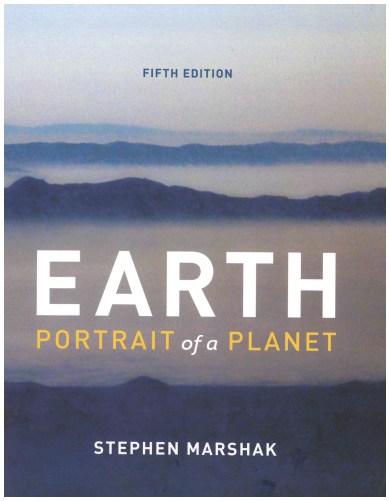
CEEES/SC 10110-20110

Rock Groups, the Rock Cycle, Weathering & Soils



Earth

Portrait of a Planet
Fifth Edition

Interludes A, B, & C

What is a Rock?

Relationship between rock type and the process of formation means rocks preserve a historical record of geological events and give insights into the interactions among components of the Earth system.

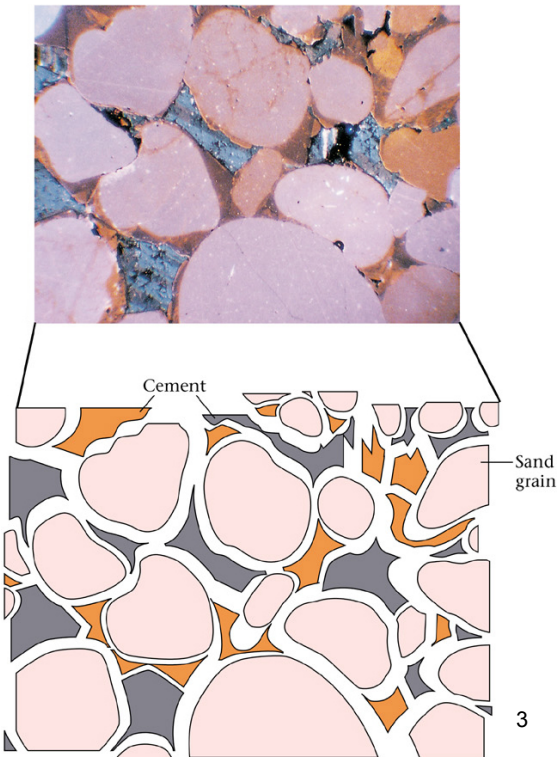
A ***rock*** is a coherent, naturally occurring solid, consisting of an aggregate of minerals.
Stone = rock used as a construction material.

Crystals have crystal faces evident and grew into its present shape, mineral grain = no crystal faces.
Grain = fragment of mineral, rock, or glass.

Rocks are basically a bunch of chemicals bonded together, but not all rocks contain the same chemicals

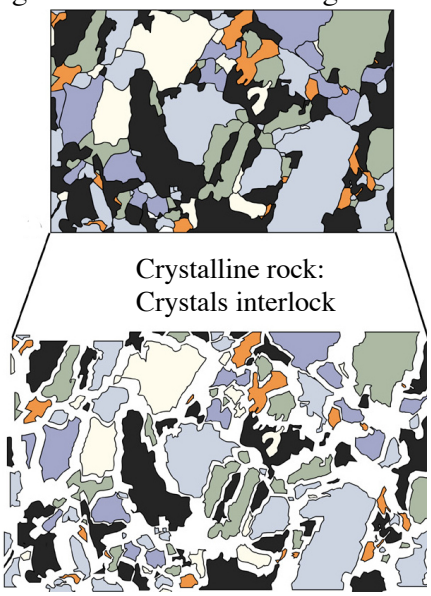
"Rockification" = Lithification

A ***sediment*** is a collection of grains. It becomes a rock when the grains become a coherent mass. Grains are held together by a ***cement*** that precipitated from water to fill the pore space between grains.



"Rockification" = Lithification

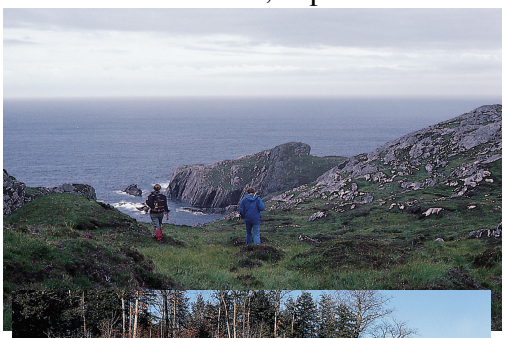
Rocks whose grains are held together by cement = ***Clastic***;
Rocks whose crystals interlock = ***Crystalline*** (non-Clastic).
Glassy rocks are held together either because they originate as a continuous mass (i.e., no separate grains) or because glassy grains became welded together.

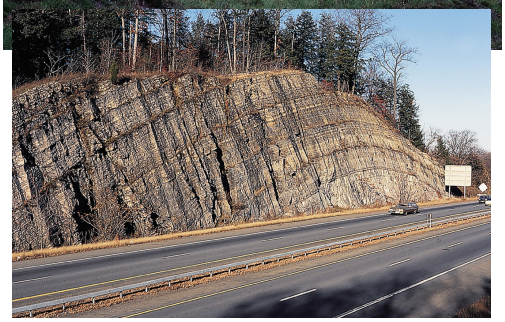


Rock: In situ or not?

Rocks that have been transported by water, wind, ice, or gravity are NOT in situ. If unrelated to underlying geology = ***erratics***.

In situ rocks = ***Bedrock***; exposed at the surface as ***Outcrops***.





Rock: In situ or not?

Depth of bedrock is important for urban planning - foundations of large buildings need to have their foundations set on bedrock.

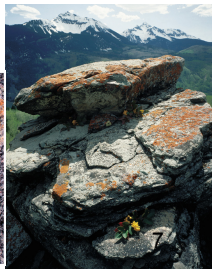
The skyscrapers of New York City rise in two clusters on the island of Manhattan, one at the south end and the other in the center, where the bedrock lies close to the surface.

Rock Classification

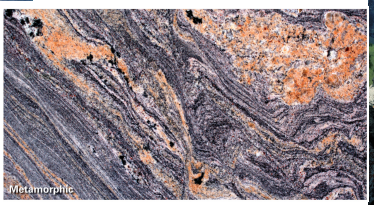
Proposed by James Hutton in the eighteenth century as a "genetic classification" because it focuses on rock genesis.

Igneous Rocks: formed by solidification of magma.

Sedimentary Rocks: formed by the cementing together of fragments of pre-existing rocks or precipitation of crystals out of water.

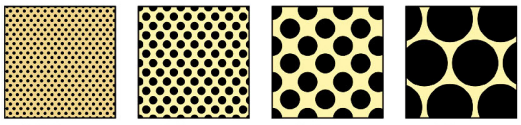


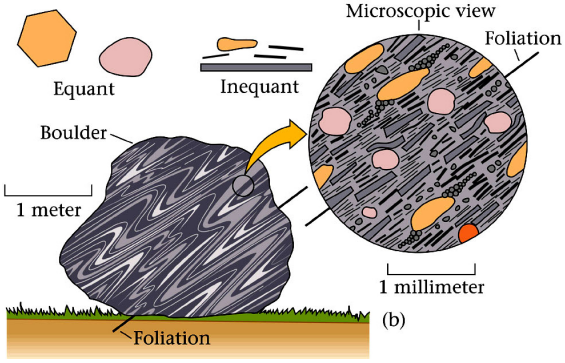
Metamorphic Rocks: formed by transformation in the solid state of pre-existing rocks by a change in temperature and/or pressure.



Rock Classification

Grain Size: Equant or Inequant.





Composition: chemical make up. Note - chemical composition does not completely control mineralogy; pressure and temperature also play a part, so two rocks can have the same chemical composition but have completely different mineralogies.

Texture: The way the grains interact with each other and whether or not inequant grains are aligned parallel to each other.

Rock Classification

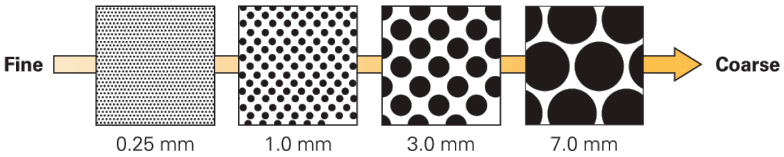
Layering: caused by bands of different compositions or textures,or by the alignment of inequant grains.

