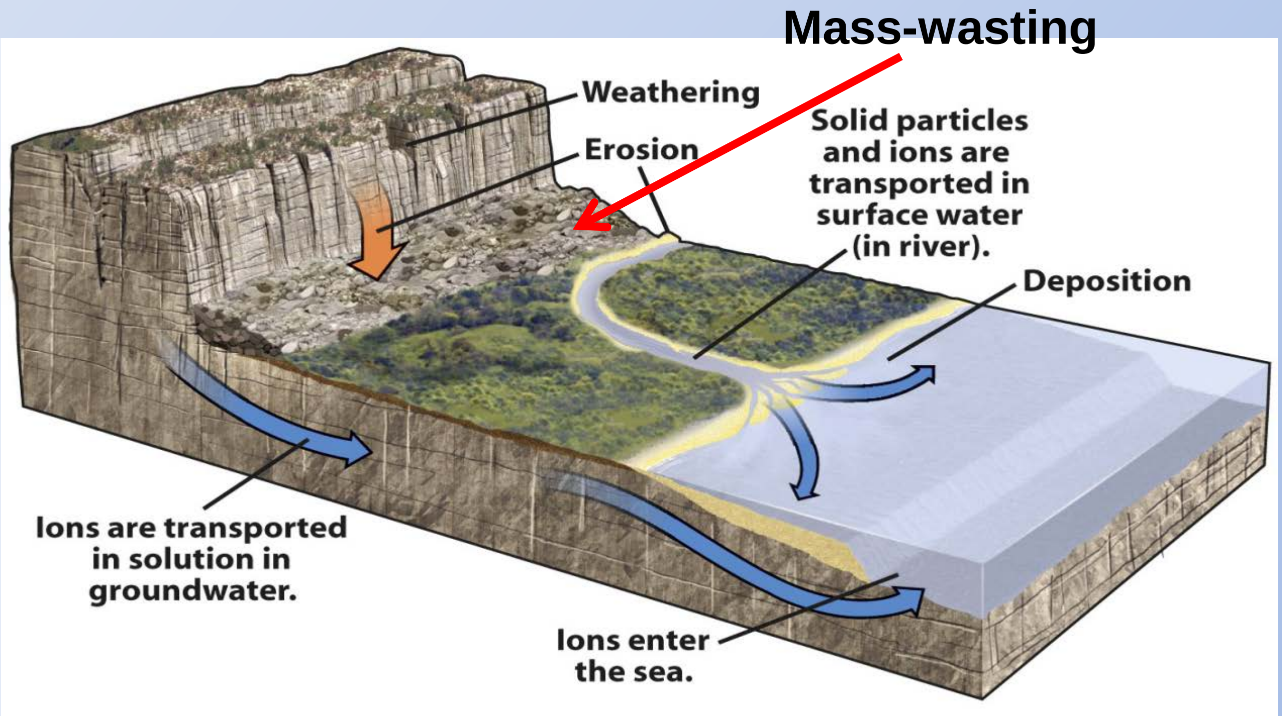
Weathering – The alteration of rock and minerals (in-situ), at or near the surface of the Earth and under conditions that prevail there.

http://eps.mcgill.ca/~courses/c220/

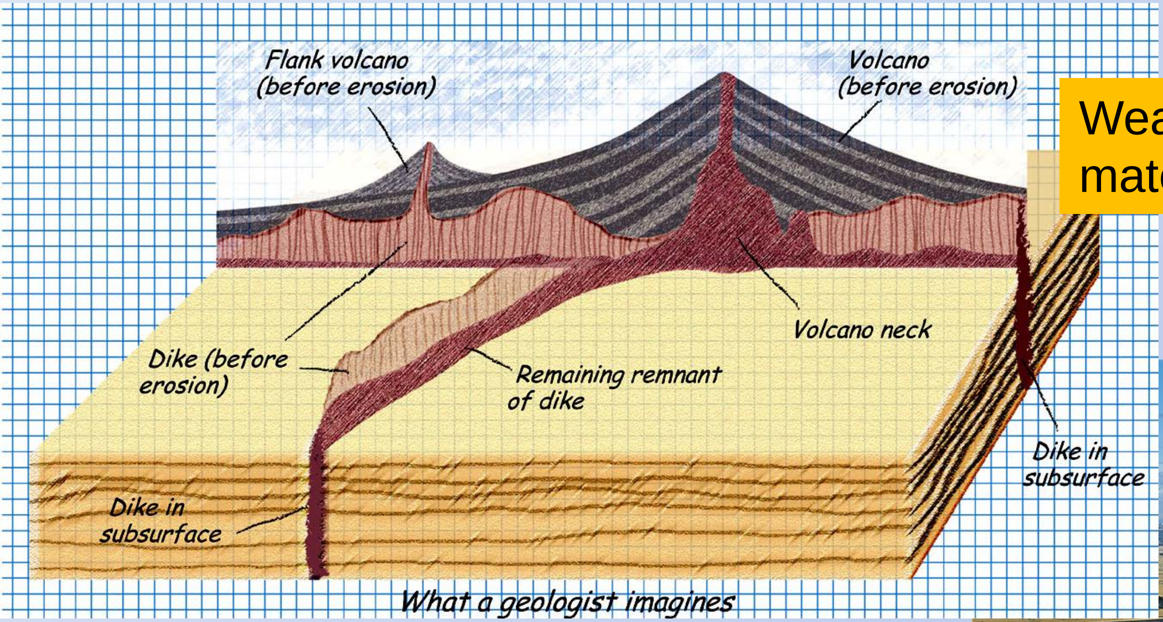
Weathering and the composition of natural waters

Weathering: chemical decay & physical fragmentation of rock at/near the Earth surface.
Erosion: incorporation and transport of material by a mobile agent (water, wind, ice).
Mass-wasting: transfer of rock material downslope under the influence of gravity (rockfalls/rockslides, landslides, slumps, avalanches, debris flow, mud flows, creep, etc.)

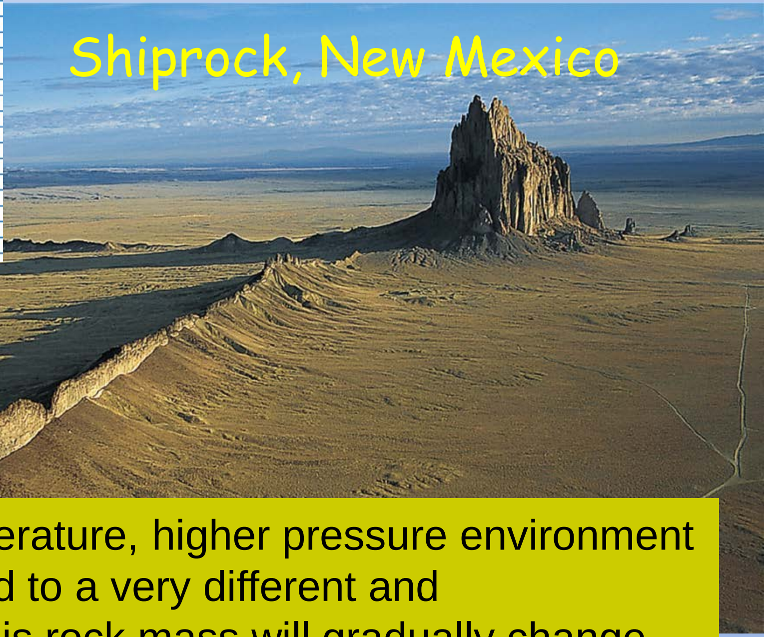


Weathering, erosion and mass-wasting cannot be totally dissociated from each other because, as weathering breaks rocks apart, it facilitates the movement of rock debris by erosion and mass-wasting and by removing the products of weathering, erosion and mass-wasting expose fresh, unaltered rock to weathering.

Intrusive igneous rocks revealed by erosion and now subjected to weathering

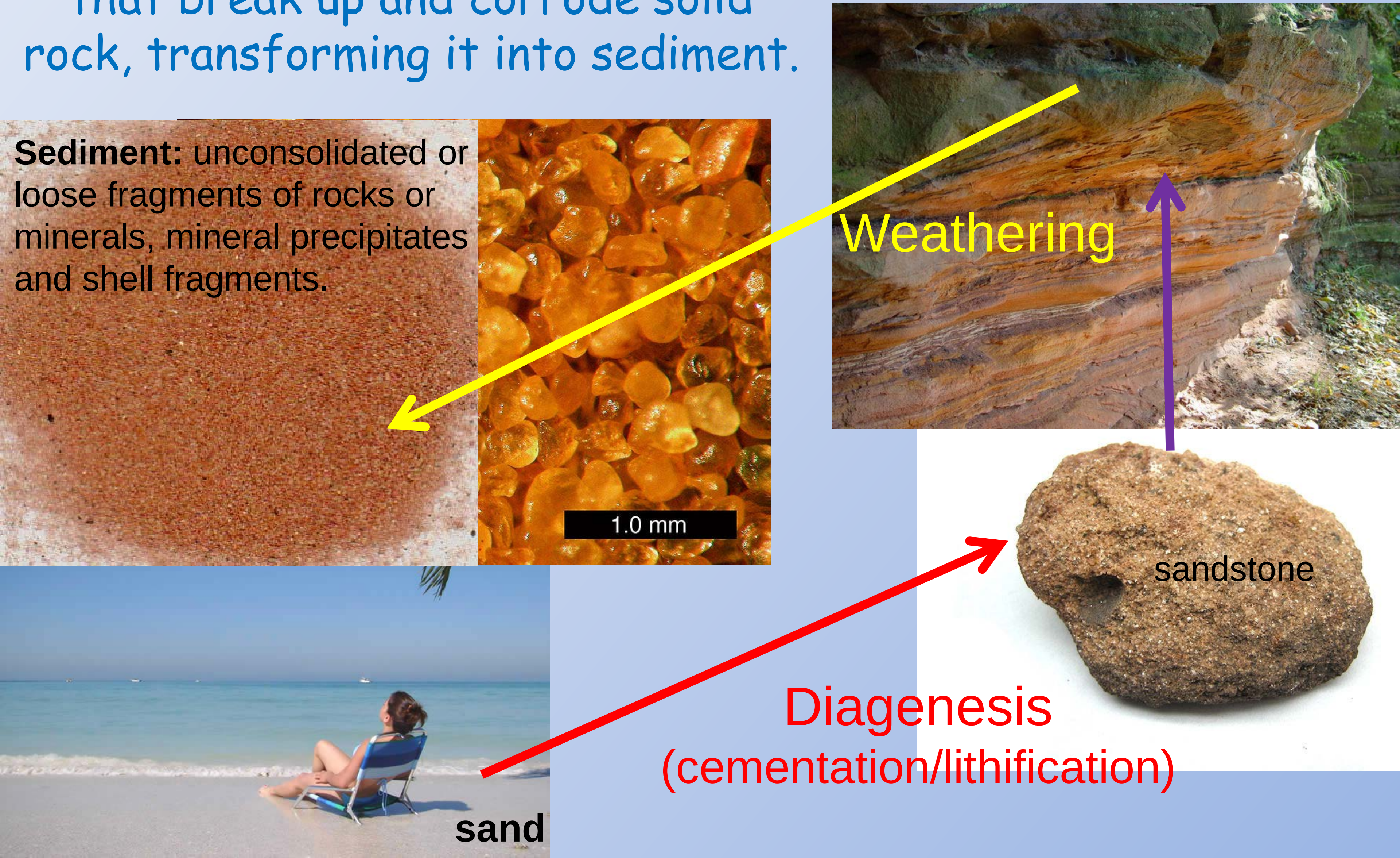


Weathering is the response of earth material to a changing environment.



This mass of crystalline rock, which formed in a high temperature, higher pressure environment perhaps several kilometres below ground, is now subjected to a very different and comparatively hostile surface environment. In response, this rock mass will gradually change until it is once again in equilibrium, or balance, with its environment **= weathering**.

Weathering: processes that break up and corrode solid rock, transforming it into sediment.



Sediment: unconsolidated or loose fragments of rocks or minerals, mineral precipitates and shell fragments.

1.0 mm

Weathering

sandstone

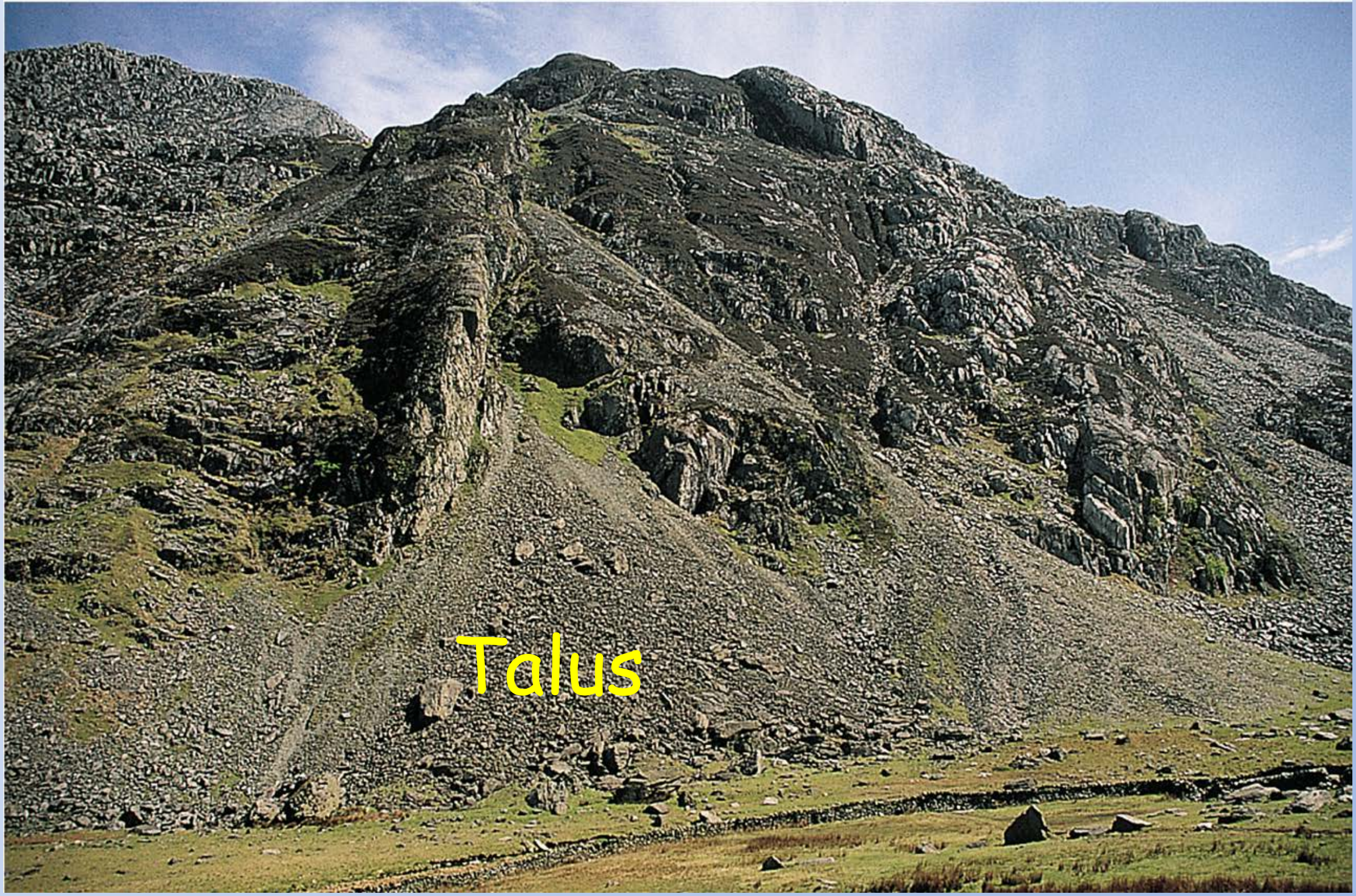
Diagenesis

(cementation/lithification)

