

Weathering and soils

Origin of sedimentary materials

- Weathering plays a critical role in generating the constituents that make up sediments and sedimentary rocks
- **Weathering**: the physical disintegration and chemical decomposition of older rock to produce solid particulate residues and dissolved chemical substances

However...

- Weathering can be bypassed and **mechanical erosion** can remove substantial volumes of fresh, unweathered rock

Weathering processes

- Some minerals are completely dissolved, whereas more chemically stable minerals accumulate as residues
- New minerals (e.g. iron oxides, clay minerals) may form *in situ*
- Weathering processes are significantly influenced by climatic conditions

Physical (mechanical) weathering

- The process by which rocks are broken into smaller fragments without significant change in chemical or mineralogical composition
 - Freeze-Thaw weathering (frost action)
 - Wetting and drying
 - Stress-release weathering
 - Biologic factors

Freeze-Thaw weathering

- Water → ice = 9% increase in volume
 - Enough pressure in fractures to crack most rock types
 - Repeated freeze-thaw cycles are necessary to disintegrate a rock mass
 - Slow process
- Produces large, angular blocks of rock
 - The internal fracture network exerts an important control on the resulting size and shape of fragments
- Mechanically weak rocks (e.g. shale) tend to disintegrate more readily...

Frost weathering

Felsenmeer or block-field



Northern Manitoba



Austria

Role of pre-existing joints



Nunavut

Exfoliation (pressure release)



Source: The University of Iowa (RG Baker)

Exfoliation (pressure release)

