WEATHERING

Weathering Instructional Case: A series of student-centered science lessons

Teacher Background

Weathering is the physical breakdown and chemical alteration of rocks and minerals at or near the Earth's surface due to interactions with living organisms, water and the atmosphere. Weathering occurs in place and does not involve the movement or transport of sediment. *Erosion* differs from weathering in that it is the physical transport of sediment (the products of weathering) by mobile agents such as water, wind or ice. *Mass Wasting* (commonly called landslides) is the transfer of rock, soil and sediment downslope under the influence of gravity.

There are two major types of weathering processes:

1. *Physical (also known as Mechanical) Weathering* is the result of physical forces that break rock into smaller and smaller pieces without changing the rock's mineral composition (it is still composed of the same minerals).
2. *Chemical Weathering* involves a chemical transformation of rock into one or more new minerals or other compounds.

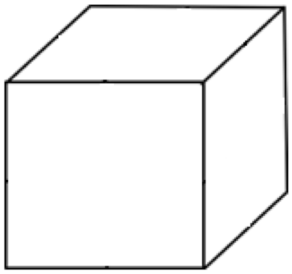
Weathering is a rock's response to a changing environment. For example, plutonic (intrusive) rocks form under conditions at high pressures and temperatures deep in the Earth's crust. These rocks may be uplifted to the surface where they are not as stable as the conditions under which they originally formed. In response to the environmental change, they gradually weather (transform to minerals that are chemically stable at the surface). Physical and chemical weathering work simultaneously and aid one another.

Physical/Mechanical Weathering

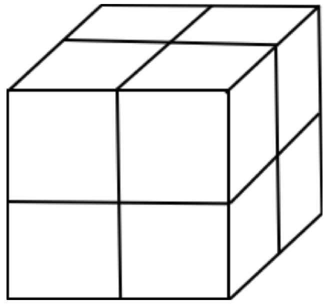
There are four common physical processes that lead to physical weathering:

1. Frost Wedging
2. Unloading (release of pressure)
3. Thermal Expansion
4. Biologic Activity

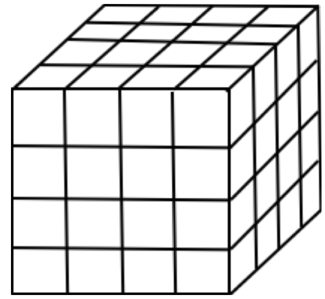
Physical weathering increases the surface area available for chemical weathering. Increased surface area usually results in more rapid chemical reactions (chemical weathering). The agents of erosion (water, wind & ice) may also contribute to physical weathering by "breaking rocks" during the movement of sediment. The figure shows that the surface area of a cube may increase dramatically as it is cut into smaller cubes.



1 cube x 6 sides x 1 m
= 6 m^2 surface area



8 cubes x 6 sides x .5 m
= 24 m^2 surface area



64 cubes x 6 sides x .25 m
= 96 m^2 surface area

1. *Frost Wedging* is caused by repeated cycles of freezing and thawing. Water has the unique property of expanding (~9% increase in volume) when it freezes (that's why ice floats in liquid water). In the geologic environment, water works its way into cracks in rock, and upon freezing, expands and enlarges these openings. After many freeze-thaw cycles, the rock is broken into angular fragments. *Frost wedging* is most prevalent in mountainous regions where a daily freeze-thaw cycle is common. It is also *frost wedging* that causes potholes in roads during the winter.

2. *Unloading* is where rocks that form deep in the Earth's crust (like granite) will begin to *expand* when they reach the Earth's surface (decompression). This can result in the generation of onion-like layers or sheets of rock that begin to separate.

The photo to the right shows Half-Dome in Yosemite National Park where the sheet-like structures are due to unloading at the Earth's surface.

Weathering due to unloading on Half-Dome
Scott Marshall, Appalachian State University

3. *Thermal Expansion* is caused by daily and seasonal changes in temperature. As the temperature changes, thermal expansion and contraction of individual minerals can exert destructive forces on the cohesion of a rock. This is especially true in desert environments where the change in temperature during the day may be as great as 30°C. This mechanism is probably the least effective of all the weathering processes.

4. *Biological Activity*
Physical weathering can be accomplished by the actions of organisms such as trees and burrowing animals. Plant roots grow into fractures, and as they grow larger, they wedge the rock apart. A common example of this can be seen where tree roots uplift and damage a sidewalk as roots under the sidewalk grow larger.

The primary agents of erosion (water, wind and ice) may also contribute to the physical weathering of rocks.

1. Water may transport rocks, knocking them together and breaking them into small pieces. Commonly, rocks found in streams are rounded by physical weathering while being transported by water.
2. Ice (glaciers) grinds rock as glaciers move across the surface of the Earth. Rock flour is produced by the grinding action of glaciers where the rock is pulverized into a fine dust.
3. Wind may blow particles such as sand that can abrade rocks (similar to sand blasting).

Chemical Weathering

The chemical weathering of rocks and minerals is due to a variety of chemical processes and reactions that result in the transformation of the original minerals into new minerals that are stable at surface conditions. Chemical weathering may also involve putting mineral components into solution such as dissolution in water.

Water is the most important agent in the three different processes of chemical weathering:

1. Dissolution
2. Oxidation
3. Hydrolysis

Generally, chemical reactions occur more rapidly at higher temperatures. Thus it is clear that chemical weathering of rocks and minerals is more intense in warmer environments (low latitudes) than in colder environments (high latitudes).

Dissolution is when minerals dissolve in water by disintegration of the mineral into separate ions. Water is an effective solvent (good at dissolving a wide variety of solids) because the molecule has a bent shape with different electrical charges at the ends of the molecule (polar). In a water molecule, the oxygen atom has a slight negative charge and the hydrogen atoms have slight positive charge.