sand

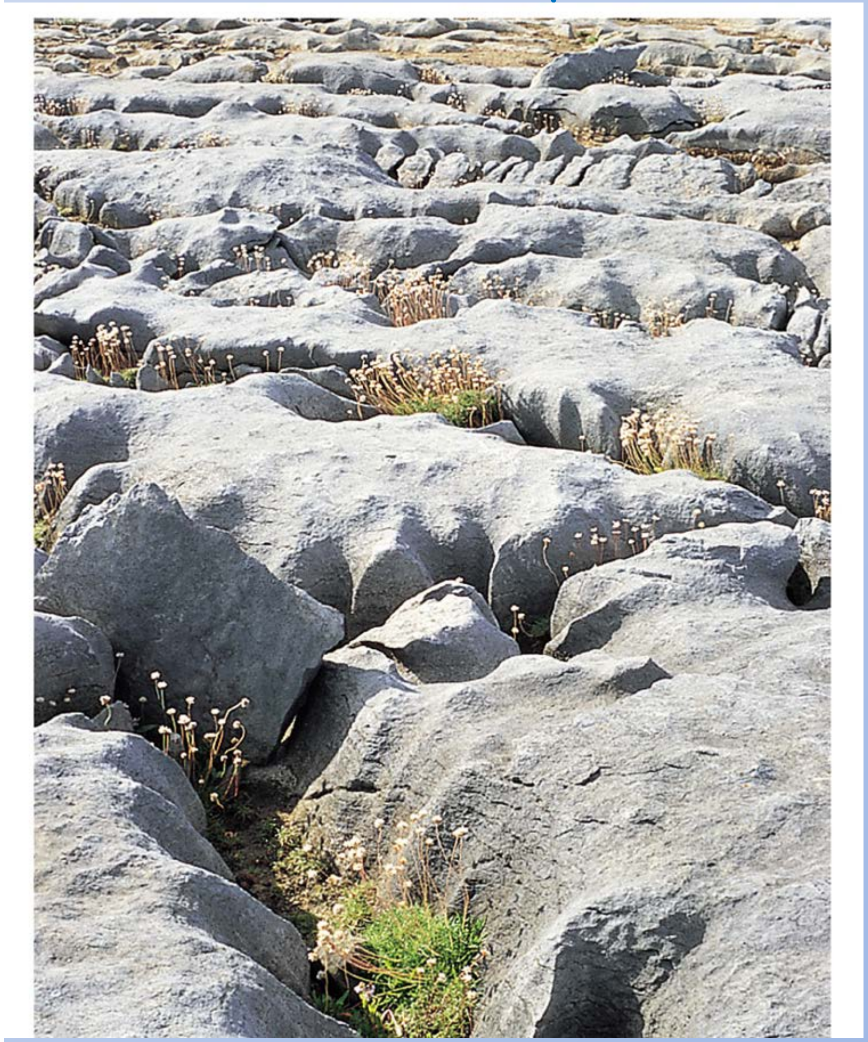
Mechanical/Physical Weathering

(rocks are broken down or disintegrated by physical processes, but retain the characteristics (mineralogy, composition) of the original parent rock)



Chemical Weathering

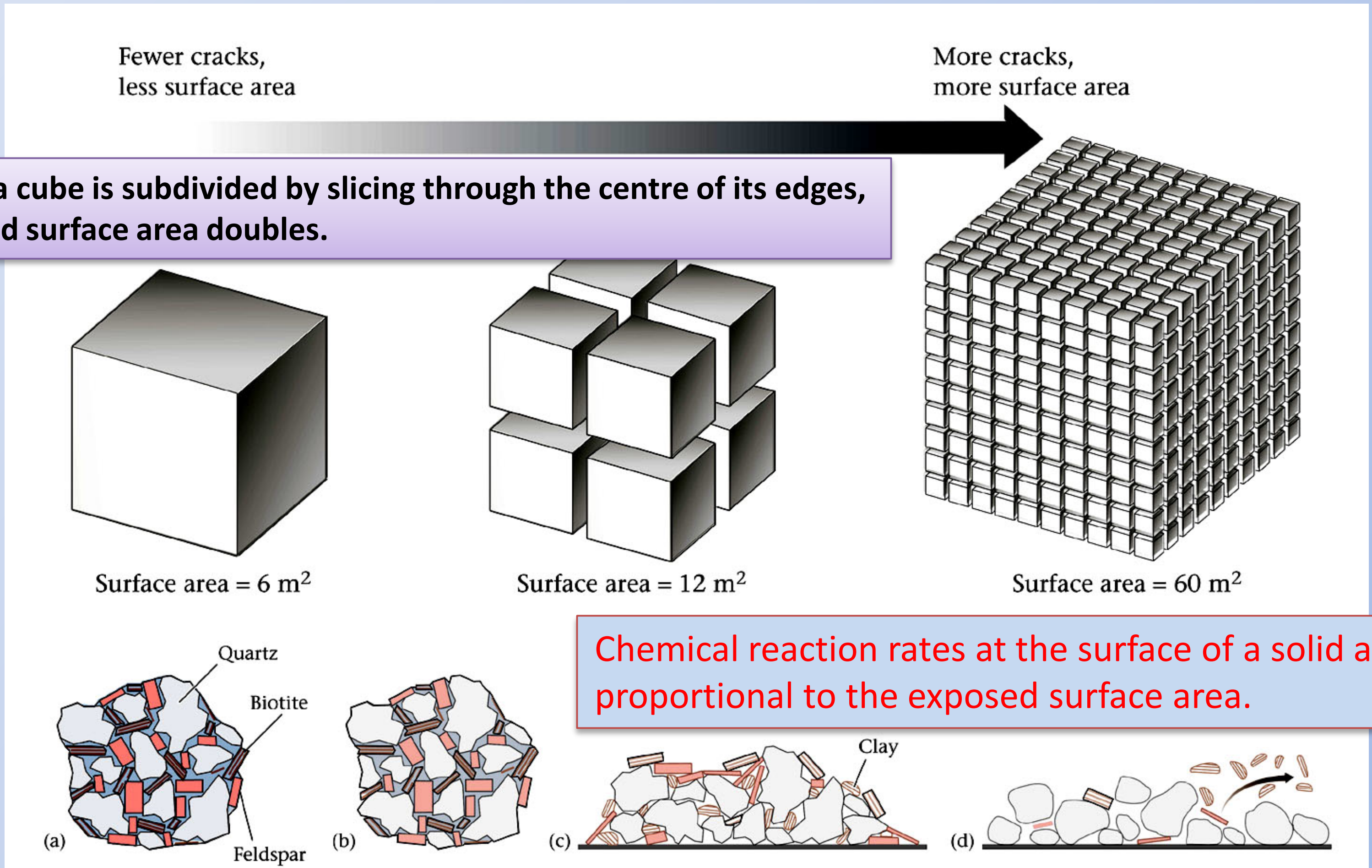
(the constituents of the rock breakdown and undergo chemical changes → decomposition, leaching, and formation of secondary minerals)



Mechanical Weathering & Surface Area

By breaking rocks into smaller pieces, mechanical weathering increases the amount of surface area available for chemical weathering/reactions.

Each time a cube is subdivided by slicing through the centre of its edges, the exposed surface area doubles.



Chemical reaction rates at the surface of a solid are proportional to the exposed surface area.

Much of the variability in the size of rocks/minerals you encounter in nature, from the fine sand grains to the larger boulder, reflects the various degrees of mechanical weathering.

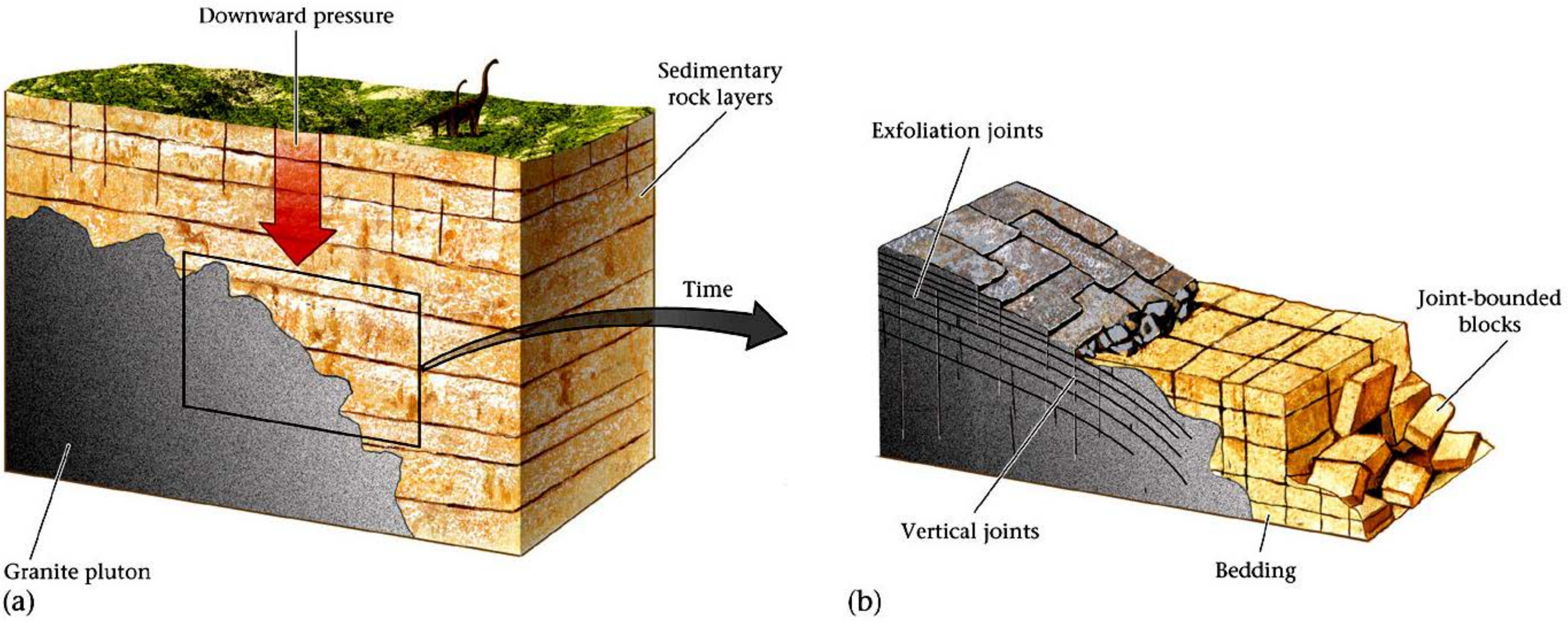
Time (or degree of mechanical weathering)

Physical/Mechanical Weathering

- Unloading
- Frost wedging (& mineral crystallization)
- Thermal expansion
- Organic activity
- Others

Unloading

(Expansion of rock upon the release of pressure as erosion wears down the surface or overburden or rocks are excavated)

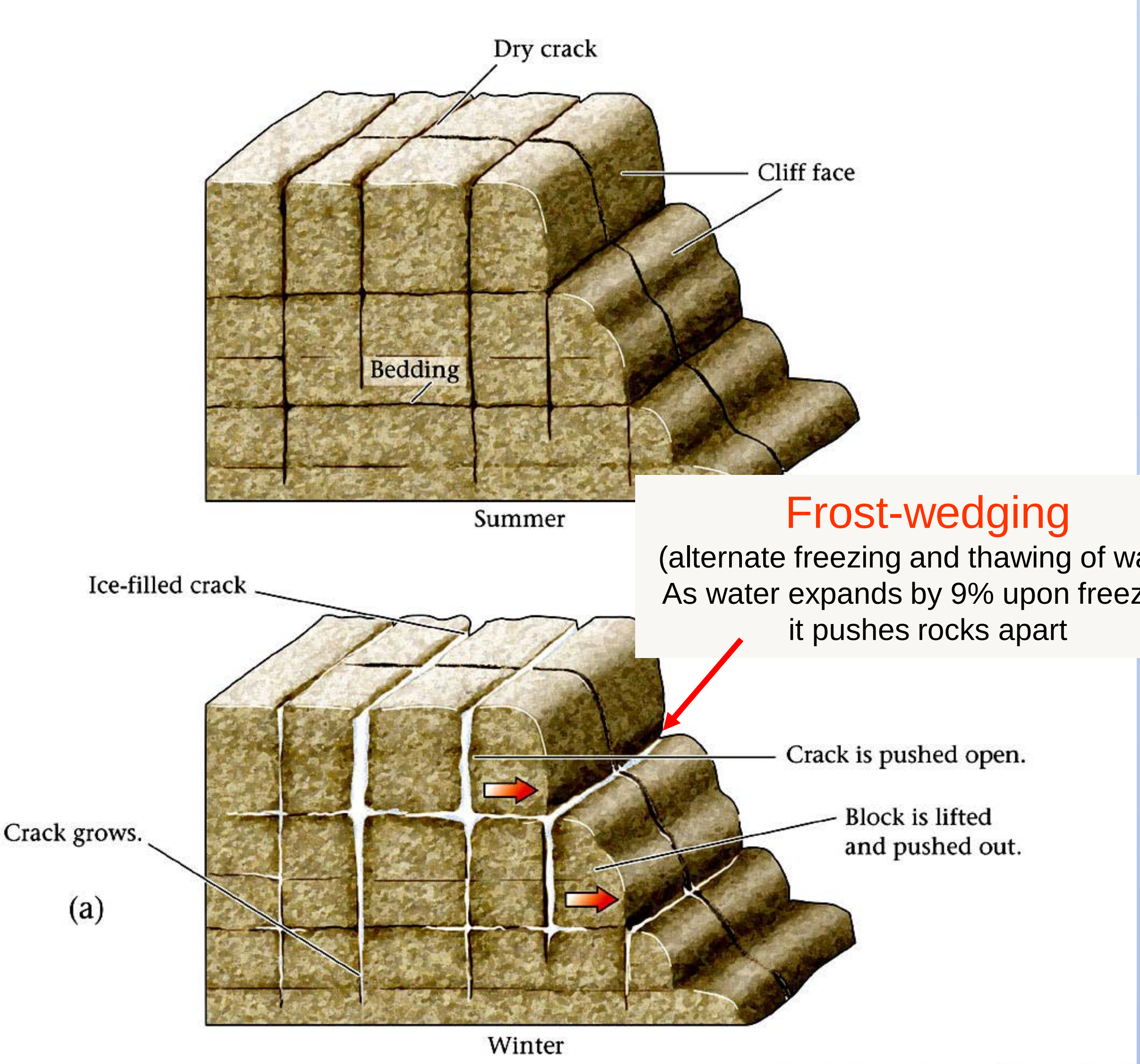


As pressure is removed, rocks expand, fractures or joints develop (e.g, mine shafts and quarry floors).

Physical/Mechanical Weathering

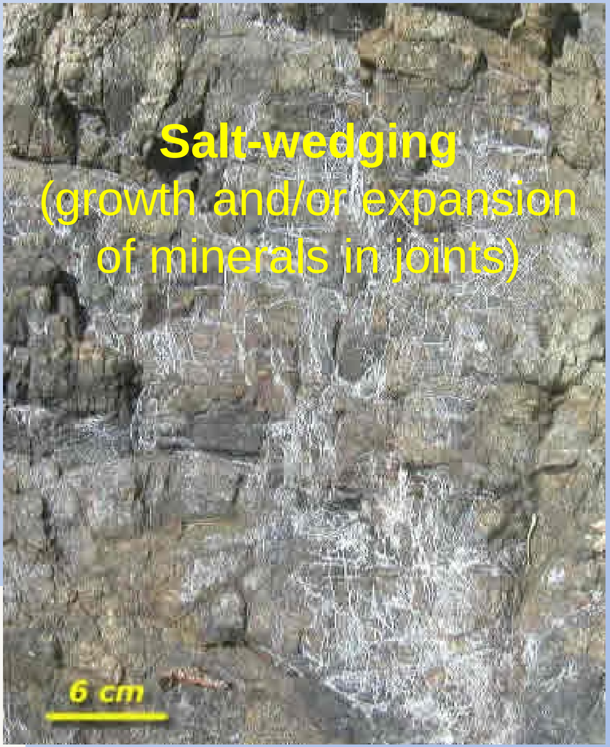
- Unloading
- Frost wedging (& mineral crystallization)
- Thermal expansion
- Organic activity
- Others

Physical Weathering



Frost-wedging

(alternate freezing and thawing of water)
As water expands by 9% upon freezing,
it pushes rocks apart



Salt-wedging
(growth and/or expansion
of minerals in joints)

Talus slope

Frost-wedging is most effective in mountaineous regions in mid-latitudes.

