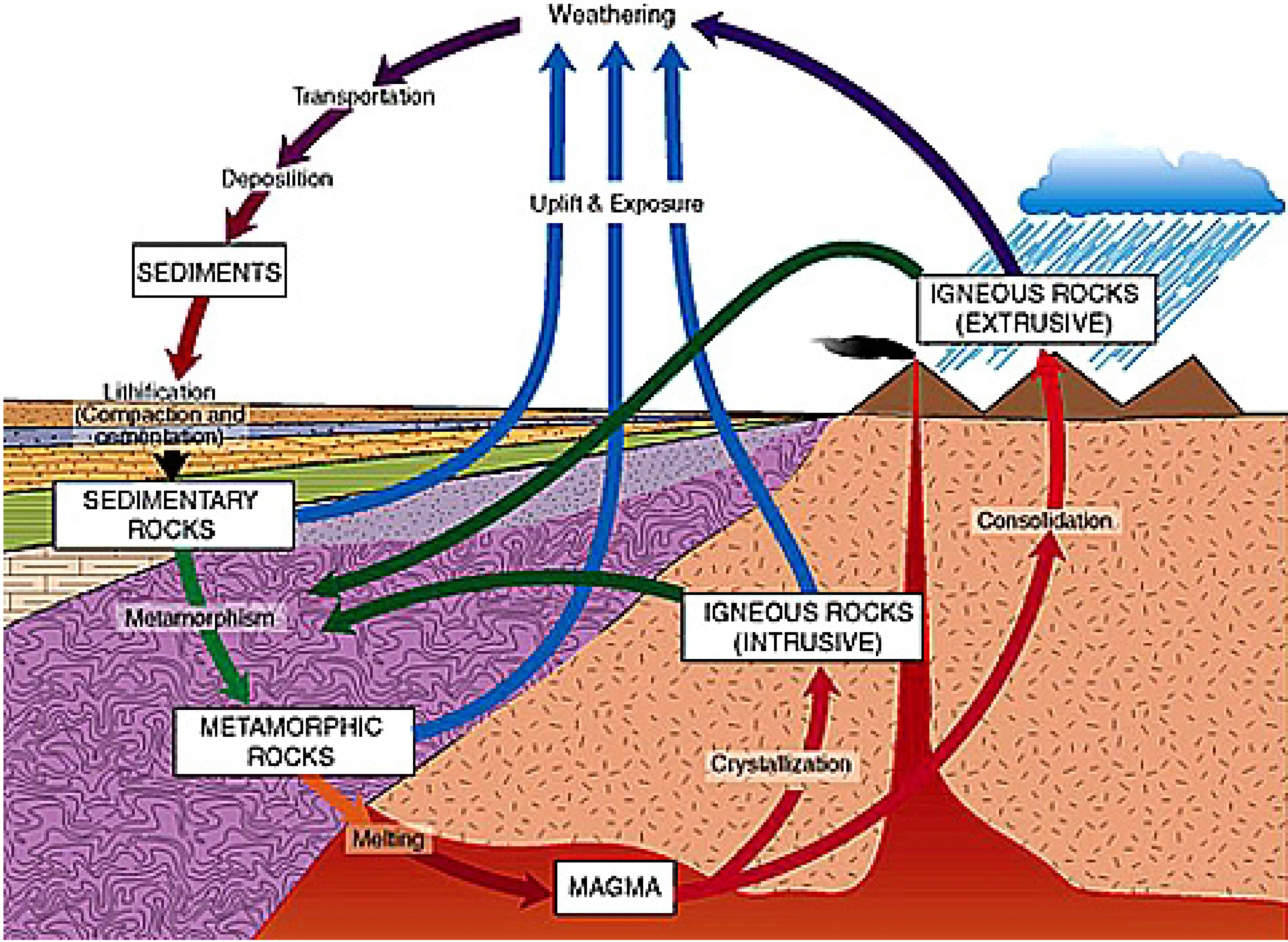
Parent Material & Weathering

Soils and Landscapes

Rock Cycle

- Igneous
  - Extrusive
  - Intrusive
- Sedimentary
  - Clastic
  - Chemical
- Metamorphic
  - Foliated
  - Non-foliated



Cl, O, R, P, T

Hans Jenny (1941)

cl, climate

o, biotic influence

r, topographic relief

p, parent material

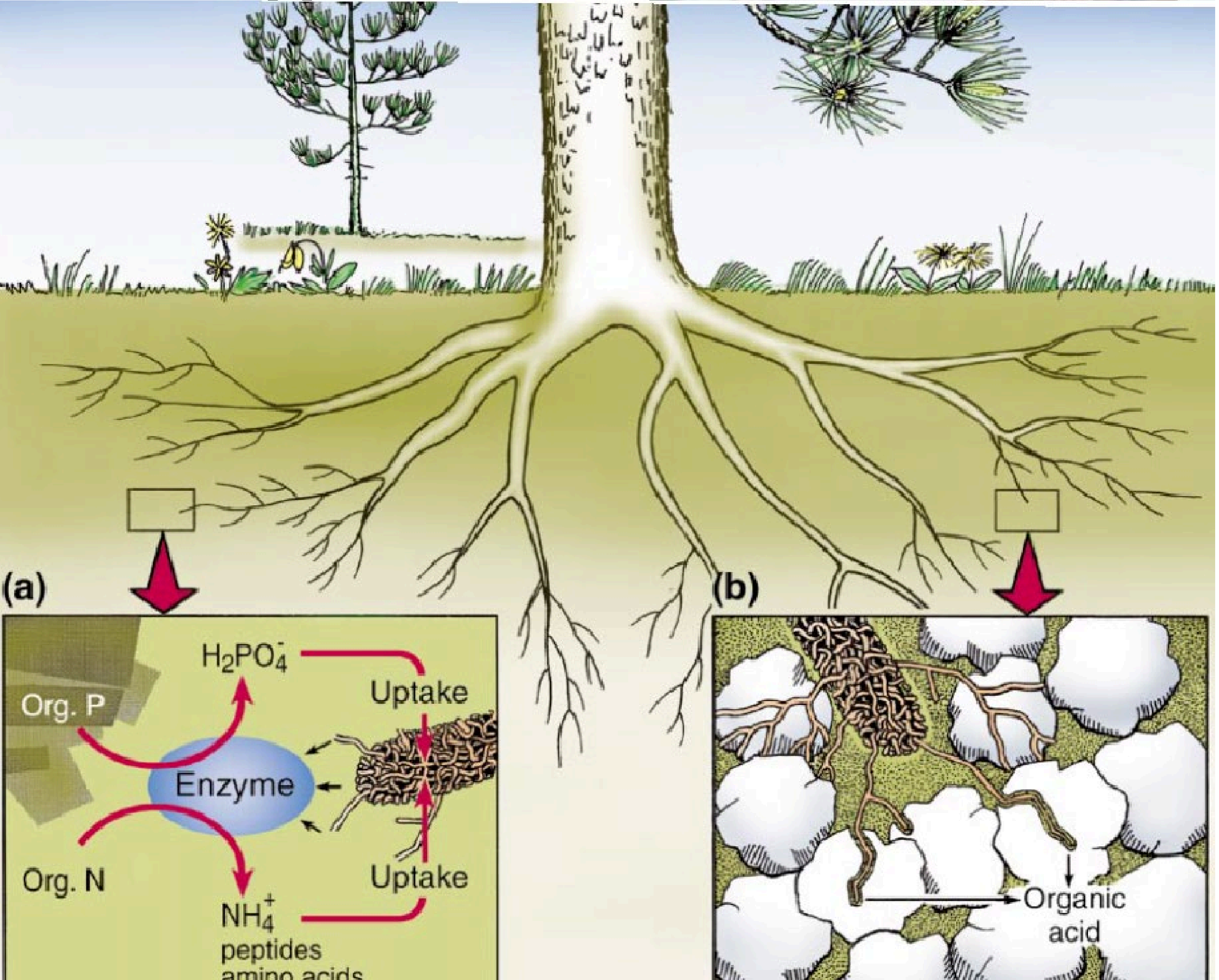
t, time

Weathering – what to know…

- **Biologic weathering** processes, pedogenesis role
- **Physical weathering** processes, end products, pedogenesis role
- **Chemical weathering** processes, end products and how different mineral types are affected by different process (be able to give examples)
- **Relative stability** of common minerals under weathering
- **Significance** of weathering to geomorphology?

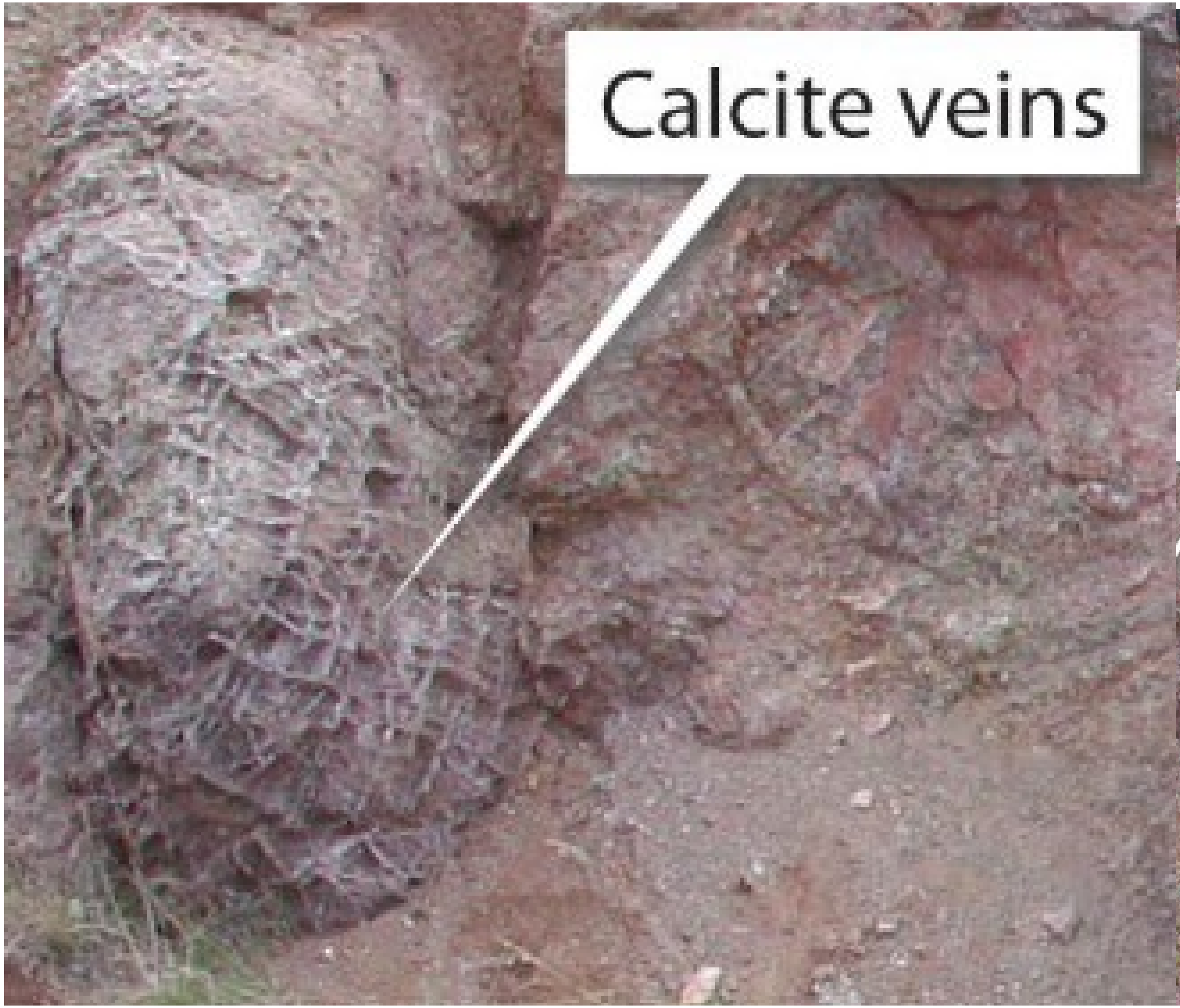
Weathering
vs.
Erosion
&
Landscape
Stability