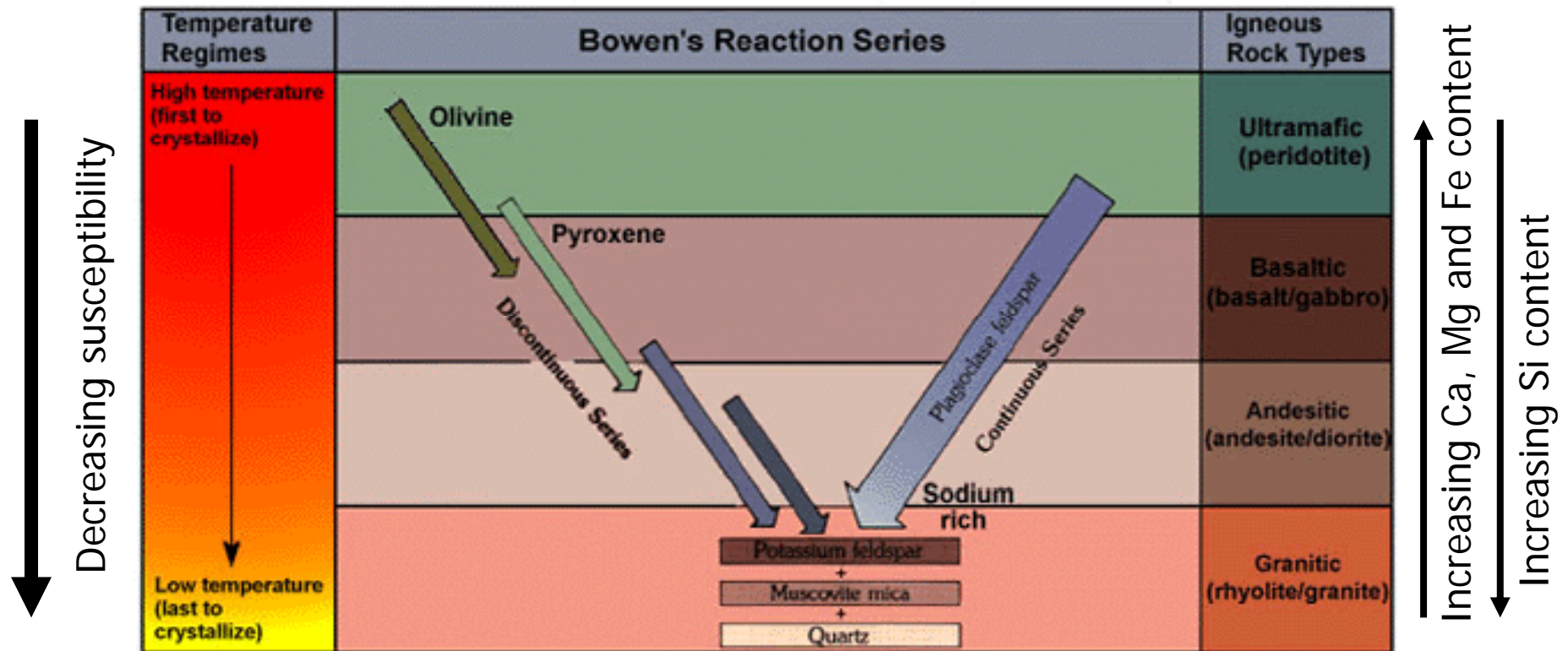


Weathering and sediment river load

- Physical weathering **high** and chemical weathering **low**:
 - **Primary minerals** and **rock fragments** contribute substantially to the river load
 - Sand-size fraction: quartz, feldspars, pyroxene, hornblende)
 - Fine fraction: quartz, feldspars, calcite and dolomite, clay minerals (e.g. chlorite)
 - **Carbonate minerals** indicate absence of deeply weathered soils in parts of the drainage area (common in regions of high relief or arid conditions; e.g. Nile, Mackenzie, Himalayan rivers)

Chemical weathering

- Rocks are stable in the environment in which they form and unstable in any other
- Mineral stability is inversely proportional to the temperature at which they formed



The role of water

- Water is the principal agent of chemical weathering
- H^+ and OH^- ions in water react with minerals
 - Some constituents dissolve and sometimes recombine *in situ* to form new mineral phases
 - Produce a loose residue of resistant grains and secondary minerals
- Low temperature and very slow process

Neo-mineral group

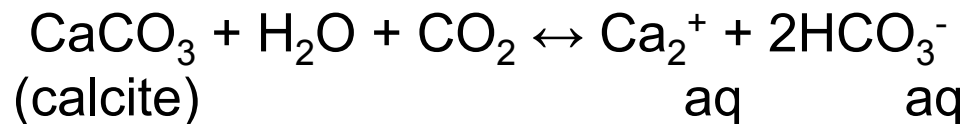
- Temperate to sub-tropical climates
 - Montmorillonite/smectite types
- Humid temperate climate
 - Illite/muscovite type
- Semi-arid to tropical climates
 - Kaolinite and gibbsite
 - Iron oxide goethite
 - Humid conditions (goethite)
 - Semi-arid to subtropical climate (hematite)

Simple (congruent) solution

- Pure water is a poor H^+ donor
- However, CO_2 dissolves in water to produce carbonic acid
 - Solubility of CO_2 is inversely proportional to water temperature
- Solution potential is enhanced through carbonation

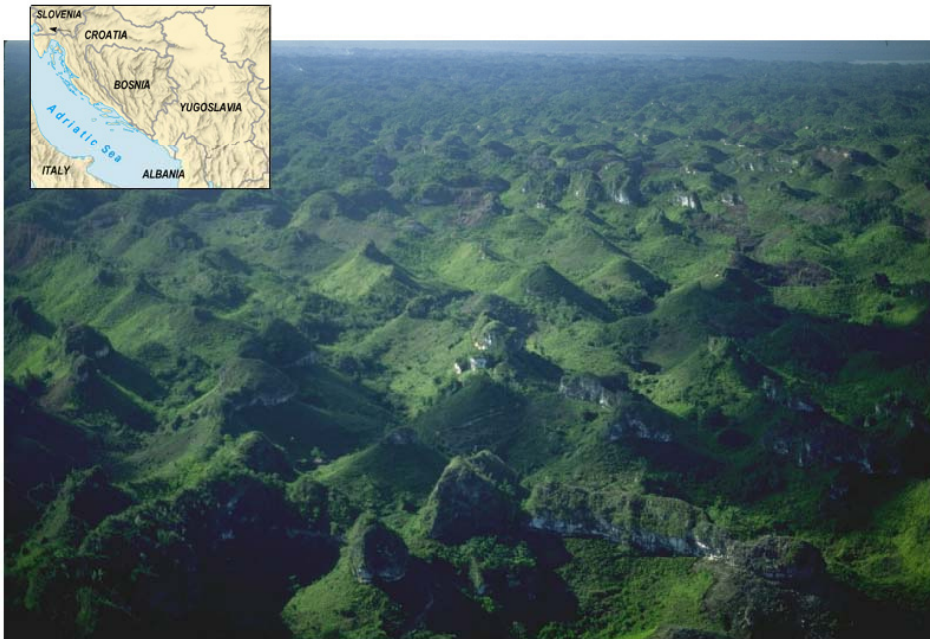


- Biogenic CO_2 (decay of humus) is the major source of carbonated groundwater
- **Carbonation** is a common form of chemical weathering, particularly of limestone