Sedimentary rocks = *bedding*;

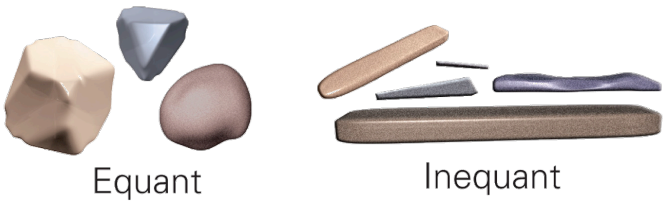
Metamorphic rocks = *foliation*?

Rock Classification

Grain Size:



Grain Shape:



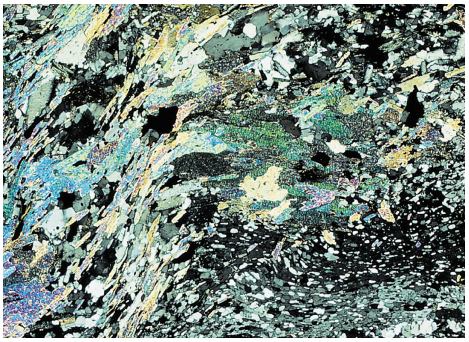
Study of Rocks

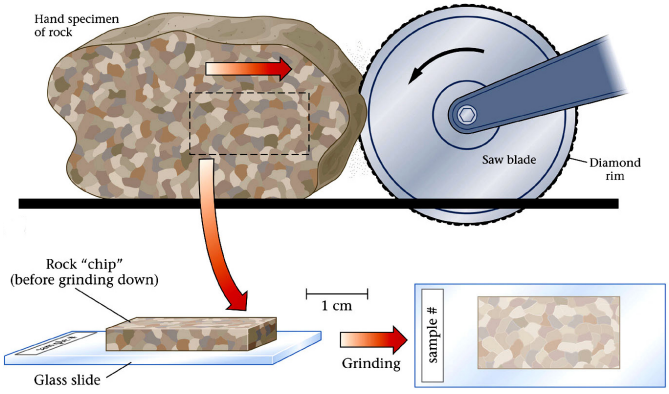
Rocks are studied at various scales starting at the outcrop:

Rock hammer used to obtain hand specimens

Study of Rocks

Take a hand specimen for study using a hand lens and for back in the lab.
Make a thin section (30 μm thick) and study under the petrographic microscope (polarizing light). Take a photomicrograph.

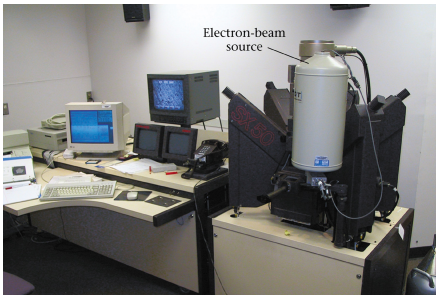




Study of Rocks

Analytical techniques to determine chemical compositions are either mineral- or rock-specific:

Microprobe techniques (SIMS, EMP, Laser Ablation ICP-MS): mineral.



Bulk rock or whole rock techniques:

X-Ray Fluorescence (XRF);

Atomic Absorption (AA);

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Optical Emission Spectroscopy (ICP-OES);

Neutron Activation Analyses (NAA).

IGNEOUS ROCKS

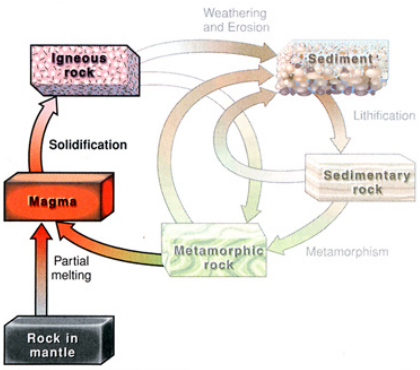
Minerals crystallize from solution (magma). Mineral identities/compositions depend on the composition of the magma & cooling history.

Texture: Randomly oriented, interlocking crystals. Quicker the cooling rate, smaller the crystals.

INTRUSIVE: magma crystallizes below the surface. Cooled slowly so it is coarse-grained - small number of large crystals (e.g., Granite, Gabbro, Diorite).

EXTRUSIVE: Magma erupts onto surface = Volcano. Cools quickly - lots of tiny crystals (e.g., Basalt, Andesite, Rhyolite) or glass (if quenched. E.g., Obsidian).

Magma = high temperature. At/near surface rock is "metastable" -**WEATHERING**.



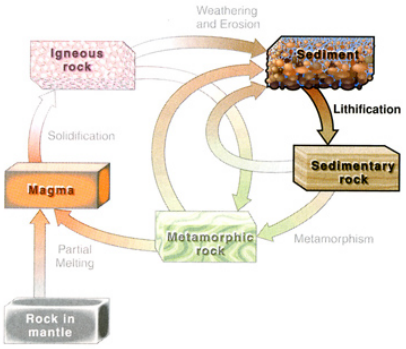
SEDIMENTARY ROCKS

Sediments: deposited products of weathering and erosion (river bed, ocean floor, lake floor, etc.).

Clastic: Made of bits! (minerals & rock fragments, sometimes biological fragments).
Long transportation produces round grains & well sorted material.
Bits cemented together (e.g., Conglomerate, sandstone, siltstone, shale.

Non-Clastic/Crystalline: Inorganic precipitation – chemical sedimentary rocks (e.g., limestone & salt - interlocking crystals).

Sedimentary rocks are buried – heat up (geothermal gradient ~25˚C/km).
Solid-state mineral transformation – re-equilibration.



METAMORPHIC ROCKS

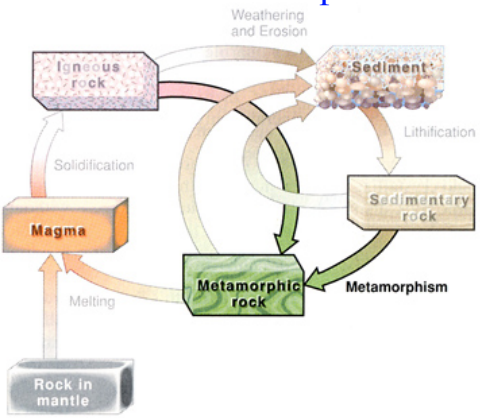
Altered in the solid state by subjecting pre-existing rocks to different pressures and temperatures (+/- fluids).

Process = recrystallization, recombination.

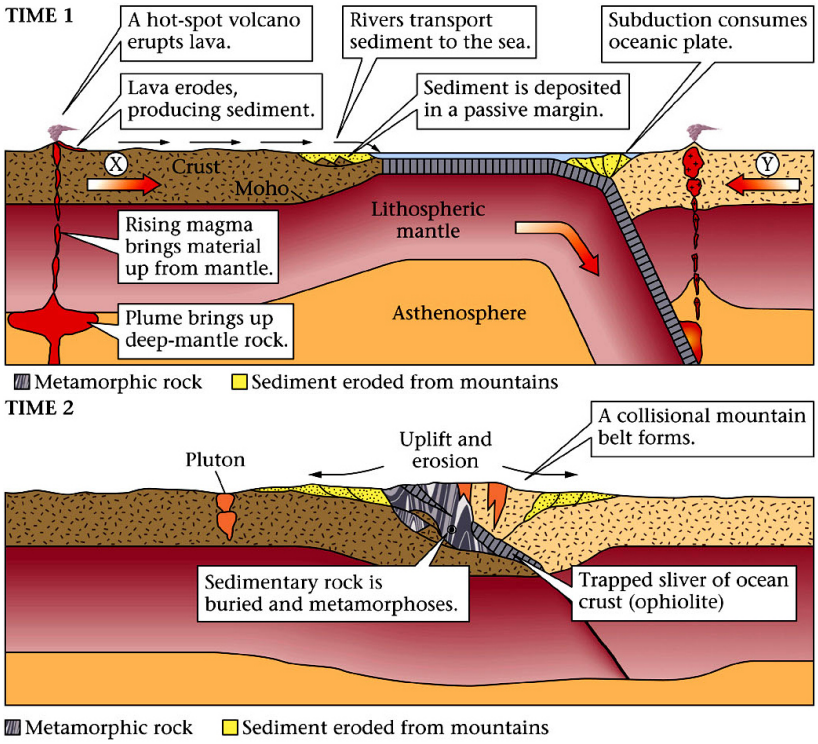
Solid-state transformation.