Biologic


(a)
$H_2PO_4^-$
Org. P
Uptake
Enzyme
Org. N
Uptake
NH_4^+
peptides
amino acids
(b)
Organic
acid

Bioturbation

Saprolite – Weathering > Erosion



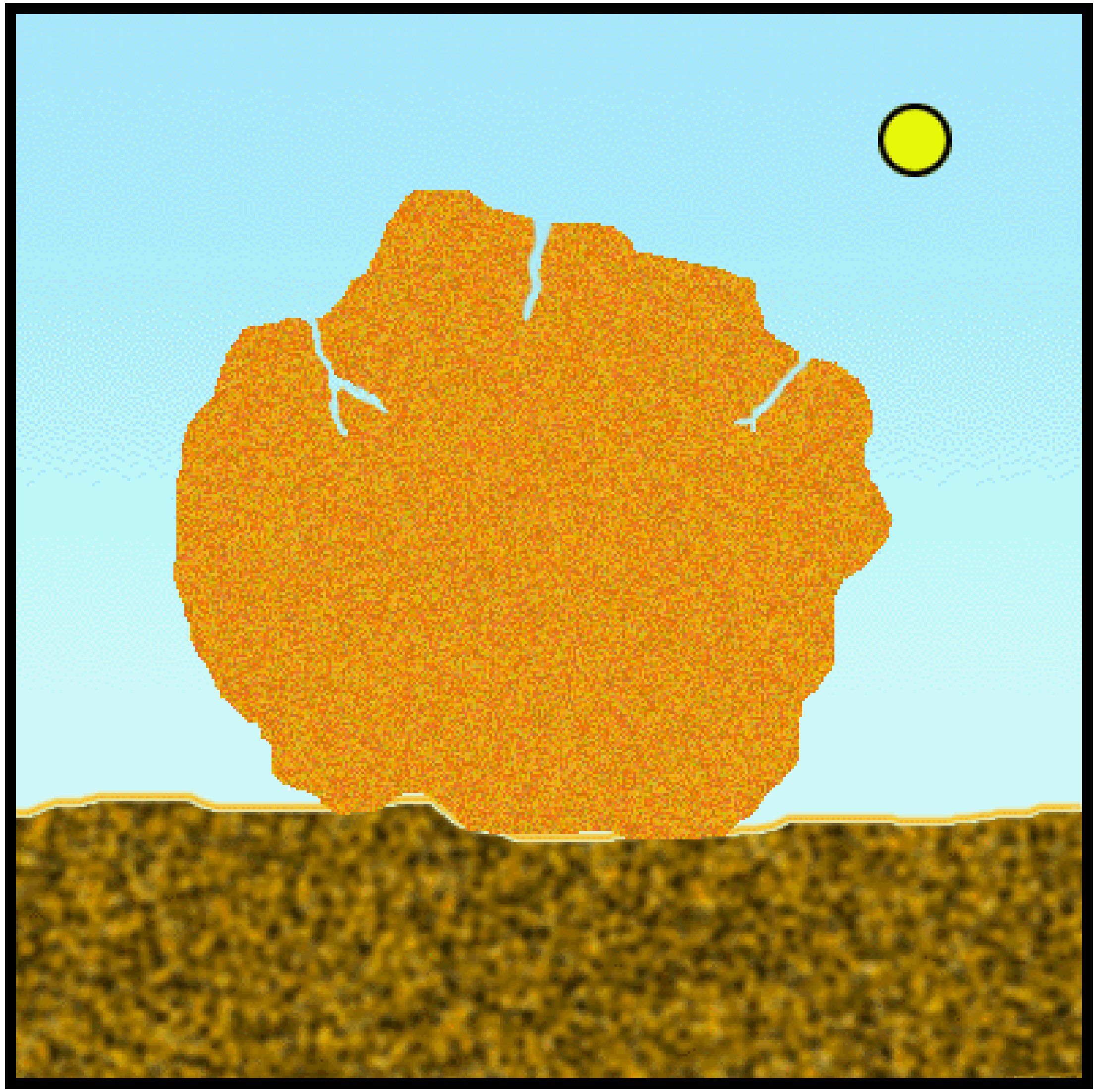
Biogeochemical weathering

Mechanical
Physical

Physical weathering

- The mechanical disintegration of rocks into smaller individual grains/sediments
    - **Frost wedging** (freeze/thaw cycles)
    - **Sheeting** (release of overburden pressure)
    - Break-up of rocks by **plant and animal activity**
- Relatively less important than chemical weathering, **operates in concert with chemical weathering**
- **End product = sand sized grains**

Freeze-thaw - Hydrofracturing

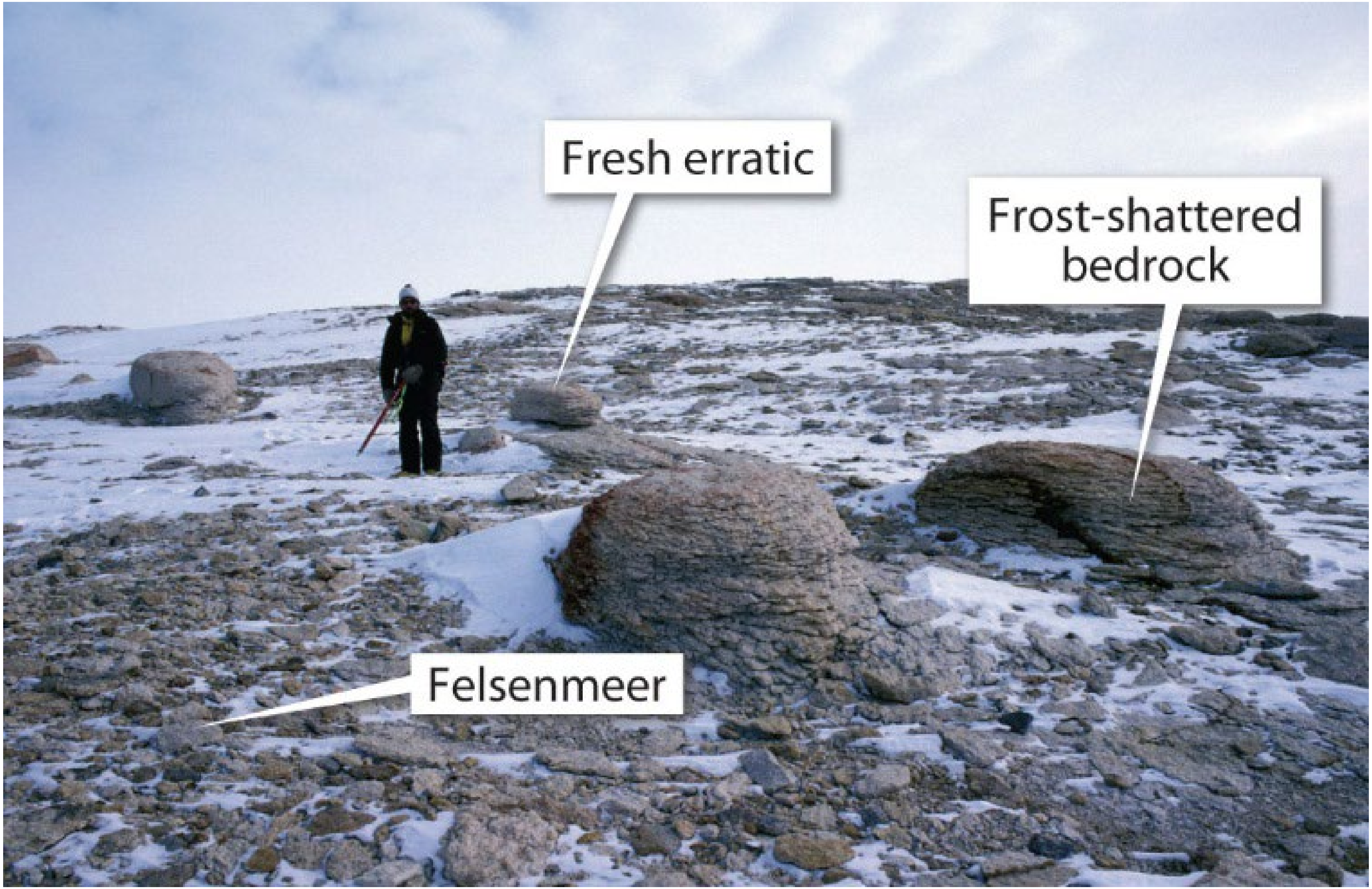


Web adventure: [Frost at work]()