Physical/Mechanical Weathering

- Unloading
- Frost wedging (& mineral crystallization)
- Thermal expansion
- Organic activity
- Others

Thermal shock fracture of rocks

(because rock is such a poor heat conductor, the outer shell of rock will spall off or explode if exposed to intense heat)

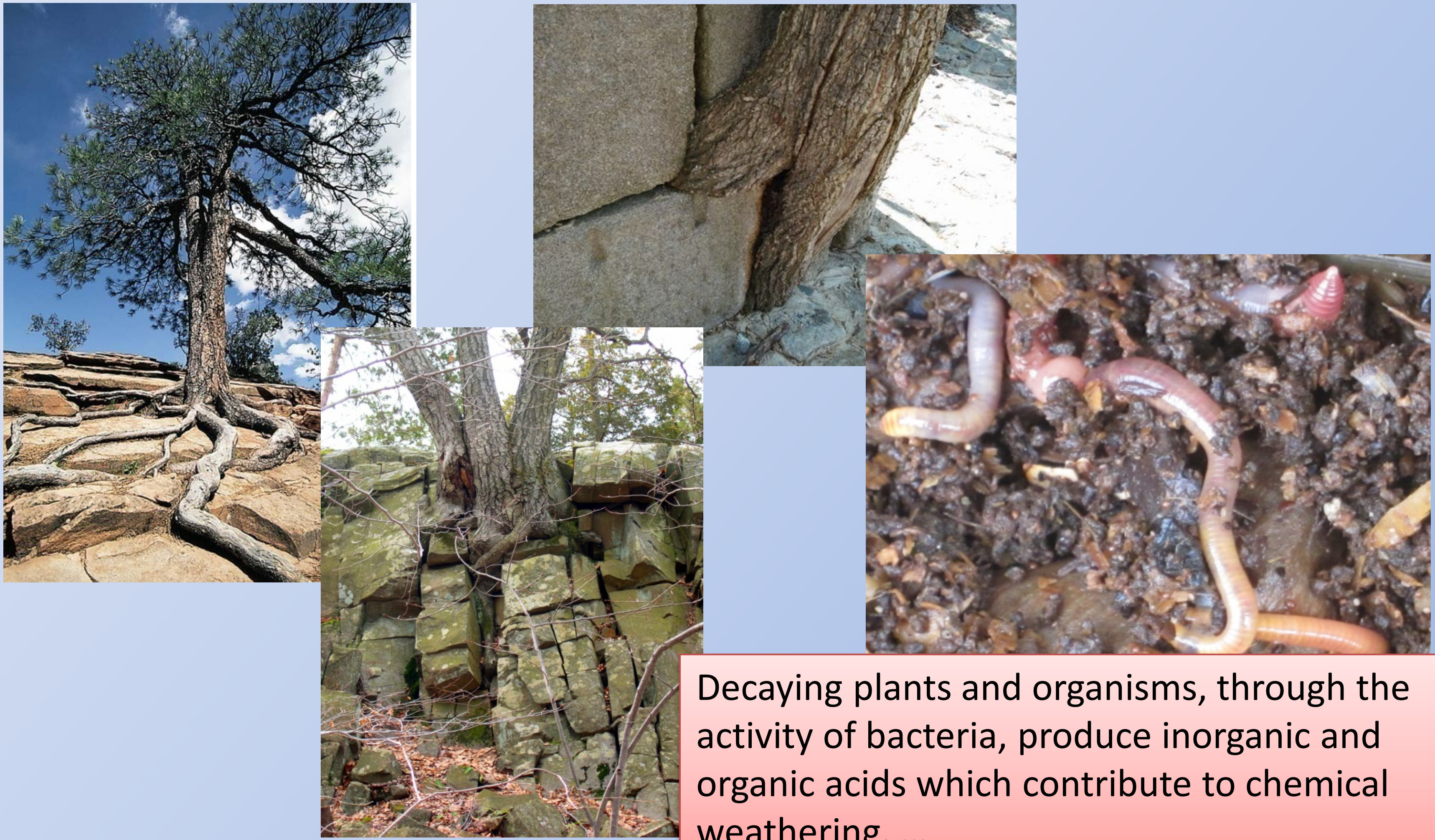
Physical/Mechanical Weathering

- Unloading
- Frost wedging (& mineral crystallization)
- Thermal expansion
- Organic activity
- Others

Physical Weathering

Organic activity

(burrowing animals, seed germination, roots, organic decay)



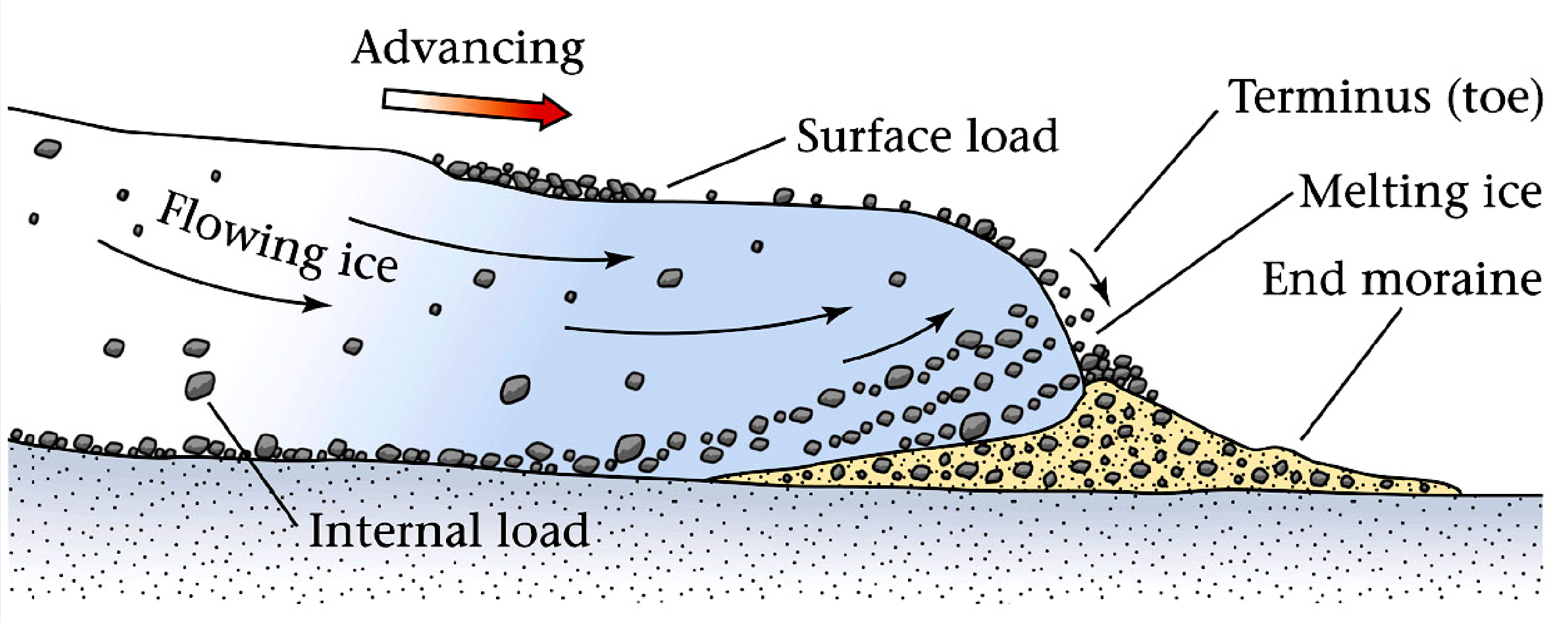
Decaying plants and organisms, through the activity of bacteria, produce inorganic and organic acids which contribute to chemical weathering. …

Physical/Mechanical Weathering

- Unloading
- Frost wedging (& mineral crystallization)
- Thermal expansion
- Organic activity
- Others

Grinding by moving glaciers

(as the glacier flows over bedrock, both the glacier's load and the bedrock get ground to a fine powder - rock flour)



Glacial Moraine

When the glacier eventually melts, the pebbles, boulders and finer particles carried by the glacier are left behind (e.g., glacier erratics) and creates a distinctive layer of sediment, **glacial till**, at the foot of the glacier.

Weathering:

mechanical and chemical denudation of the continents

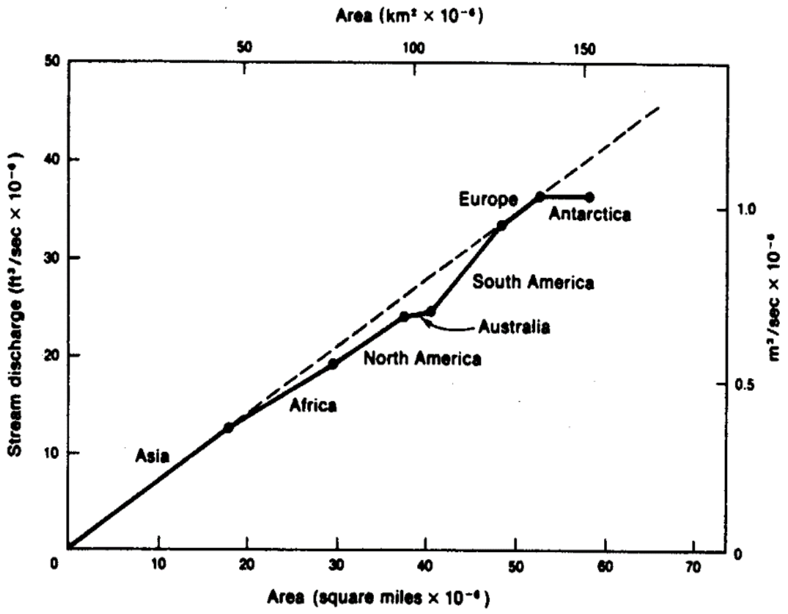


Figure 5.1 Cumulative plot of river discharge versus continental area. Note that Asia and Europe are representative of the world average, Australia and Africa are dry, and South America is very wet (data from Livingstone, 1963).

On average, the continents receive about the same amount of precipitation per unit surface area.

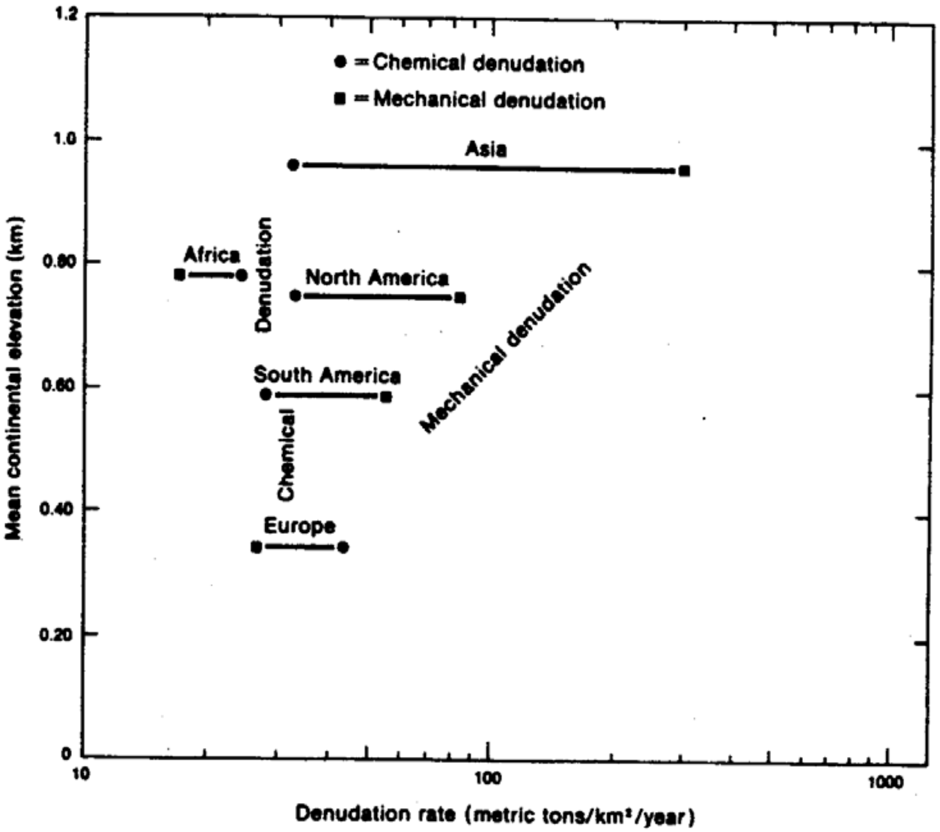


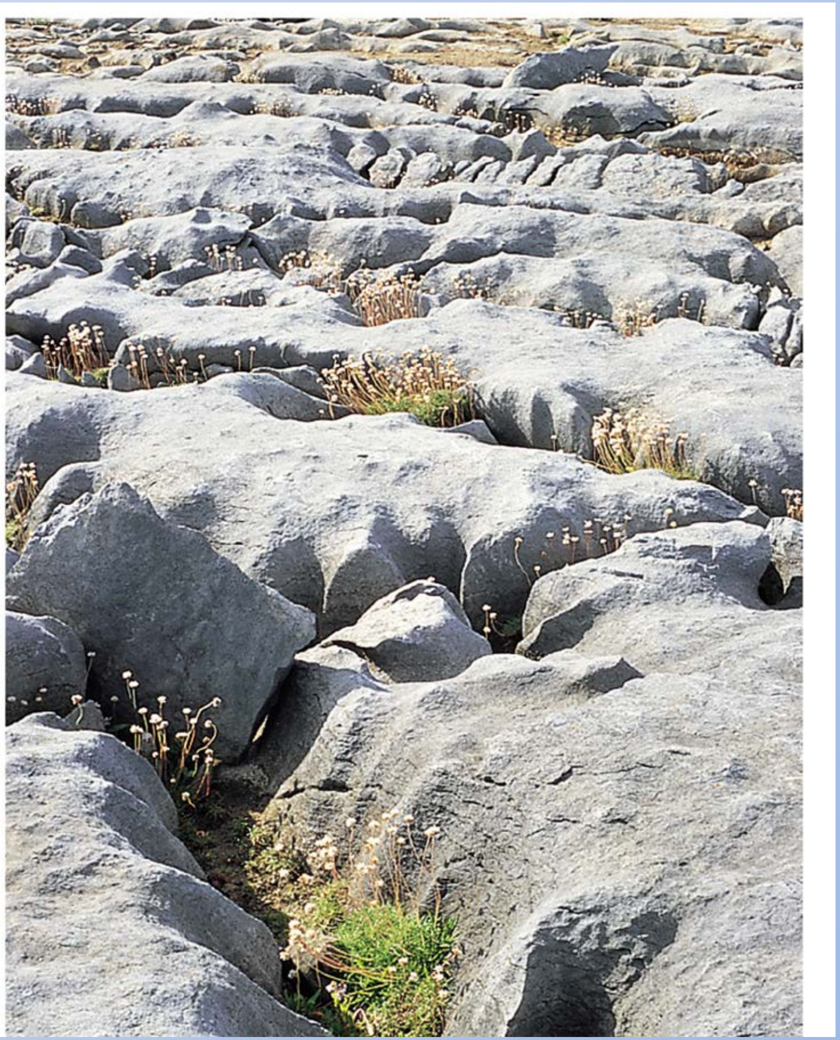
Figure 5.2 Graph showing that chemical denudation is independent of continental elevation, whereas mechanical denudation generally increases with increasing elevation. Africa shows "abnormally" low values for both types of denudation (data from Livingstone, 1963; Holeman, 1968).

