Weathering
The mechanical and chemical destruction of rock at the surface of the Earth

Weathering
- Breaks down rock to make sediments.
- Forms soils.
- Forms economic mineral deposits.
- Removes CO$_2$ from the Earth’s atmosphere.

Mechanical Weathering
physical disintegration of rock
- jointing
- sheeting
- wedging
Jointing
spontaneous fracturing due to cooling or tectonic stress

Cooling joints Stress joints

Columnar Jointing
• Fine-grained igneous rock
• Internal contraction during cooling
• Fractures develop during weathering
• Hexagonal pattern

Columnar Jointing
Fingals Cave, Great Britain
Pressure-release sheeting: an example from Texas

Enchanted Rock Granite Batholith
Sheeting and Exfoliation of Granite forming Exfoliation Dome

Enchanted Rock, Texas

Half Dome
Yosemite National Park
California

Physical Weathering
• Exfoliation
• Glacial

Vertical joints

Failed geology
Passed geology

Lysefiord, Norway
Spheroidal Weathering

Newly jointed block
Weathered boulder

Wedging
enlargement of fractures by pressure

• ice and frost
• mineral crystals
• plant roots
Ice and Frost Wedging

• caused by freeze-thaw cycles.
• water expands when it freezes.
• ice has 9% more volume than liquid water.

Root Wedging

Chemical Weathering

The chemical reaction of minerals with air, water and organic compounds.

• hydrolysis (acid attack)
• oxidation
• dissolution (leaching)
• hydration
• chelation
Carbonic Acid
Natural acidity in rainwater and groundwater

\[ \text{H}_2\text{O (water)} + \text{CO}_2 \text{(gas)} = \text{H}^+ \text{(carbonic acid)} + \text{HCO}_3^- \text{(bicarbonate)} \]

\[ \text{H}^+ \text{in solution is very reactive!} \]

Hydrolysis of Feldspar

Feldspar + H$^+$ (carbonic acid) + HCO$_3^-$ = Ca ions + clay + silica + bicarbonate ion

\[ \text{CaAlSi}_3\text{O}_8 + \text{CO}_2 + \text{H}_2\text{O} = \text{Ca}^{++} + \text{Al}_4\text{Si}_4\text{O}_{10}\text{(OH)}_8 + 8\text{SiO}_2 + \text{HCO}_3^- \]
Weathering feldspar in granite

\[ \text{CO}_2 + \text{H}_2\text{O} = \text{H}^+ + \text{HCO}_3^- \]

Carbonic acid is carried in rainwater

\[ \text{H}^+ + \text{feldspar} = \text{Ca}^+ + \text{clay} + \text{silica} \]

\[ \text{HCO}_3^- , \text{Ca}^+ , \text{silica} \]
Inorganic Carbon Cycle

Ca\(^{2+}\) + 2HCO\(_3^-\) \rightarrow \text{Carbonate mineral}

\[ \text{CaCO}_3 + \text{H}_2\text{CO}_3 \]

Volcanism

Mantle (CO\(_2\))

Subduction and metamorphism

Atmosphere (CO\(_2\))

Chemical weathering

Solubility Pump

Oceans (HCO\(_3^-\))

Carbonate formation

Crust (CaCO\(_3\))

Carbon Cycle Thermostat

Cooler Earth

Warmer Earth

Increasing CO\(_2\) greenhouse

Decreasing CO\(_2\) greenhouse

CO\(_2\) depleted by weathering and carbonate production

more carbonate production

less carbonate production

less weathering

more weathering
**Dissolution of Limestone (carbonation)**

Calcium carbonate + carbonic acid = calcium ions + bicarbonate ions

\[ \text{CaCO}_3 + \text{H}_2\text{CO}_3 = \text{Ca}^{++} + 2\text{HCO}_3^- \]

**Oxidation**

Attack by oxygen.

\[ 2\text{Fe}_2\text{SiO}_4 \text{ (olivine)} + \text{H}_2\text{O} + \text{O}_2 = \text{FeO} \cdot \text{OH} \text{ (goethite)} + \text{dissolved silica} \]

Goethite dehydrates to Hematite

**Hydration**

Combination with water.

\[ \text{CaSO}_4 \text{ (anhydrite)} + 2\text{H}_2\text{O} = \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \text{ (gypsum)} \]

Absorption of water into minerals.
Chelation
Bonding of a metal ion and an organic compound produced by soil microbes, fungi and lichens.

Removal of metal ions disrupts crystal structure.

Minerals prone to chemical weathering
- feldspars
- pyroxenes
- amphiboles
- micas
- calcium carbonate

Stable minerals
- quartz
- clay minerals (e.g. kaolinite)
- iron oxides (e.g. hematite)

Weathering
- World distribution of rainfall is important for weathering, because weathering is driven by water delivery to the land

This has consequences for soil ore distribution.

Bauxites (Al rich ores) are located primarily in the tropics.
Weathering

- Streams are main agent for moving materials by either solution or particles.
- Stream discharge roughly equal to surface area for world's continents.
- …except Australia and Antarctica: low because of especially low rainfall.

Weathering

- Chemical weathering per unit area is 20-40 metric tons/km\(^2\)/year and is pretty constant for continents.
- Mechanical weathering has more variation (20-300 metric tons/km\(^2\)/year), because of large variation in slopes. Asia is largest, because of large mountain ranges (e.g. Himalayas).
- Continents with high mean elevations have high mechanical weathering.
Weathering

- Very high erosion where there are mountains and high rainfall (e.g. Indus from Himalayas and Amazon from Andes: both are in areas of high rainfall and have high sediment load).

- Mean rate of denudation 3-4 cm per thousand years. But this is a misleading figure, since it mostly comes from mountains, which have a small surface area.

- Mountains are being worn down very quickly.

- Implies recent geologic processes make mountains.

Human influence

- Human beings move more sediment through mining and building than rivers do.

- Agricultural practices also increase erosion in rivers. Rates thousands of years ago were less than today.

- Inpounded water from lakes behind dams prevents sediment from reaching the sea.

- Acid rain greatly accelerates chemical weathering.