Exfoliation

Felsenmeer

Frost
shattered
rocks

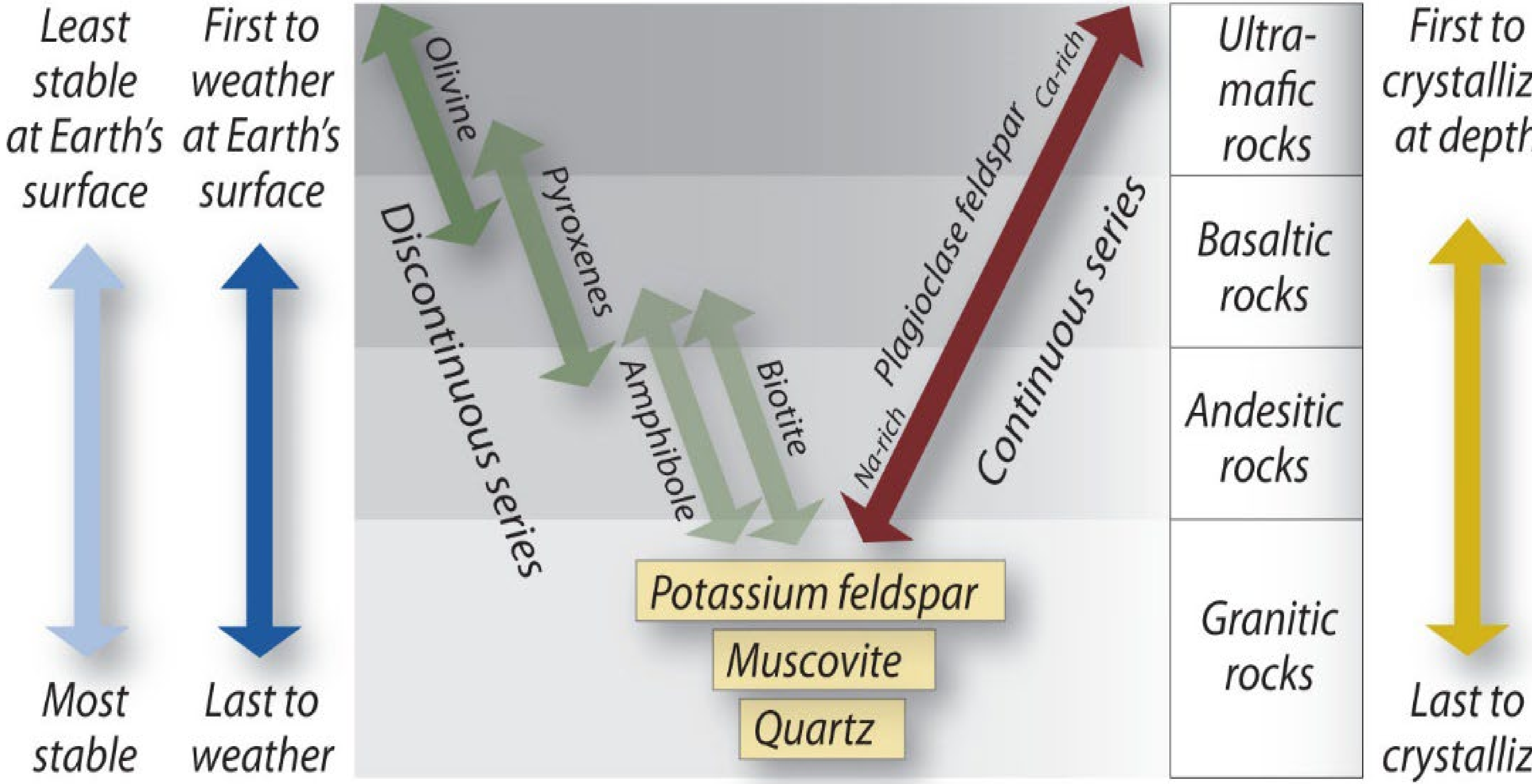


Thermal expansion

Chemical Weathering

- Requires, ‘free/accessible’ water
- Increased temperatures accelerate reactions
- Breaking - Metallic, ionic, covalent bonds
- End product = clay-sized particles to dissolved ions

Goldich's Weathering Series/Bowen's Reaction Series



Hydration

- Process that adds water to a mineral forming a new mineral

anhydrite + water ⇔ gypsum

$CaSO_4 + 2H_2O \Leftrightarrow CaSO_4 \times 2H_2O$

  - Hydration generally does not produce secondary products, it does result increased volume that may enhance the potential for mechanical disintegration

Hydration – Dehydration

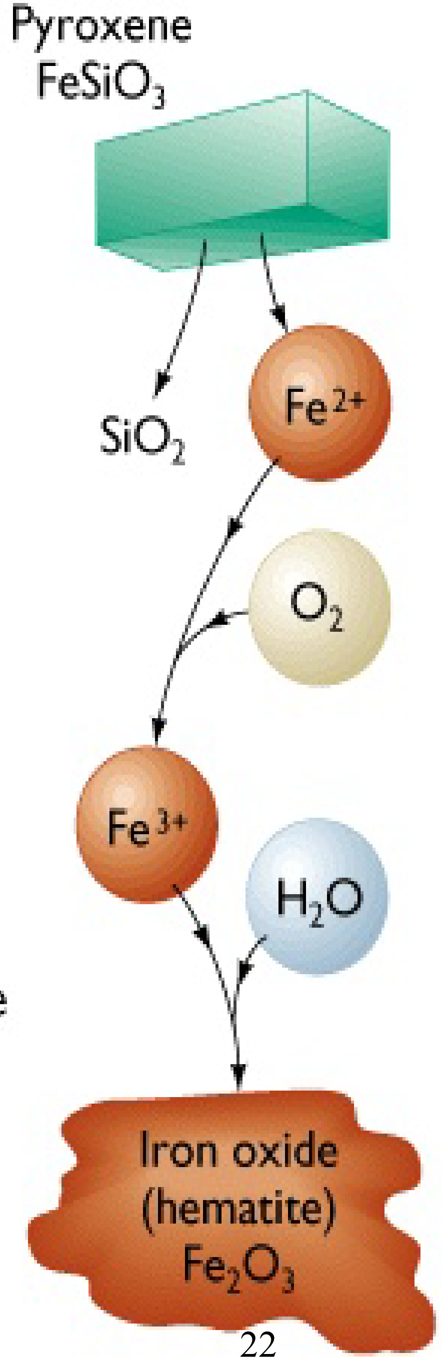
Oxidation

- **Oxidation** is the decomposition of iron- and manganese-bearing silicates by oxygen dissolved in water

$Fe^{2+} \rightarrow Fe^{3+} + e^{-}$, where the loss of the electron leads to the loss of other cations, such as Si^{4+}, in order to maintain electrical neutrality. This leads to collapse of the crystal lattice

$$\underset{\text{pyroxene}}{4Fe^{2+}SiO_3} + O_2 \rightarrow \underset{\text{hematite}}{2Fe^{3+}{}_2O_3} + \underset{\text{quartz}}{4SiO_2}$$

Oxidation



Iron pyroxene dissolves to release silica and ferrous iron to solution

Ferrous iron is oxidized by oxygen molecules to form ferric iron

Ferric iron combines with water to precipitate a solid, iron oxide, from solution

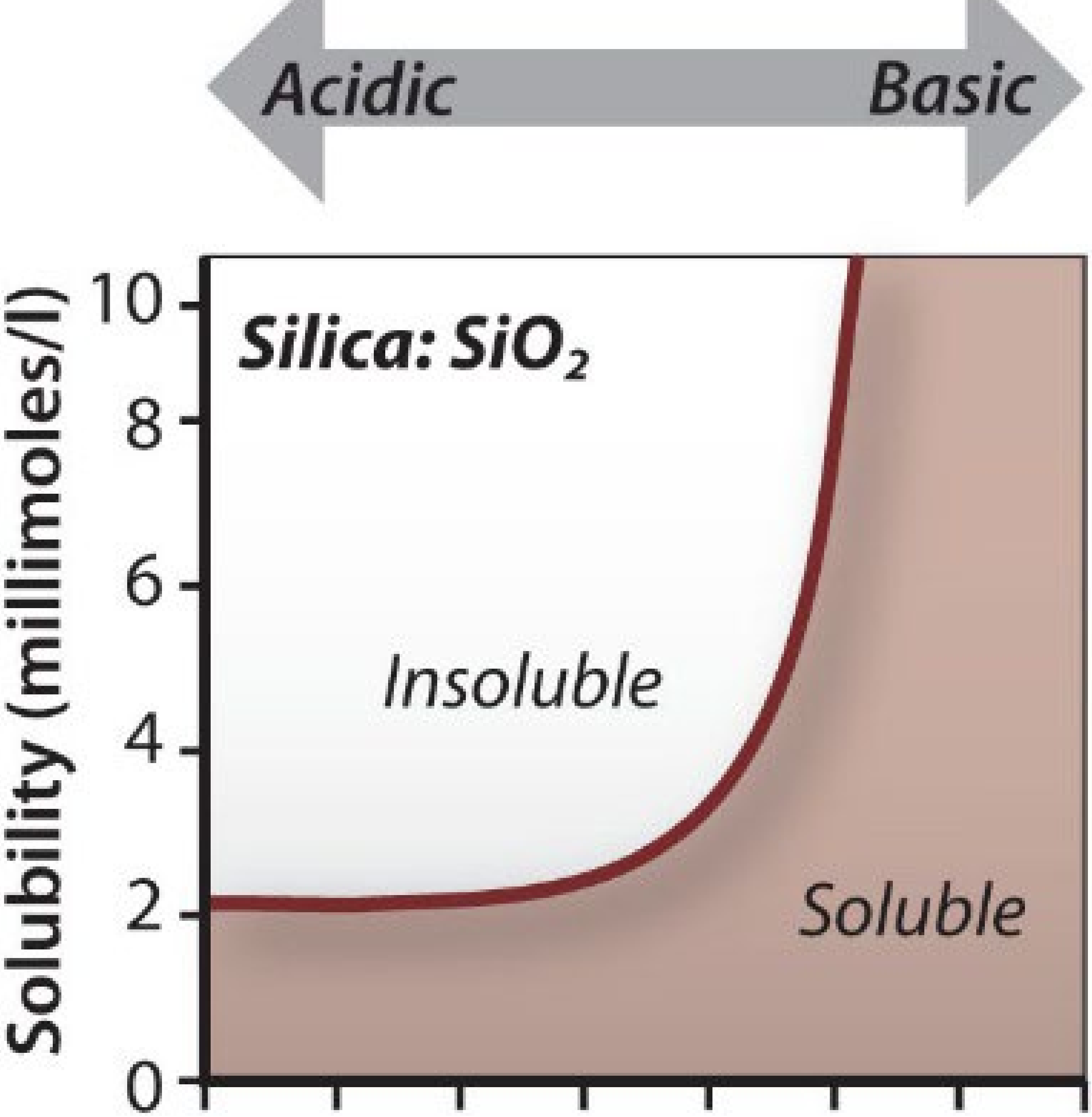
Solution

- **Simple solution** is the dissolution of soluble minerals upon contact with water
- Highly soluble minerals include
  - Evaporites (gypsum, halite)
  - Calcite
  - Dolomite