From: Garrels and Mackenzie (1971)
Evolution of Sedimentary Rocks

Particulate load carried by rivers to the oceans: ~ 13.5 x 10^{15} g/yr (mechanical denudation)
Dissolved load carried by rivers to the oceans: ~ 4.1 x 10^{15} g/yr (chemical denudation)

Chemical Weathering

(the constituents of the rock breakdown and undergo chemical changes → decomposition, leaching, and formation of secondary minerals)



Chemical weathering:

the breakdown of rocks by chemical alteration of the constituent minerals and the formation of other minerals that are more stable.

- **Dissolution**: passing into solution
- **Hydrolysis**: substitution by H^+ or OH^-
- **Oxidation**: reaction with oxygen
- **Hydration**: absorption of water

Chemical Weathering
Congruent Dissolution

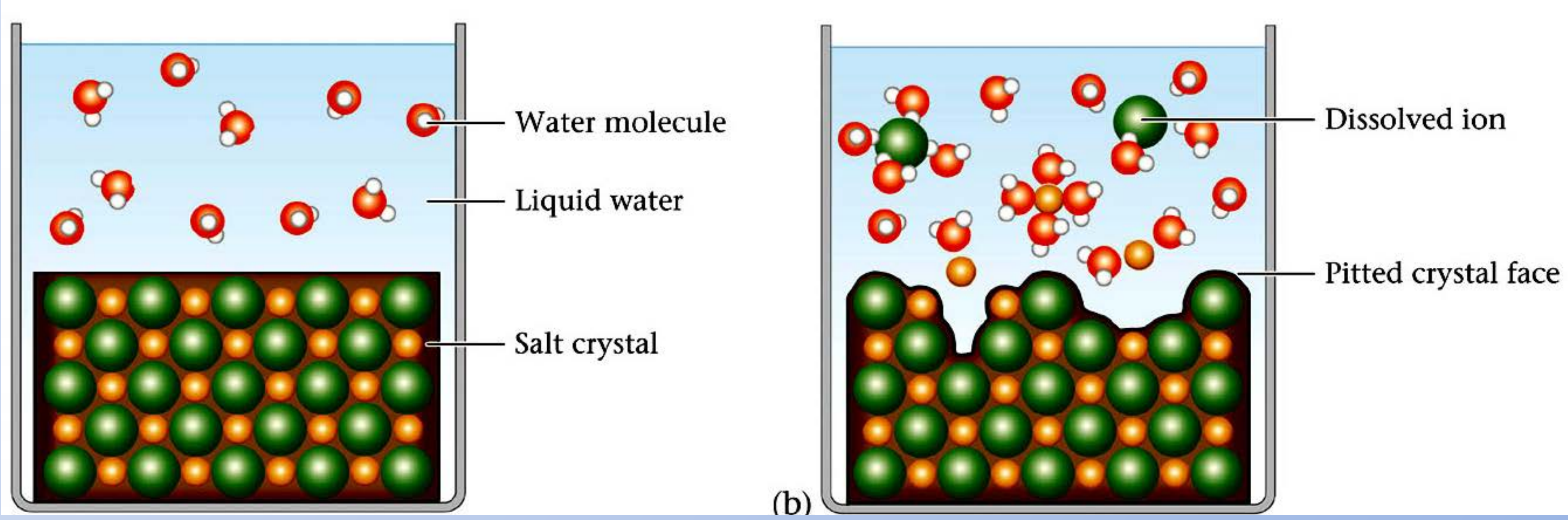
(all mineral constituents pass into solution but the amount is determined by the solubility of the parent mineral)

$$CaSO_4 \cdot 2H_2O \leftarrow\rightarrow Ca^{2+} + SO_4^{2-} + 2H_2O$$

Gypsum

$$CaCO_3 + \underbrace{CO_2 + H_2O}_{H_2CO_3 \text{ – carbonic acid}} \leftarrow\rightarrow Ca^{2+} + 2HCO_3^{-}$$

Calcite



Major components of various rivers of the continents of the world

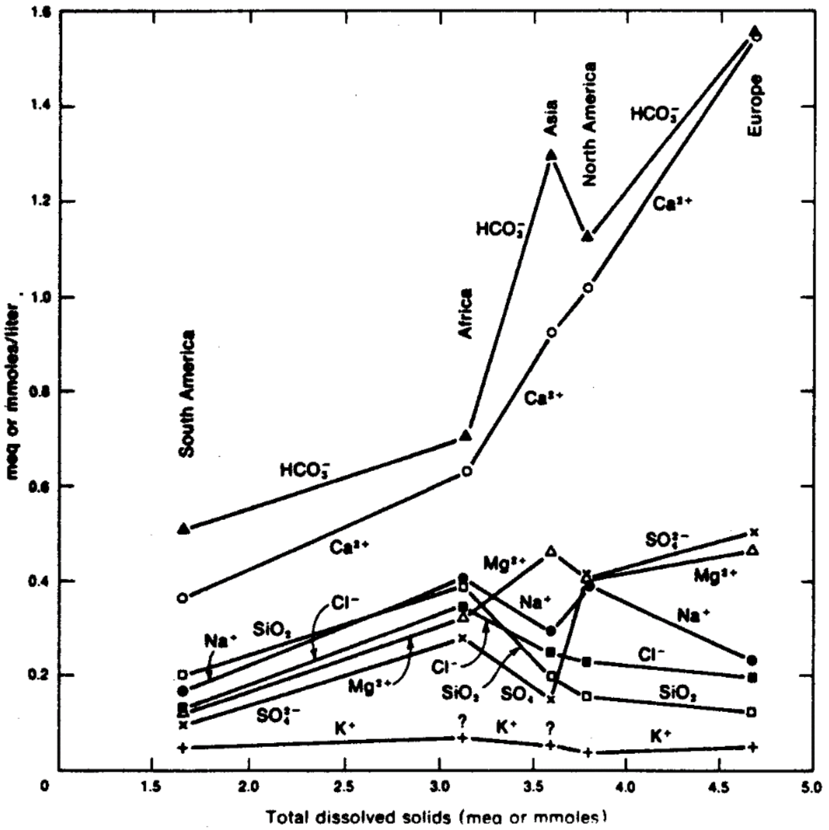
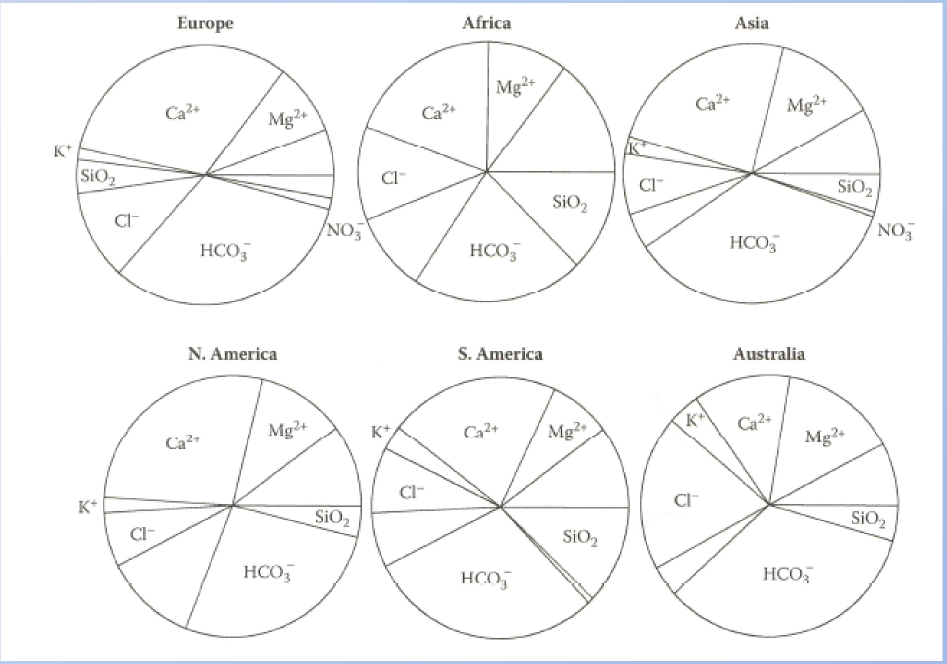


Figure 5.3 Concentrations of dissolved species in continental drainage. The major differences from continent to continent are in the contents of Ca^{2+} and HCO_3^- (data from Livingstone, 1963).



Chemical Weathering

Hydrolysis/Incongruent Dissolution

(H^+ or OH^-, the constituents of water, replace other ions of a mineral)

Weathering of granite

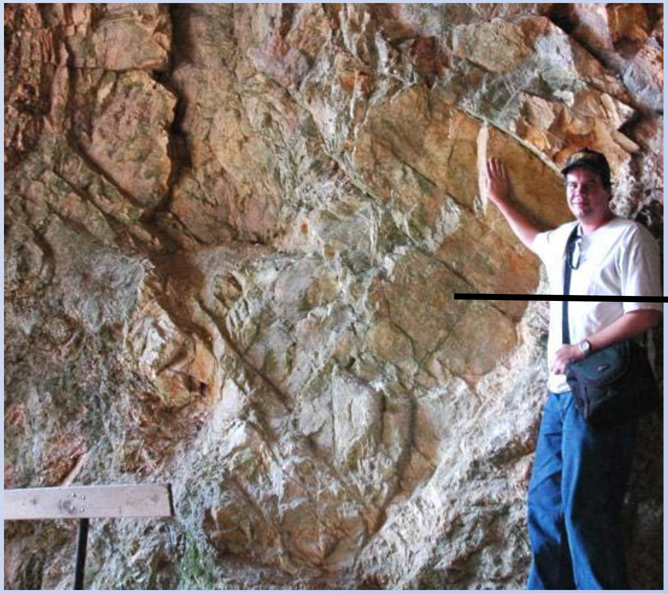
$$2KAlSi_3O_8 + 2H^+ + H_2O \rightarrow 2K^+ + Al_2Si_2O_5(OH)_4 + 4SiO_2$$

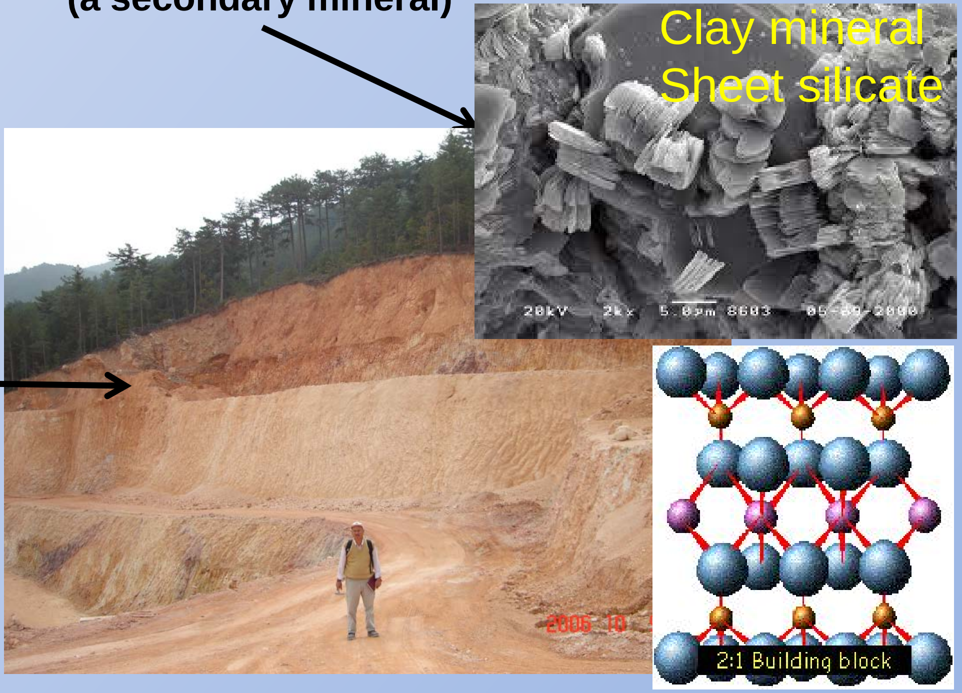
K-feldspar

Kaolinite

Quartz

(a secondary mineral)





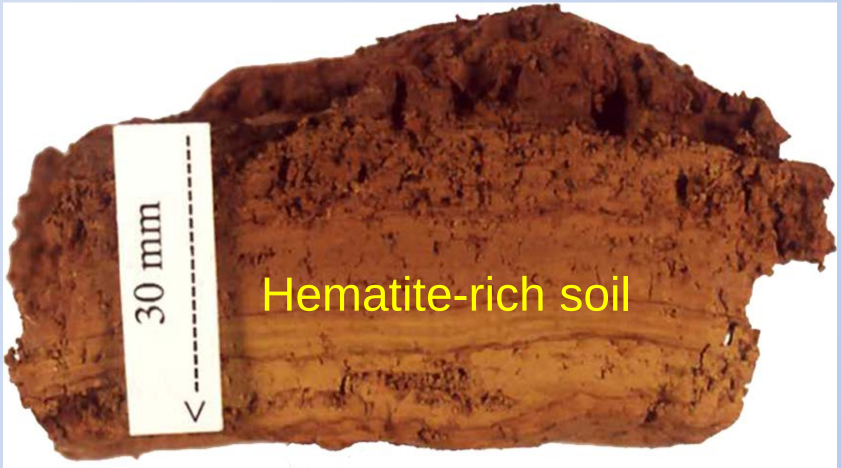
Chemical Weathering

Oxidation

(combination of atmospheric oxygen with a mineral constituent to produce an oxide, especially important in the weathering of minerals rich in reduced iron – ferrous iron -, such as olivine, pyroxenes and amphiboles)

$$2FeS_2 + 7.5O_2 + 5H_2O \rightarrow 2FeO(OH) + 4H_2SO_4$$

Pyrite Goethite Sulfuric acid

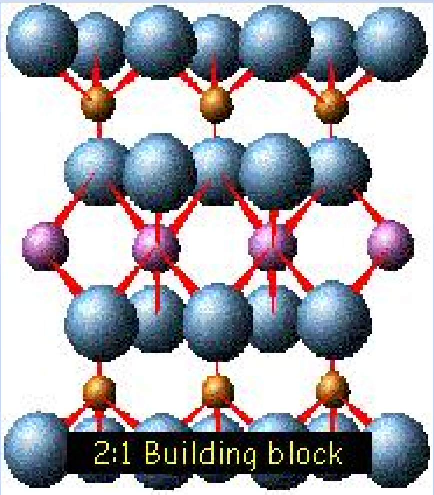


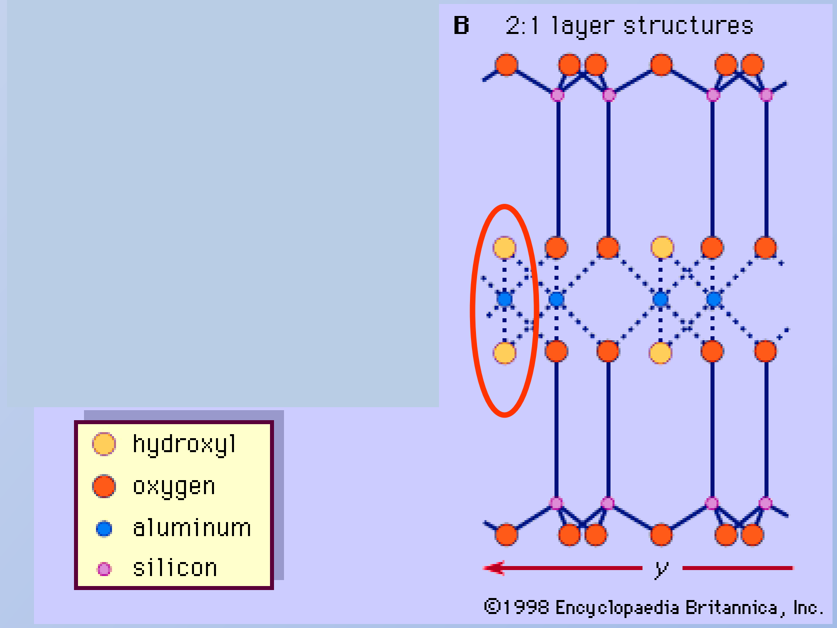
Chemical Weathering

Hydration

(addition of water – H_2O - into the crystal structure of minerals)

