Indian Institute of Technology, Kanpur
Department of Earth Sciences

ESO213A: Fundamentals of Earth Sciences

Lecture 38. Weathering & Erosion - I

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IITK Experimental Rock Deformation Laboratory

Aims of this lecture

Concepts of Weathering and Erosion

Classification and Controlling factors of Weathering

Readings:
Grotinger & Jordan's Book: Chapter 16

Concept of Weathering and Erosion

In the last lecture we learnt: the Earth's topography is dynamic

However, natural forces always try to achieve an equilibrium

Weathering is the first step in flattening the high-lands (also an important part of Rock Cycle) and the Erosion (and mass wasting) takes the lead to move the weathered rock materials.

Concept of Weathering and Erosion

Weathering is the breaking down or dissolving of rocks and minerals on Earths surface

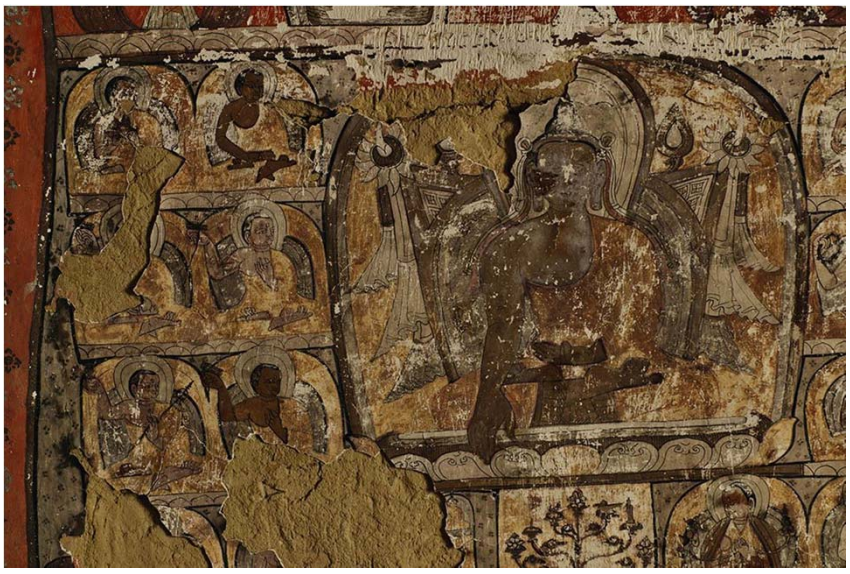
Erosion generally refers to processes that move Earth materials on a grain-by-grain basis.

Mass wasting refers to processes that cause large masses of material to collapse and move downslope.

Weathering?




Weathering?



Ritseling Cave in Upper Mustang, Nepal. (NatGeo)

Controlling factors of Weathering

WEATHERING RATE

SLOW → Medium → FAST

PROPERTIES OF PARENT ROCKS			
Mineral solubility in Water	Low (quartz)	Moderate (pyroxene, feldspar)	High (calcite)
Rock Structure	Massive	Some zones of weakness	Highly fractured/layered
CLIMATE			
Rainfall	Low	Moderate	High
Temperature	Cold	Temperate	Hot
PRESENCE OR ABSENCE OF SOIL AND VEGETATION			
Thickness of soil layer	None-bare rock	Thin to moderate	Thick
Organic content	Low	Moderate	High
LENGTH OF EXPOSURE			
	Short	Moderate	Long

Classification of Weathering

Physical (mechanical) weathering: Rock material does NOT change, i.e., composition remains same

Examples: Hitting, frost action, scratching (abrasion), breaking from changes in temp., pressure or living organisms

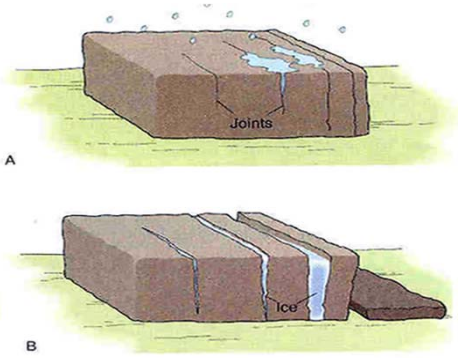
Chemical weathering: Rock material is changed into another substance.