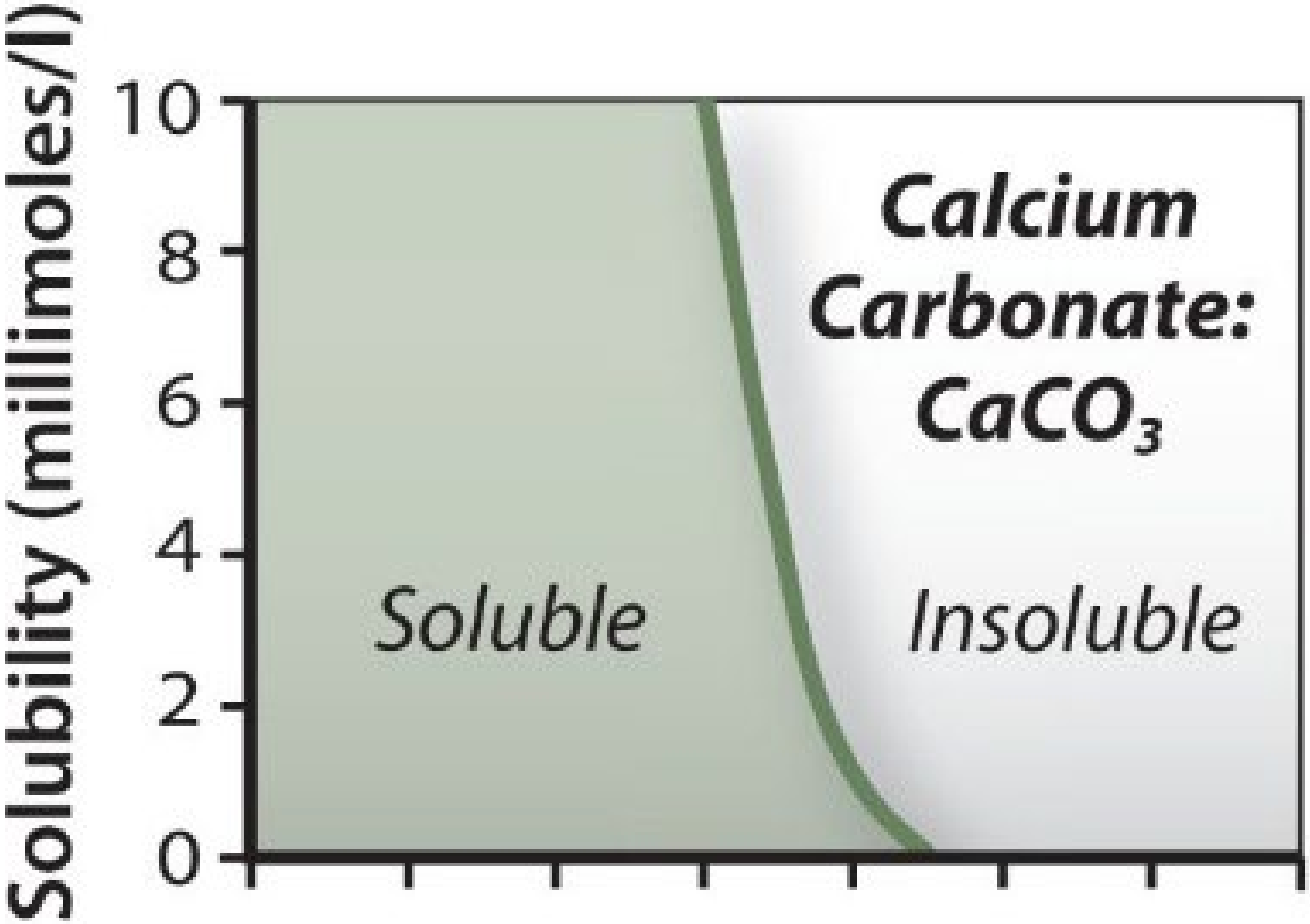
$$H_2O + CO_2 + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$

calcite bicarbonate

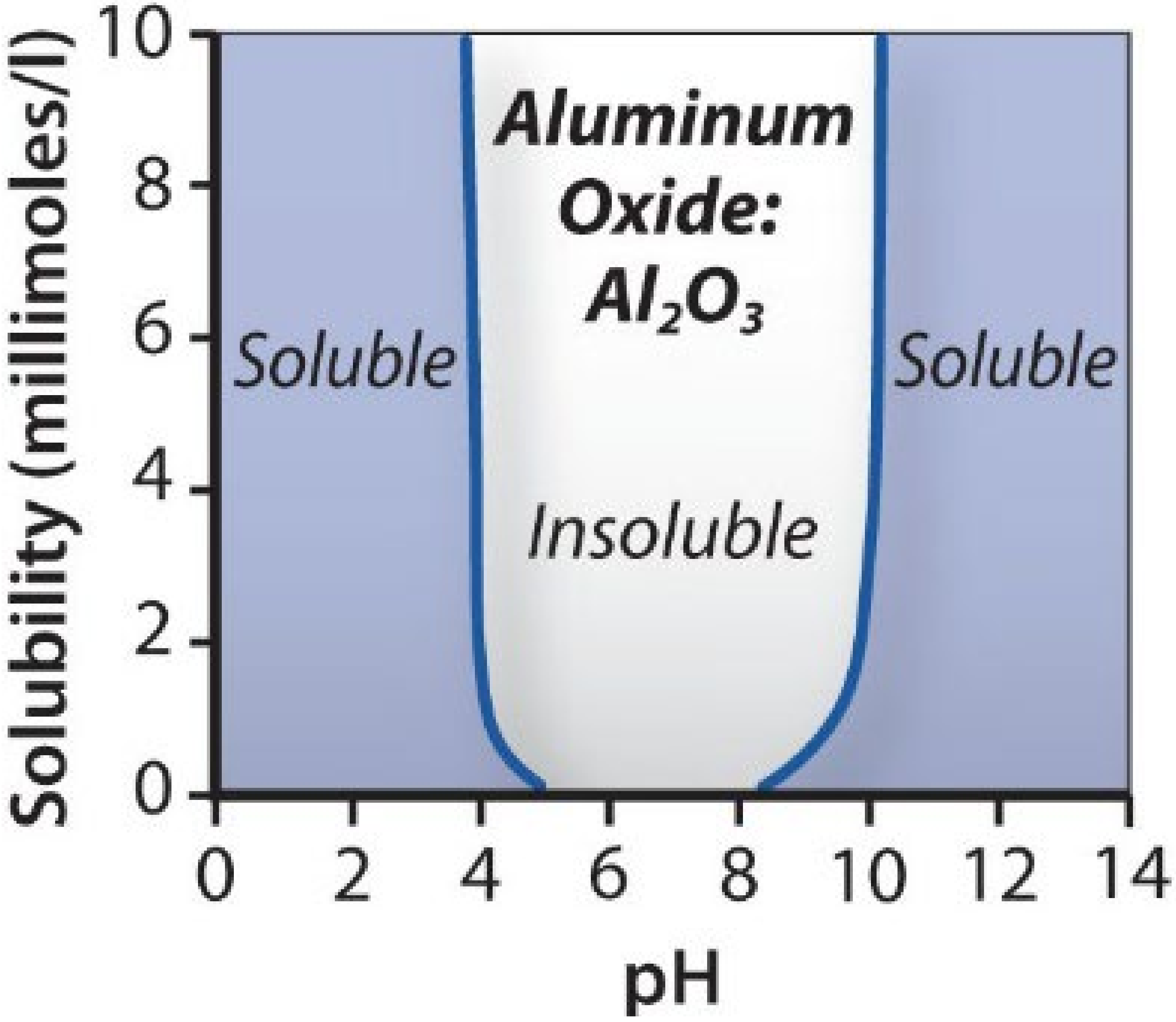
Solution



Silica has very low solubility in acidic and neutral solutions; it has much higher solubility in strongly alkaline (basic) solutions.



Calcium carbonate is highly soluble in acidic and neutral solutions and is virtually insoluble in alkaline solutions.

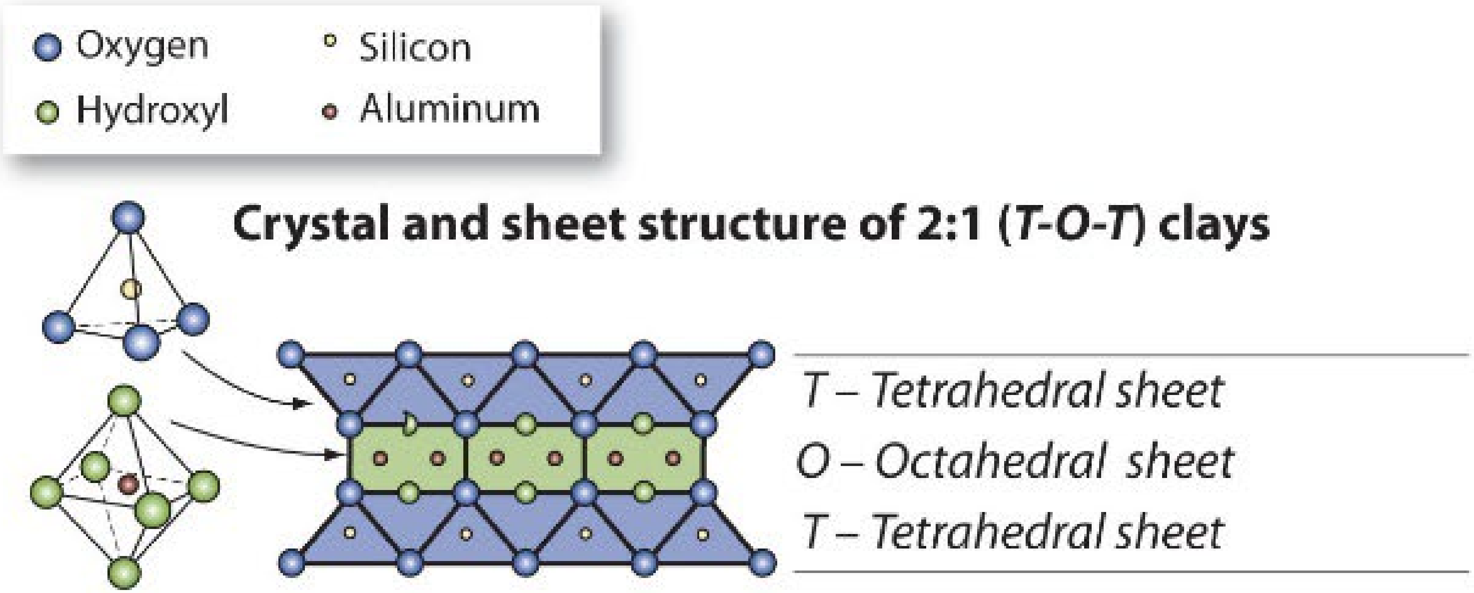


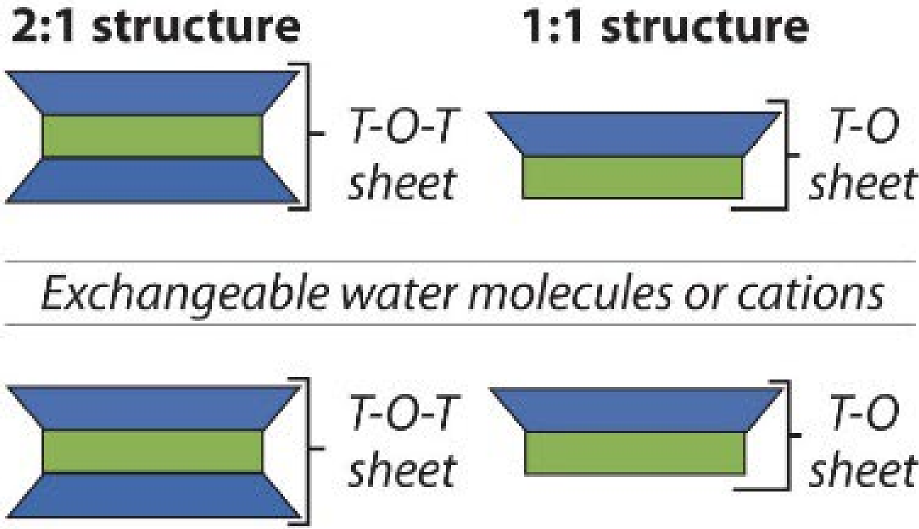
Aluminum oxide is highly soluble in strongly acidic or alkaline solutions but is relatively insoluble in neutral solutions.

