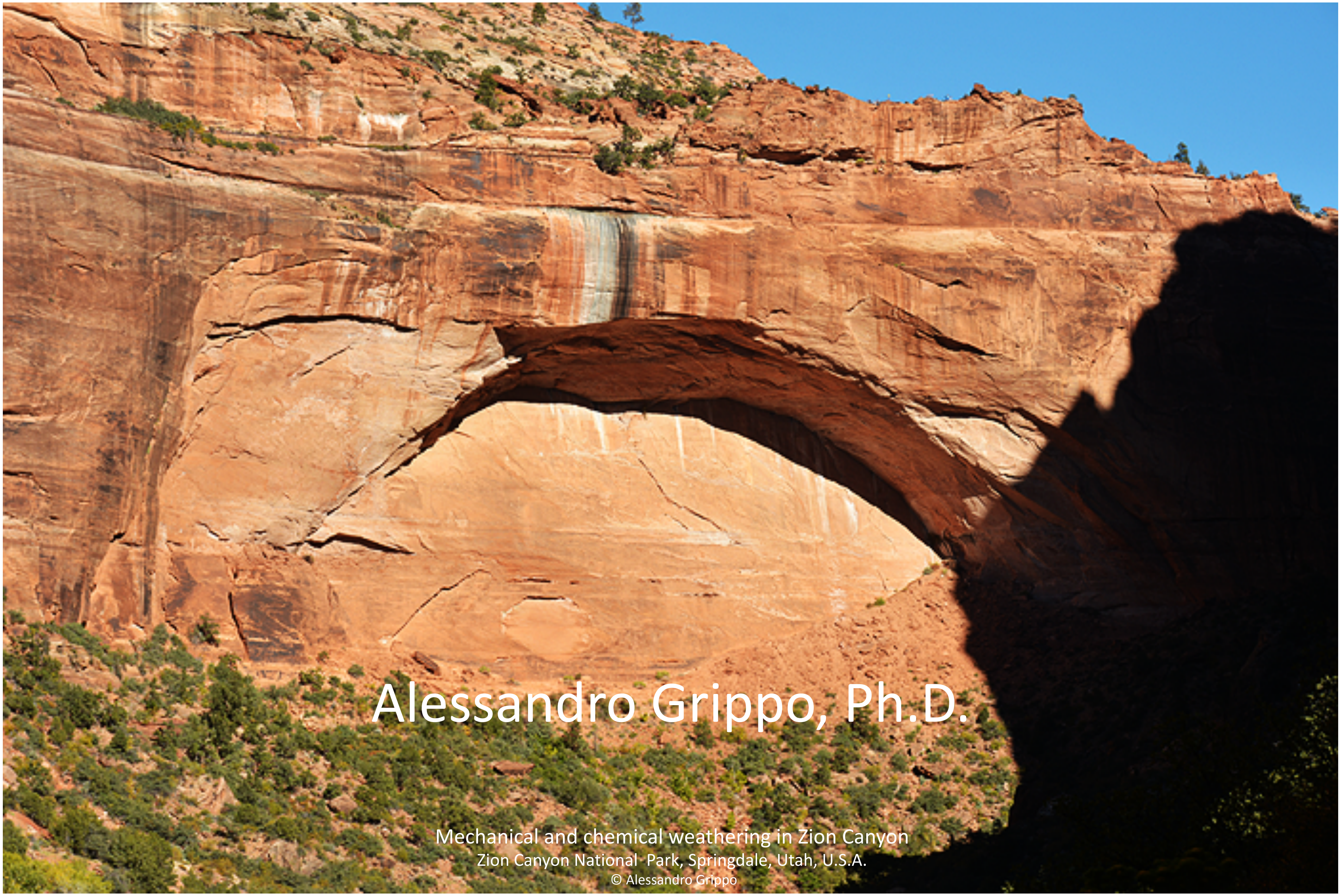
WEATHERING and SOILS



Weathering, Erosion, Transportation

- Rocks exposed at Earth's surface are *constantly changed* by water, air, temperature variations and other factors
- *Weathering* is the group of destructive processes that change physical and chemical character of rocks at or near Earth's surface
- *Erosion* is physical picking up of rock particles by water, ice, or wind
- *Transportation* is the movement of eroded particles by water, ice, or wind


CO 5

A

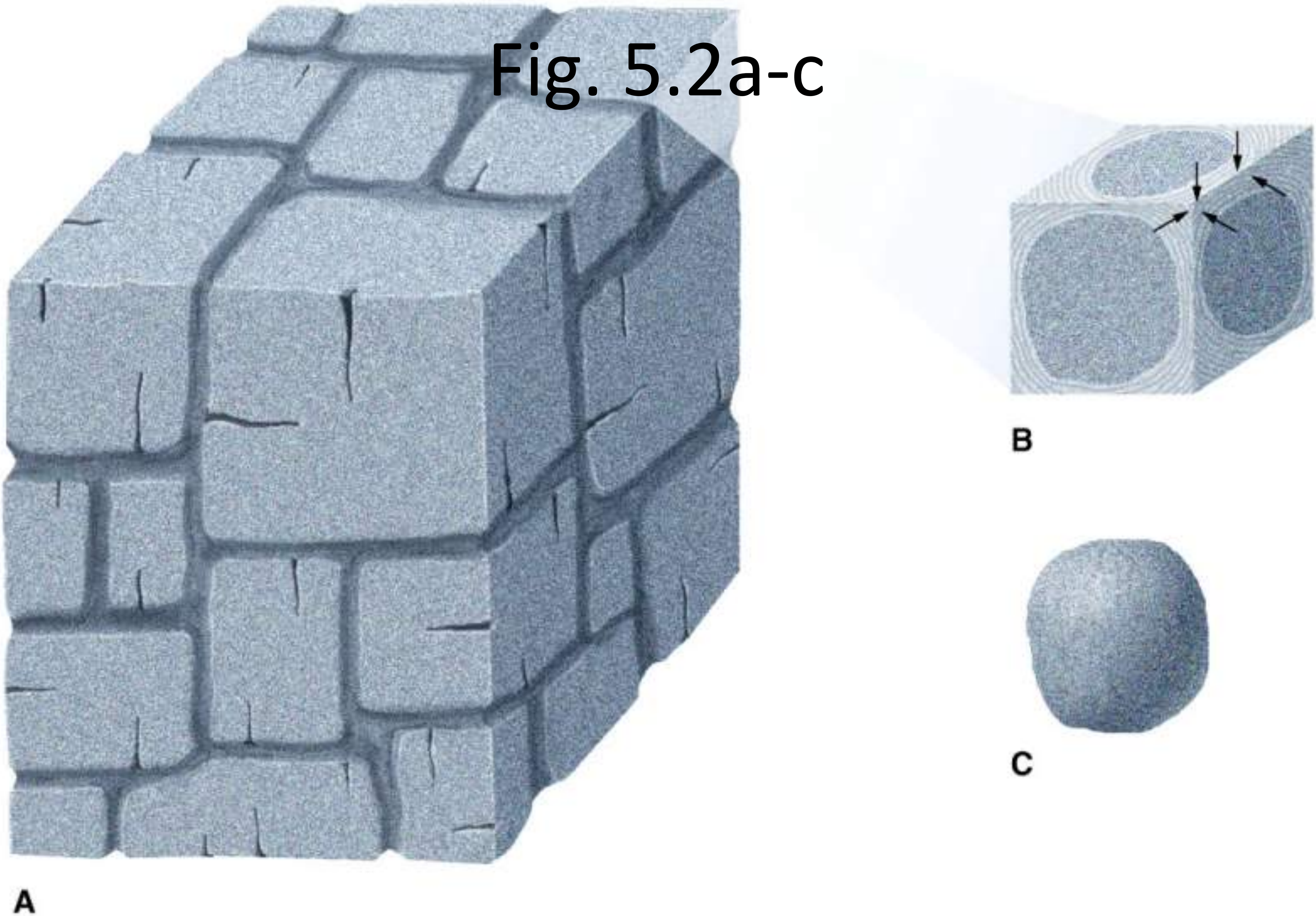
B

Weathering

- Weathering processes disintegrate or decompose rocks at or near the surface

- While different weathering processes might work at the same time, they can be broadly categorized in:
    - Mechanical (or Physical) Weathering processes
    - Chemical Weathering processes