Examples: Oxidation (exposure to air), Acid (acid rain), Hydrolysis (Water)

Physical Weathering

Frost Wedging

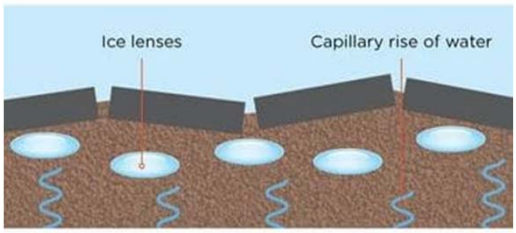
Water seeps into cracks in rocks ;then freezes and expands causing the rock to crack.



Physical Weathering

Frost Heaving

The upward or outward movement of the ground surface (or objects on, or in, ground) caused by formation of ice in soil.



Physical Weathering

Salt Wedging

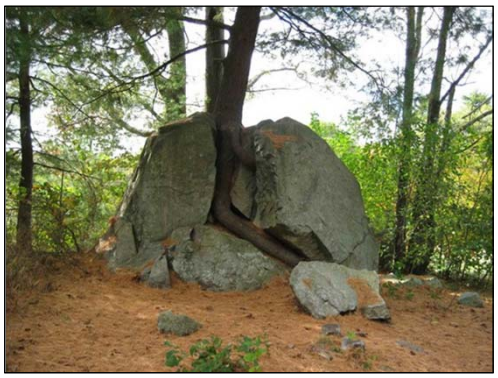
Saltwater seeps into rocks and then evaporates on a hot sunny day. Salt crystals grow within cracks and pores in the rock, and the growth of these crystals can push grains apart, causing the rock to weaken and break. Common in rocky shorelines.

Tafoni (Honeycomb weathering) in sandstone on Gabriola Island, British Columbia. The holes are caused by crystallization of salt within rock pores.

Physical Weathering

Plant roots

Plants roots grow into rocks and cohesive aggregates and crack them.

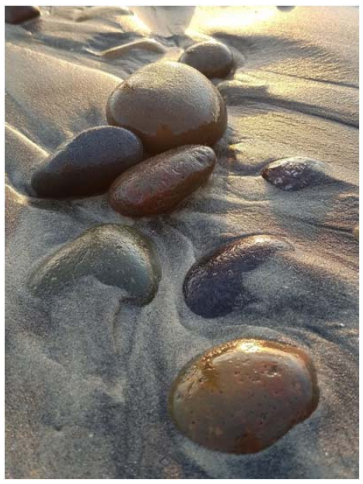


Physical Weathering

Friction and Repeated Impacts

Actions of flowing water, wind and glacier break and smoothen the rocks





Physical Weathering

Thermal expansion and Contraction

The outer layer of the rock is heated by the sun which causes it to **expand**, and, as it cools during the night, it **contracts**. This expanding and contacting causes the outer layer of the rock to peel away. The process also breaks the rocks along pre-existing joints and cracks.


Physical Weathering

Organic Activities

Burrows by animals, insects and worms

Chemical Weathering

Resistance to Chemical Weathering

Stability of Minerals	Rate of Weathering
MOST STABLE	Slowest
Iron oxides (hematite)	
Aluminum hydroxides (gibbsite)	
Quartz	
Clay minerals	
Muscovite mica	
Orthoclase feldspar	
Biotite mica	
Sodium-rich plagioclase feldspar (albite)	
Amphiboles	
Pyroxenes	
Calcium-rich plagioclase feldspar (anorthite)	
Olivine	
Calcite	
Halite	
LEAST STABLE	Fastest

Unweathered granite is hard and solid because an interlocking network of feldspar, quartz, and other crystals holds it tightly together.
When the feldspar is transformed by weathering into a loosely adhering clay, the network is weakened and the mineral grains are separated.

Chemical weathering, by producing the clay, also promotes physical weathering because the rock now fragments easily along widening cracks at the boundaries between grains.

Chemical Weathering

Dissolution

Dissolution weathering produce ions, but no minerals, and are reversible if the solvent is removed (think of dissolving salt in a glass of water). Natural Halite, Gypsum and anhydrite are other minerals that will dissolve in water alone. Calcite, will dissolve in acidic water (*Carbonation*).

Sinkhole downstream of the Mosul Dam in Iraq. The sinkhole is a result of dissolution of gypsum and anhydrite layers.