Hydrolysis

- Reaction between silicate minerals and acid (H^+) - leads to mineral breakdown and the release of metal cations and silica
- Source of acids is CO_2 dissolved in water
  - $CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$
  - Acids also originate from plants
- Feldspars that undergo hydrolysis typically produce secondary clay minerals
  - Orthoclase (K) feldspar ➔ kaolinite or illite + silicic acid
  - Plagioclase (Na) feldspar ➔ kaolinite or smectite + silicic acid

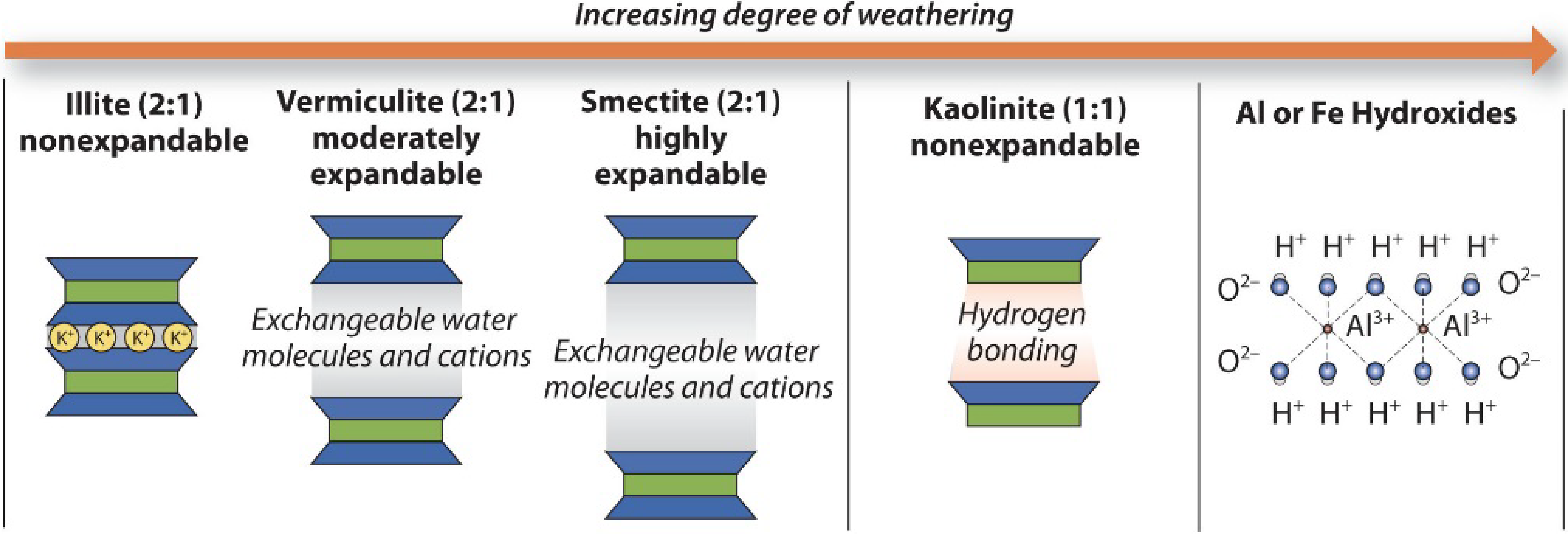
Forming clay





Because silicate tetrahedra are linked in sheets, the **phyllosilicate** group of minerals have sheetlike properties. Muscovite and biotite are two common phyllosilicate minerals that exist as layers. The **clay minerals** are part of the phyllosilicate group and form from surface and near-surface weathering of common rock-forming minerals. The clay minerals are "sandwiches" of silicate tetrahedral layers and octahedral layers, the latter of which are commonly of $Al_2(OH)_6$ composition.

A 2:1 clay mineral has two tetrahedral sheets and one octahedral sheet, and a 1:1 clay mineral has one of each type of layer. Various cations or H_2O molecules can be incorporated between the composite layers in some types of clays, particularly those termed **expandable clays.**

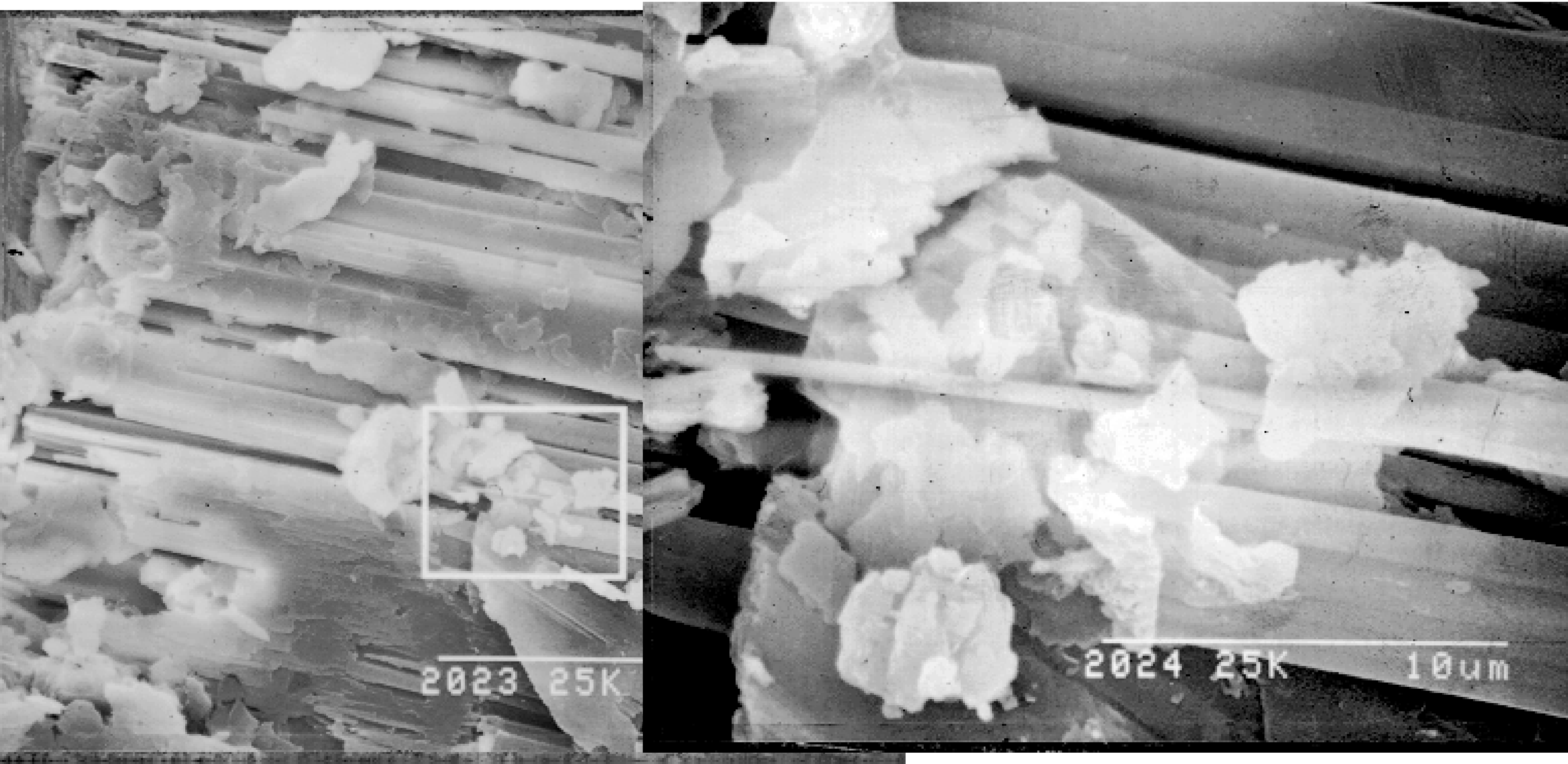


Illite and smectite have a 2:1 structure with alumina sheets sandwiched between silica sheets. They exhibit a wide range of properties, chemical compositions, and **cation exchange capacities** due to substitution of ions between layers.

Kaolinite has a 1:1 structure and low **cation exchange capacity** with alumina and silica sheets held together by strong ionic bonds.

Extremely weathered soils may result in a lateritic residuum of weathering-resistant Fe and Al oxides.