- Results in karst topography

Karst topography



West Virginia

Chemical denudation

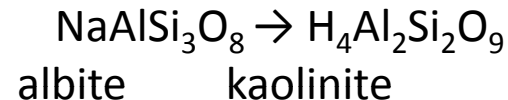
- **Carbonate rocks**
- Most of the carbonate dissolution takes place near the surface (exokarst and epikarst)
 - Carbonate denudation rates controlled by
 - Vegetation cover
 - Type and thickness of soil
 - CO₂ production by decomposing organic matter
 - Dense vegetation (green karst)
 - High effective precipitation (tropical zone, some mountainous areas)
 - Denudation rates = 50 – 150 mm/ka
 - Temperate climate and medium rainfall
 - DR = 20 – 50 mm/ka

Hydrolysis

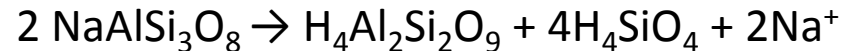
- Hydrolysis involves reactions between H^+ and OH^- ions with minerals and is important, for example, in the weathering of granite containing plagioclase feldspar, yielding soluble cations, silicic acid and the clay mineral kaolinite (by-product)
 - H^+ ions are commonly supplied by the dissociation of carbonic acid in water
 - The more CO_2 in water, the more aggressive the hydrolysis reaction

Transformation of plagioclase feldspar to kaolinite

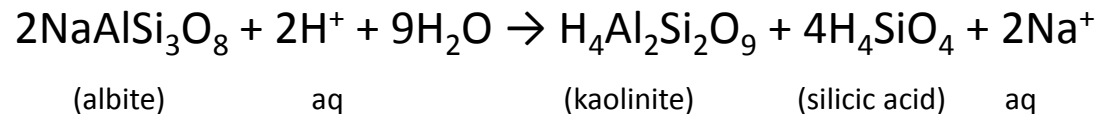
- We must first write the equation that represents this reaction:
- We start by writing down the known reactant and its product



Next, we balance Al and then take care of Na and Si



We now have **16 oxygens** on the left and **25 oxygens** on the right. Also, we have **0 hydrogen** on the left and **20 hydrogens** on the right. Therefore, we add $9\text{H}_2\text{O}$ and two H^+ to the left side of the equation to balance oxygen and hydrogen.

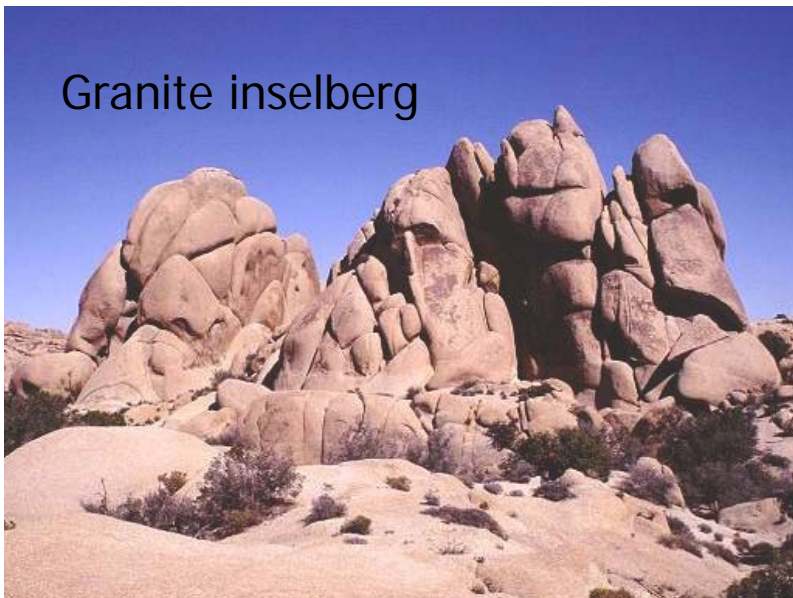


The equation is balanced in all respects and also satisfies the requirement for electrical neutrality with two positive charges on each side.

Favorable natural conditions

- Reactions in nature may not achieve equilibrium if one product escapes from the system
 - This could occur if Na^+ and H_4SiO_4 are removed by the movement of the water in which the reaction is taking place
 - Therefore, the conversion of Na-feldspar to kaolinite is favored by the **movement of groundwater** or surface water in response to a **hydraulic gradient**
 - We also note that **9 moles of water are consumed** for each mole of kaolinite that is produced
 - Therefore, the formation of kaolinite is favored by an abundance of water, which, in addition, must be acidic to provide the H^+ needed by the reaction
 - Also, the reaction rates generally double for every 10°C in temperature
- The formation of kaolinite is favored by tropical humid climatic conditions such as near the equator ($P \gg E$)**