Directed pressure = oriented minerals.

Ultimate metamorphism = melting.



The Rock Cycle and Plate Tectonics



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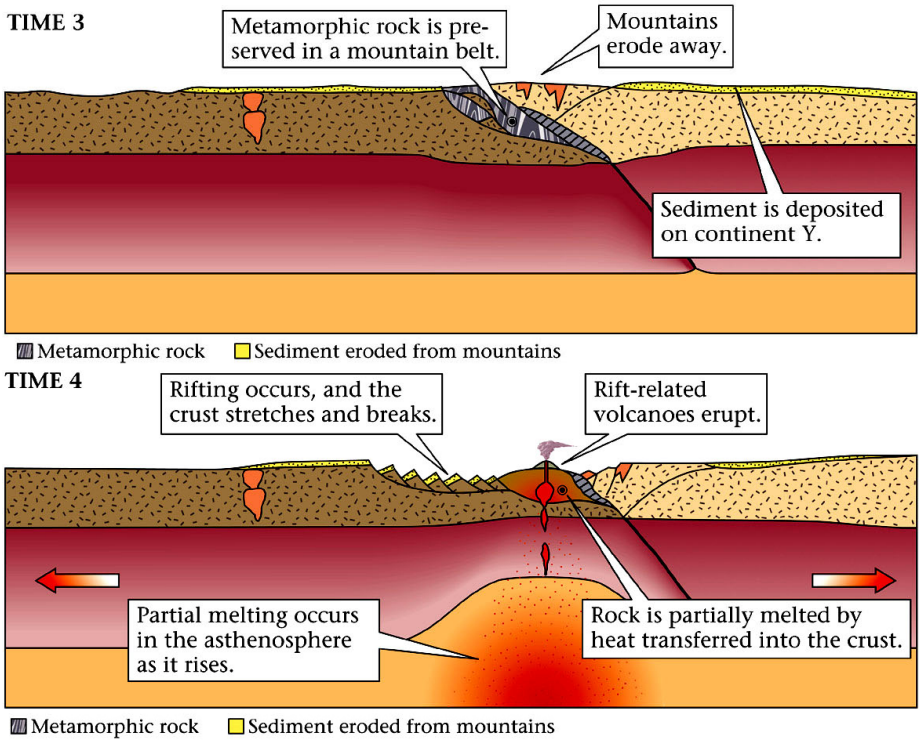
The Rock Cycle and Plate Tectonics



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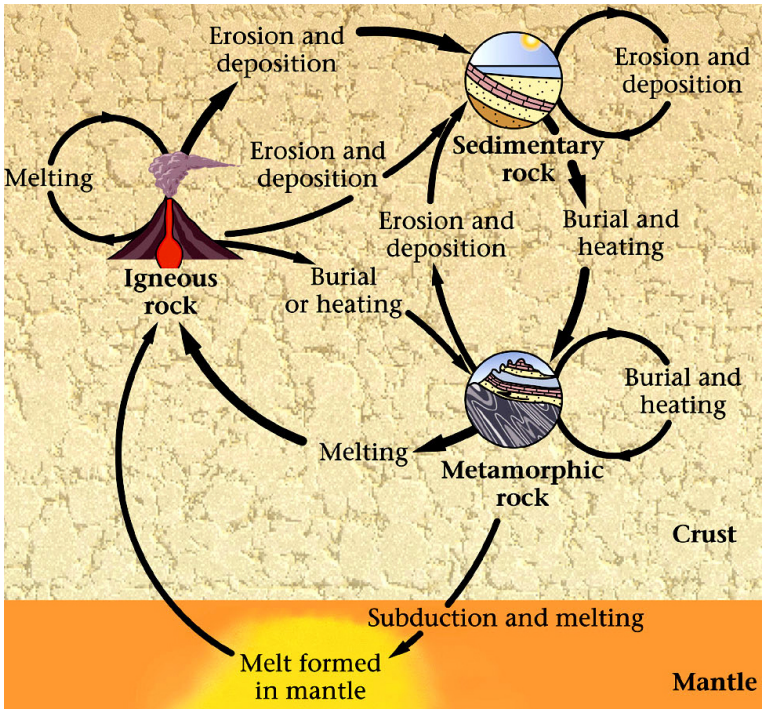
Cycles of the Earth System

A reef off the coast of a Caribbean island consists of calcite extracted from sea water by living organisms during the process of growing shells. The calcite becomes biochemical rock. This process is part of a biogeochemical cycle.

THE ROCK CYCLE

ROCK: Naturally occurring aggregate of two or more minerals.

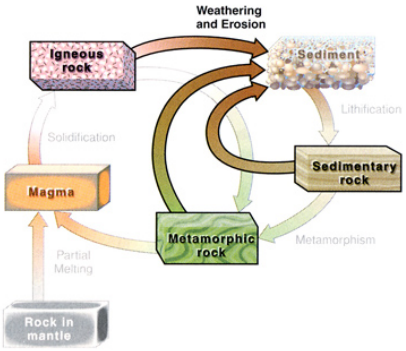
Rock-Types:
IGNEOUS
SEDIMENTARY
METAMORPHIC

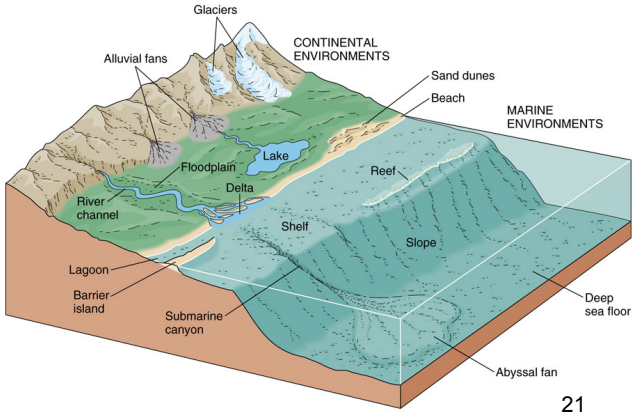


Weathering & Erosion

WEATHERING: Process that transforms high temperature minerals to low-temperature ones stable at the Earth's surface.

EROSION: Transport away from weathering site. This process exposes intrusive igneous rocks to weathering & the process continues. Transport by Wind, Ice, Gravity, Water (solution/ suspension).

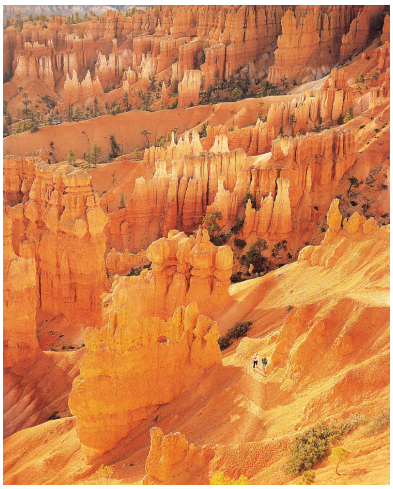


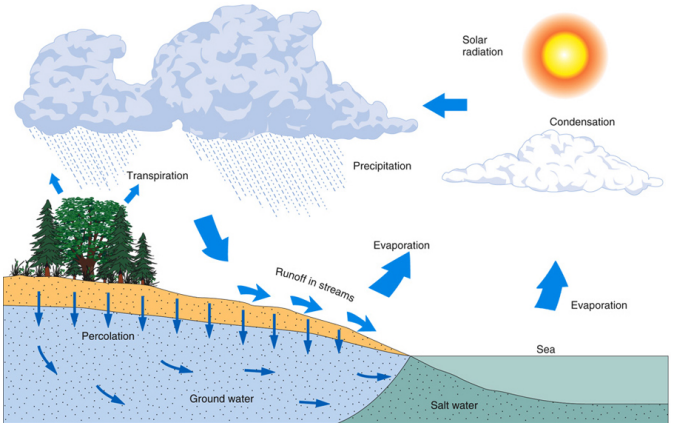


Weathering & Erosion

Weathering & Erosion: how the hydrologic cycle interacts with geology.