Orthoclase to Kaolinite (Clay)



Ion-exchange (chelation, cation exchange)

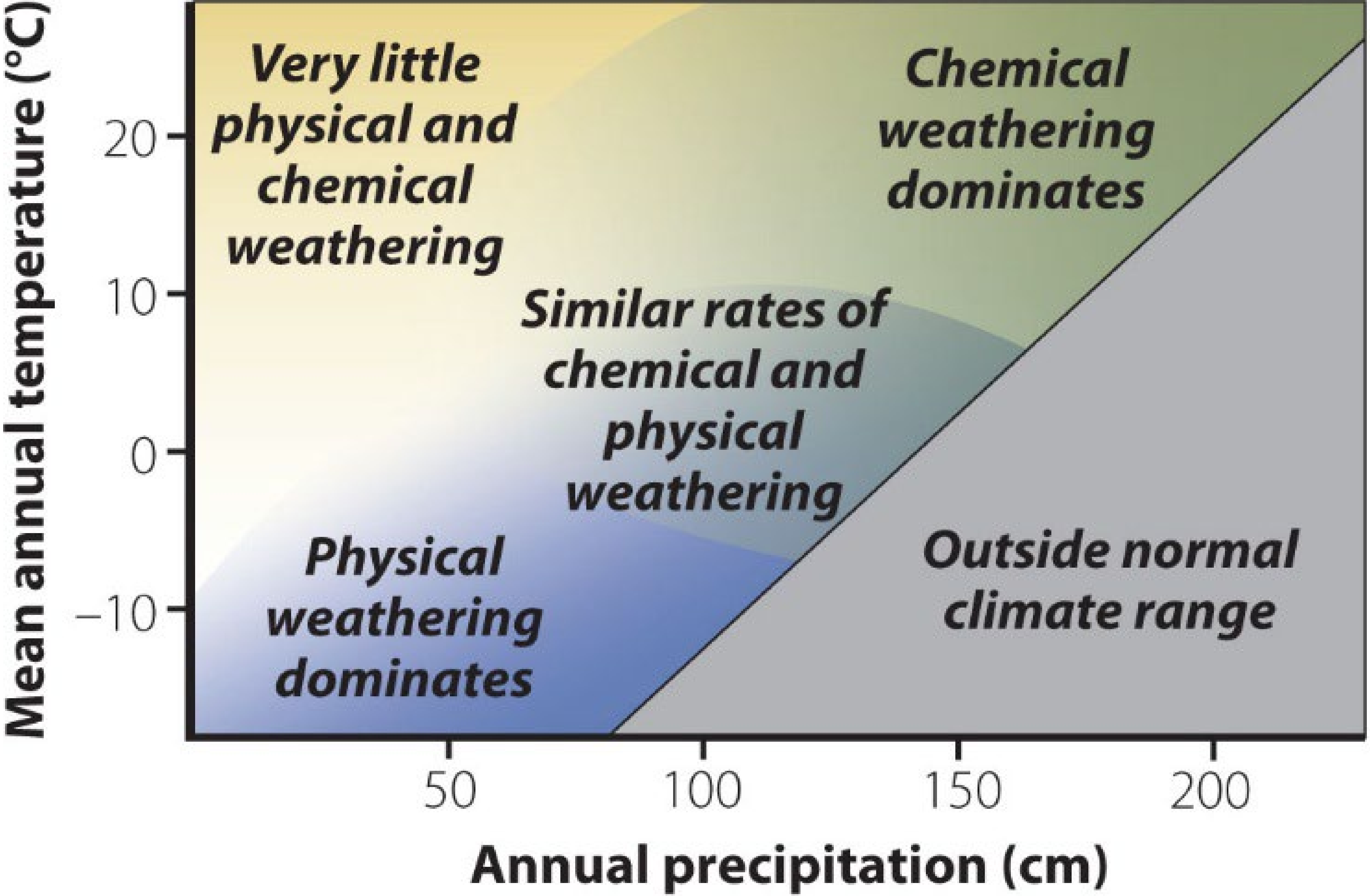
- Chelation – moving metal ions (Al, Fe) in a soil through the production of organic compounds/organic acids
- Eg. Conifer forests
- E-horizons

- Cation-Exchange Capacity (CEC)
- Secondary minerals and organic matter exchange cations (e.g. Ca, Mg, K)

Chemical weathering

- ***Rates*** of chemical weathering vary with climate and mineral composition and grain size of the parent rock
  - Chemical weathering is faster in wet climates
  - Chemical weathering rates increase with increasing temperature
  - Coarse grained rocks of a given composition weather more slowly than their fine grained equivalents

Environmental variability



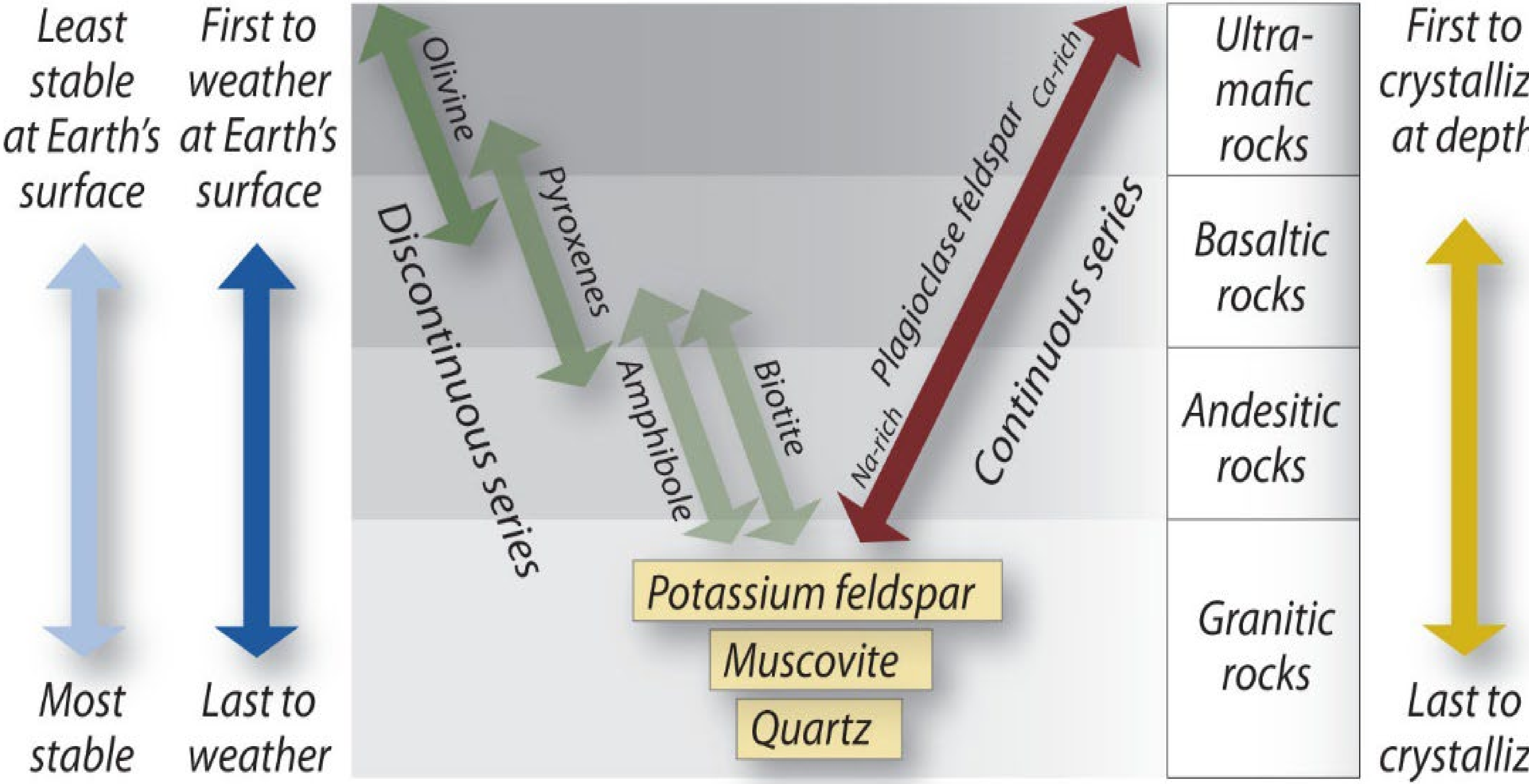
Chemical weathering

- Relative stability of sand- and silt-sized common minerals under weathering conditions (note relationship to Bowen’s Reaction Series):

increasing stability ↓

Mafic minerals	**Felsic minerals**
olivine	
	Ca plagioclase
pyroxene	
	Ca-Na plagioclase
amphibole	Na-Ca plagioclase
	Na plagioclase
biotite	
	orthoclase, muscovite, quartz