Fig. 5.2a-c



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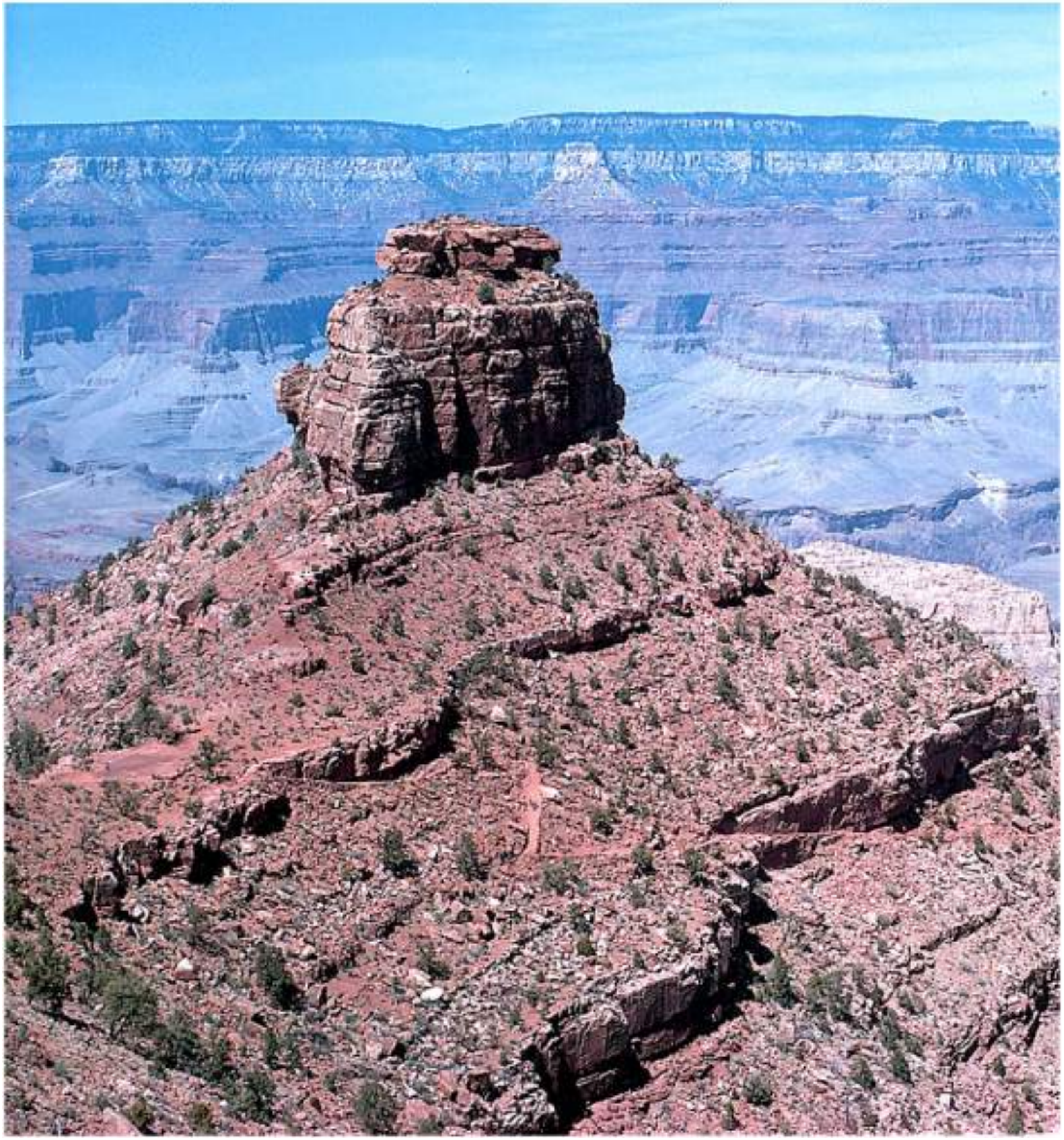


Weathering and Earth Systems

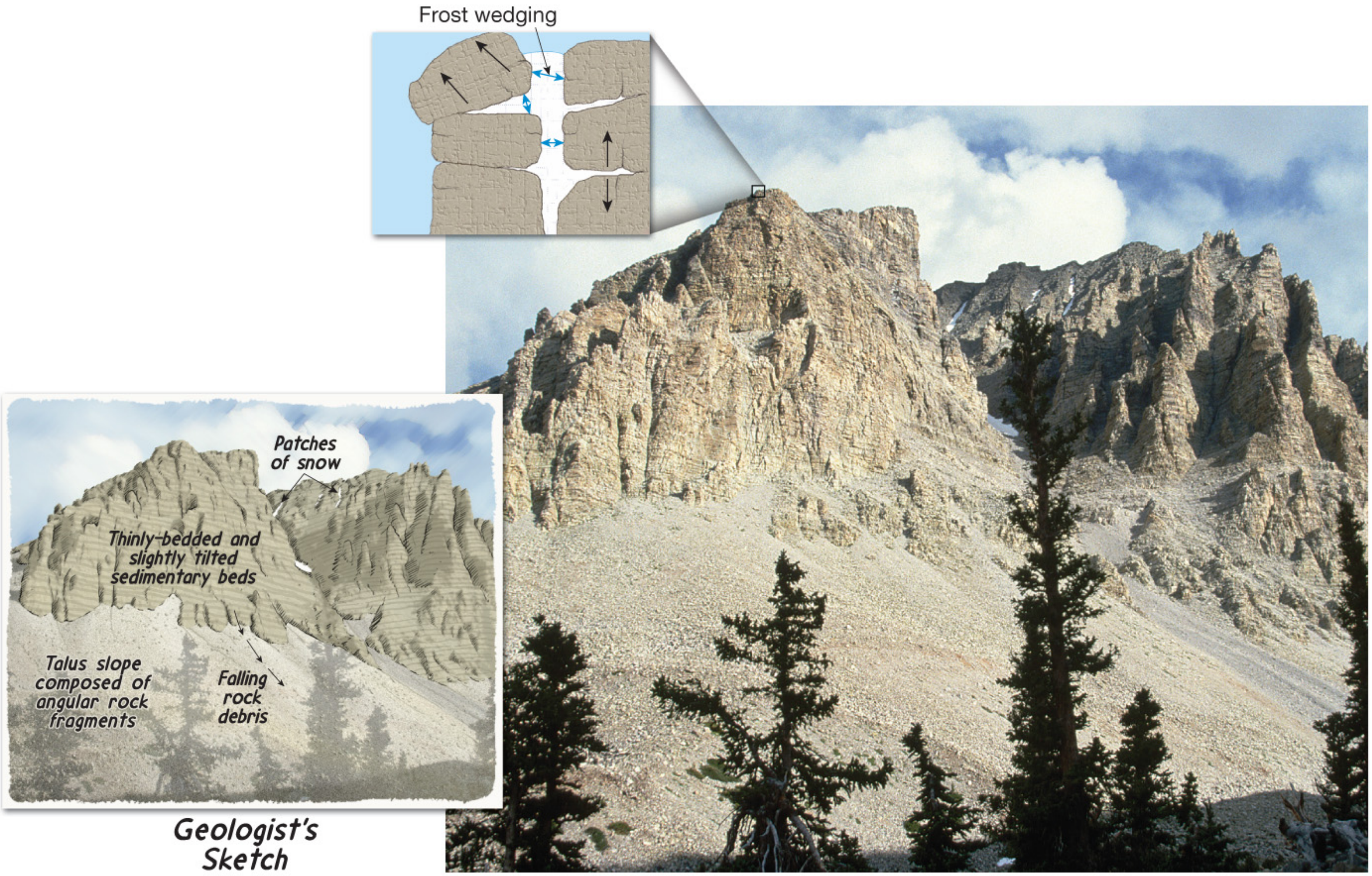
- *Solar system*
  - Earth-style weathering (water, ice, wind) is nearly unique to our planet, at present. Small amounts of weathering (primarily by wind) still occur on Mars, and water erosion appears to have been important there in the distant past.
- *Atmosphere*
  - Oxygen and carbon dioxide critical to chemical weathering
  - Water cycled through atmosphere is critical to chemical and mechanical weathering processes
  - Air in soils contributes to biological action that can produce chemical and mechanical weathering

Weathering and Earth Systems

- *Hydrosphere*
  - Water is necessary for *chemical weathering*
  - Oxygen dissolved in water *oxidizes iron* in rocks
  - Carbon dioxide dissolved in water creates *carbonic acid*
    - Primary cause of chemical weathering
  - Running water loosens and abrades particles
  - Glacial ice removes and abrades particles
  - Freeze/thaw cycling mechanically weathers
- *Biosphere*
  - Plant root growth widens cracks
  - Animal foot traffic and human activity mechanically weather
  - Decaying organic matter in soils produces acidic soil moisture