Weathered granite

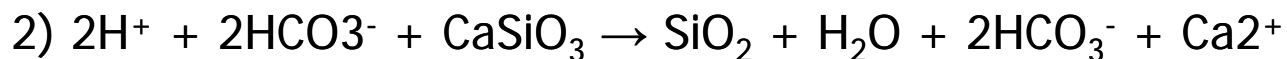
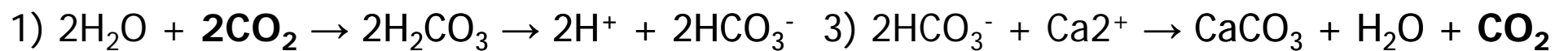
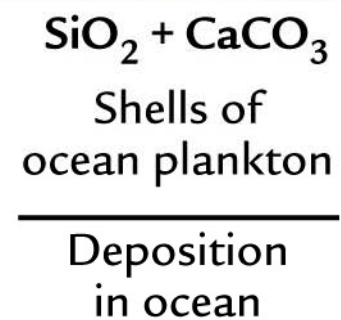
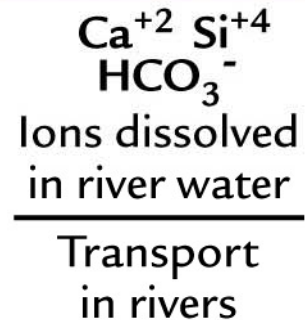
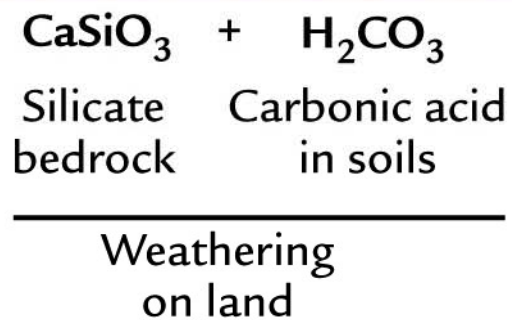
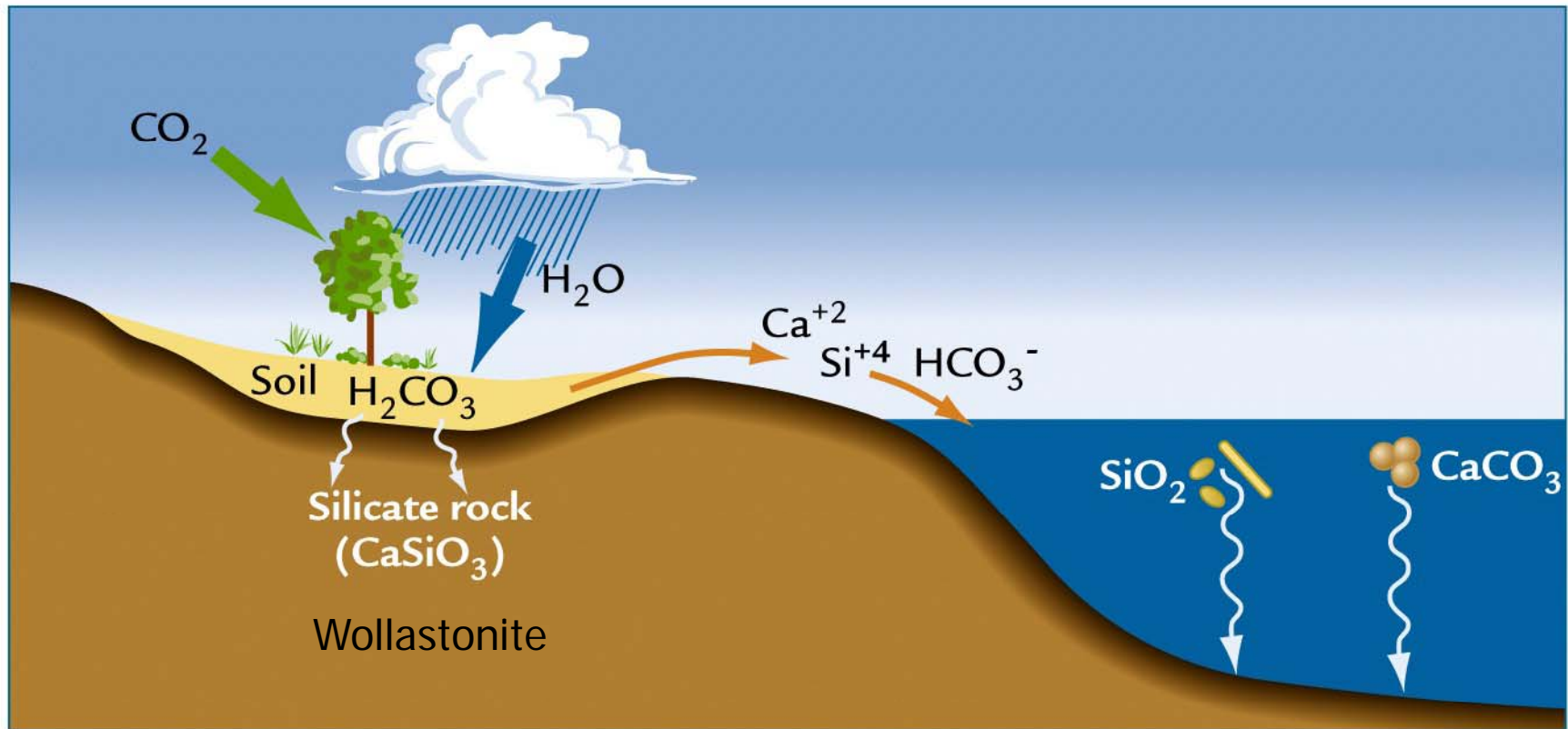