Goldich's Weathering Series/Bowen's Reaction Series

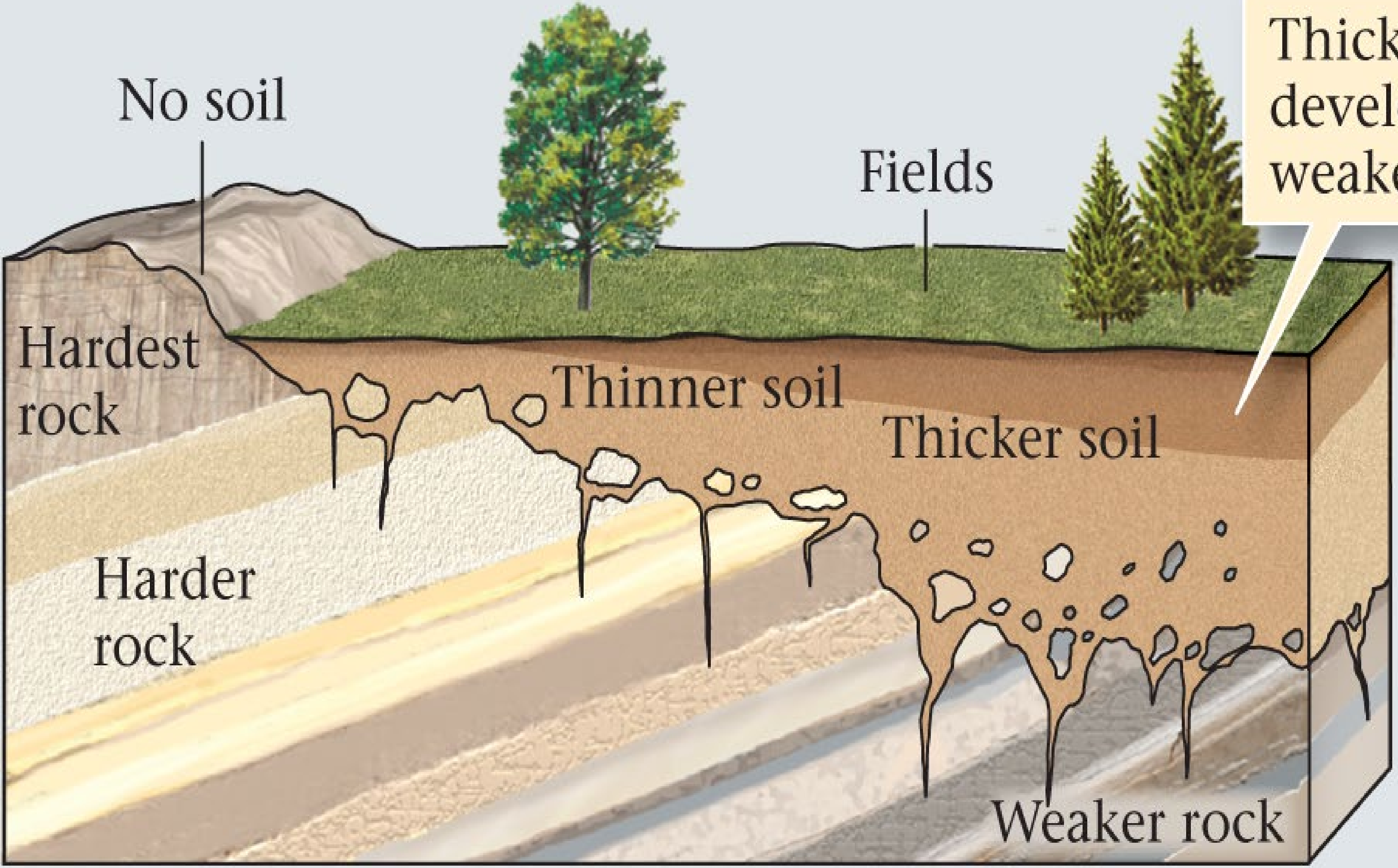


Weathering products -1

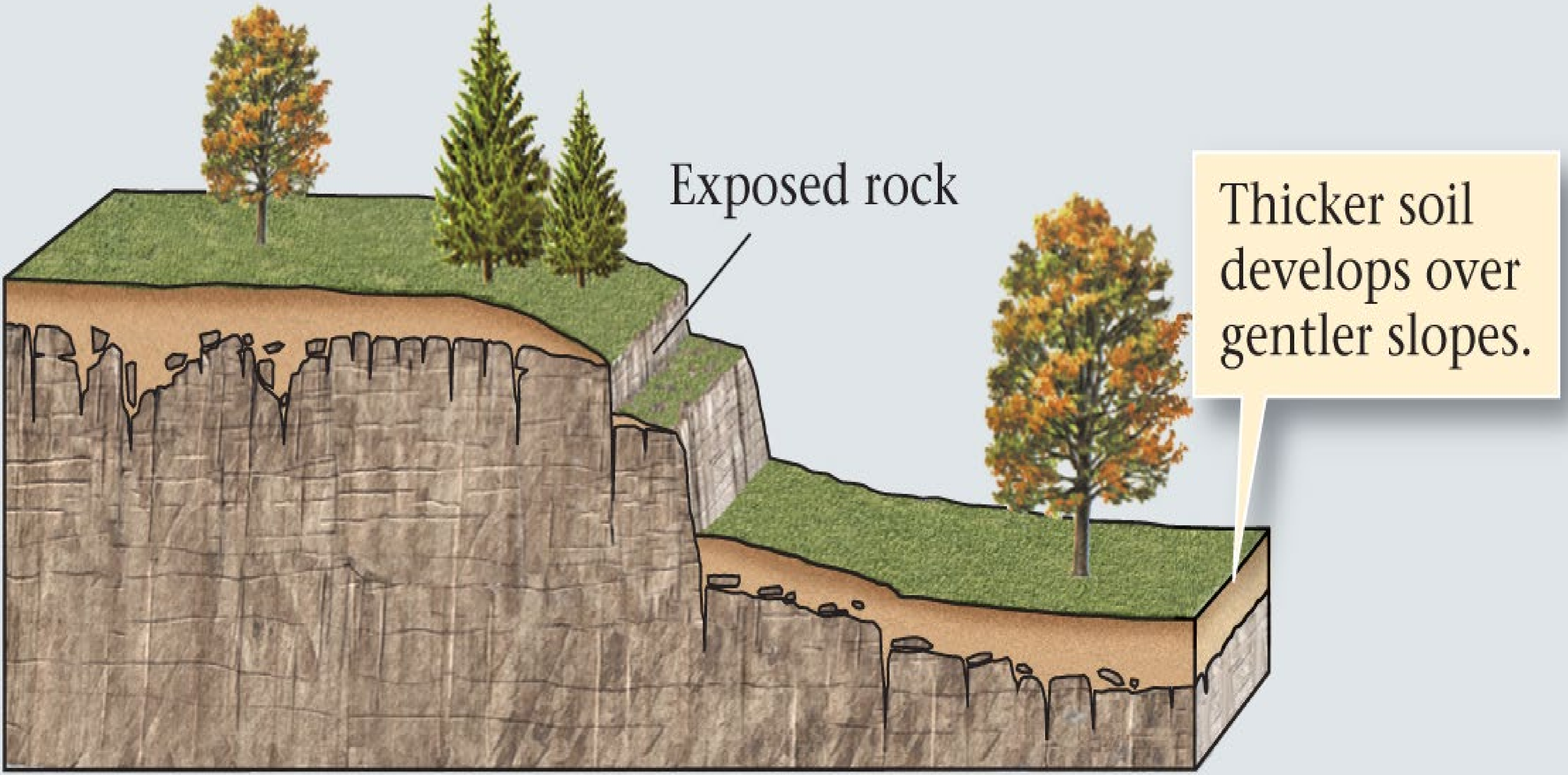
- New sedimentary particles:
  - Parent rock **residues**, composed of resistant minerals and rock fragments
  - **Secondary minerals**, largely the result of hydrolysis and oxidation
- Raw material for chemical sedimentary rocks:
  - **Soluble compounds**, largely the result of hydrolysis and simple solution
- *Until they are removed by erosion, particulate residues and secondary minerals remain* in situ *to form a* ***soil***

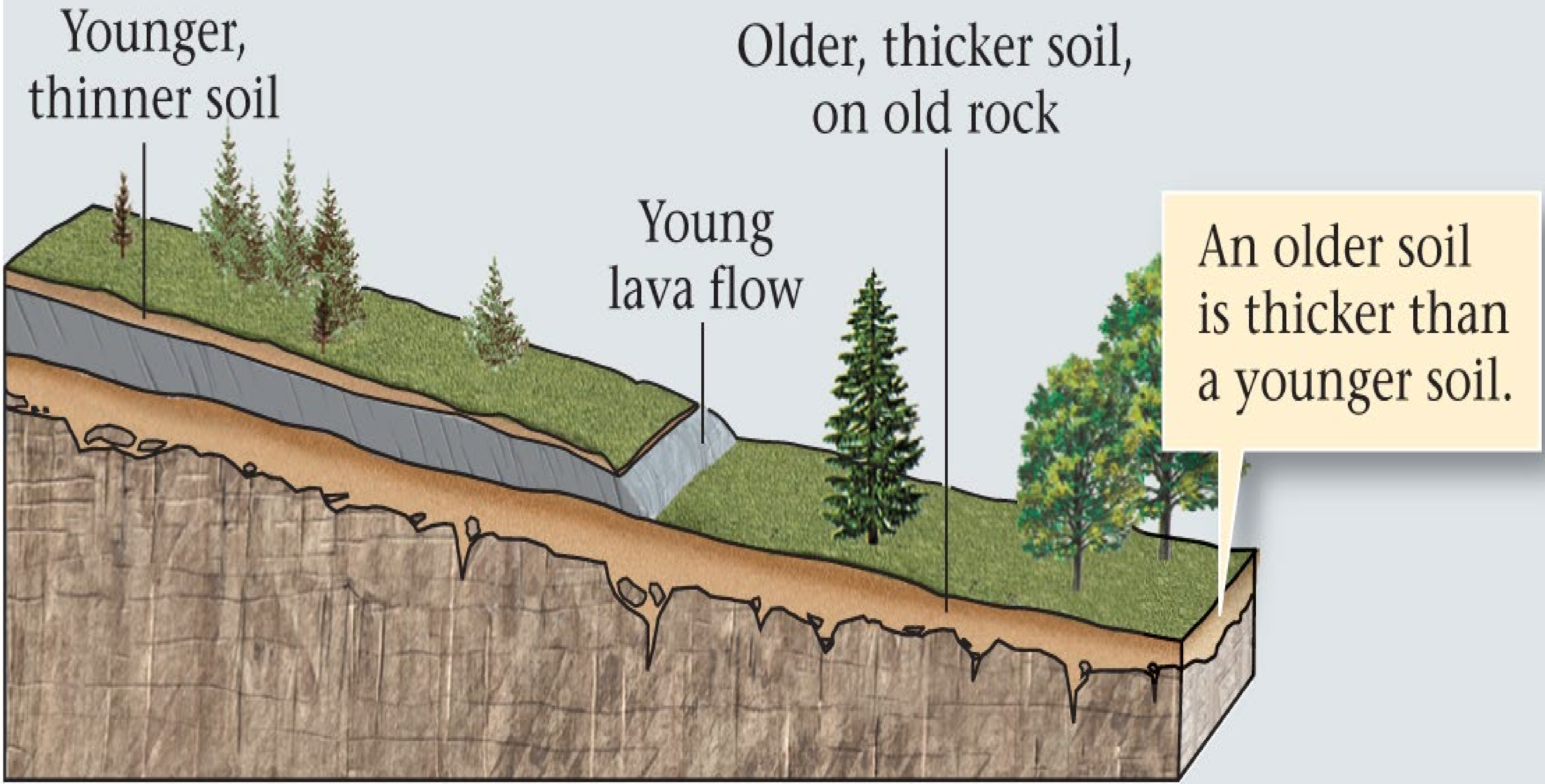
Weathering products -2

- **Igneous & metamorphic** rocks produce immature soils rich in unstable minerals. As the soil matures, it retains only resistant minerals.
  - Clays, iron oxides or hydroxides and aluminum hydroxides are present as secondary minerals
- **Siliciclastic sedimentary** rocks produce soils that are depleted in unstable minerals (because unstable minerals are eliminated in a previous weathering cycles)
- **Limestone** produce thin soils with insoluble silicates and iron-oxide residues

