## Role of Oxygen

Oxygen is abundant in the atmosphere and quite active chemically, so it often combines with minerals or with elements within minerals that are exposed at the earth's surface.

The rusting of an iron nail exposed to air is a simple example of chemical weathering. Oxygen from the atmosphere combines with the iron to form iron oxide, the reaction being expressed as follows:

$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$
$$\text{iron} + \text{oxygen} \rightarrow \text{iron oxide}$$

Iron oxide formed in this way is a weathering product of numerous minerals containing iron, such as the ferromagnesian group (pyroxenes, amphiboles, biotite, and olivine). The iron in the ferromagnesian silicate minerals must first be separated from the silica in the crystal structure before it can oxidize. The iron oxide ($Fe_2O_3$) formed is the mineral **hematite,** which has a brick-red color when powdered. If water is present, as it usually is at the earth's surface, the iron oxide combines with water to form **limonite,** which is the name for a group of mostly amorphous, hydrated iron oxides (often including the mineral *goethite*), which are yellowish-brown when powdered. The general formula for this group is $Fe_2O_3 \cdot nH_2O$ (the $n$ represents a small, whole number such as 1, 2, or 3 to show a variable amount of water). The brown, yellow, or red color of soil and many kinds of sedimentary rock is commonly the result of small amounts of hematite and limonite released by the weathering of iron-containing minerals (figure 12.14).

## Abrasion

Another process that can mechanically weather rock is **abrasion,** the grinding away of rock by friction and impact during transportation. As loose fragments of rock are picked up and moved by a stream, they tumble against one another and against the rocky stream bottom (figure 12.8). The fragments gradually grind themselves into smaller and smaller pieces and also grind away the rock of the stream bottom. Glaciers, waves, and even wind are other agents that carry and abrade rock fragments.

## Pressure Release

The reduction of pressure on a body of rock can cause it to crack as it expands; **pressure release** is a significant type of mechanical weathering. A large mass of rock, such as a batholith, may originally form under great pressure from the weight of several kilometers of rock above it. This batholith is gradually exposed by tectonic uplift of the region followed by erosion of the overlying rock (figure 12.9). The removal of the great weight of rock above the batholith, usually termed ***unloading,*** allows the granite to expand upward. Cracks called **sheet joints** develop parallel to the outer surface of the rock as the outer part of the rock expands more than the inner part (figures 12.9 and 12.10). On slopes, gravity may cause the rock between such joints to break loose in concentric slabs from the underlying granite mass. This process of spalling off of rock layers is called **exfoliation;** it is somewhat similar to peeling layers from an onion. **Exfoliation domes** (figure 12.11) are large, rounded landforms developed in massive rock, such as granite, by exfoliation. Some famous examples of exfoliation domes include Stone Mountain in Georgia and Half Dome in Yosemite.

Several other processes mechanically weather rock but in most environments are less effective than frost action, abrasion, and pressure release. *Plant growth,* particularly roots growing in cracks (figure 12.12*A*), can break up rocks, as can *burrowing animals.* Such activities help to speed up chemical weathering by enlarging passageways for water and air.

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## Frost Action

**Frost action**—the mechanical effect of freezing water on rocks—commonly occurs as frost wedging or frost heaving.

In **frost wedging** the expansion of freezing water pries rock apart. Most rock contains a system of cracks called *joints,* caused by the slow flexing of brittle rock by deep-seated earth forces (see chapter 6). Water that has trickled into a joint in a rock can freeze and expand by as much as 9 percent when the temperature drops below 0°C (32°F). The expanding ice wedges the rock apart, extending the joint or even breaking the rock into pieces (figures 12.6 and 12.7). Frost wedging is most effective in regions with many days of freezing and thawing (mountaintops and midlatitude regions with pronounced seasons). Partial thawing during the day adds new water to the ice in the crack; refreezing at night adds new ice to the old ice.

**Frost heaving** lifts rock and soil vertically. Solid rock conducts heat better than soil, so on a cold winter day the bottom of a partially buried rock will be much colder than soil at the same depth. As the ground freezes in winter, ice forms first under large rock fragments in the soil. The expanding ice layers push boulders out of the ground, a process well known to New England farmers and other residents of rocky soils. Frost heaving bulges the ground surface upward in winter, breaking up roads and leaving lawns spongy and misshapen after the spring thaw.

## Role of Acid

The most effective agent of chemical weathering is acid. Acids are chemical compounds that give off hydrogen ions ($H^+$) when they dissociate, or break down, in water. Strong acids produce a great number of hydrogen ions when they dissociate, and weak acids produce relatively few such ions.

The hydrogen ions given off by natural acids disrupt the orderly arrangement of atoms within most minerals. Because a hydrogen ion has a positive electrical charge and a very small size, it can substitute for other positive ions (such as $Ca^{++}$, $Na^+$, or $K^+$) within minerals. This substitution changes the chemical composition of the mineral and disrupts its atomic structure. The mineral decomposes, often into a different mineral, when it is exposed to acid.

Some strong acids occur naturally on the earth's surface, but they are relatively rare. Sulfuric acid and hydrofluoric acid are strong acids emitted during many volcanic eruptions. They can kill trees and cause intense chemical weathering of rocks near volcanic vents. The bubbling mud of Yellowstone National Park's mudpots (figure 12.15) is produced by rapid weathering caused by acidic sulfur gases that are given off by some hot springs. Strong acids also drain from some mines as sulfur-containing minerals such as pyrite oxidize and form acids at the surface (figure 12.16). Uncontrolled mine drainage can kill fish and plants downstream and accelerate rock weathering.