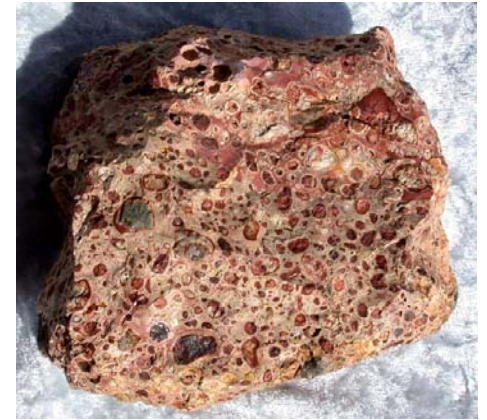
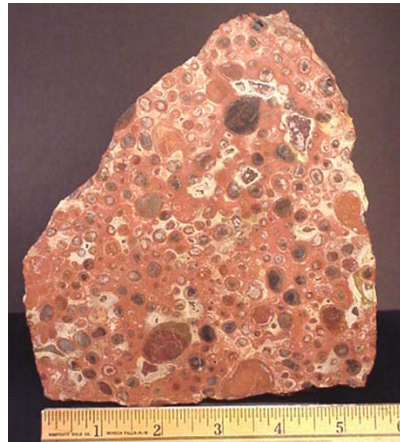
Kaolinite



Kaolinite, Mojave County, Arizona

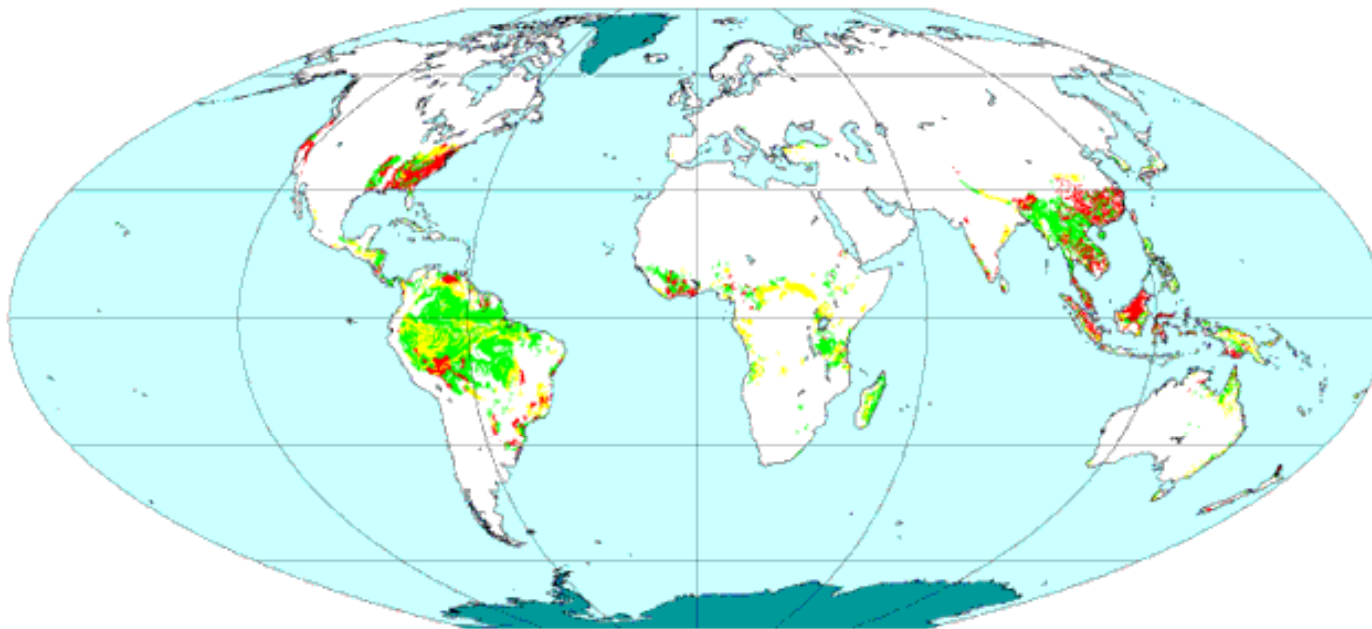


Ferricrust (laterite) and Bauxite



World distribution of lateritic soils (Acrisols)