- Swelling of clays like Montmorillonite
- Hydration of CaO to $Ca(OH)_2$
- Hydration of anhydrite ($CaSO_4$) to gypsum ($CaSO_4{\cdot}2H_2O$)





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Incongruent dissolution

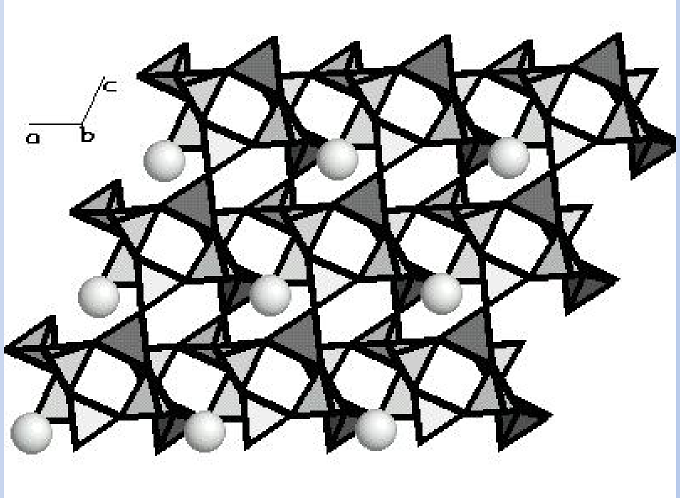
(formation of a secondary mineral)

$$4NaAlSi_3O_8 + 11H_2O \rightarrow 4Na^+ + 4OH^- + Al_2Si_2O_5(OH)_4 + 8H_4SiO_4$$

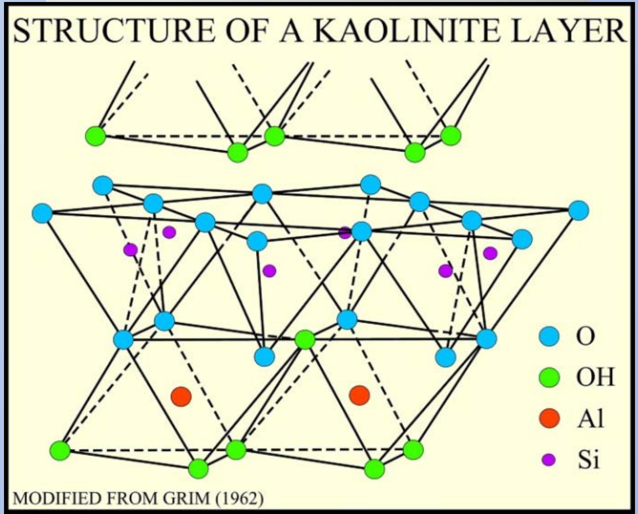
or, in the presence of a CO_2-charged solution,

$$4NaAlSi_3O_8 + 4H_2CO_3 + 18H_2O \rightarrow 4Na^+ + 4HCO_3^- + Al_2Si_2O_5(OH)_4 + 8H_4SiO_4$$

Albite



Kaolinite



Incongruent dissolution

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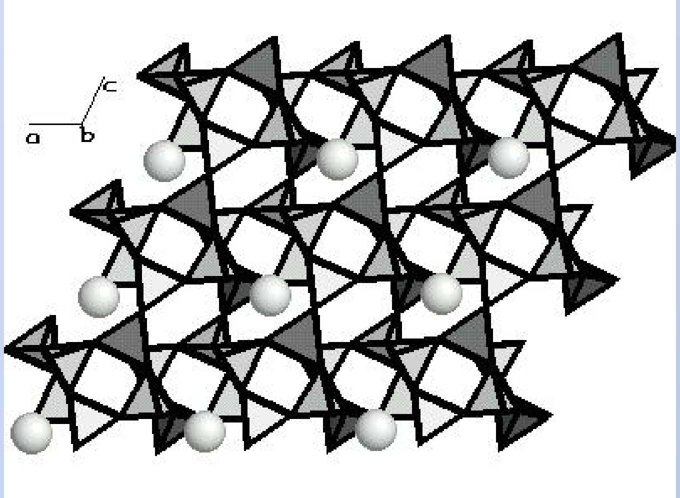
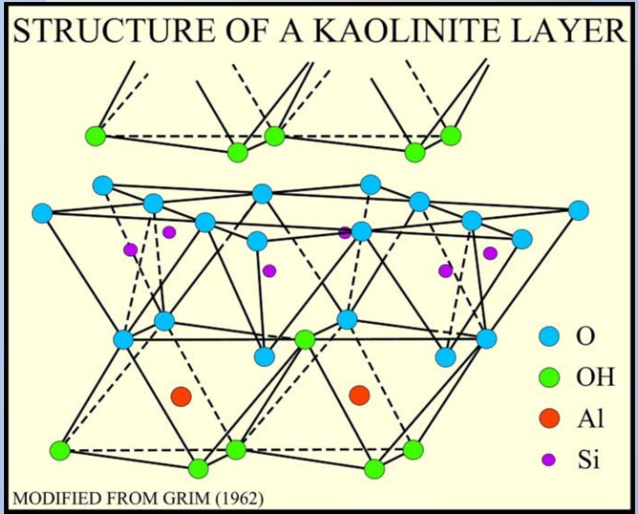
Albite


Kaolinite

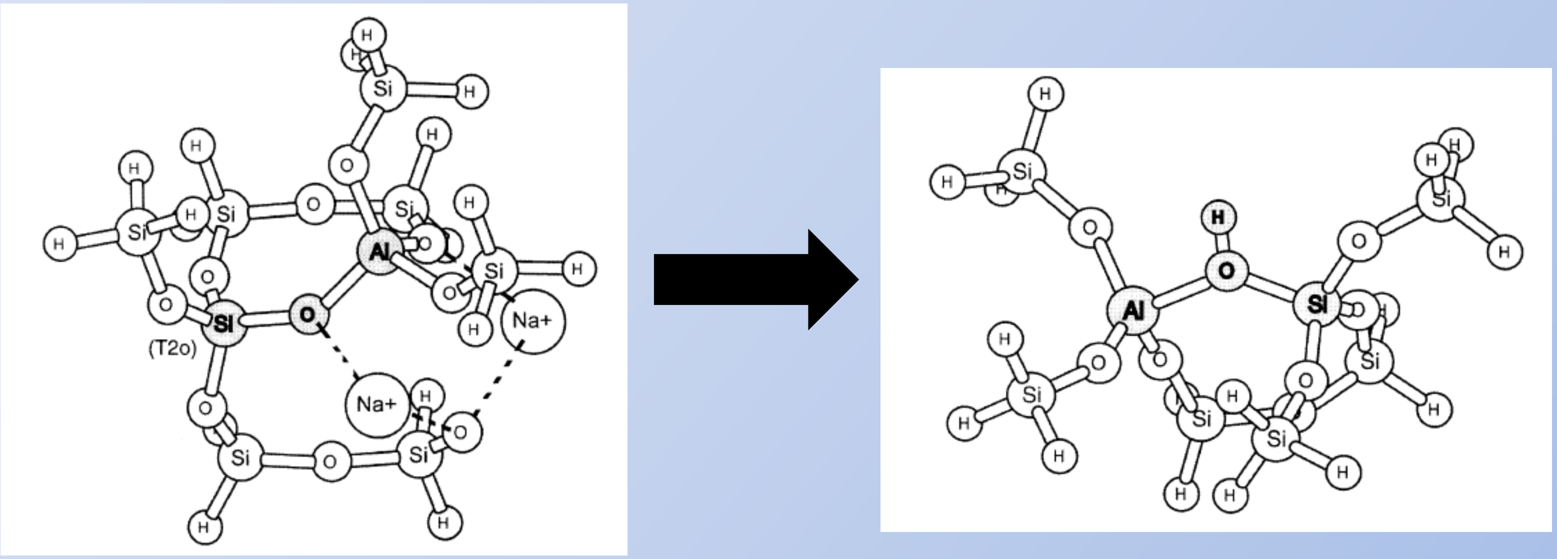



STRUCTURE OF A KAOLINITE LAYER

MODIFIED FROM GRIM (1962)

Albite dissolution (step 1)

(hydrolysis of the mineral surface and exchange of H^+ for Na^+)

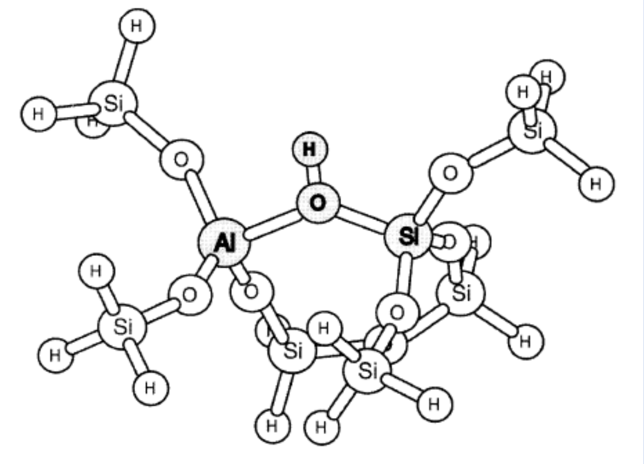


$+ H_2O$ → $+ Na^+ + OH^-$

From: Liu et al. (2002) Geochim. Cosmochim. Acta v. 66, p. 4149-4163

Albite dissolution (step 2)

(breakdown of the silicate matrix – congruent dissolution)



(+ Na^+ + OH^-)

→

$Al(OH)_4^-$

H_4SiO_4

(+ Na^+ + OH^-)

From: Liu et al. (2002) Geochim. Cosmochim. Acta v. 66, p. 4149-4163

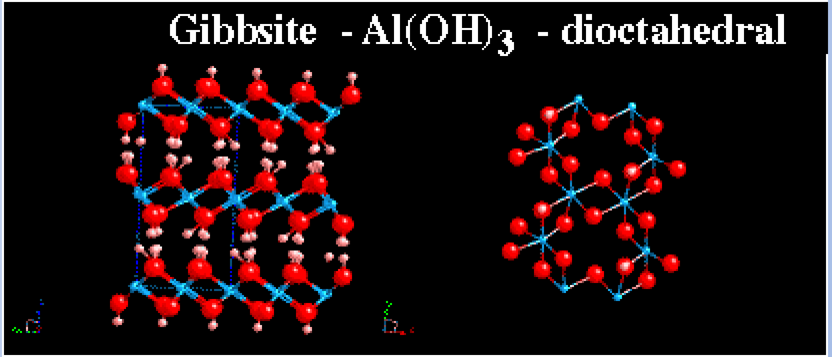
Albite dissolution (step 3)

(gibbsite precipitation as an intermediate product)

- Incongruent dissolution -

$$\mathrm{Al(OH)_4^- + H^+ \leftarrow\rightarrow Al(OH)_3 + H_2O}$$

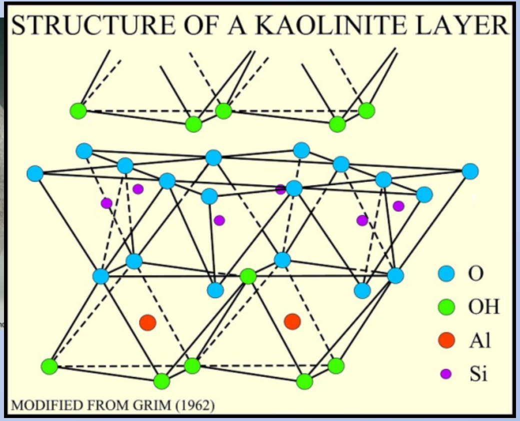
$$\mathrm{(albite + H^+ + 7H_2O \leftarrow\rightarrow Al(OH)_3 + Na^+ + 3H_4SiO_4)}$$



Albite dissolution (step 3)

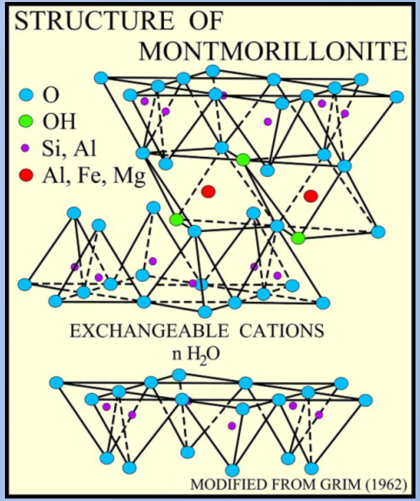
(conversion of gibbsite to kaolinite)

$$Al(OH)_3 + 0.5\ H_4SiO_4 \rightarrow Al_2Si_2O_5(OH)_4 + 2.5\ H_2O$$



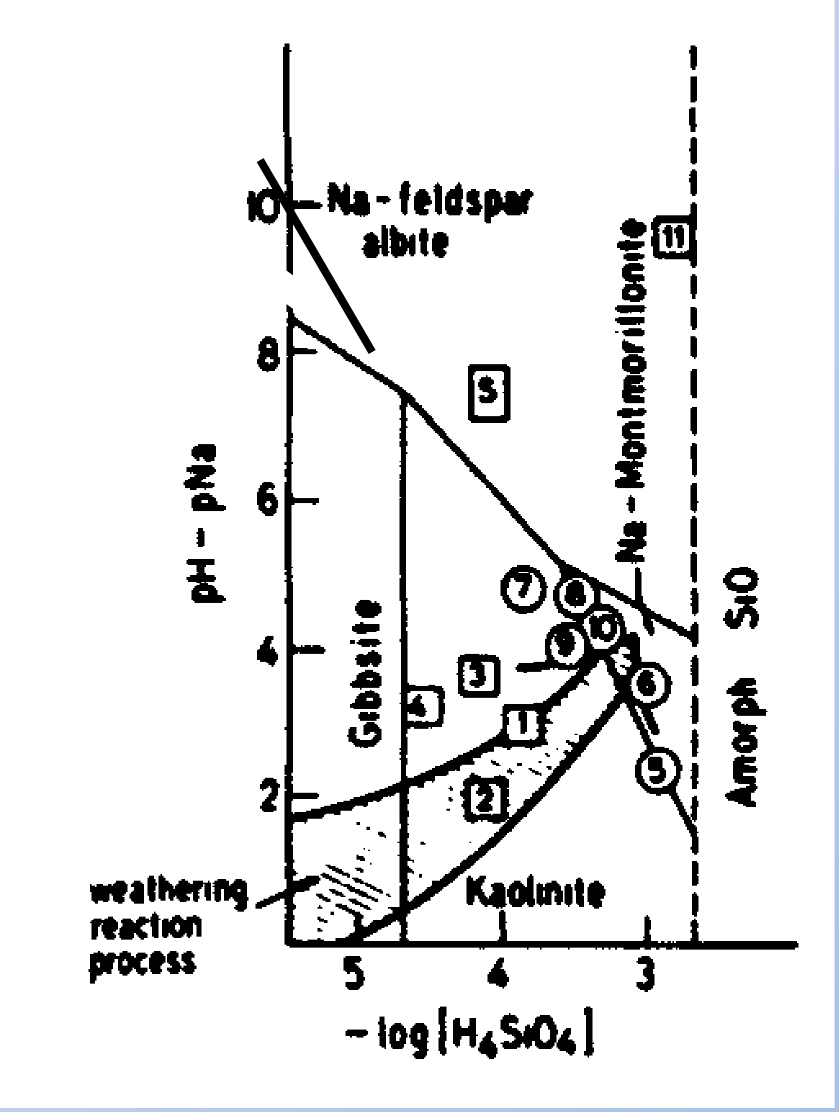
After all the gibbsite is consumed, Na-montmorillonite may form:

$$3.5\ \text{kaolinite} + 4\ H_4SiO_4 + Na^+ \rightarrow 3\ Na_{0.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 11.5H_2O$$