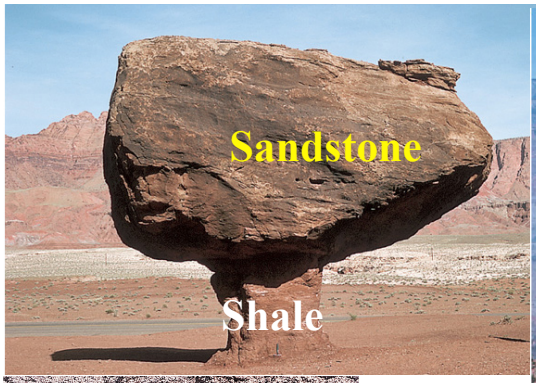
Weathering: group of destructive processes that change physical/chemical character of rock at/near surface.

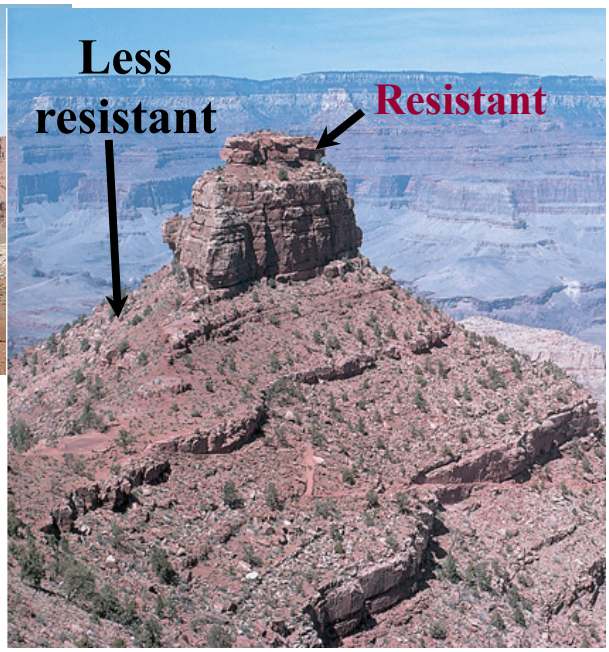




Weathering: in situ breakdown of rocks in contact with water, air, or organisms. Forms sediment and soil.

Differential Weathering

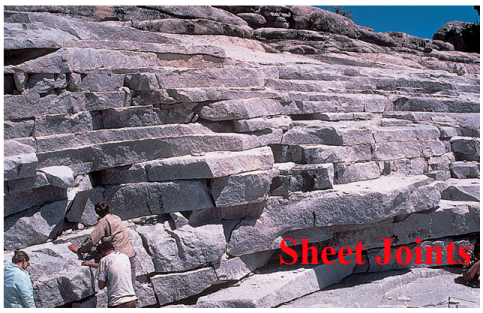




Joints

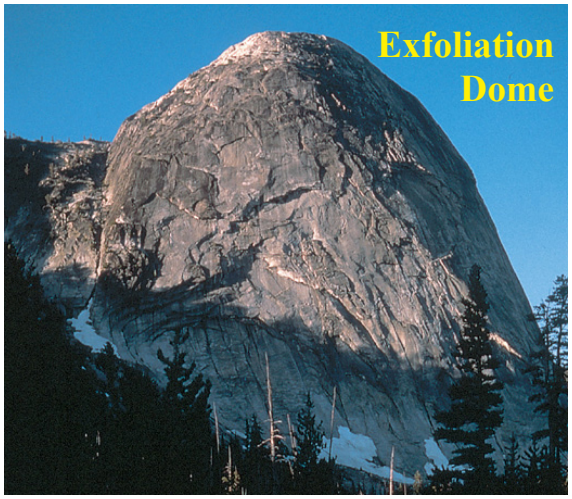
Natural cracks that form in rocks due to the removal of over burden or due to cooling, etc.

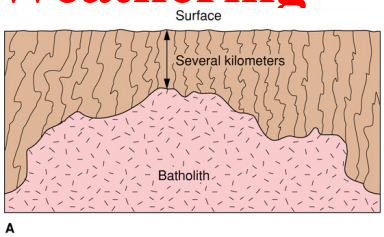
Broken blocks accumulate as ***talus***.

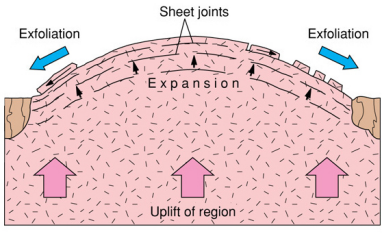


Mechanical/Physical Weathering

Pressure-Release: often called ***exfoliation***. Caused by unroofing of deep-seated rocks by erosion. Sheet joints and joint sets form (joint = break in the rock along which there has been no movement). Exfoliation domes.







Mechanical/Physical Weathering

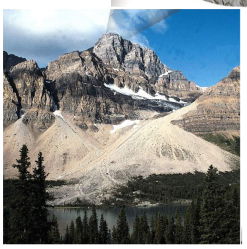
Precipitation of Crystals: salts precipitating from water in rock crevices/cracks. Forces the opening wider.

Root Systems: dominant in cold/dry climates.

Abrasion: friction/impact during transport.

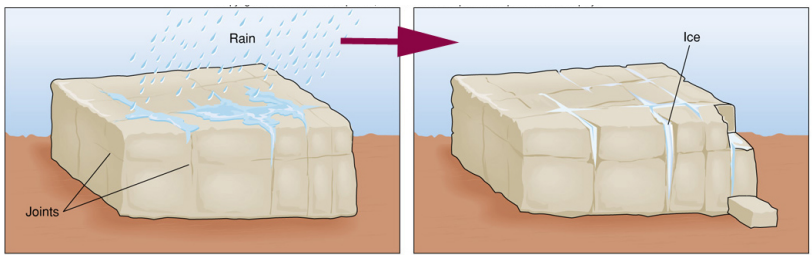
Animal Attack! Burrowing, mining, etc., opens up pathways for weathering.

Mechanical/Physical Weathering



Temperature Changes: differential expansion (deserts, mountains, & forest fires). Frost wedging in colder climates.

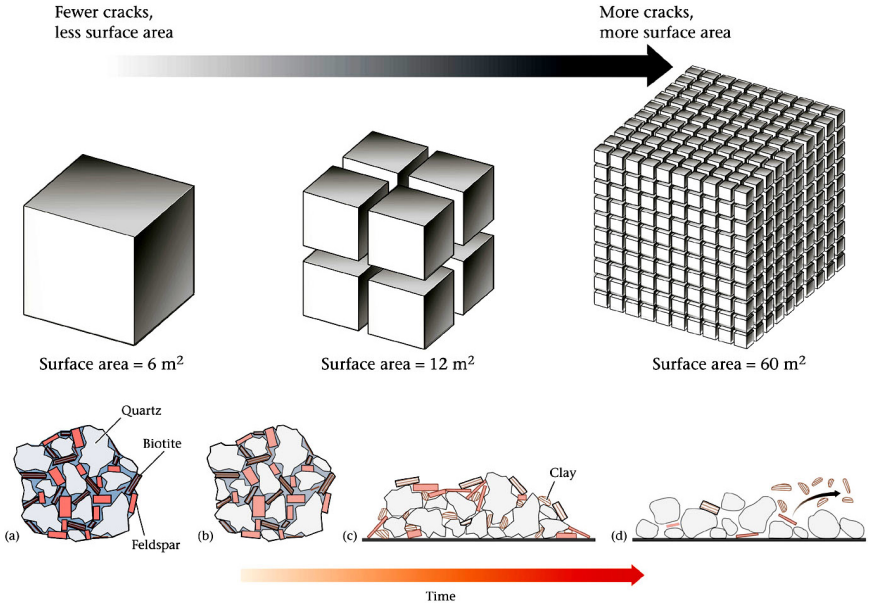
Frost-Wedging: water expands by 9% upon freezing – most significant where freeze-thaw cycle occurs often.



Frost Heaving: cooler under rocks, freezes first, expands and lifts.

Chemical Weathering

Surface area is very important: Ties to mechanical weathering as the surface area increases with fragmentation.