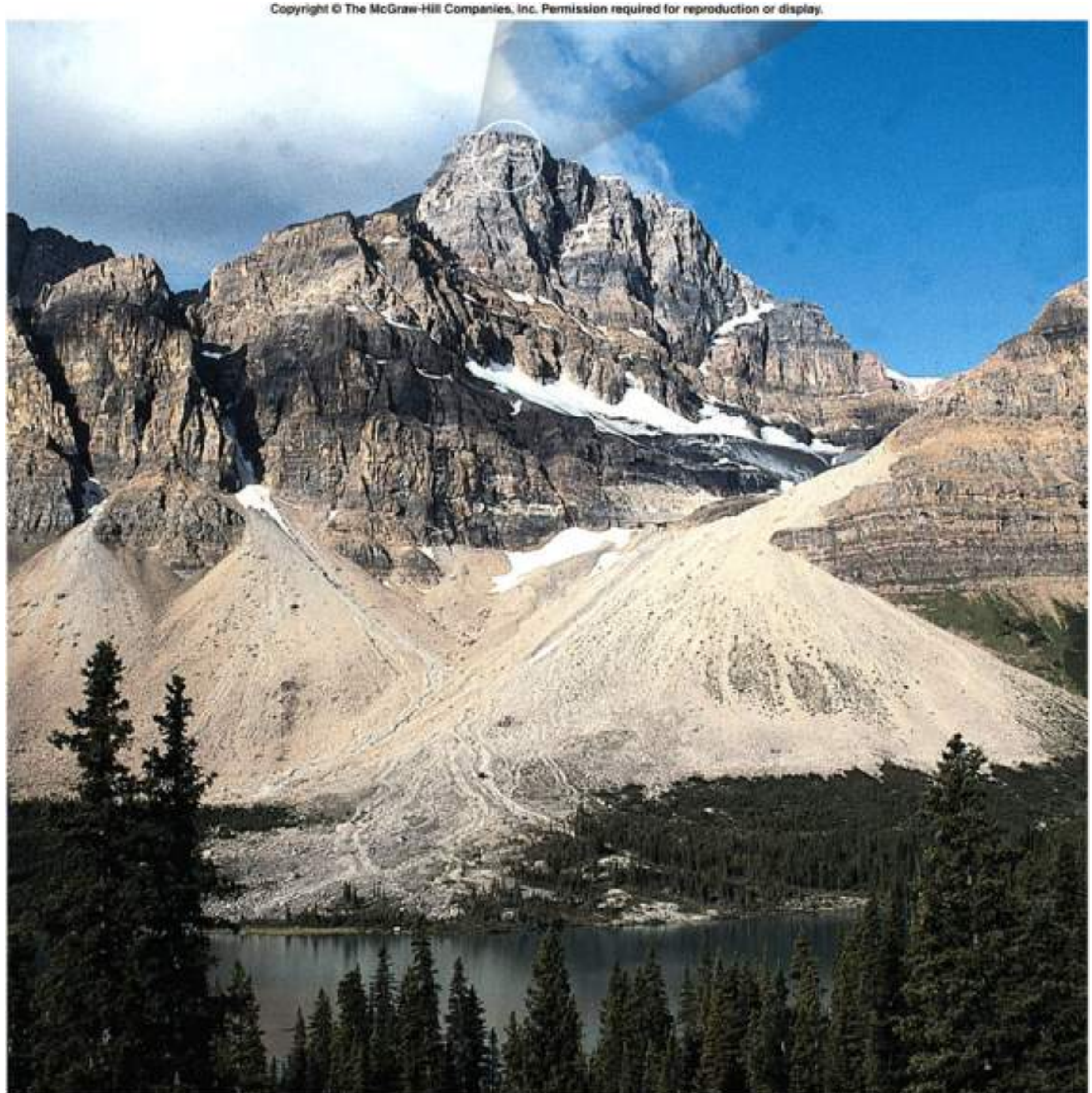
Mechanical (or Physical) Weathering

- Frost action (wedging)
  - Mechanic effect of freezing (and expanding) water on rocks
- Pressure release
  - Removal of overlying rock allows expansion and fracturing
- Biological action
  - Plants: Growing roots widen fractures
  - Animals: burrowing and breaking rocks
- Crystal growth
- Thermal shocks
  - Large temperature changes fracture rocks by repeated expansion and contraction



Frost wedging
Patches of snow
Thinly-bedded and slightly tilted sedimentary beds
Talus slope composed of angular rock fragments
Falling rock debris
Geologist's Sketch