Distribution of ACRISOLS
Based on WRB and the FAO/Unesco Soil Map of the World



Acrisols worldwide
cover is about 1000
million hectares

■ Dominant ■ Associated ■ Inclusions ■ Miscellaneous lands
(Inland waterbodies, Glaciers, No data)

Flat Polar Quartic Projection

FAO-GIS, February 1998

Duricrust



Calcretes



A **duricrust** is a hard crust on the surface of, or layer in the upper horizons of, a soil that is formed as a result of climatic fluctuations in **arid** and **semiarid climates**. It is formed by the accumulation of soluble minerals deposited by mineral-bearing waters that move upward by **capillary action** and evaporate during the dry season

$$P < E$$

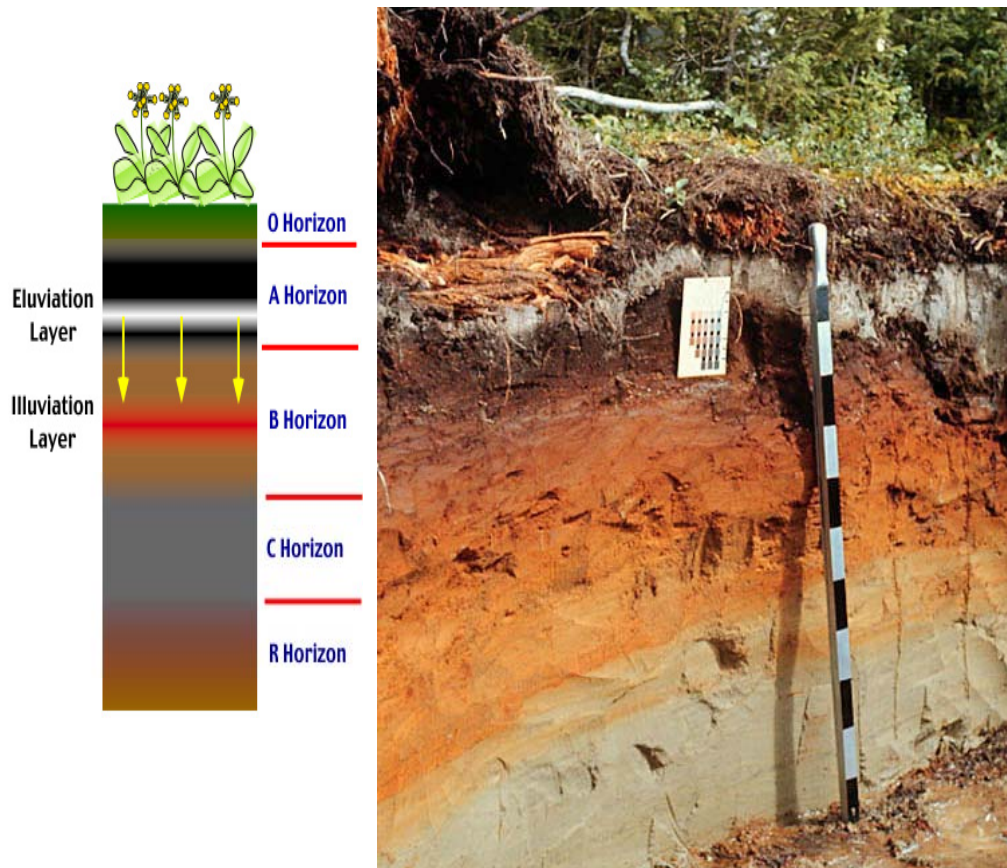
Vegetation is sparse

Infiltrated water can rarely percolate down to the water table

Cool and temperate conditions

- Under good drainage conditions and coniferous forest vegetation, organic litter decays slowly and acidic soil water transports Fe and Al hydroxides and organic matter downward by groundwater percolation (**eluviation**) and accumulate in a lower horizon (**illuviation**)
 - Formation of **podzols**
- Under conditions of poor drainage, a grey upper horizon develop indicative of reduced iron (Fe^{2+})
 - Formation of **gleysols**