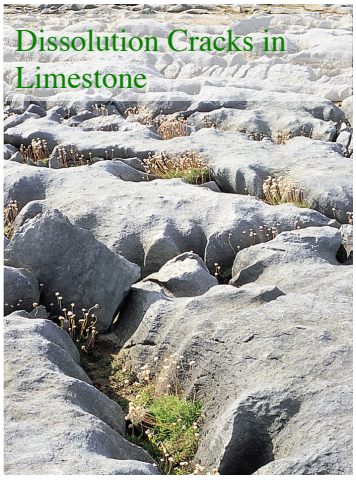


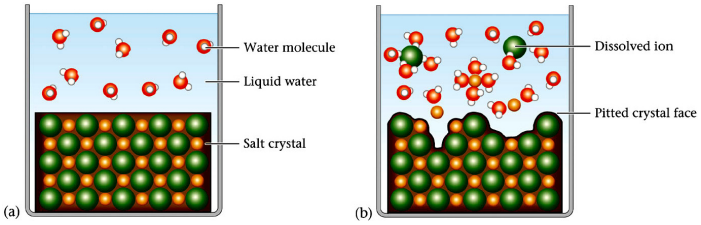
Chemical Weathering

Chemical weathering in warm, wet climates can produce a layer of "rotten" rock called ***saprolite*** up to 100 m thick.

Chemical weathering occurs through 4 main processes:
Dissolution; Hydrolysis; Oxidation; Hydration.

Dissolution





Carbonization (addition of CO_2):

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

Carbonic Acid **Bicarbonate Ion**

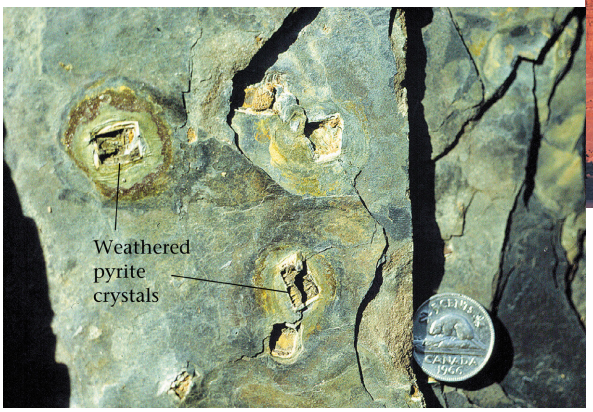
$$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$

Chemical Weathering

The main chemical weathering reactions are ***oxidation*** and ***hydration***.

Oxidation (addition of oxygen):

$$4Fe^{2+} + 3O_2 \rightarrow 2Fe_2^{3+}O_3$$



Chemical Weathering

Oxidation (addition of oxygen):

$$\underset{\text{Magnetite}}{2Fe^{2+}Fe_2^{3+}O_4} + 0.5O_2 \rightarrow \underset{\text{Hematite}}{3Fe_2^{3+}O_3}$$

Hydration (addition of H_2O):

$$\underset{\text{Hematite}}{Fe_2O_3} + nH_2O \rightarrow \underset{\text{Limonite}}{Fe_2O_3 \bullet nH_2O}$$

Carbonization (addition of CO_2):

$$CO_2 + H_2O \rightarrow \underset{\text{Carbonic Acid}}{H_2CO_3} \rightarrow H^+ + \underset{\text{Bicarbonate Ion}}{HCO_3^-}$$

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

Chemical Weathering

Hydrolysis (addition of OH^-):

$$\underset{\text{K-Feldspar}}{2KAlSi_3O_8} + 3H_2O + 2CO_2 \rightarrow$$

$$\underset{\text{Kaolinite}}{Al_2Si_2O_5(OH)_4} + \underset{\text{Quartz}}{4SiO_2} + 2KHCO_3$$

Chemical Weathering by Organisms

Roots, fungi, and lichen secrete organic acids to extract nutrients.

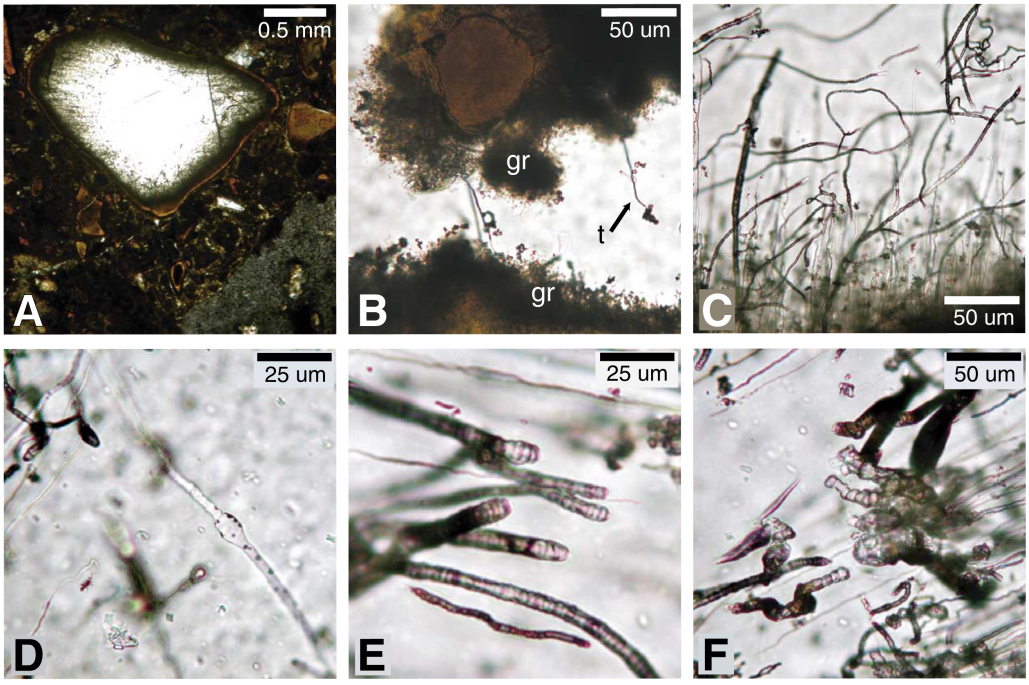
Bacteria can literally eat minerals - have been found several kilometers within the Earth and within solid rock.

Rates of Chemical Weathering

TABLE B.2 Relative Stability of Minerals at the Earth's Surface

Fastest Weathering		Least Stable
	Halite	
	Calcite	
	Olivine	
	Ca-plagioclase	
	Pyroxene	
	Amphibole	
	Na-plagioclase	
	Biotite	
	Orthoclase (potassium feldspar)	
	Muscovite	
	Clay (various types)	
	Quartz	
	Gibbsite (aluminum hydroxide)	
Slowest Weathering	Hematite (iron oxide)	Most Stable

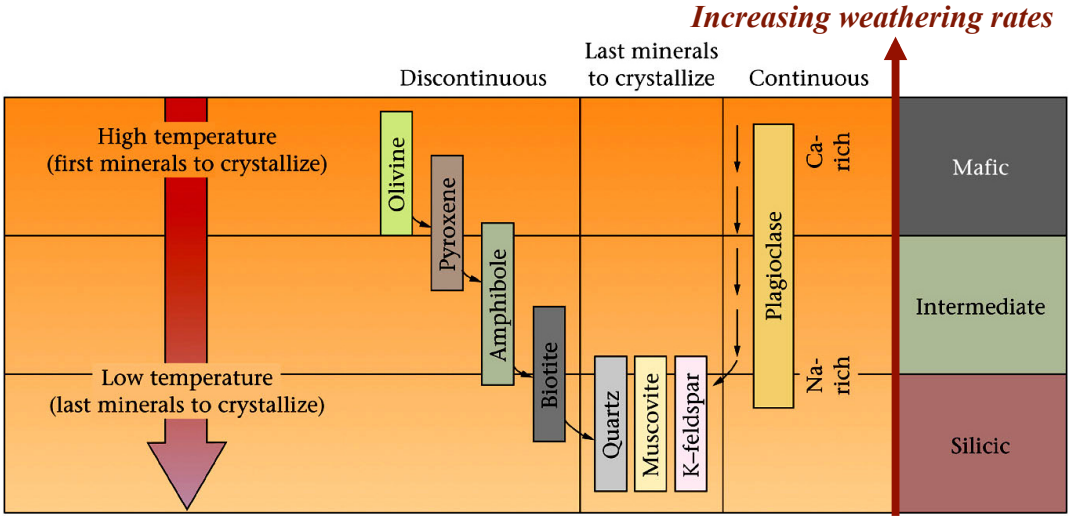
Note that minerals that form early in Bowen's reaction series (see Box 6.1) are among the least stable minerals at the Earth's surface. Minerals that are the products of weathering reactions (e.g., hematite) are among the most stable minerals at the Earth's surface. Mafic minerals weather by oxidation, felsic minerals by hydrolysis, and carbonates and salts by dissolution; oxide minerals don't weather at all.