A



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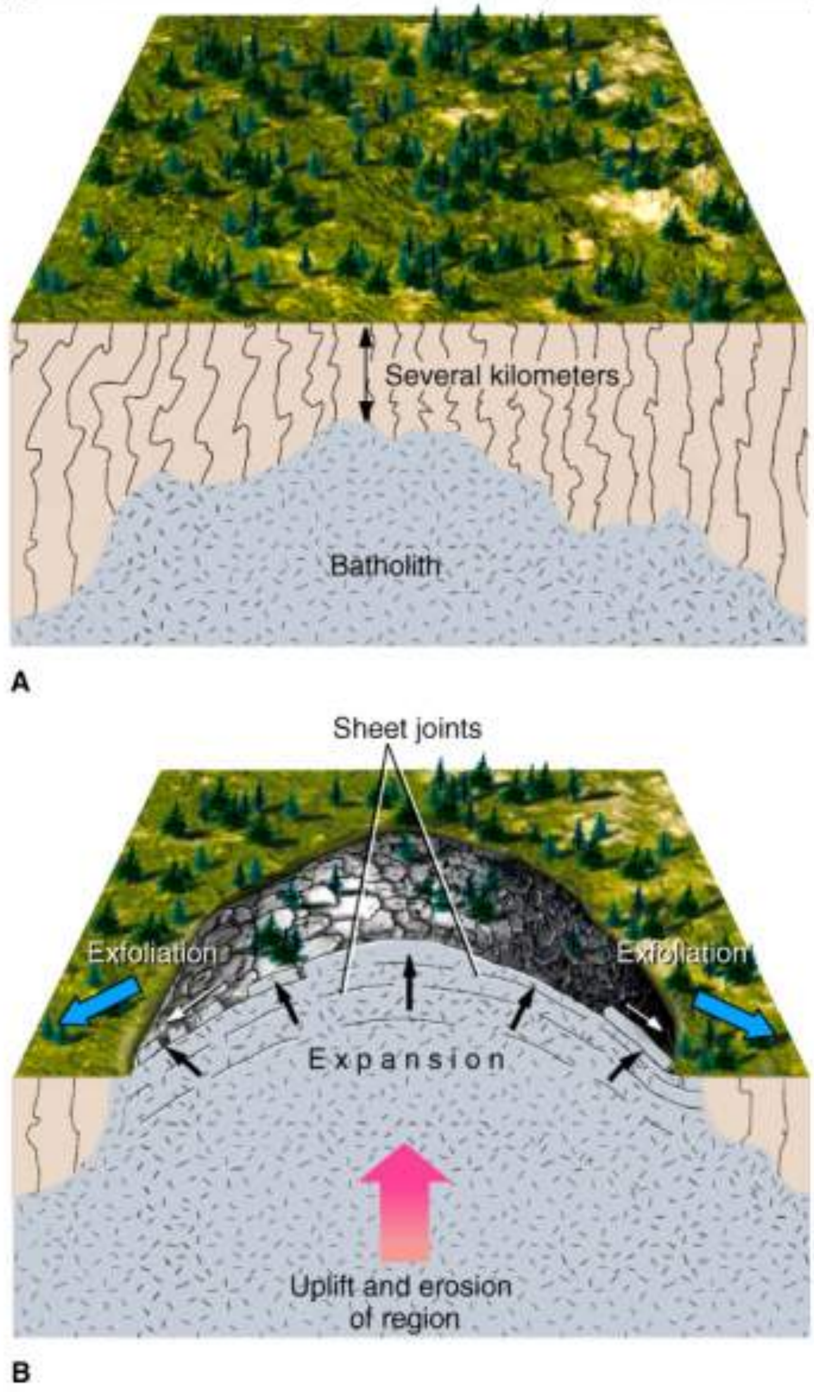
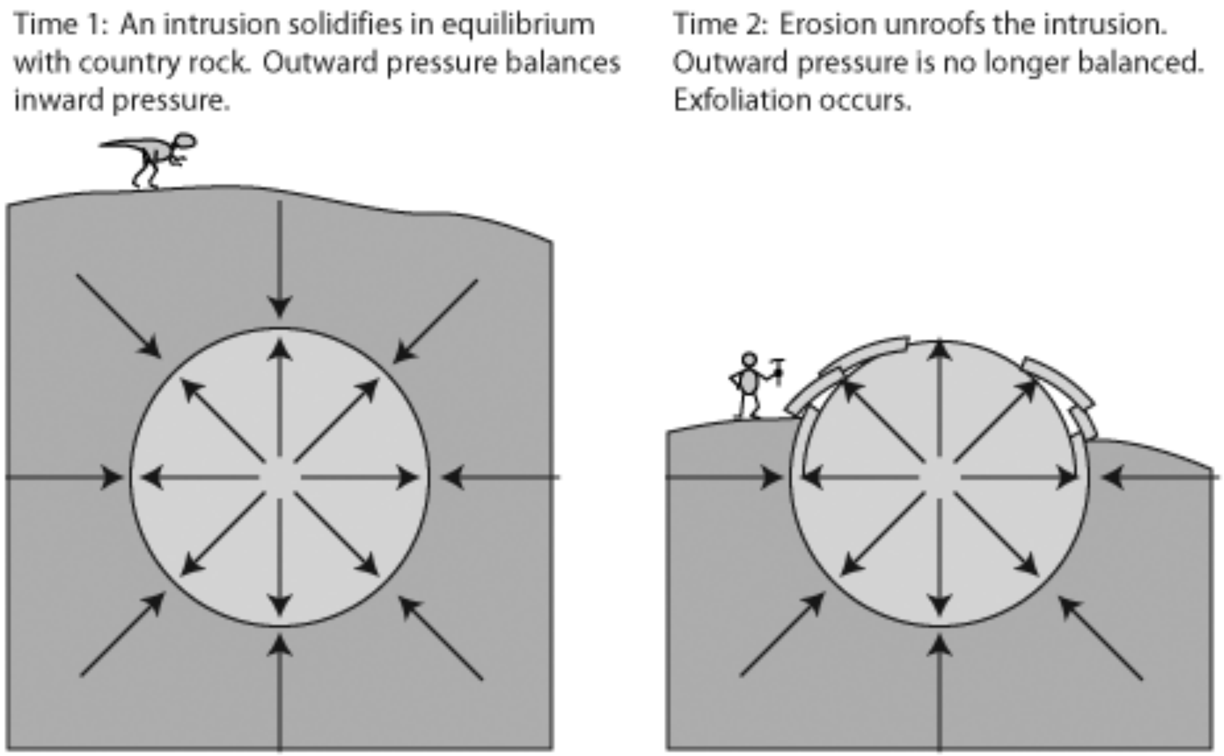
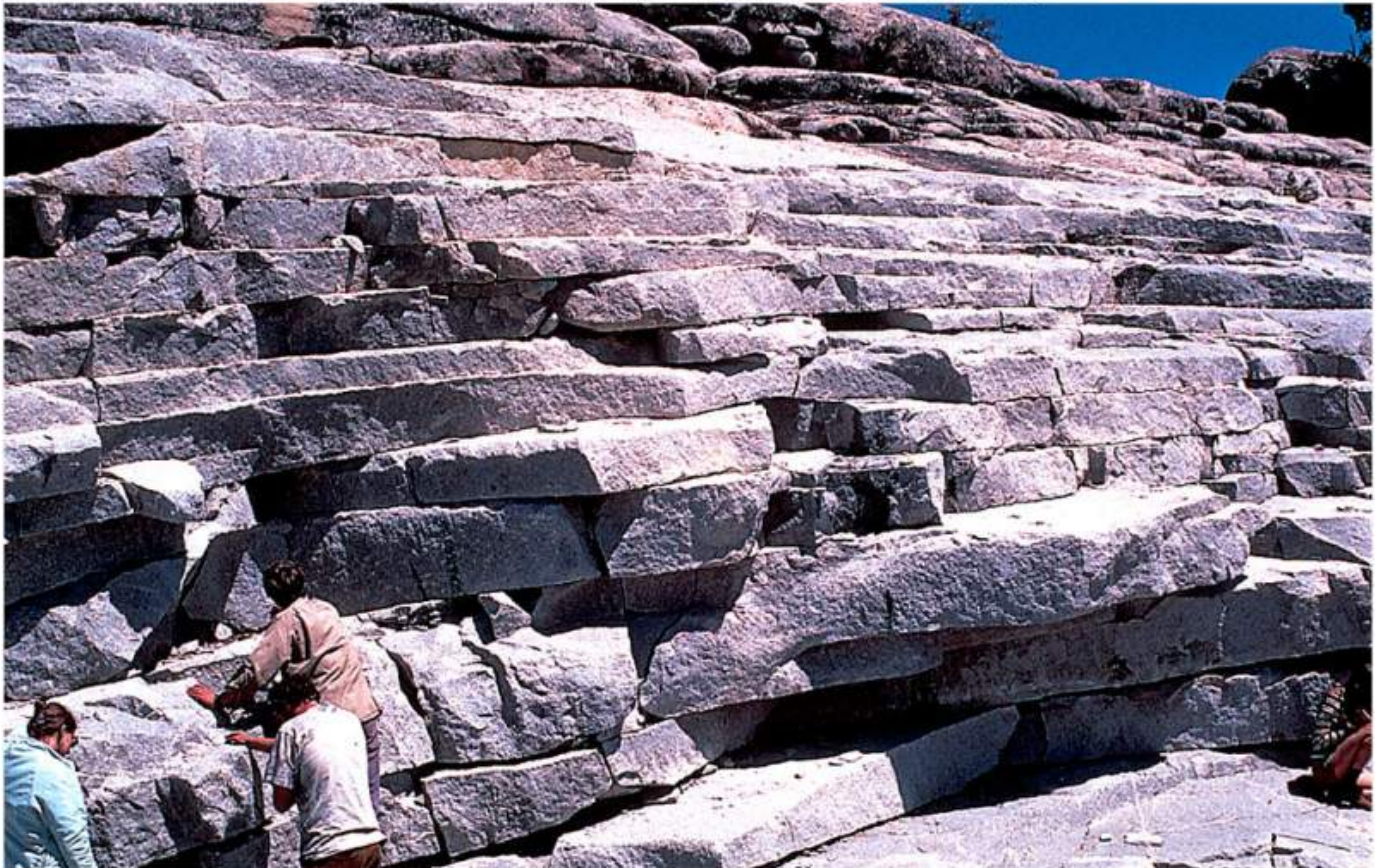

Several kilometers
Batholith
A
Sheet joints
Exfoliation
Exfoliation
Expansion
Uplift and erosion of region
B