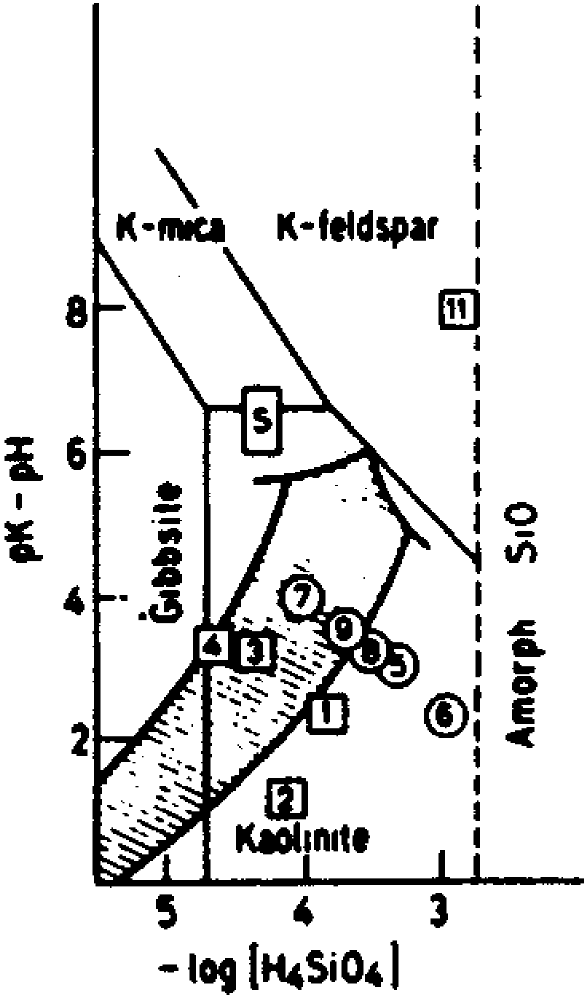
Albite dissolution reaction

(predominance diagram showing the stability relations between mineral phases)



The dissolution of K-spar

(predominance diagram showing the stability relations between mineral phases)



Thermodynamic constraints

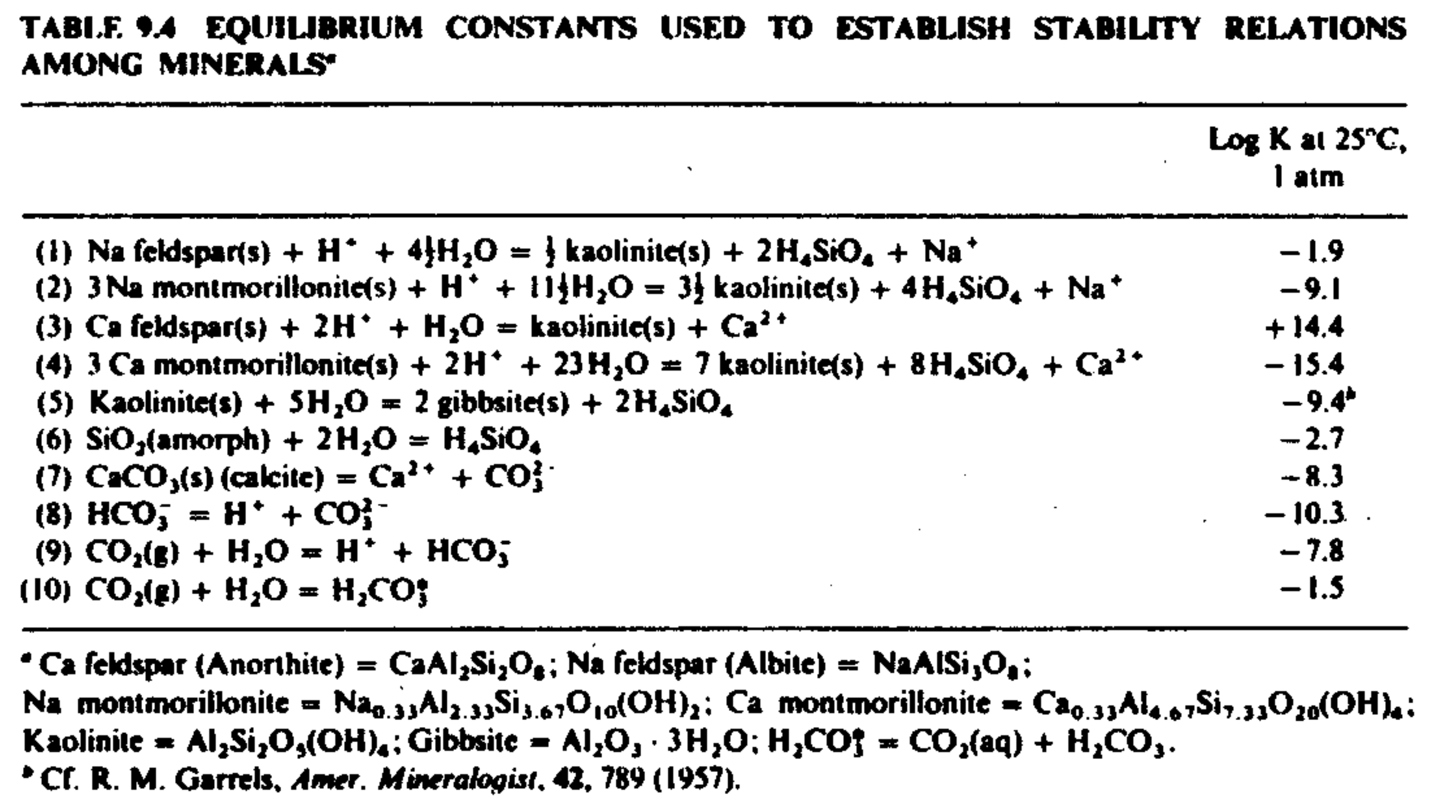


TABLE 9.4 EQUILIBRIUM CONSTANTS USED TO ESTABLISH STABILITY RELATIONS AMONG MINERALS[a]

	Log K at 25°C, 1 atm
(1) Na feldspar(s) + H^+ + $4\frac{1}{2}H_2O$ = $\frac{1}{2}$ kaolinite(s) + $2H_4SiO_4$ + Na^+	−1.9
(2) 3 Na montmorillonite(s) + H^+ + $11\frac{1}{2}H_2O$ = $3\frac{1}{2}$ kaolinite(s) + $4H_4SiO_4$ + Na^+	−9.1
(3) Ca feldspar(s) + $2H^+$ + H_2O = kaolinite(s) + Ca^{2+}	+14.4
(4) 3 Ca montmorillonite(s) + $2H^+$ + $23H_2O$ = 7 kaolinite(s) + $8H_4SiO_4$ + Ca^{2+}	−15.4
(5) Kaolinite(s) + $5H_2O$ = 2 gibbsite(s) + $2H_4SiO_4$	−9.4[b]
(6) SiO_2(amorph) + $2H_2O$ = H_4SiO_4	−2.7
(7) $CaCO_3$(s) (calcite) = Ca^{2+} + CO_3^{2-}	−8.3
(8) HCO_3^- = H^+ + CO_3^{2-}	−10.3
(9) CO_2(g) + H_2O = H^+ + HCO_3^-	−7.8
(10) CO_2(g) + H_2O = $H_2CO_3^*$	−1.5

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[a] Ca feldspar (Anorthite) = $CaAl_2Si_2O_8$; Na feldspar (Albite) = $NaAlSi_3O_8$; Na montmorillonite = $Na_{0.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2$; Ca montmorillonite = $Ca_{0.33}Al_{4.67}Si_{7.33}O_{20}(OH)_4$; Kaolinite = $Al_2Si_2O_5(OH)_4$; Gibbsite = $Al_2O_3 \cdot 3H_2O$; $H_2CO_3^*$ = $CO_2(aq)$ + H_2CO_3.

[b] Cf. R. M. Garrels, *Amer. Mineralogist*, 42, 789 (1957).

Constructing predominance diagrams

$\log(H_4SiO_4)$ & $(pH – pNa)$ are used as a measure of the reaction progress

Albite/gibbsite boundary:

$NaAlSi_3O_8 + H^+ + 7H_2O \leftrightarrow Al(OH)_3 + Na^+ + 3H_4SiO_4$

$K = (Al(OH)_3)\ (Na^+)\ (H_4SiO_4)^3 / (NaAlSi_3O_8)\ (H^+) = 10^{-2.53}$

$\log K = \log(Na^+) + 3 \log(H_4SiO_4) – \log(H^+) = pH – pNa + 3 \log(H_4SiO_4)$

$\log K - 3 \log(H_4SiO_4) = (pH – pNa)$

Gibbsite/kaolinite boundary:

$Al(OH)_3 + H_4SiO_4 \leftrightarrow 0.5\ Al_2Si_2O_5(OH)_4 + 2.5\ H_2O$

$K = (H_4SiO_4) = 10^{-4.7}$

$\log K = \log\ (H_4SiO_4) = -4.7$

Albite/kaolinite boundary:

$2NaAlSi_3O_8 + 2H^+ + 9H_2O \leftrightarrow Al_2Si_2O_5(OH)_4 + 2\ Na^+ + 4\ H_4SiO_4$

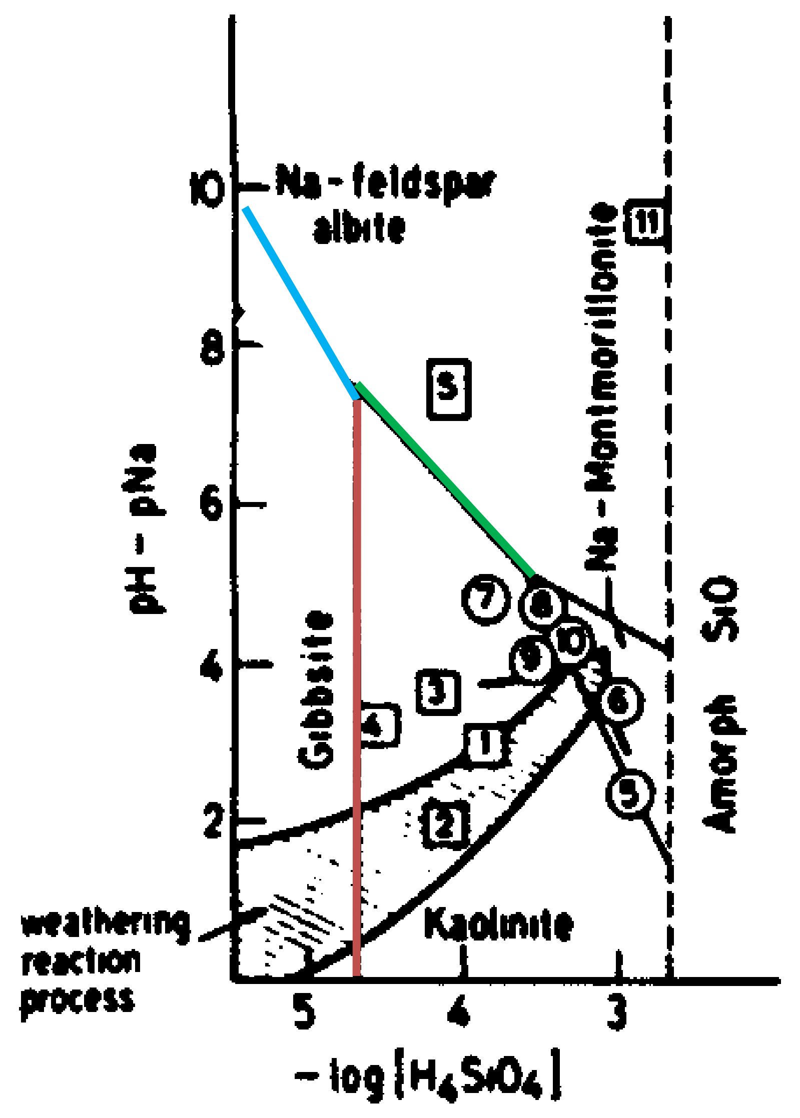
$K = (Na^+)^2\ (H_4SiO_4)^4 / (H^+)^2 = 10^{-0.38}$

$\log K = 2 \log(Na^+) + 4 \log(H_4SiO_4) + 2\ pH$

$0.5 \log K – 2 \log(H_4SiO_4) = (pH – pNa)$

Predominance diagram

log(H_4SiO_4) & (pH – pNa) are used as a measure of the reaction progress



Constructing predominance diagrams

Albite/Na-Montmorillonite boundary:

$7\ NaAlSi_3O_8 + 6\ H^+ + 20\ H_2O \leftrightarrow 3\ Na_{0.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 2Na^+ + 10\ H_4SiO_4$

$K = (Na^+)^6\ (H_4SiO_4)^{10} / (H^+)^6 = 10^{7.2}$

$\log K = 6 \log(Na^+) + 10 \log(H_4SiO_4) – 6 \log (H^+)$

$\quad\quad = 6\ pH – 6\ pNa + 10 \log(H_4SiO_4)$

$0.\ 166 \log K – 1.67 \log(H_4SiO_4) = (pH – pNa)$

Kaolinite/Na-Montmorillonite boundary:

$7\ Al_2Si_2O_5(OH)_4 + 8\ H_4SiO_4 + 2Na^+ \leftrightarrow 6\ Na_{0.33}Al_{2.33}Si_{3.67}O_{10}(OH)_2 + 2H^+ + 23\ H_2O$

$K = (H^+)^2 / (H_4SiO_4)^8\ (Na^+)^2 = 10^{-9.1}$

$\log K = 2 \log (H^+) - 8 \log(H_4SiO_4) - 2 \log(Na^+)$

$\quad\quad = -2\ pH - 8 \log(H_4SiO_4) + 2\ pNa$

$-0.5 \log K – 4 \log(H_4SiO_4) = (pH – pNa)$

Amorphous silica boundary:

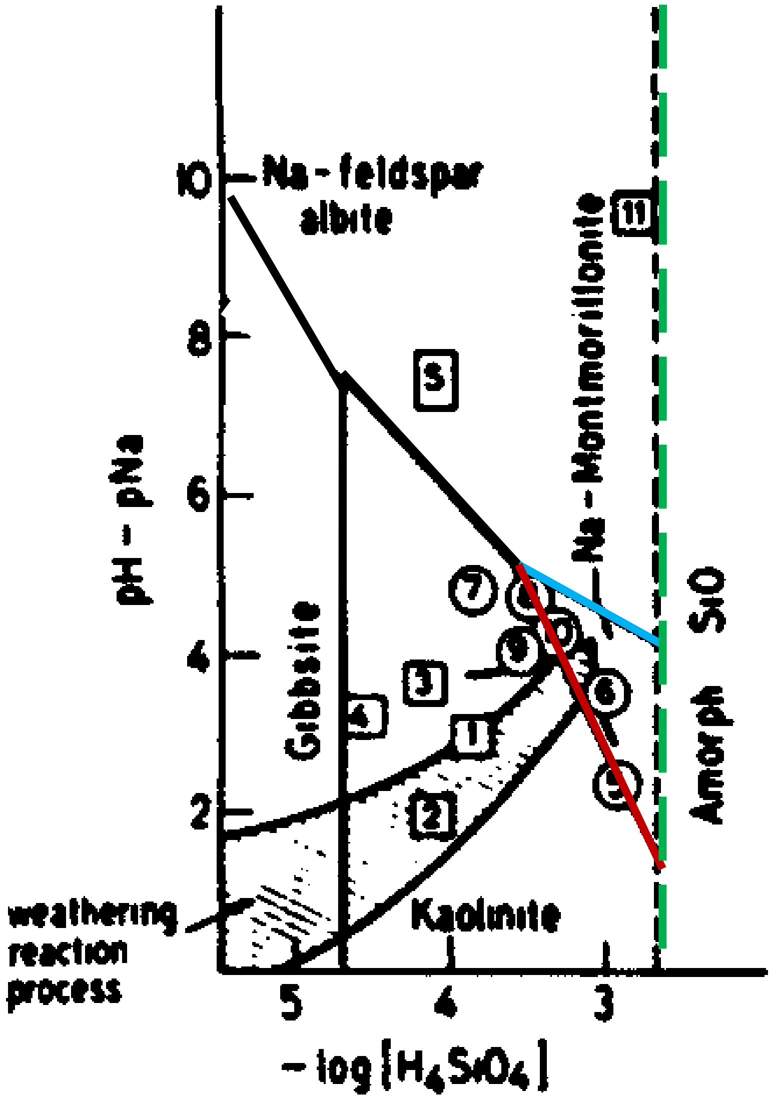
$SiO_2(s) + 2H_2O \leftrightarrow H_4SiO_4$

$K°_{sp} = 10^{-2.7} = (H_4SiO_4)$

$\log K = \log (H_4SiO_4) = -2.7$

Predominance diagram

log(H_4SiO_4)& (pH – pNa) are used as a measure of the reaction progress



Reactivity of silicate minerals

(first proposed by Samuel S. Goldich in 1938)

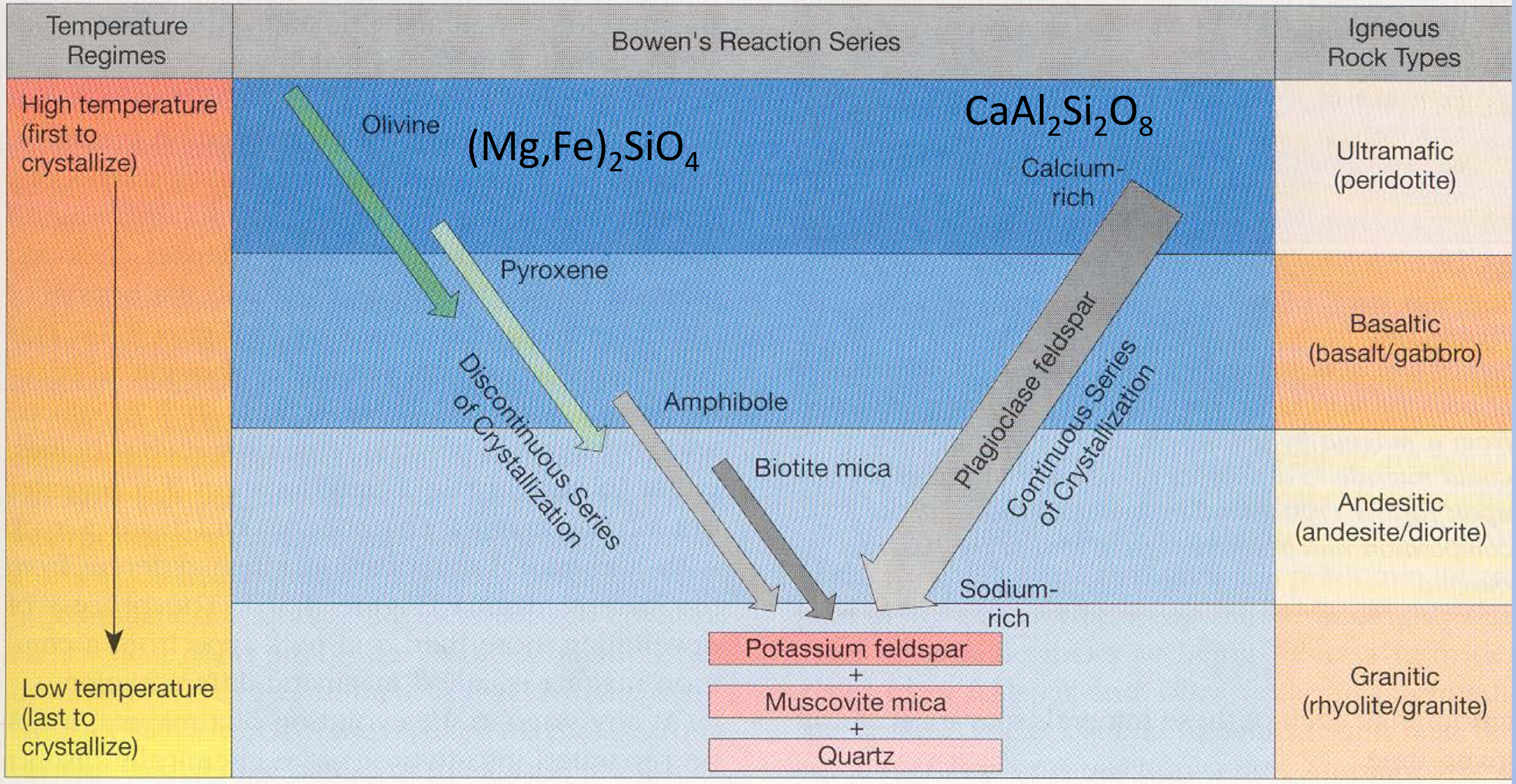


Figure 3.7

Bowen's reaction series shows the sequence in which minerals crystallize from a magma. Compare this figure to the mineral composition of the rock groups in Table 3.1. Note that each rock group consists of minerals that crystallize at approximately the same time.

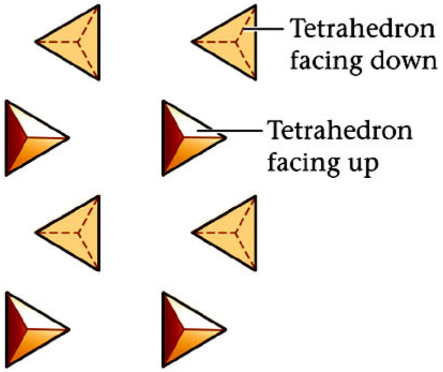
From: Lutgens and Tarbuck (1995) Essentials of Geology

Silicate Structures

Nesosilicate

SiO_4^{4-}

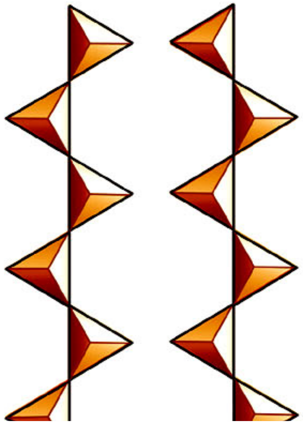
(Olivine)



Inosilicate

(Single chain)

(Pyroxenes)

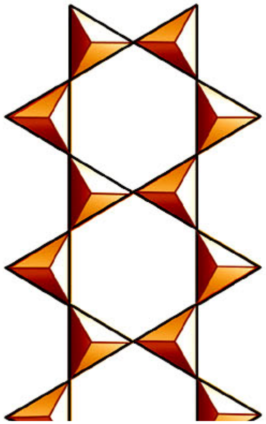


SiO_3^{2-}

Inosilicate

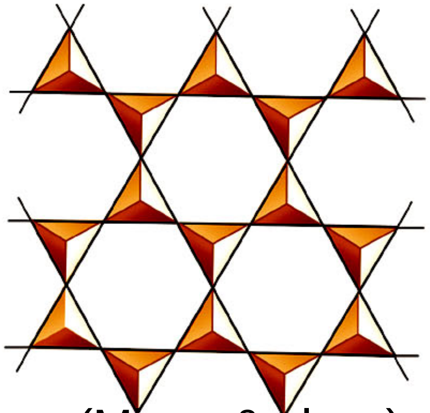
(Double chain)

(Amphiboles)



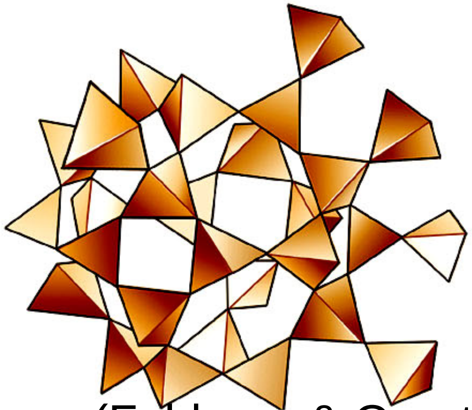
$Si_4O_{11}^{6-}$

$Si_4O_{10}^{4-}$



(Micas & clays)

Sheet silicate



SiO_2

(Feldspar & Quartz)

Framework silicate

Relative resistance of minerals to weathering

(first proposed by Cliff D. Ollier in 1975)

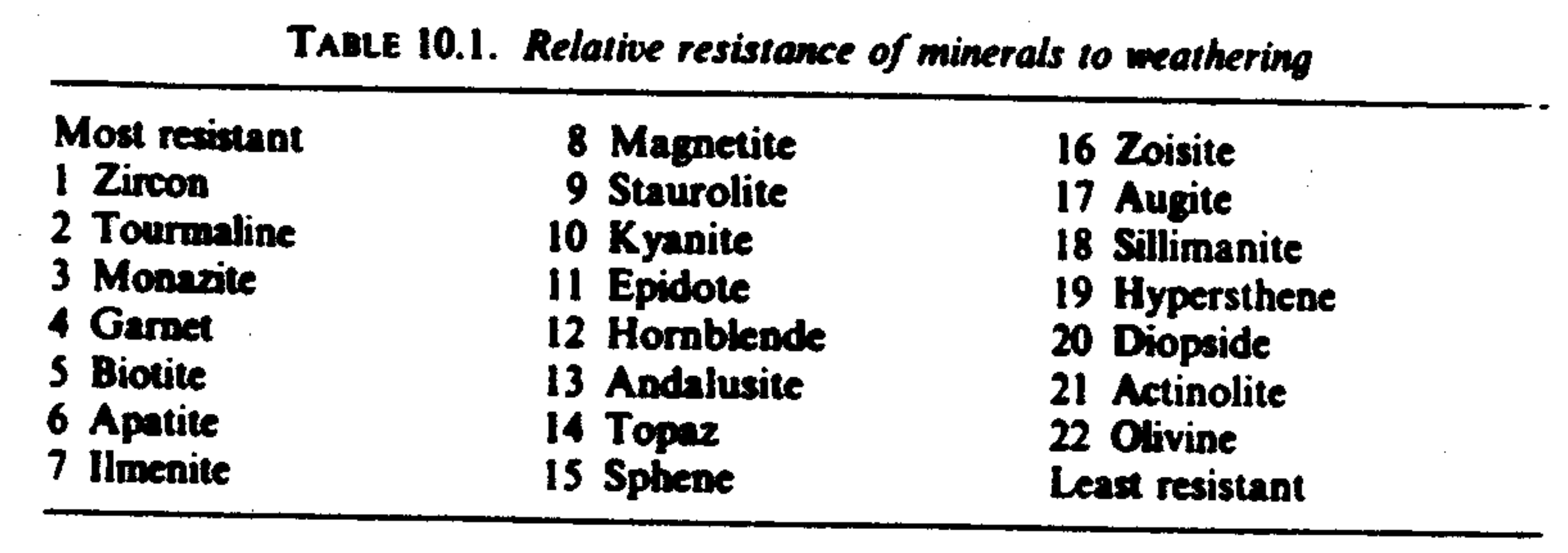
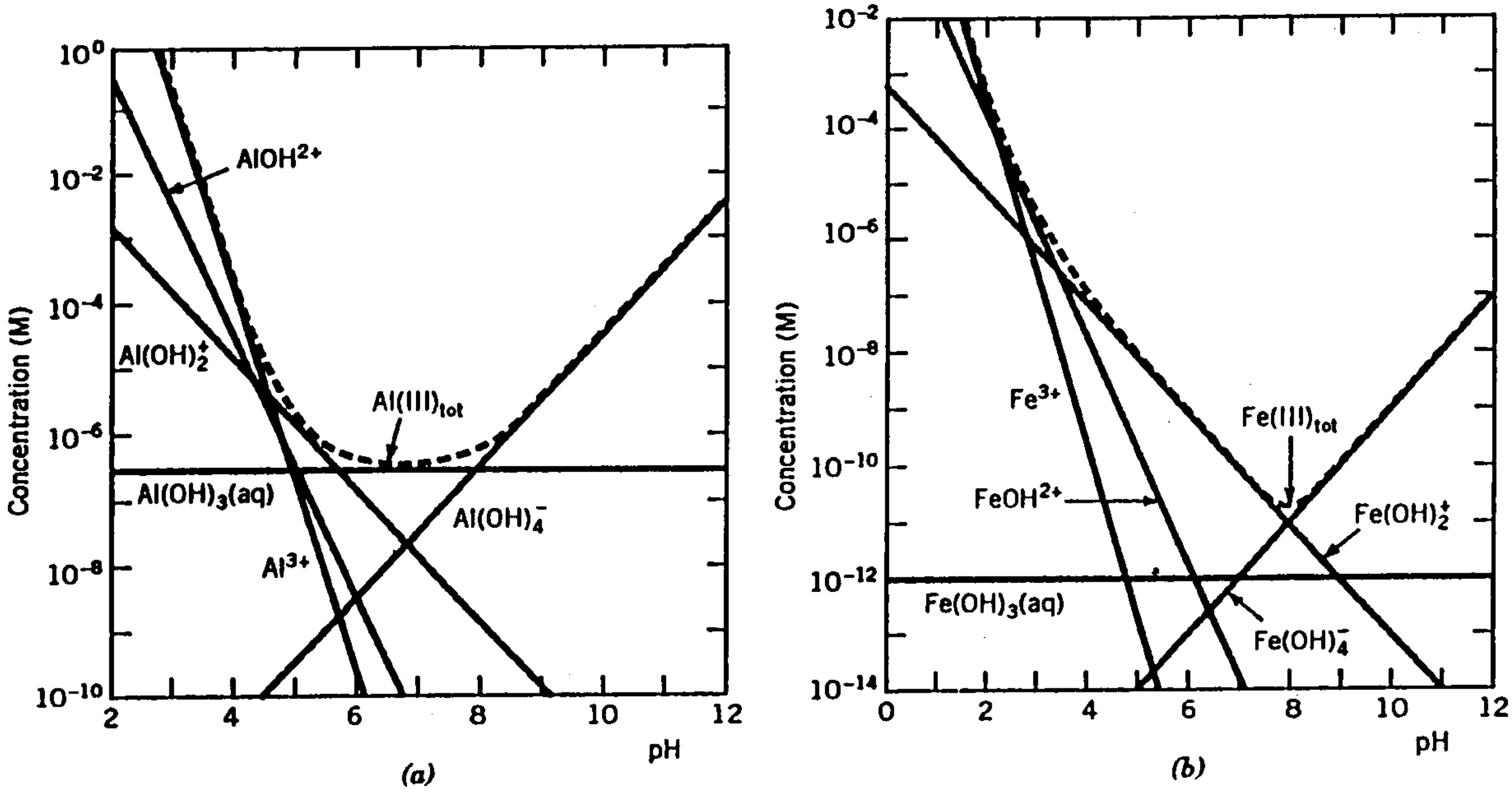


