Mother Nature's Chisel:
Processes of weathering and erosion

Remember:

Erosion is the physical (or chemical) *removal* of material by mobile agents such as water, wind, ice, or gravity.

In most cases, erosion is aided by *weathering* (the physical or chemical breakdown of materials at or near Earth's surface).

Weathering enhances the ability of erosion processes to remove components of the material (either as solid particles or as dissolved ions).

A few words on weathering…

Among the most striking geological features on Earth are physiographic/geomorphological features that result from erosion and particularly differential erosion.

Mechanical Weathering

Mechanical weathering: involves the physical breakup or disintegration of material (without changes in the composition of the material).

Principal forms of mechanical weathering include:

Frost Wedging
Root Wedging
Unloading/Exfoliation
Rapid heating and cooling?

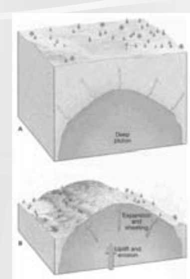
Frost wedging. This occurs when water flows penetrates cracks within a rock and freezes.

Water expands when it is converted to ice (ice is less dense than water-floats on top), widening the cracks.

With repeated cycles of water penetration and freezing, cracks get increasingly large, ultimately resulting in the breakup of the material.

This boulder in the Northwest Territories has been split apart by frost wedging

Unloading/Exfoliation. When an igneous rock body (e.g. a pluton) expands as overlying rock is removed by erosion, the remnant material overlying the intrusion will be bent and will tend to break into sheets. These sheets (folia) will slide off the elevated top of the intrusion (downslope) as its expansion continues.



Pluton confined by pressure of overlying rock

Pressure released, rock expands - upper rock layers pop away from pluton

Root wedging. This occurs when roots of plants (e.g. trees) penetrate into small cracks.

As the root increases in size, it increases the size of the crack until pieces of the rock break apart.

This block of dolostone on the top of the Niagara Escarpment is being split apart by roots of cedar trees.

Chemical weathering

Chemical weathering: involves the partial or complete removal of minerals within rocks due to chemical reactions of the minerals with water or gases in the air.

Three processes are largely responsible for chemical weathering:

Dissolution
Oxidation
Hydrolysis

Dissolution

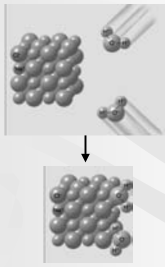
Dissolution: The process in which a material is dissolved in a liquid (e.g. salt in water).

Simple Dissolution

The dissolution of halite (sodium chloride or NaCl) occurs in this way:

The negatively charged ends of water molecules (those with oxygen ions) cluster around positively charged sodium ions (Na+).

Positively charged ends of water molecules (those with hydrogen) cluster around chloride ions (Cl-).



Acid Dissolution

Most minerals (with the exception of a few such as halite) are, for practical purposes, insoluble in pure water,

However, the presence of acids in the natural environment greatly increases the corrosive action of water.

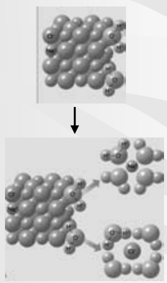
For our purposes, we will think of an acidic solution as being a solution containing lots of hydrogen ions (H^+).

As you probably know, acids are partially defined by the fact that they liberate hydrogen ions when dissolved in water.

The strengths of ionic bonds between Na+ and Cl- at the surface of a mineral grain are locally weakened.

This bond weakening allows the Na+ and Cl- ions to be plucked away from the grain and to remain held apart by water molecules (i.e. to remain in solution).

Halite is one of the few minerals that can directly dissolve in pure water



Sources of Acid.

For example, carbonic acid is formed when carbon dioxide reacts with water in the atmosphere:

$$CO_2 + H_2O \rightarrow 2H^+ + CO_3^{2-}$$

carbon dioxide — water — carbonic acid

Likewise, sulphuric acid is formed when sulphur dioxide reacts with water in the atmosphere:

$$SO_2 + H_2O \rightarrow 2H^+ + SO_4^{2-}$$

sulphur dioxide — water — sulphuric acid

Both acids occur naturally in rainwater (although carbon dioxide and sulphur dioxide pollution can greatly increase this acid content and lead to the production of harmful acid rain).