Leg 192, Ontong Java Plateau, Site 1184

Chemical Weathering

Common mineral stability is the reverse of Bowens Reaction Series.



Chemical Weathering

Olivine [$(Mg,Fe)_2SiO_4$] weathers very quickly – it is not present in sediments, soils, or sedimentary rocks.

Quartz is very resistant to chemical weathering; it is a major constituent of mature sediments.

Weathering Products of Common Rock-Forming Minerals

Original Mineral	Under Influence of CO_2 and H_2O	Main Solid Product		Other Products (Mostly Soluble)
Feldspar	→	Clay mineral	+	Ions (Na^+, Ca^{++}, K^+), SiO_2
Ferromagnesian minerals (including biotite mica)	→	Clay mineral	+	Ions (Na^+, Ca^{++}, K^+, Mg^{++}), SiO_2, Fe oxides
Muscovite mica	→	Clay mineral	+	Ions (K^+), SiO_2
Quartz	→	Quartz grains (sand)		
Calcite	→	—		Ions (Ca^{++}, HCO_3^-)

Typical weathering patterns:

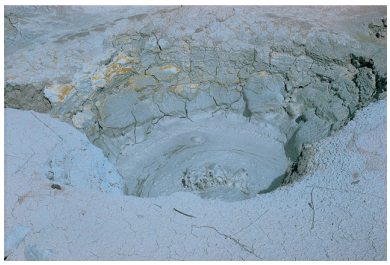
Feldspars → clay minerals, salts (change of structure).

Fe-Mg silicates → Fe oxides, Mg salts, clay minerals.

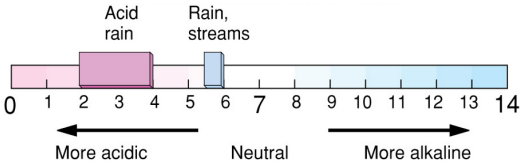
Quartz = stable.

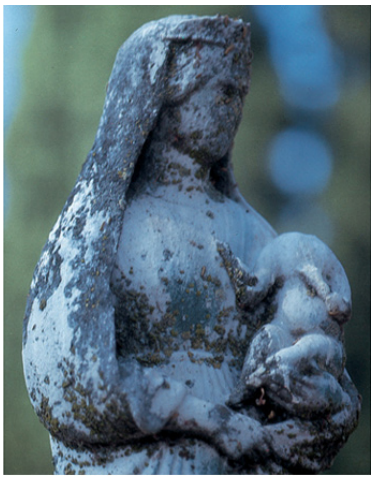
Chemical Weathering

Acids: around volcanoes (HF, H_2SO_4, HCl); carbonic (natural), pH 5.5-6. Run off from mines.



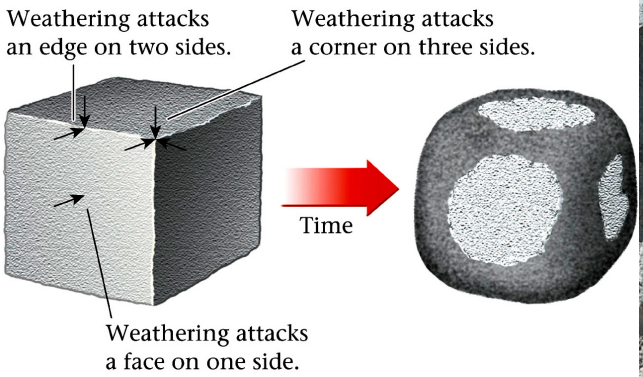
Acid rain – pH down to 2!



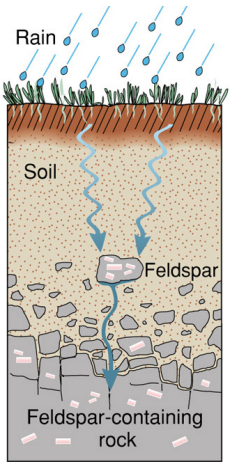


Physical & Chemical Weathering

Spheroidal Weathering



From Weathering to Soils

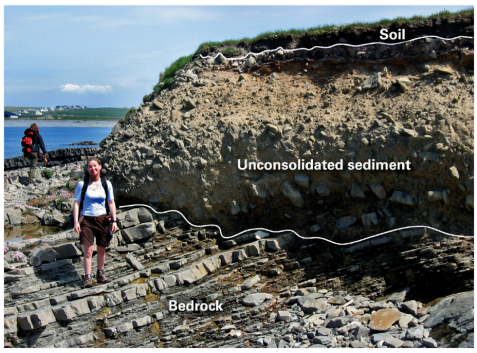


Rain picks up CO_2 from the atmosphere and becomes acidic

Water percolating through the ground picks up more CO_2 from the upper part of the soil, becoming more acidic

A rock particle containing a feldspar crystal, loosened from the rock below, slowly alters to a clay mineral as it reacts with the acidic water

The water carries away soluble ions and SiO_2 to the ground-water supply or to a stream



Soil Development

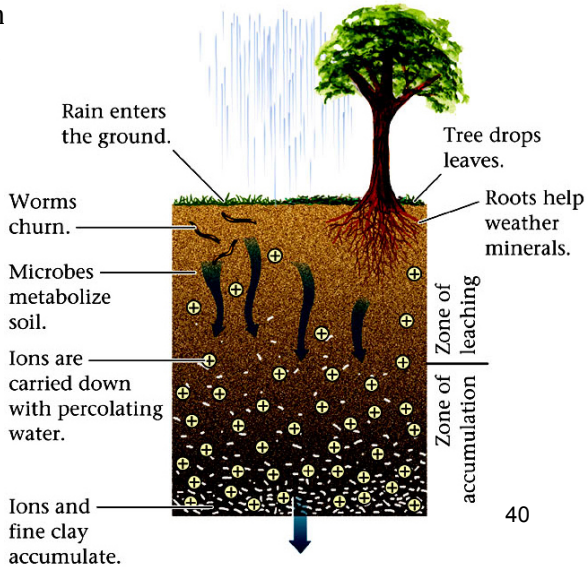
Soil: weathered sediment, often with an organic content and capable of supporting plants.

Geologists = weathered unconsolidated material on top of bedrock.

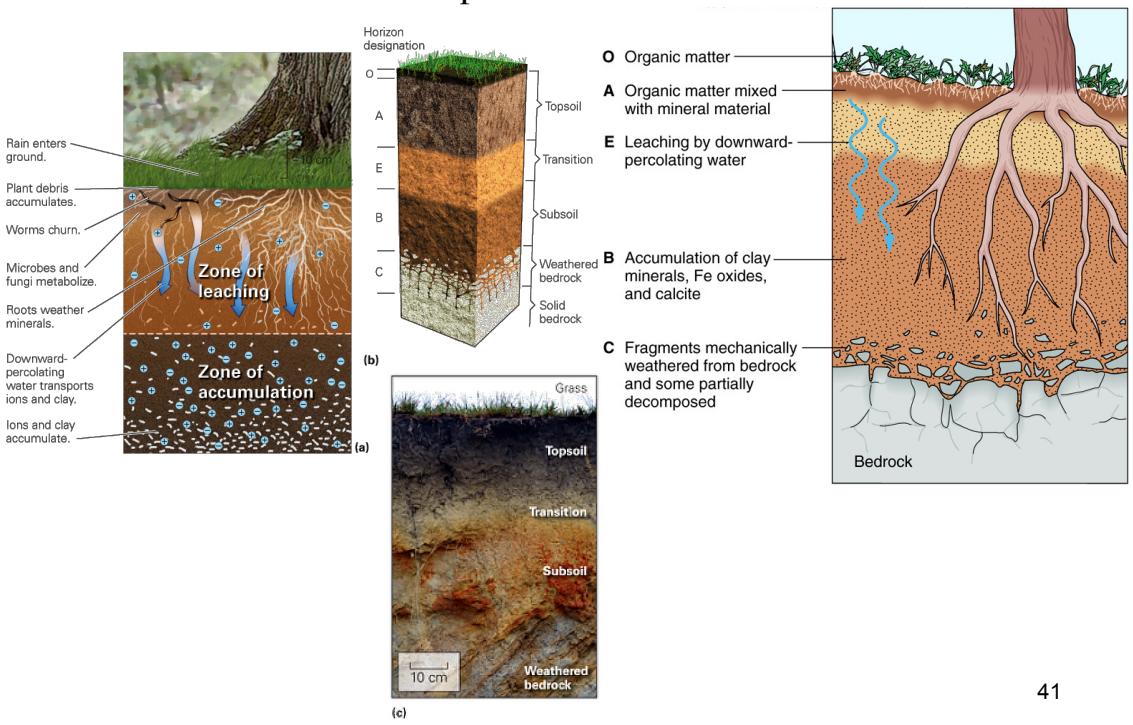
Soil Scientists = weathered material containing organic material and capable of supporting plant life. If this strict term is used, then unconsolidated sediment = **Regolith**.