Podzols and gleysols



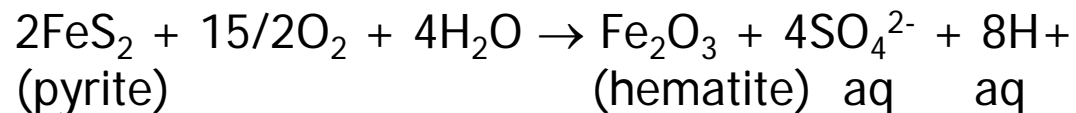
Podzols occur mainly in Russia, Siberia, and Canada
485 million hectares



About half of the **gleysols** of the world occur in sub-arctic areas of northern Russia, Siberia, and North America. The remaining areas occur mainly in humid temperate and lowland intertropical regions (720 million hectares)

Oxydation

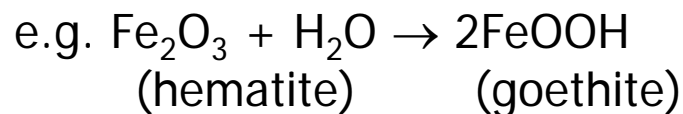
- Chemical alteration of iron and manganese in silicate minerals such as biotite and pyroxenes, and sulfur in pyrite, caused by oxygen dissolved in water
- Oxidation promotes weathering by changing a ferrous iron oxide (FeO) to its ferric form (Fe₂O₃), destabilizing the crystal lattice and requiring the compensating loss of another cation to maintain electrical neutrality



Fe and Mn-bearing silicate
Minerals, iron sulfides

Hydration/dehydration

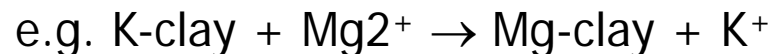
- The process whereby water molecules are added to a mineral to form a new mineral
- Hydration is accompanied by volume changes that may lead to physical disruption of rocks
- Under some conditions, hydrated minerals may lose their water, a process called dehydration, with accompanying decrease in mineral volume (uncommon)



Ferric oxides

Ion exchange

- A process whereby ions in a mineral are exchanged with ions in solution
- This reaction causes one mineral (e.g. smectite) to be altered to another mineral (e.g. illite) and, in the process, releases soluble ions into solution
- This process mainly affects clay minerals



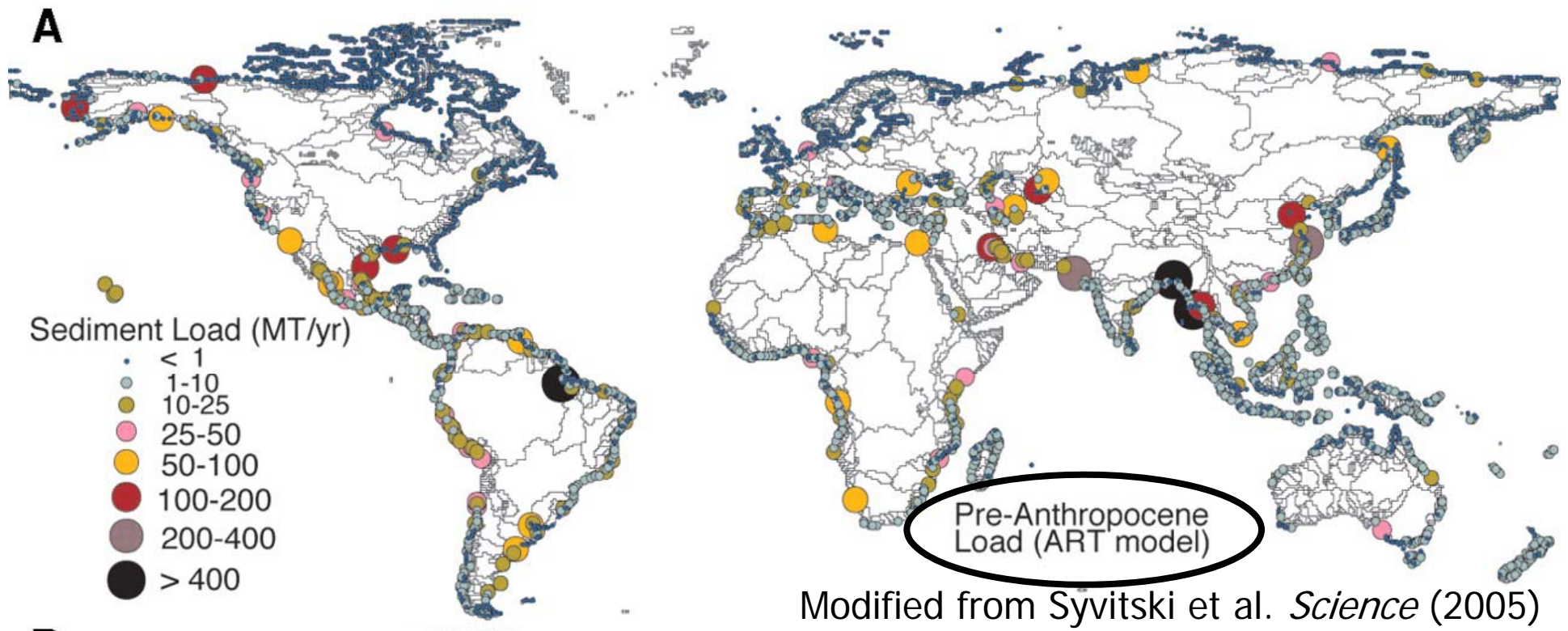
Chelation (organic complexing)