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$$

$$CaCO_3 + H_2CO_3 \rightarrow 2HCO_3^- + Ca^+$$

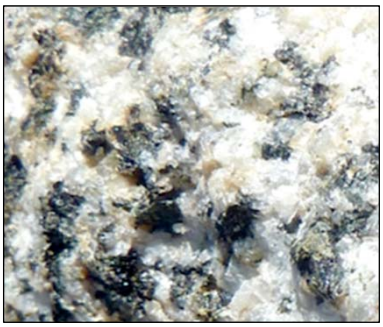
Chemical Weathering

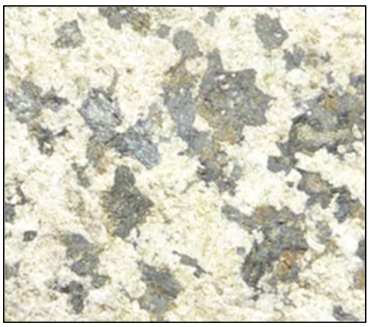
Hydrolysis

Hydrolysis as a chemical reaction where water loosens the chemical bonds within a mineral. This is different from Dissolution, as it produces new minerals, with or without ions.

$$2KAlSi_3O_8 + 3H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 4SiO_2 + 2K+ + 2OH-$$

K-Feldspar Water Kaolinite Quartz Ions





Chemical Weathering

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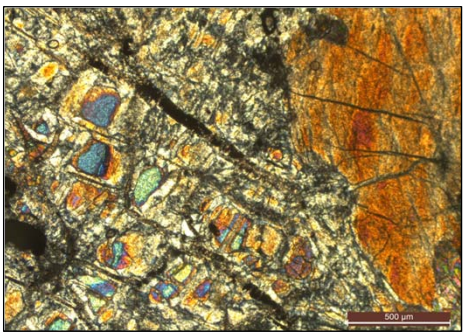
$(MG,Fe)_2SiO_4 + 3H_2O \rightarrow (MG,Fe)_3SiO_5(OH)_4 + (MG,Fe)(OH)_2 + Fe_3O_4 + H_2$

Olivine Water Serpentine Brucite Magnesite

Serpentine (hand specimen)



Serpentine (thin section)

Chemical Weathering

Hydrations

Hydration reactions involve water being added to the chemical structure of a mineral.

$CaSO_4 + 3H_2O \rightarrow (CaSO_4).2H_2O$

Anhydrite Water Gypsum

$2Fe_2O_3 + 3HOH \rightarrow 2Fe_2O_3 .3H_2O$

Hematite Limonite

$Al_2O_3 + 3HOH \rightarrow Al_2O_3 .3H_2O$

Bauxite Hyd. Aluminum Oxide

Chemical Weathering

Oxidation

Oxidation happens when free oxygen is involved in chemical reactions. *[Oxidation reactions provide valuable insight into Earth's early surface conditions: transition in the rock record from rocks containing no minerals that are products of oxidation reactions, to rocks containing abundant minerals produced by oxidation. This reflects a transition from an oxygen-free atmosphere to an oxygenated one]*

$4FeO$ (Ferrous oxide) + O_2 → $2Fe_2O_3$ (Ferric oxide)
$4Fe_3O_4$ (Magnetite) + O_2 → $6Fe_2O_3$ (Hematite)
$2Fe_2O_3$ (Hematite) + $3H_2O$ → $2Fe_2O_3 .3H_2O$ (Limonite)

Chemical Weathering

Oxidation

The oxidation reaction begins in Olivine with taking iron out of the mineral and putting it into solution as an ion. Olivine reacts with carbonic acid, leaving dissolved iron, bicarbonate, and silicic acid:

$$Fe_2SiO_4 + 4H_2CO_3 \rightarrow 2Fe_2^{+} + 4HCO_3^{-} + H_4SiO_4$$

Iron and oxygen dissolved in water react in the presence of bicarbonate to produce hematite and carbonic acid:

$$2Fe_2^{+} + ½\ O_2 + 2H_2O + 4HCO_3^{-} \rightarrow Fe_2O_3 + 4H_2CO_3$$

Chemical Weathering

Oxidation

Oxidation applies to almost any other ferromagnesian silicate, including pyroxene, amphibole, or biotite.

Iron in the sulphide minerals (e.g., pyrite) can also be oxidized in this way.

Chemical Weathering

Acid Rock Drainage (ARD)

If rocks have elevated levels of sulphide minerals, oxygen and water react with them and the runoff areas are known as Acid Rock Drainage. Also possible in mines (Acid Mine Drainage – AMD). metals such as copper, zinc, and lead easily dissolve in water, which can be toxic to aquatic life and other organisms.

Weathering: Controls and Rates

Now, if you go back to slide 7; you will understand better the controlling factors and rates of weathering.

Clearly, weathering does not happen at the same rate in all environments. The same types of weathering do not happen in all environments.

CLIMATE

O_2 CO_2

Minerals

Next Lecture

Weathering & Erosion - II