Contains ~45% weathered rock with humus (bacterial decay of organic matter, dark color, enriched in carbon).

Soil may be residual (formed in place) or transported (water, wind, gravity, ice).



Soil Horizons: O (organics = humus), A, B, C. Boundaries usually transitional rather than sharp.



Soil Horizons

O-Horizon: thin, few cms, organic matter, lower part is decayed to humus.

A-Horizon: groundwater percolates down and removes solubles, contains more organic matter than B and C. Dark humus layer at top. May be light and sandy with clays, Fe-oxides, and carbonates at the base.

E-Horizon: Transition between A and B horizons.

O+A = Topsoil; O+A+E = *Zone of leaching*.

B-Horizon: Sub-soil, ***Zone of Accumulation*** of material leached down from A. Red/brown/grey. May contain soluble minerals, but little organic material.

C-Horizon: mixture of soil and bedrock. Bedrock attacked by acids, frost action, roots from above. Transitional.

Soil Horizons

Arid = larger A and B horizons.
Humid = smaller A and B horizons.

Loam: soil of equal amounts of sand, silt, and clay.
Topsoil: fertile area.
Sub-soil: more stony and less fertile, lacks organics.

Factors Controlling Soil Formation

ORGANIC ACTIVITY: Required to develop humus. Vegetation type also - different kinds of plants extract different nutrients and have different root systems.

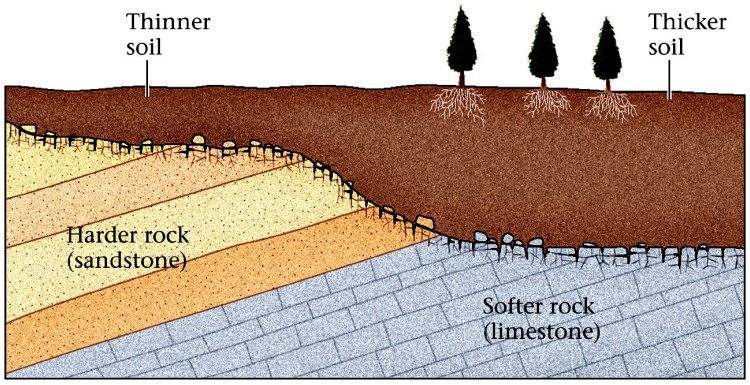
DRAINAGE: Soils formed from saturated sediment tend to have more organic material. Depends on depth to water table and slope.

Factors Controlling Soil Formation

CLIMATE: Most important.

Tropics = thick soils, heavily leached, intense chemical weathering.

Arctic + desert: thin soils that contain soluble material & large component of mechanically weathered debris.



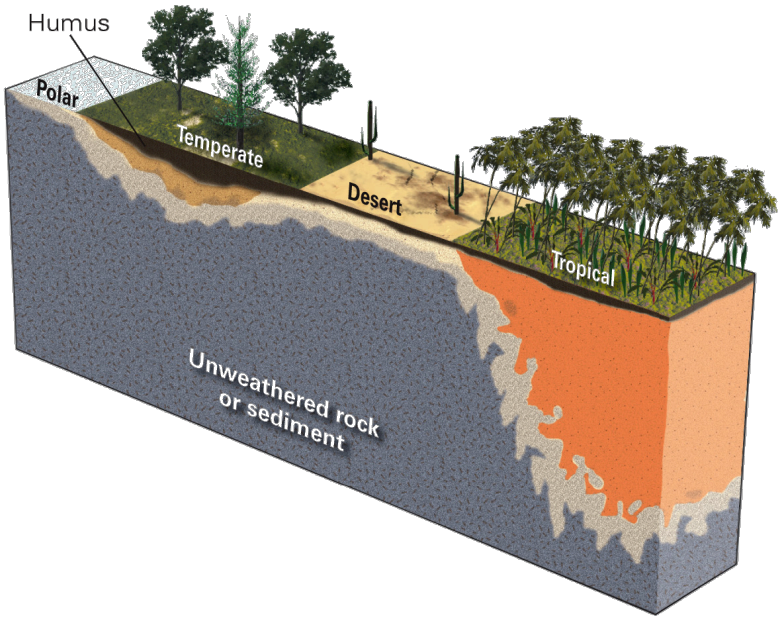
PARENT MATERIAL:

Same rock type = different soils depending upon climate.

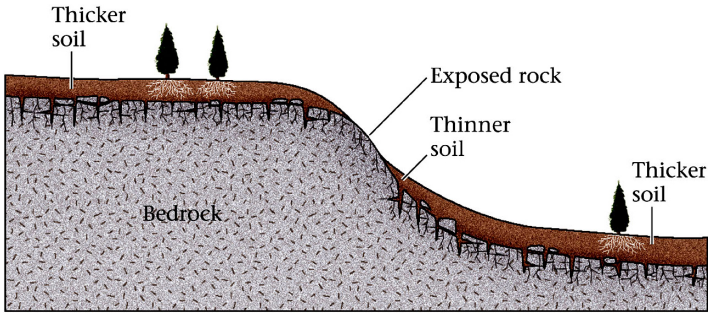
Rock type – granite = deep soils, quartzite thin soil, basalt = dark soil, rich in Fe oxides.

Factors Controlling Soil Formation

Climate and vegetation

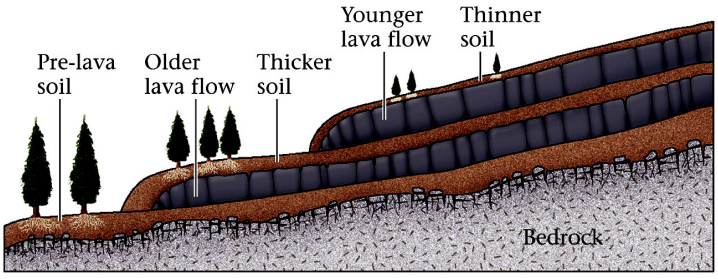


Factors Controlling Soil Formation



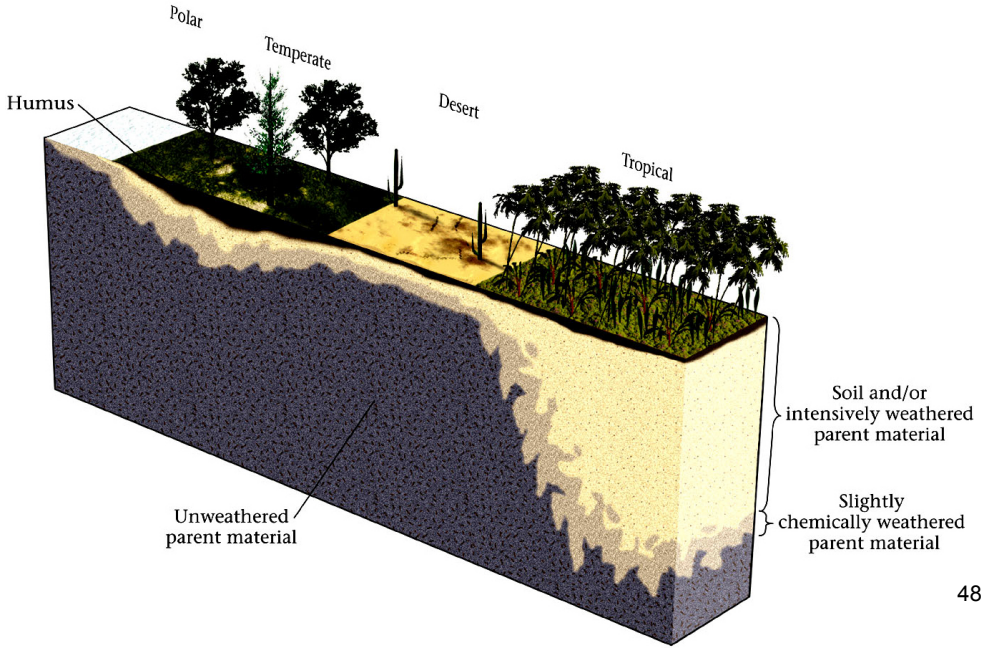
TOPOGRAPHY: Soil development is difficult when topography is steep.