Acids are very reactive and are capable of breaking down most minerals.

A mineral that is particularly prone to acid dissolution is calcite. As you will remember, calcite fizzes (liberates carbon dioxide gas) when exposed to comparatively weak acid solutions.

Dissolved hydrogen ions of the acid react with calcite in the following way:

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

calcite(s) — hydrogen ions (aq) — calcium ion (aq) — carbon dioxide (g) — water (l)

Hydrolysis

Hydrolysis occurs when minerals react with water to form other products.

For example, the weathering of potassium feldspar involves the following reaction:

$$4KAlSi_3O_8 + 4H^+ + 2H_2O \rightarrow Al_4Si_4O_{10}(OH)_8 + 4K^+ + 8SiO_2$$

potassium feldspar (s) — hydrogen ions (aq) (from acid) — water (l) — clay (s) — potassium ions (aq) — silica (aq)

Note that oxygen and hydrogen from the water have combined with the feldspar to produce clay. Additional hydrogen is provided by the "loose" hydrogen ions provided by acid. As acid is required, this is known as an "acid hydrolysis reaction".

Alteration of the rock's minerals (and the release of ions in solution) result in the weakening of rock. Obviously, in this case, (e.g. a granite) a hard, well consolidated rock would be partially transformed into tiny grains of poorly consolidated mud or clay.

Oxidation

Oxidation, occurs when oxygen in the atmosphere or in a solution combines with another element to form an oxide that can be subsequently removed by physical erosion or dissolution. In nature, iron is particularly prone to oxidation, forming the mineral hematite (we call this rust).

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

Iron (e.g. in pyrite) — oxygen — iron oxide (hematite)

Oxidation is an important process in the decomposition of mafic (iron and magnesium rich) minerals. The rate of oxidation is accelerated when water is present (as most car owners can appreciate).

Summary: Chemical Weathering of Minerals

Simple ionic salts (e.g. halite) most easily weathered
Form of chemical weathering: simple dissolution.
Occurrence: sedimentary rocks.

Carbonate minerals (e.g. calcite)
Form of chemical weathering: acid dissolution
Occurrence: sedimentary rocks (e.g. limestone), metamorphic rocks (e.g. marble), rarely in some igneous intrusive and extrusive rocks (Carbonatites).

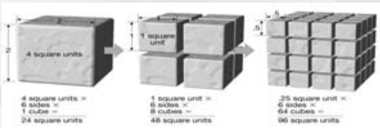
Silicate minerals (e.g. ferromagnesian minerals, feldspars, quartz)
Forms of chemical weathering: acid hydrolysis, oxidation, acid dissolution
Occurrence: igneous, metamorphic, siliciclastic sedimentary rocks

Mechanical and Chemical Weathering Work Hand-in-Hand

Weathering processes are not mutually exclusive – work together to weaken and break down rock.

Mechanical weathering increases the amount of exposed surface that can be acted upon by chemical weathering.

As rocks are broken down into smaller and smaller fragments, the rate of chemical (and biochemical) weathering increases.



One big block: low surface area → Many small blocks: high surface area

Differential Weathering and Erosion

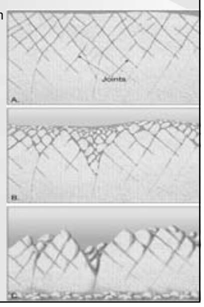
A logical extension of the surface area effect is that rocks generally show differential weathering (i.e. they weather in a non-uniform manner). This is understandable in cases where rocks are consolidated to different degrees, or contain mineral components of varying hardnesses.

Differential weathering may also in more-or-less homogenous rock as shown.

Here, weathering tends to be concentrated at intersections of cracks.

These cracks, also know as joints, are produced by stresses within the rock.

As you can see from the diagram, exposed, angular blocks at the top are likely to be rounded off by wind or water, and also are more likely to be "plucked" and "wasted".



