally planted their crops in the valley bottoms, where the soil was rich and water was abundant. Recently, as population has expanded, farmers have moved to the thinner, less stable hillside soils.



Figure 6-18 Saline seep on a ranch in Wyoming. Saline water seeps into this depression and then evaporates to deposit white salt crystals on the ground and on the fence posts.

TIME

Most chemical weathering occurs at the relatively low temperatures of the Earth's surface. Consequently, chemical weathering goes on slowly in most places, and time becomes an important factor in determining the extent of weathering.

Recall that feldspars weather to form clay, whereas quartz does not decompose easily. In geologically young soils, the decomposition of feldspars may be incomplete and the soils are likely to be sandy. As soils mature, more feldspars decompose, and the clay content increases.

SOIL TRANSPORT

By studying recent lava flows, scientists have determined how quickly plants return to an area after it has been covered by hard, solid rock. In many cases, plants appear when a lava flow is only a few years old, even before weathering has formed soil. Closer scrutiny shows that the plants have rooted in tiny amounts of soil that were transported from nearby areas by wind or water.



Figure 6-19 Iron oxide colors this Georgia laterite. (USGS)



(a)



(b)

Figure 6–20 (a) Tropical soil of Costa Rica supports lush growth, but organic material decays so rapidly that little humus accumulates. (b) Arctic soil of Baffin Island, Canada, supports sparse vegetation and contains little organic matter.

In many of the world's richest agricultural areas, most of the soil was transported from elsewhere. Streams may deposit sediment, wind deposits dust, and soil slides downslope from mountainsides into valleys. These for-

eign materials mix with residual soil, changing its composition and texture. River deltas and the rich windblown loess soils of China and the North American Great Plains are examples of transported soils.

SUMMARY

Weathering is the decomposition and disintegration of rocks and minerals at the Earth's surface. **Erosion** is the removal of weathered rock or soil by moving water, wind, glaciers, or gravity. After rock or soil has been eroded from the immediate environment, it may be transported large distances and eventually deposited.

Mechanical weathering can occur by **frost wedging**, **abrasion**, **organic activity**, **thermal expansion and contraction**, and **pressure-release fracturing**.

Chemical weathering occurs when chemical reactions decompose minerals. A few minerals dissolve readily in water. Acids and bases often markedly enhance the solubility of minerals. Rainwater is slightly acidic due to reactions between water and atmospheric carbon dioxide. A serious environmental problem is caused by **acid rain**. The **hydrolysis** of feldspar and other common minerals, except quartz, is a form of chemical weathering. **Oxidation** is the reaction with oxygen to decompose minerals.

Chemical and mechanical weathering often operate together. For example, solution seeping into cracks may cause rocks to expand by growth of salts or hydrolysis.

Hydrolysis combines with pressure-release fracturing to form **exfoliated** granite.

Soil is the layer of weathered material overlying bedrock. **Sand**, **silt**, **clay**, and **humus** are commonly found in soil. Water **leaches** soluble ions downward through the soil. Clays are also transported downward by water. The uppermost layer of soil, called the **O horizon**, consists mainly of litter and humus. The amount of organic matter decreases downward. The **A horizon** is the **zone of leaching**, and the **B horizon** is the **zone of accumulation**.

Six factors control soil characteristics: parent rock, climate, rates of growth and decay, slope aspect and steepness, time, and transport. In dry climates, **pedocals** form. In pedocals, leached ions precipitate in the B horizon, where they accumulate and may form **caliche**. In moist climates, **pedalfer** soils develop. In these regions, soluble ions are removed from the soil, leaving high concentrations of less soluble aluminum and iron. **Laterite** soils form in very moist climates, where all of the more soluble ions are removed.

KEY WORDS

weathering 94	hydrolysis 98	soil horizons 102	capillary action 102
erosion 94	oxidation 99	O horizon 102	pedocal 103
mechanical weathering 94	spheroidal weathering 99	A horizon 102	caliche 103
chemical weathering 94	salt cracking 100	topsoil 102	salinization 103
pressure-release fracturing 95	exfoliation 100	B horizon 102	pedalfer 103
frost wedging 95	regolith 101	C horizon 102	laterite 103
talus slope 95	soil 101	leaching 102	bauxite 103
abrasion 95	loam 101	zone of leaching 102	aspect 104
	litter 101	zone of accumulation 102	
	humus 101		

REVIEW QUESTIONS

1. Explain the differences among the terms weathering, erosion, transport, and deposition.
2. Explain the differences between mechanical weathering and chemical weathering.
3. List five processes that cause mechanical weathering.
4. Explain how thermal expansion can establish forces that could fracture a rock.
5. What is a talus slope? What conditions favor the formation of talus slopes?
6. What is oxidation? Give an example.
7. Explain why limestone dissolves very slowly in pure water. Why does it dissolve more rapidly in strong acids? Why does it dissolve in rainwater?
8. What is hydrolysis? What happens when granitic rocks undergo hydrolysis? What minerals react? What are the reaction products?
9. What is pressure-release fracturing? Why is pressure-release fracturing an example of chemical and mechanical processes operating together?
10. List the products of weathering in order of decreasing size.
11. What are the components of healthy soil? What is the function of each component?
12. Characterize the four major horizons of a mature soil.
13. List the six soil-forming factors and briefly discuss each one.
14. Imagine that soil forms on granite in two regions, one wet and the other dry. Will the soil in the two regions be the same or different? Explain.
15. Explain how soils formed from granite will change with time.
16. What are laterite soils? How are they formed? Why are they unsuitable for agriculture?

DISCUSSION QUESTIONS

1. What process is responsible for each of the following observations or phenomena? Is the process a mechanical or chemical change?
 - a. A board is sawn in half.
 - b. A board is burned.
 - c. A cave is formed when water seeps through a limestone formation.
 - d. Calcite is formed when mineral-rich water is released from a hot underground spring.
 - e. Meter-thick sheets of granite peel off a newly exposed pluton.
 - f. Rockfall is more common in mountains of the temperate region in the spring than in mid-summer.
2. Most substances contract when they freeze, but water expands. How would weathering be affected if water contracted instead of expanded when it froze?
3. Discuss the similarities and differences between salt cracking and frost wedging.
4. What types of weathering would predominate on the following fictitious planets? Defend your conclusions.
 - a. Planet X has a dense atmosphere composed of nitrogen, oxygen, and water vapor with no carbon dioxide. Temperatures range from a low of 10°C in the winter to 75°C in the summer. Windstorms are common. No living organisms have evolved.
 - b. The atmosphere of Planet Y consists mainly of nitrogen and oxygen with smaller concentrations of carbon dioxide and water vapor. Temperatures range from a low of -60°C in the polar regions in the winter to +35°C in the tropics. Windstorms are common. A lush blanket of vegetation covers most of the land surfaces.
5. The Arctic regions are cold most of the year, and summers are short there. Thus decomposition of organic matter is slow. In contrast, decay is much more rapid in the temperate regions. How does this difference affect the fertility of the soils?