TIME: Typical development = 2.5 cm/100 yrs. to 2.5 cm/1,000 yrs.

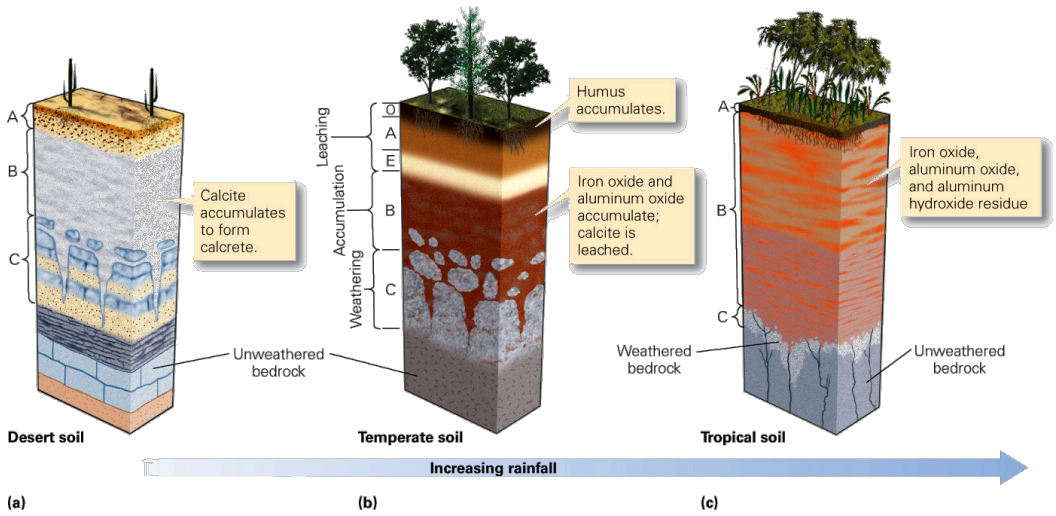


Factors Controlling Soil Formation

LATITUDE: Soil thickness varies with latitude, because of variations in temperature, rainfall, and vegetation.



Example Soils



SOIL TYPES

PedAlFer (Alfisol)

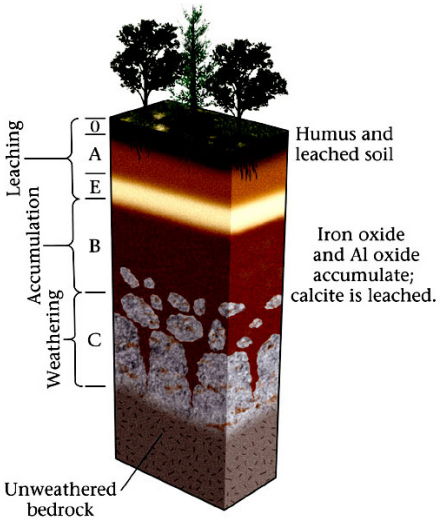
Formed in temperate/humid climates beneath forests.

A Horizon: Al & Fe rich (Fe oxides and clays). No soluble materials.

Leached material accumulates in the B Horizon.

Requires ≥ 25" rain per year.

East of Texas, most of Canada.



SOIL TYPES

PedoCal (Aridisol)

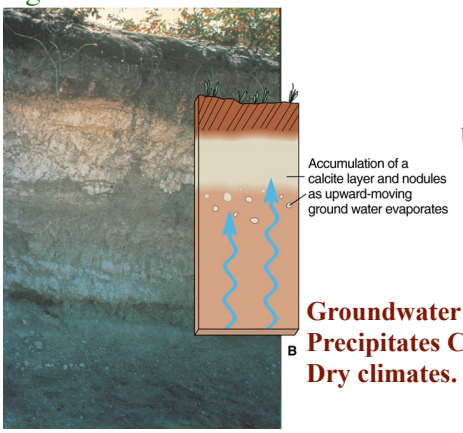
Found in deserts. A Horizon is thin.

Rich in Calcite: ***Caliche*** sometimes forms – ppt of Ca salts (calcite).

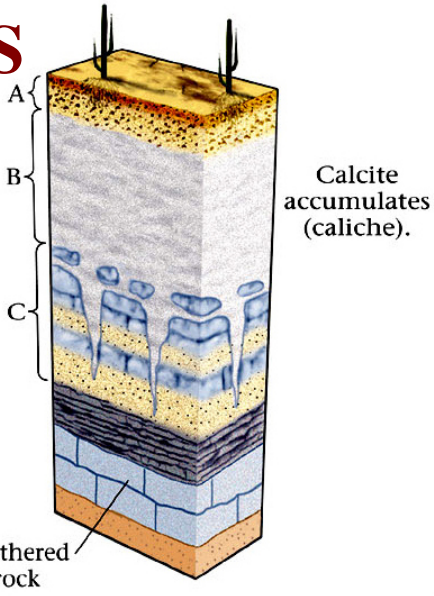
$CaCO_3$ & $MgCO_3$ concentrated in the B Horizon.

HARDPAN – difficult to drill through – cemented clays in humid climate, caliche (calcrete) in arid.

Upward migration of water causes salt to form at top.



Groundwater evaporates.
Precipitates $CaCO_3$.
Dry climates.



SOIL TYPES

Laterite ("oxisol")

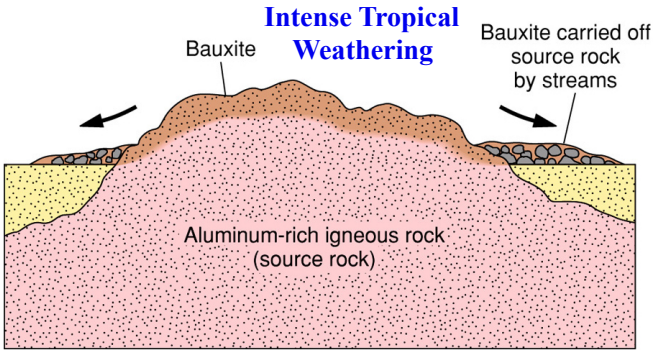
Hydrated Al and Fe silicates.

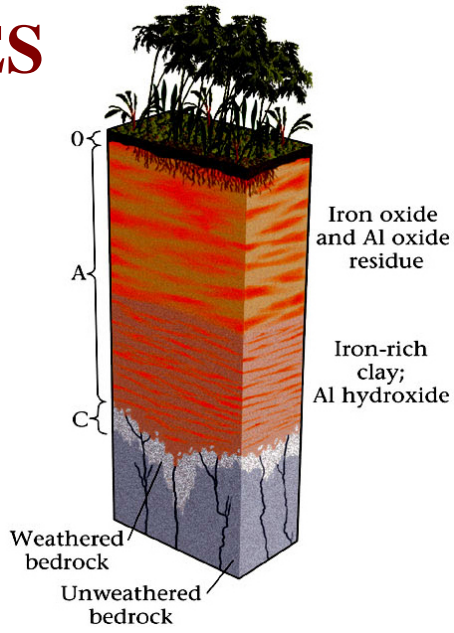
A, B, C Horizons difficult to distinguish.

Intense leaching – high rainfall = tropics.

Bauxite – $Al(OH)_3$ can accumulate.

Fe-rich clays at depth.





Environmental: Loss of Soil

Deforestation.

Figure 5.27
Soil erosion caused by clear cutting of rain forest, north of Kuantan, Malaysia.

Over farming

Environmental: Loss of Soil

Nutrient removal

Soil erosion