From: https://www.geol.umd.edu/~jmerck/geol100/lectures/12.html



c

A

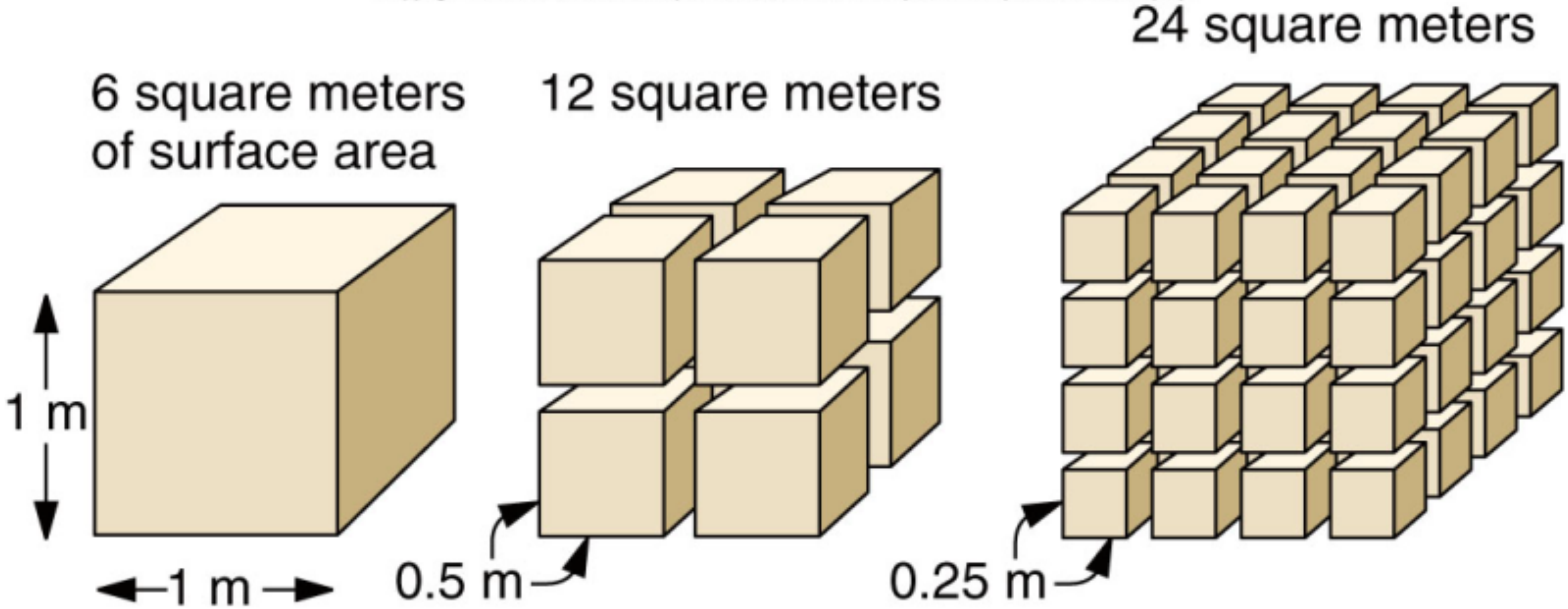
B

products of Mechanical (or Physical) Weathering

- Mechanical Weathering breaks down rocks in fragments

- Fragments are named not based on composition but *based on size*:
  - Gravel (bigger than 2 mm)
  - Sand (between 2 mm and 1/16 mm)
  - Silt (between 1/16 mm and 1/256 mm)
  - Clay (smaller than 1/256 mm)

How mechanical weathering helps chemical weathering



Chemical Weathering
and its products

- Two agents:
  - Oxygen
  - Acids

- Oxygen causes Iron to “rust”
- Acids disintegrate most minerals into:
  - Quartz
  - Clay minerals
  - Ions in solution

Action of Oxygen

- Free oxygen (O_2), found in both the atmosphere and dissolved in water, attacks iron (Fe) present in mafic rocks (e.g., basalt)
  - $4Fe + 3O_2 \rightarrow 2Fe_2O_3$ (Hematite)
  - $2Fe_2O_3 * nH_2O$ (Limonite)
  - Fe_3O_4 (Magnetite)
  - Other iron oxides, such as Goethite

  - Most important: **Hematite**, then **Limonite**
  - Soil and sedimentary rocks often stained with iron oxides

Action of Acids

- An **acid** is a substance that, when put in water, releases protons (H^+)

- Protons are very reactive:
  - Looking to saturate their electrical charge
  - They are very small and would try attack other molecules to replace their positively charged ions

- **Strong acids** would release a lot of protons
  - Very dangerous
  - Only common around volcanic vents
  - Controlled substances
  - HCl, H_2S, H_2SO_4
- **Weak acids** would release just a few protons
  - Vinegar, lemon juice, and many more
  - In nature, carbonic acid is weak, but omnipresent

Carbonic Acid

- Forms naturally from water and carbon dioxide
  - H_2O + CO_2 → H_2CO_3
    Water | Carbon Dioxide | Carbonic Acid

- In water, carbonic acid dissociates into protons and bicarbonate ions
  - H_2CO_3 ←→ H^+ + HCO_3^-
    Carbonic Acid | Proton | Bicarbonate Ion

- It can go further by dissociating another proton and carbonate ions
  - H^+ + HCO_3^- ←→ $2H^+$ + CO_3^{2-}
    Proton | Bicarbonate Ion | Two Protons | Carbonate Ion

Products of chemical weathering

- Oxygen causes iron to "rust"
- Acids disintegrate most minerals into:
  - Quartz
  - Clay minerals
  - Ions in solution

- Example: potassium feldspar ($KAlSi_3O_8$)
  - Proton (H^+) replaces K^+ but cannot substitute for it, causing the structure to collapse
  - K^+ goes in solution, SiO_2 (quartz) forms, the rest creates a clay mineral

- **Quartz** usually becomes a rounded particle the size of sand

- **Clay minerals** are flat crystals the size of clay
  - Difference between the concepts of “clay mineral” and “clay particle”
  - General formula for flat silicate crystals:

    .... $Al_2Si_2O_5(OH)_4$

- **Ions in solution** are dissolved in water and can precipitate salts

- Among common minerals, calcite is an exception

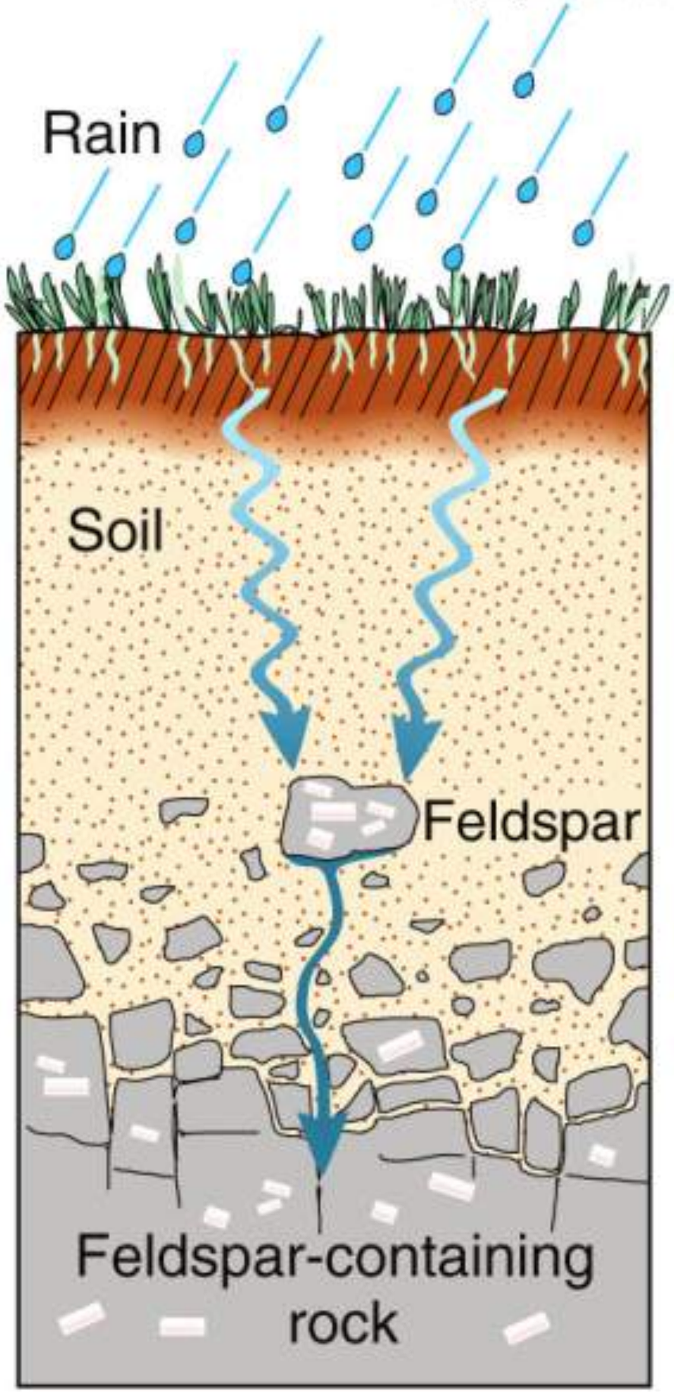
- It does not yield quartz or clay, but only ions in solution

- Equilibrium reaction of calcite in water:
  - $CaCO_3 + H_2O + CO_2 \leftrightarrow Ca^{2+} + 2HCO_3^-$

- Quartz, clay minerals, and ions in solution are the three byproducts of chemical weathering

- Quartz is usually reduced to the size of sand
- Clay minerals are components of mud
- Calcium ions have affinity with carbonate ions

- As a consequence the three most common rocks at Earth’s surface are sedimentary, and are:
  - **Sandstone** (from quartz sand)
  - **Shale**, or mudstone (from clay minerals)
  - **Limestone** (from ions in solution)