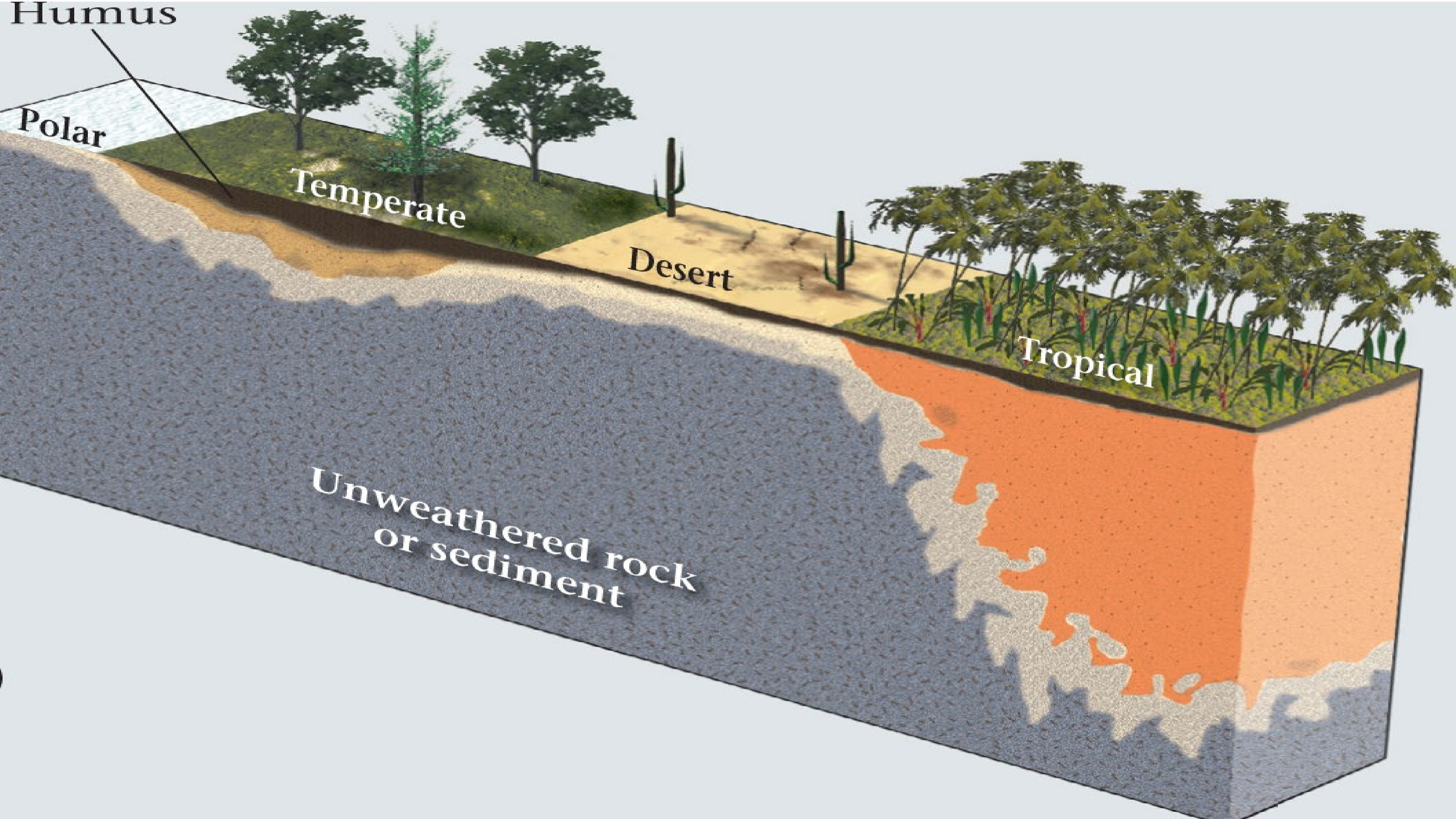


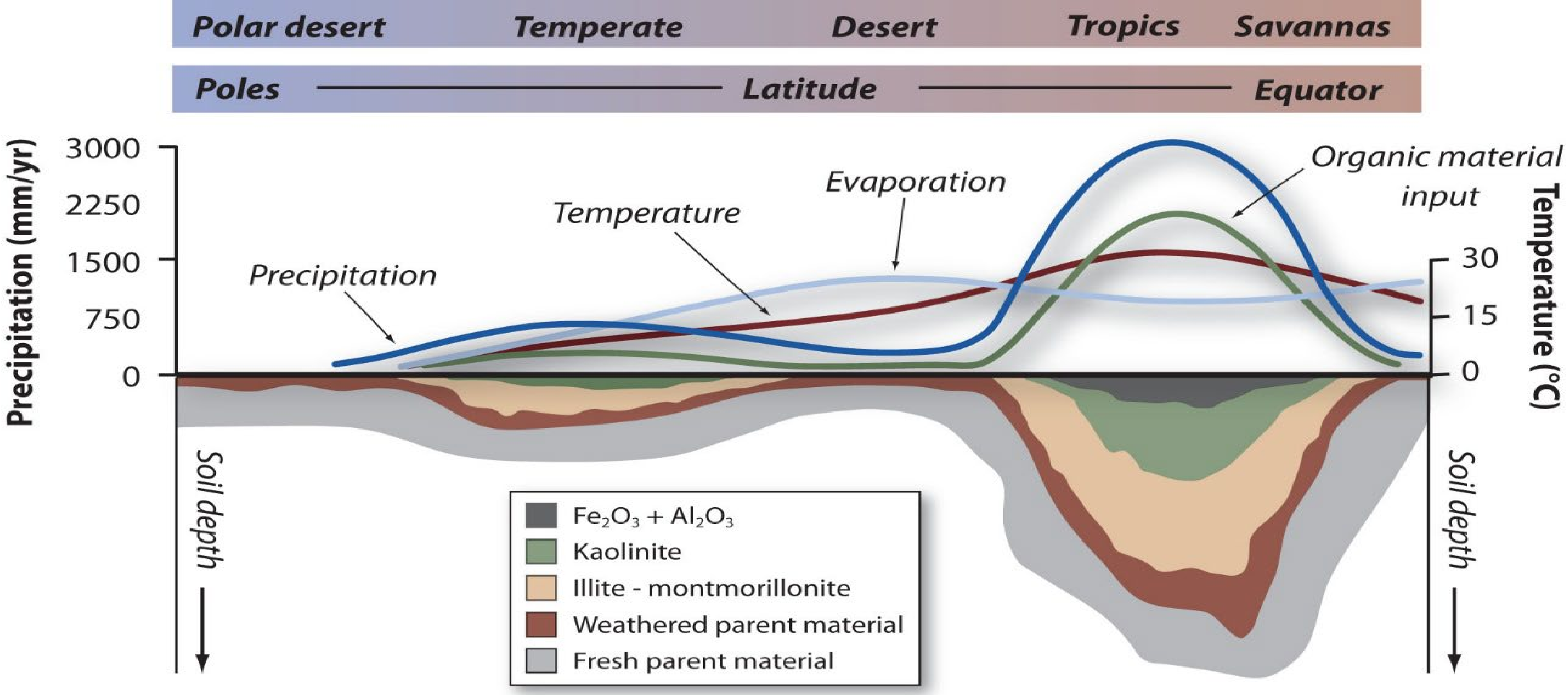
Thicker soil develops over a weaker substrate.


Exposed rock
Thicker soil develops over gentler slopes.

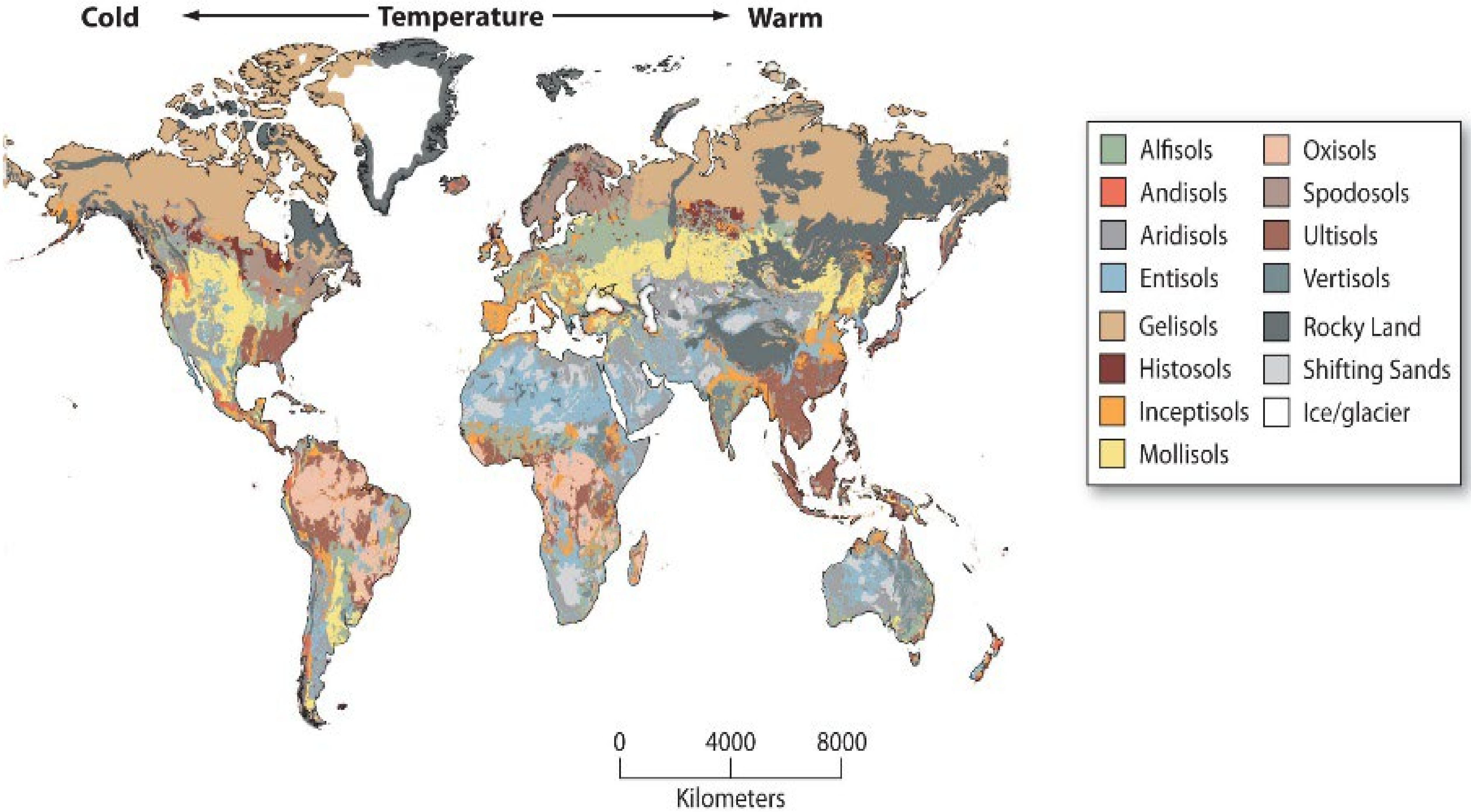


An older soil is thicker than a younger soil.


Humus
Polar
Temperate
Desert
Tropical
Unweathered rock
or sediment



Strong environmental controls on weathering (i.e., precipitation, temperature, and evaporation) and organic material inputs (i.e., leaf litter fall) lead to strong latitudinal gradients in soil depth and the mineralogy of weathering products. Soils tend to be thickest and most intensively weathered in tropical regions.


Cold
Temperature
Warm
Alfisols
Andisols
Aridisols
Entisols
Gelisols
Histosols
Inceptisols
Mollisols
Oxisols
Spodosols
Ultisols
Vertisols
Rocky Land
Shifting Sands
Ice/glacier
0
4000
8000
Kilometers

Palimpsest