- It involves the bonding of metal ions to organic substances to form organic molecules having a ring structure
- Removes cations from mineral lattices and keeps them in solution
- Plants are natural chelating agents

Weathering and denudation

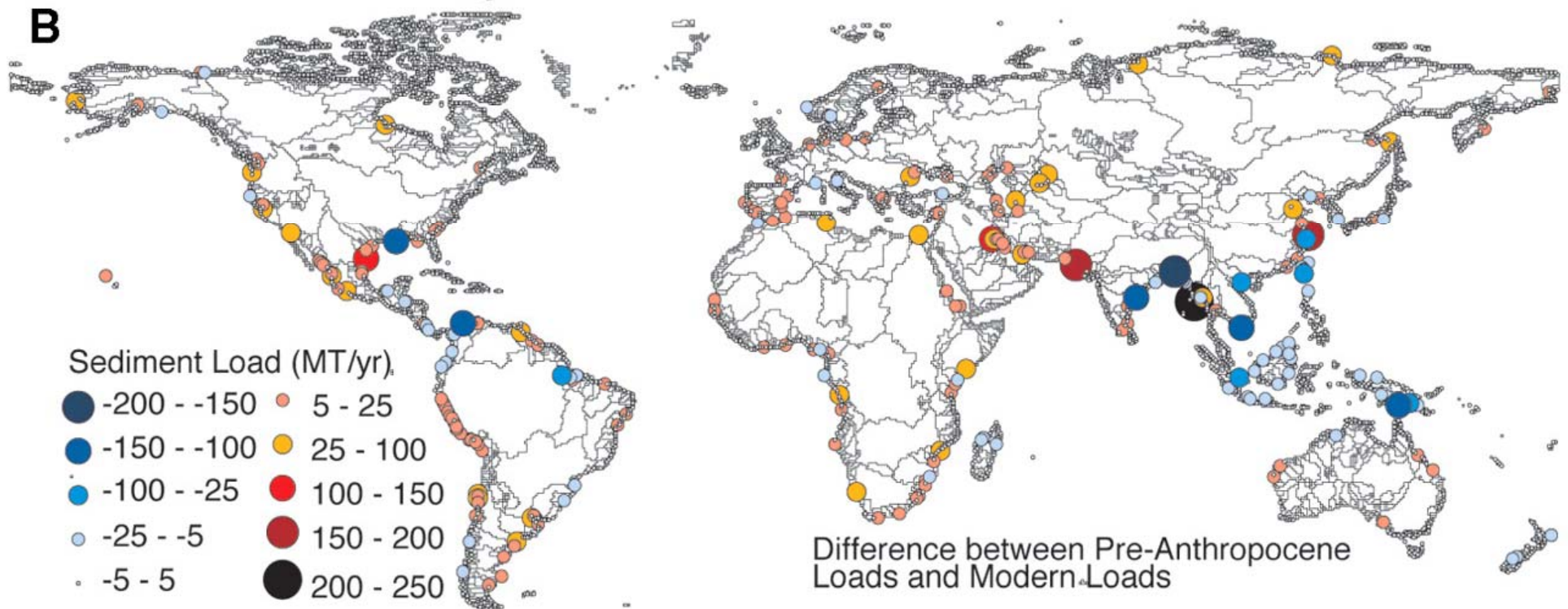
- Large quantities of sediment deposited in sedimentary basins are derived from land areas exposed to subaerial weathering
- Due to weathering and erosion, the land surface is slowly lowered (denudation)
 - Involves the transport of sediments into continental basins or into the oceans
 - Mass transfer controlled by a variety of physical, chemical and biological processes
 - Rainfall, surface run-off, river flow, wind, ice flow, groundwater flow

Solid load delivered to the oceans



Globally, the total river flux of suspended sediment to the oceans is 15 – 20 BT/a

Impact of humans



Modified from Syvitski et al. *Science* (2005)