Rain picks up CO_2 from the atmosphere and becomes acidic

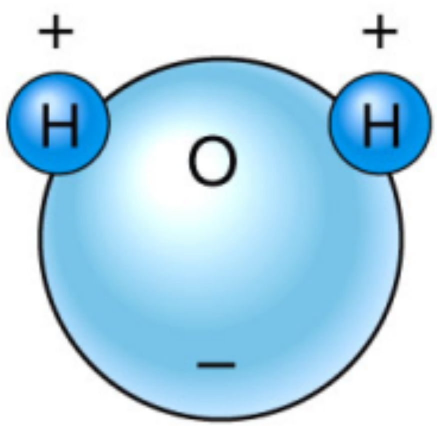
Water percolating through the ground picks up more CO_2 from the upper part of the soil, becoming more acidic

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

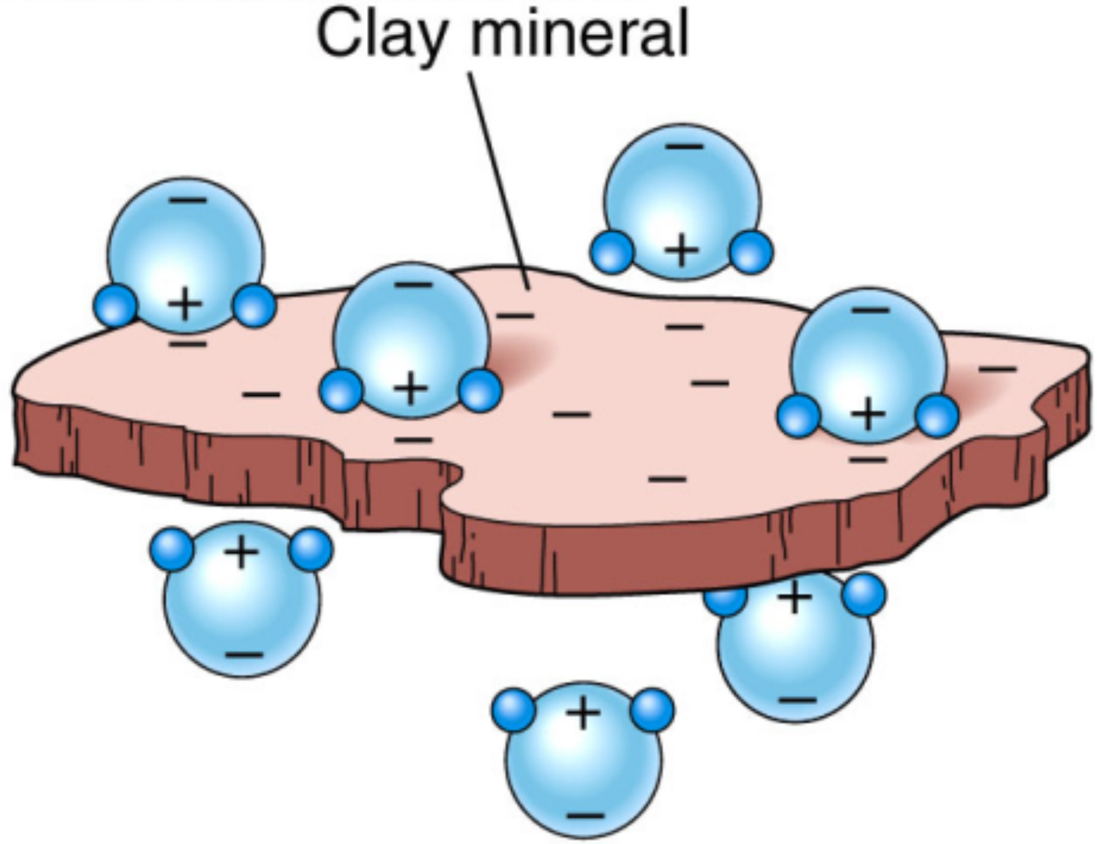
The water carries away soluble ions and SiO_2 to the ground-water supply or to a stream

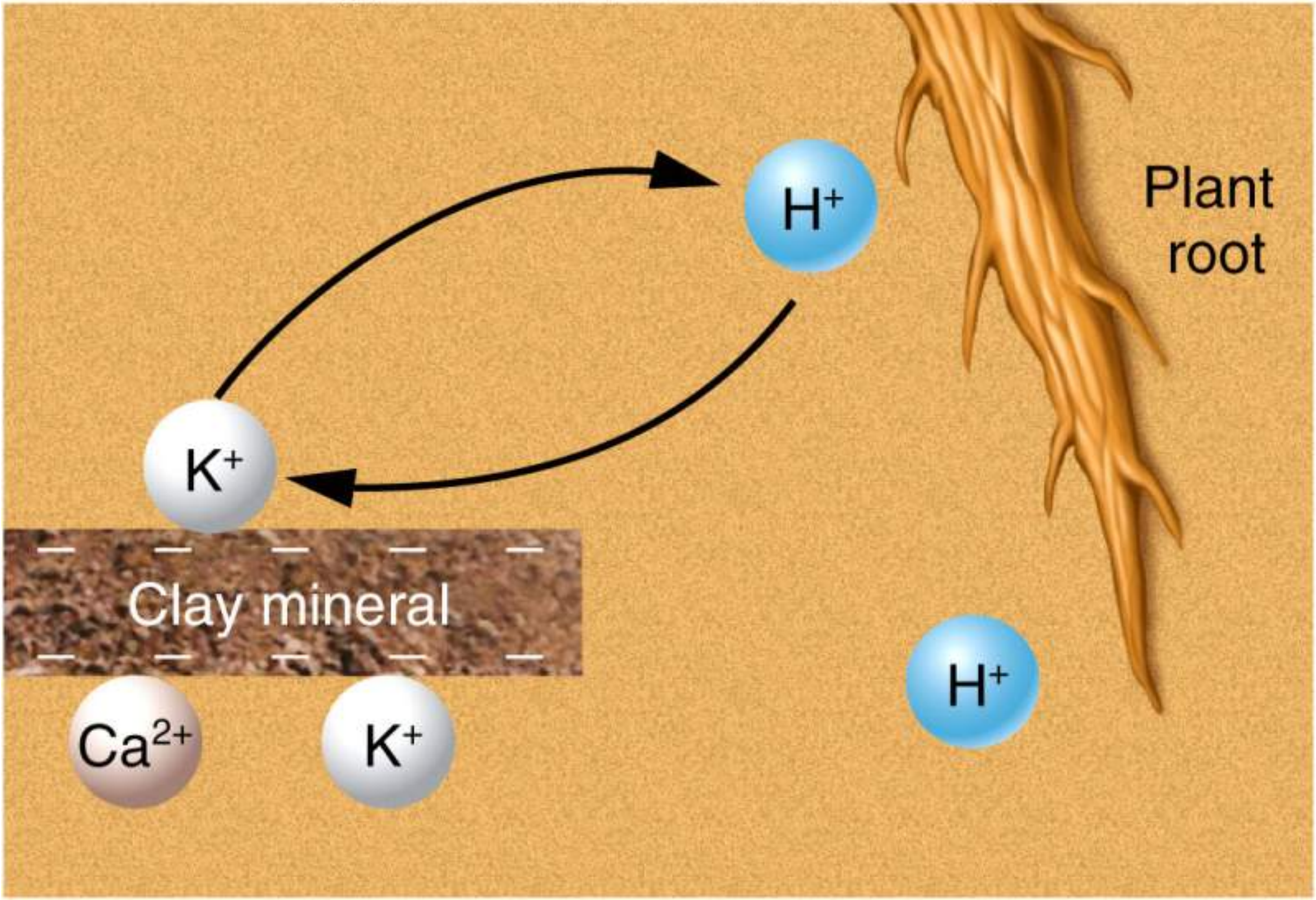
Properties of clay minerals

- Clay minerals are flat
- Clay minerals absorb water and positively charged ions
- Clay minerals virtually prevent water form circulating through them
  - Compare water in sand, percolating freely, vs. water in mud, causing swelling



Water molecule
(H_2O)