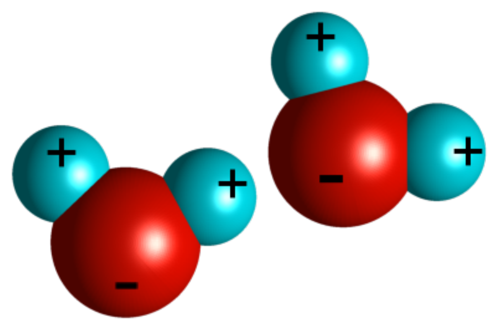


Diagram showing structure and charge distribution of water molecules.

This uneven charge distribution on the water molecule may disrupt the attractive forces holding a mineral together. The charged ends act as little wedges to take a mineral surface apart - dissolve it.

Although pure water acts as a solvent, the presence of even a small amount of acid in water dramatically increases the ability of water to dissolve different materials. Carbonic acid occurs in rainwater and surface waters where it contains dissolved atmospheric CO_2. Other naturally occurring acids include:

organic acid from the decay of organic matter
sulfuric acid from the weathering of sulfide minerals like pyrite.

The mineral calcite is particularly susceptible to dissolution by acid (remember the acid test for calcite).

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

In this process, calcite is dissolved. This reaction is important for the formation of caves in limestone.

2. *Oxidation* is a chemical process where some atoms lose electrons to another element (a chemical reaction that involves the transfer of electrons between different chemical components). Oxygen is the most common oxidation agent and is responsible for oxidation reactions that form rust from iron.

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

The oxidation of iron is greatly accelerated in the presence of water. Many igneous minerals contain iron (such as olivine, pyroxene and amphibole) and oxidize in the presence of water at surface conditions. The change is the oxidation state of iron in these minerals results in the disintegration of the original mineral. The oxidation of iron is responsible for many rocks having rusty or red colors.

3. *Hydrolysis* is a chemical reaction where chemical bonds may be broken by the addition of water. As an example, feldspars chemically alter (hydrolysis) to form clay minerals such as kaolinite. Although feldspar minerals contain no water in their crystal structure, clay minerals such as kaolinite contain water that is bonded to the crystal structure of the mineral. Typically, natural waters at the Earth's surface contain some dissolved ions that accelerate the chemical process of hydrolysis.

Clay minerals are a very common product of chemical weathering by hydrolysis. The clay minerals are very stable at the Earth's surface and represent the end products of the weathering of igneous silicate minerals (that are generally unstable at the Earth's surface).

Unlike other silicate minerals, quartz is particularly resistant to weathering. Quartz sand tends to accumulate in sediments (the products of weathering) such as on beaches and sand dunes since other minerals in the rock have weathered away.

Rates of Weathering

There are different factors that may influence the type and rate of weathering.

1. Rock characteristics. The chemical composition of rocks (as expressed by the minerals in the rock) and the presence of fractures (that permit the infiltration of water) may dramatically affect its susceptibility to chemical weathering.

2. Climate. Climate (temperature and the presence of water) may dramatically influence the weathering of rocks and minerals. For example, the physical weathering of rocks by frost wedging is dependent upon the presence of surface water. In addition, frost wedging and thermal expansion are dramatically affected by climate. Both of these processes are enhanced in climates with large daily changes in temperature. Lastly, chemical weathering chemical weathering is enhanced in warm, moist climates. Tropical environments represent regions with the most intense chemical weathering of rocks.

Connections to other Topics in Earth Science
Uniformitarianism is a key principle in geology that states that the natural processes that are occurring today have occurred throughout the geologic past. Thus, changes to the Earth are dominantly the result of small incremental changes due to ordinary processes such as weathering and erosion. Uniformitarianism replaced the idea of catastrophism that states that features of the Earth (such as mountains an valleys) were the result of sudden and violent events. Thus, the weathering of rocks and minerals at the Earth's surface can be viewed as one of the slow gradual processes that may result in large-scale changes (over geologic time) such as the leveling of mountain ranges.

Erosion is a process that is related to weathering but is distinctly different; it is common to confuse weathering and erosion. Erosion is the physical transport of sediment by mobile agents such as water, wind or ice. The products of weathering (sediments) represent the materials that are transported by erosion. The most effective agent of erosion is water that is also a necessary component of physical and chemical weathering processes. The transport of sediments during erosion commonly contributes to weathering. For example, sediments transported during erosion may be broken into small pieces (physical weathering).

The ***water cycle*** (aka hydrologic cycle) describes the movement of water at or near the Earth's surface and is essential for processes that are responsible for the weathering of rocks and minerals. The transfer of water through the water cycle is responsible for precipitation on continents that aids weathering and erosion.

Sedimentary rocks are formed from sediments that are transported to an environment where they can accumulate. Physical and chemical weathering processes produce the raw materials (sediment) for sedimentary rocks. The weathering of rocks results in two fundamentally different types of products:

1. solid particles (sand grains, clay minerals, etc.)
2. dissolved constituents in water

These two types of products from weathering result in two different types of sedimentary rocks:

1. *detrital (clastic) sedimentary rocks* - formed from transported solid particles
2. *chemical sedimentary rocks* - formed by the precipitation of dissolved substances by either inorganic or biologic processes

Soil may be defined as a layer of weathered mineral and/or organic material that is capable of supporting plant life. The formation of soil begins with the weathering of rock. The products of weathering such as quartz sand grains and clay minerals are common constituents of soils. In regions where the chemical weathering of rocks is greatest, there is generally greater soil formation. In addition, the amount of chemical weathering that is controlled by climate also dramatically affects the composition of the soil and its productivity.