Erosion Processes

Many different forms of erosion can be observed on Earth, three major erosional agents are:

Liquid water
Wind
Ice
Gravity

Liquid water

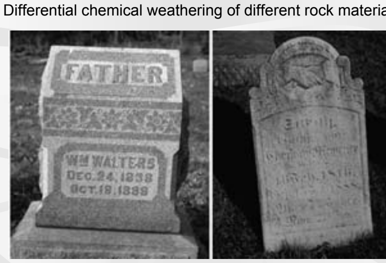
Liquid water is one of Earth's most potent agents of erosion because:

- It can readily transport dissolved substances released through chemical weathering.
- Turbulent flowing water (as generated by the interaction of waves and currents with underlying rock) can loosen and pluck particles (process of scouring).
- Particles in suspension can, in turn, impact underlying rock and abrade it.

Erosion From Water: Transport of dissolved substances.

This exposed surface of jointed limestone (in Malham Cove, Yorkshire) shows the effects of differential weathering and erosion. In this case, chemical weathering has been concentrated along the joints. Erosion has occurred due to the removal of soluble materials (i.e. these are solution enhanced joints).

Differential chemical weathering of different rock materials



Granite headstone Limestone headstone

The removal of readily dissolved material is also obvious in limestone headstones (note how the granite headstone, which is resistant to dissolution retains its detail, but the limestone headstone does not).

In turn, drainage of water into the deep cracks has allowed further dissolution of the limestone (at depth) and in smaller channels (runnels?) which feed the underground drainage network.

Erosion From Water: Plucking action (scouring)

Differential weathering and wind scouring by grains loosened by weathering has resulted in a rounded "billowy" appearance in this jointed granite (Joshua Tree National Monument, California) Materials locally weathered along joints by hydrolysis and oxidation were later removed by water in suspension and/or solution.

A combined erosive effect: scouring plus abrasion

The erosive action of water alone is enhanced by the impact of suspended sediment particles, particularly on rocky substrates. The latter produces new loose material which can be carried away by the former.

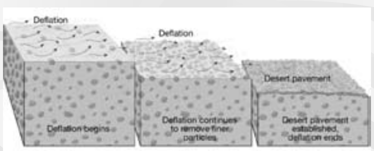
Stream erosion (plucking of grains by turbulent water and abrasion by sediment particles in running water)

Shoreline erosion (plucking of grains and abrasion by sediment particles in wave-swept environments)

Erosion by wind

Flowing air, much like flowing water, also plucks grains that are loosened by weathering, and can produce similar effects of erosion.

The plucking of sediment grains by wind is called *deflation*.



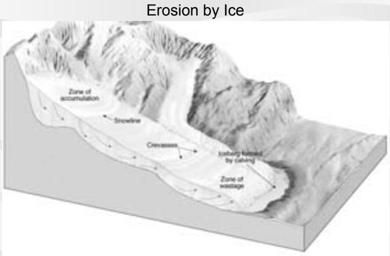
As a result of deflation, and selective removal of light/fine sediment grains (a form of sorting) many desert areas are covered by a pavement of pebbles and boulders (not all deserts are sandy !). Such area are said to be "deflated" with respect to typically transportable grains (clay-coarse sand).

Desert pavement in California

Sediment particles picked up by wind can then impact rock surfaces to abrade them. A sandblaster (used to clean residues from old buildings) works in the same way.

This rock acquired its unusual shape due to the sandblasting action of suspended sediment close to the ground.

Erosion by Ice



Ice is also a very important erosional agent. Like water and wind flowing glacial ice can plucks loose sediment grains from the ground. In turn, the plucked fragments of rock can abrade rock beneath the ice.

Rock polished by glacial abrasion

Erosion by glaciers produce spectacular features such as U-shaped valleys

Erosion by Gravity

Lastly, gravity is also very important in erosion. Material weakened by even gentle weathering can fail and be transported downslope.

The rapid downslope movement of materials due to gravity is called *mass-wasting*.

Perhaps the most spectacular form of mass-wasting: rockslides

A classic example: Frank Slide, Crowsnest Valley, Alberta

On April 29, 1903 at 4:10 AM, 30 million cubic meters (90 million tons, 82 million tonnes) of limestone fell from Turtle Mountain in just 90 seconds !

END OF LECTURE