H+
Plant
root
K+
Clay mineral
Ca2+
K+
H+

In the end…

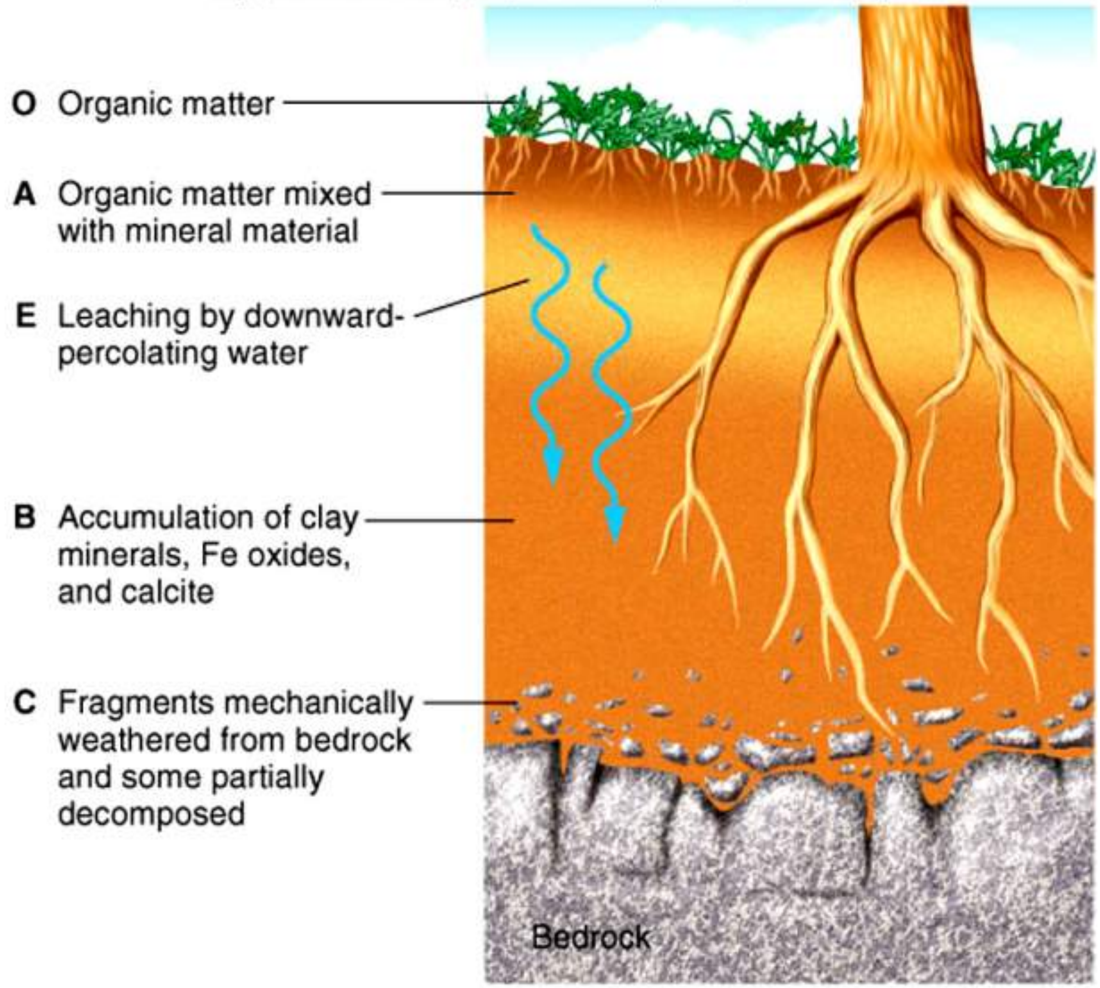
- Quartz is not affected by chemical weathering
- Feldspars and micas yield quartz, clays, ions
- Mafic minerals (olivines, pyroxenes, amphiboles, and more) yield the same and hematite and/or limonite in addition
- Calcite dissolves completely

- These processes require water, so they are maximized in warm, moist climates
  - Limestone in Arizona vs. Limestone in Massachusetts

Soil

- *Soil* - a layer of weathered, unconsolidated material on top of bedrock
  - Common soil constituents:
    - *Clay minerals*
    - *Quartz*
    - *Water*
    - *Organic matter*

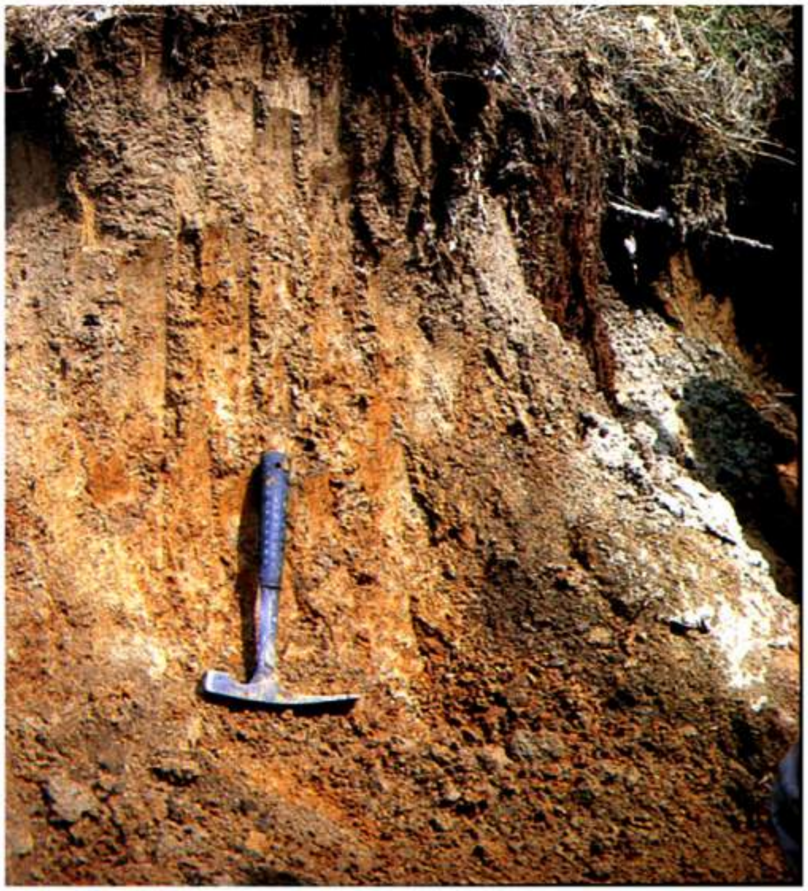
- *Soil horizons*
  - *O horizon* - uppermost layer; organic material
  - *A horizon* - dark layer rich in *humus*, organic acids
  - *E horizon* - zone of leaching; fine-grained components removed by percolating water
  - *B horizon* - zone of accumulation; clays and iron oxides leached down from above
  - *C horizon* - partially weathered bedrock



A

Soils and Climate

- Soil thickness and composition are greatly affected by climate
  - Wet climates:
    - More chemical weathering and thicker soils
    - Soils in moderately wet climates tend to have significant clay-rich layers, which may be solid enough to form a *hardpan*
  - Arid climates:
    - Less chemical weathering and thinner soils
    - Subsurface evaporation leads to build-up of salts
    - Calcite-rich accumulation zones may form, cementing soil together into a *hardpan*
  - Extremely wet climates (e.g., tropical rainforest)
    - Highly leached and unproductive soils (*laterites*)
    - Laterites can be further leached into *bauxites* (aluminum ore)
    - Most nutrients come from thick O/A horizons



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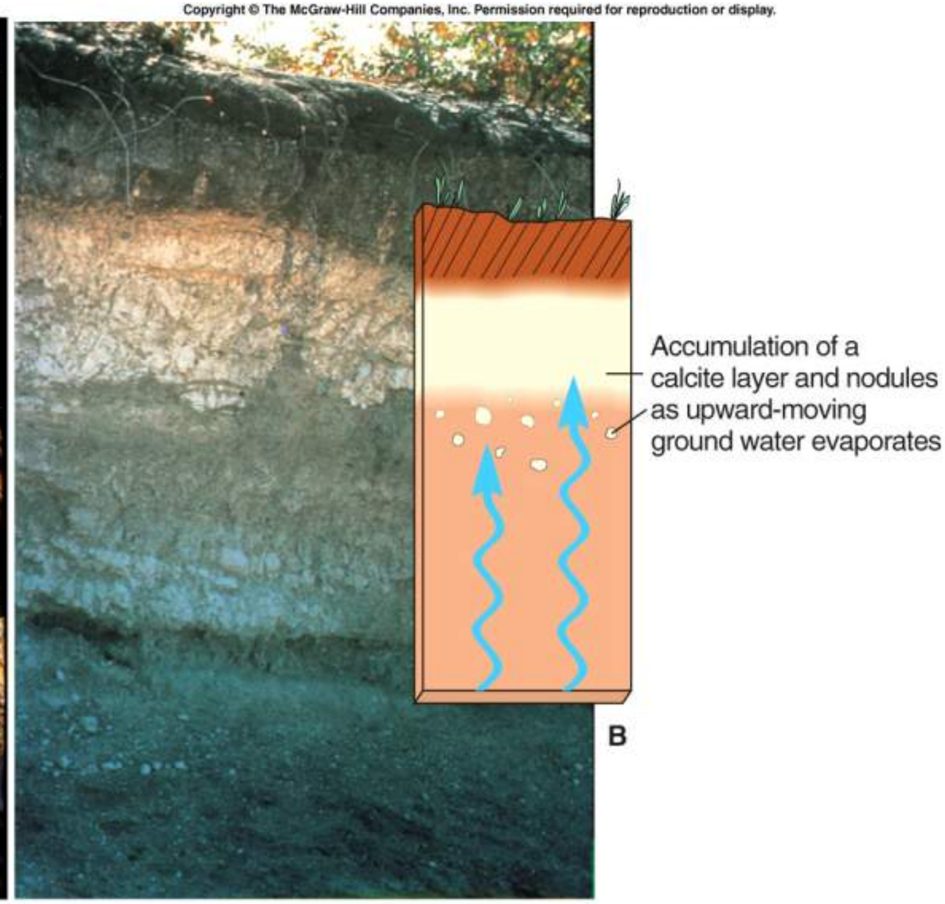
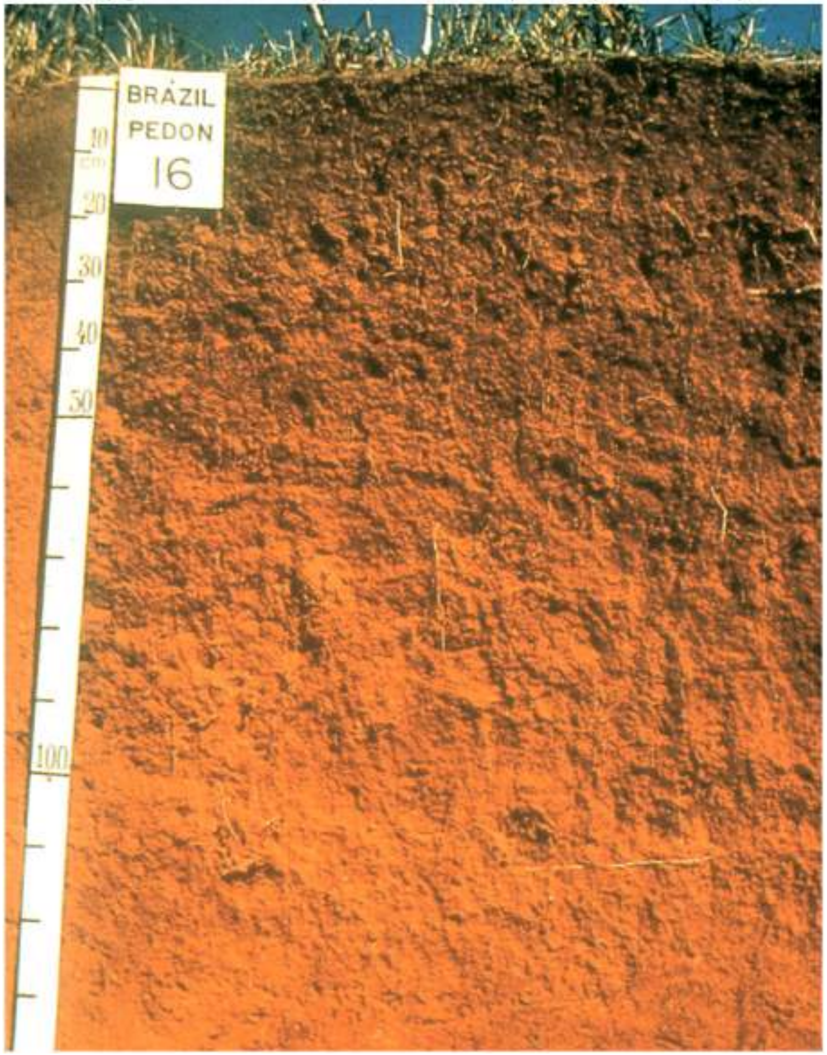
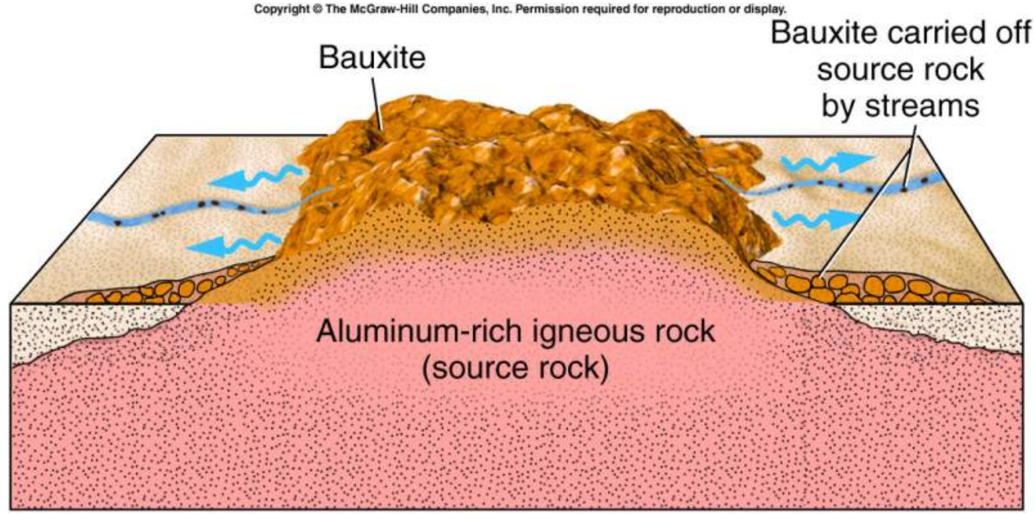

Accumulation of a
calcite layer and nodules
as upward-moving
ground water evaporates
B

A


BRAZIL
PEDON
16
10
cm
20
30
40
50
100

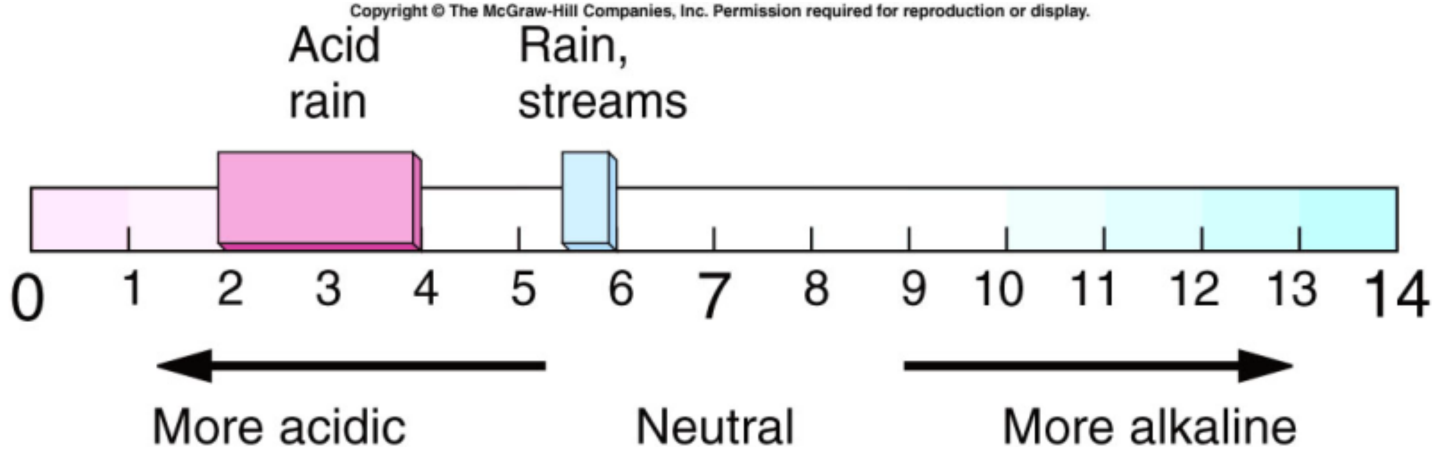

Bauxite
Bauxite carried off source rock by streams
Aluminum-rich igneous rock (source rock)

pH

- pH measures the acidity of a solution by indicating the concentration of protons in it
- $H_2O \leftrightarrow H^+ + OH^-$
- $[H^+] = [OH^-] = 10^{-7}$

- pH is the inverse logarithm of the concentration of H+ ions in water

- When $[H^+] = [OH^-] = 10^{-7}$, then the solution is neutral and the pH is 7
- Value lower than 7 indicate acidic conditions
- Values higher than 7 indicate alkaline (basic) conditions



the end