TABLE 10.1. *Relative resistance of minerals to weathering*

Most resistant
1 Zircon
2 Tourmaline
3 Monazite
4 Garnet
5 Biotite
6 Apatite
7 Ilmenite
8 Magnetite
9 Staurolite
10 Kyanite
11 Epidote
12 Hornblende
13 Andalusite
14 Topaz
15 Sphene
16 Zoisite
17 Augite
18 Sillimanite
19 Hypersthene
20 Diopside
21 Actinolite
22 Olivine
Least resistant

From: Henderson (1982) Inorganic Geochemistry

Gibbsite and ferrihydrite solubility



Mobility or solubility of weathering products

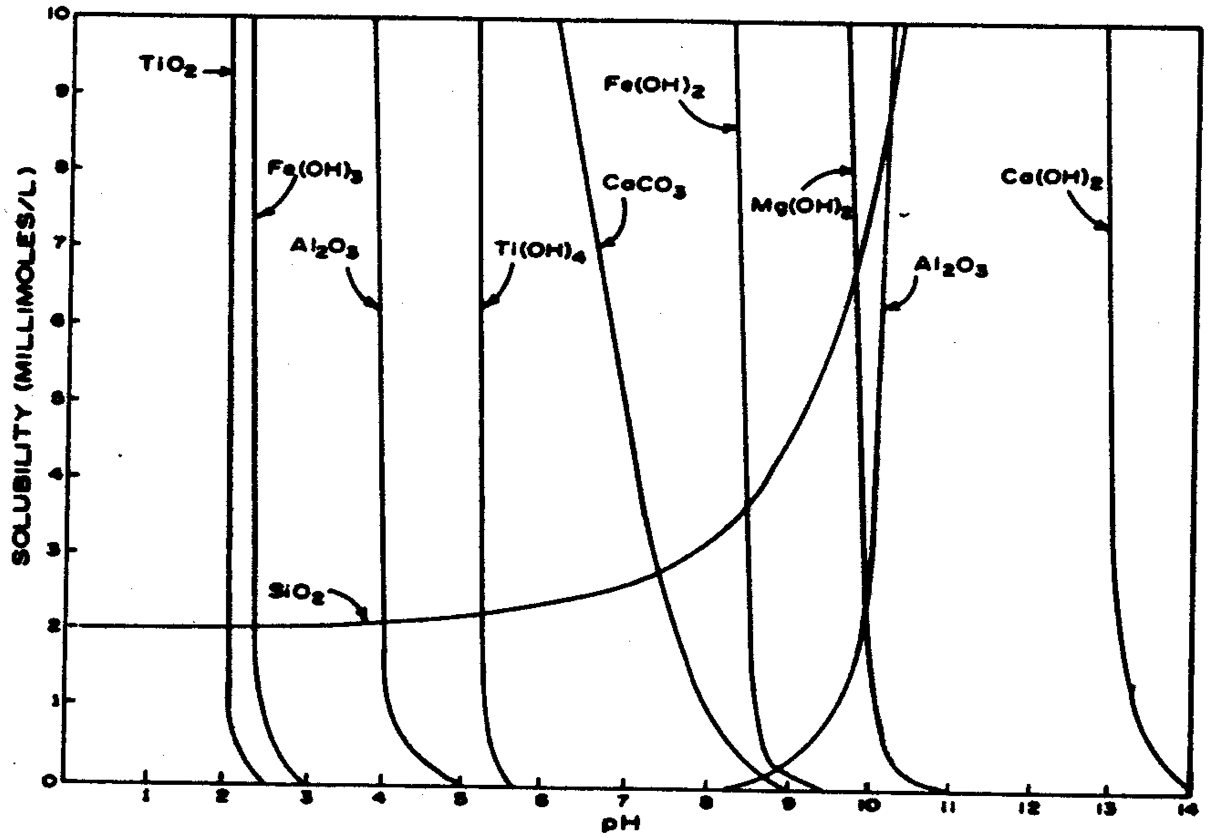
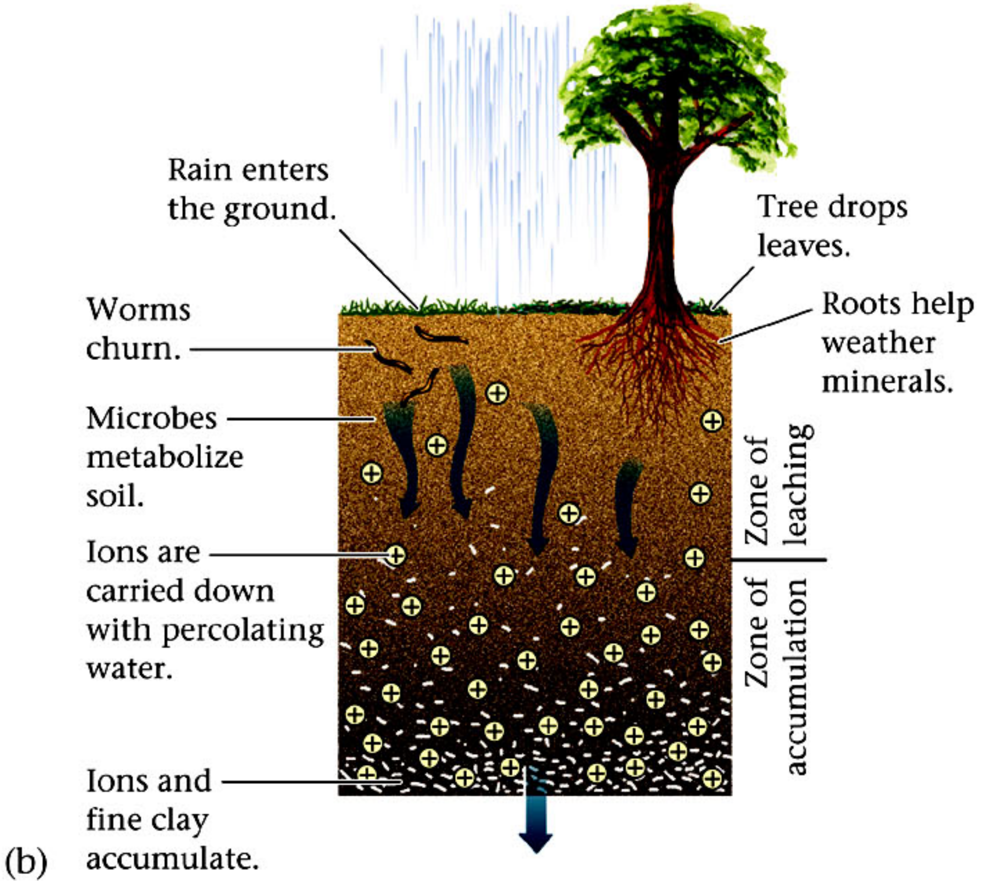


Figure 15. Solubility in relation to pH for some components released by chemical weathering.

From: Loughnan (1969) Chemical Weathering of the Silicate Minerals

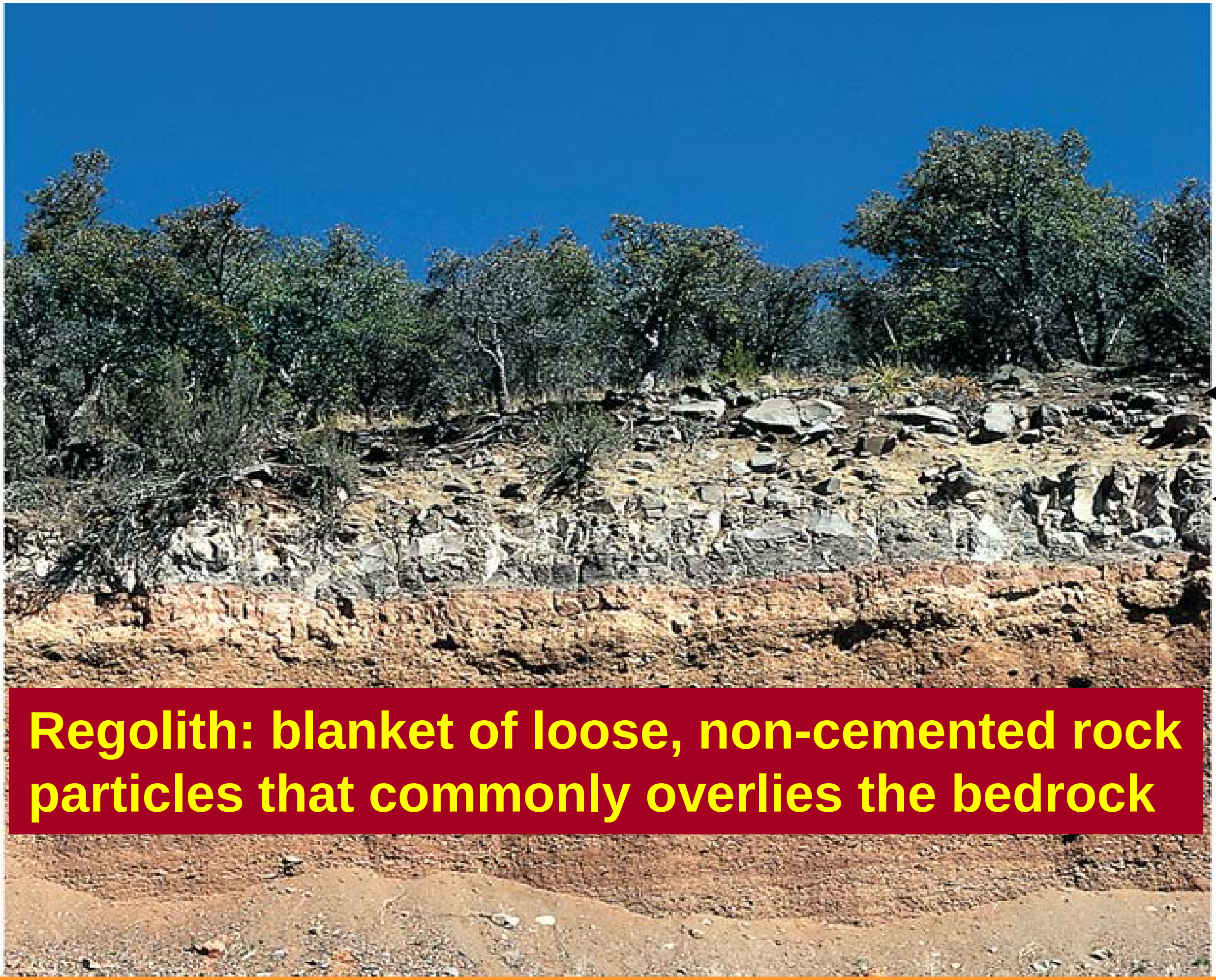
Formation of soils

A soil consists of rock or sediment that has been modified, over time, by physical and chemical interaction with organic material and rainwater to produce a substrate that can support the growth of plants (the process of soil formation is called podsolization)



As rainwater percolates through the regolith, dissolved material and very fine-grained particles are carried from the surface down – transport of material from one level in the weathered debris to another.

Developing soil profile

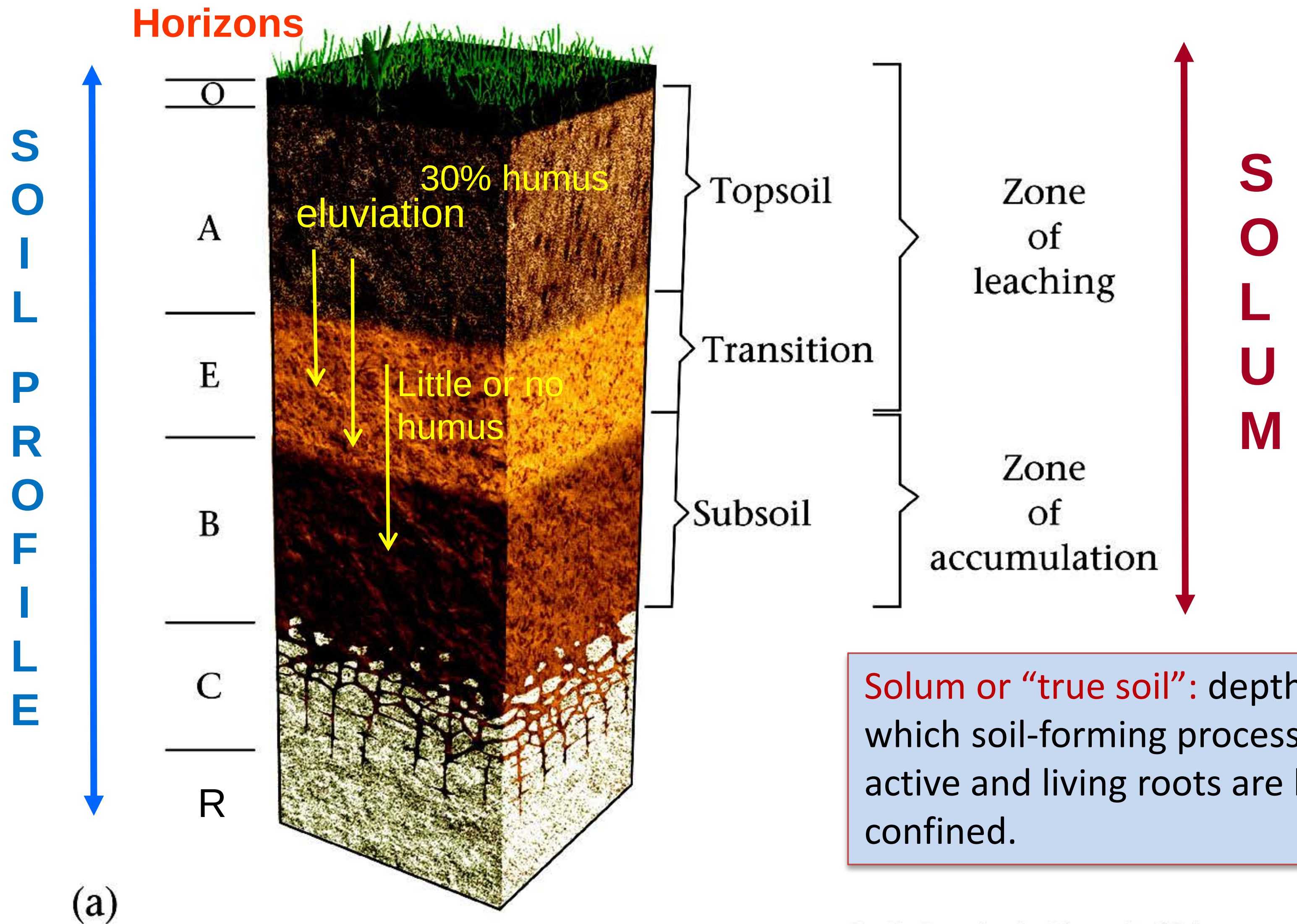


Regolith: blanket of loose, non-cemented rock particles that commonly overlies the bedrock

Soil formation is a rather complex process, involving plants, animals, microorganisms and inorganic processes…
Transportation of material from one level in the weathered debris to another gives rise to layers of different composition called **horizons.**

Soil profile

(vertical sequence of horizons from the surface down to the fresh bedrock in a temperate, humid climate)



Solum or "true soil": depth over which soil-forming processes are active and living roots are largely confined.

Soil profile

(vertical sequence of horizons from the surface down to the fresh bedrock in a temperate, humid climate)

O horizon consists largely of organic material. The upper portion of this horizon is primarily plant litter such as loose leaves and other recognizable debris whereas the lower portion of the O horizon is made up of partially decomposed organic matter or humus in which plant structures can no longer be identified.

A horizon is largely mineral matter but may contain up to 30% humus. As a consequence of **eluviation**, the texture of the A horizon gradually becomes coarser.

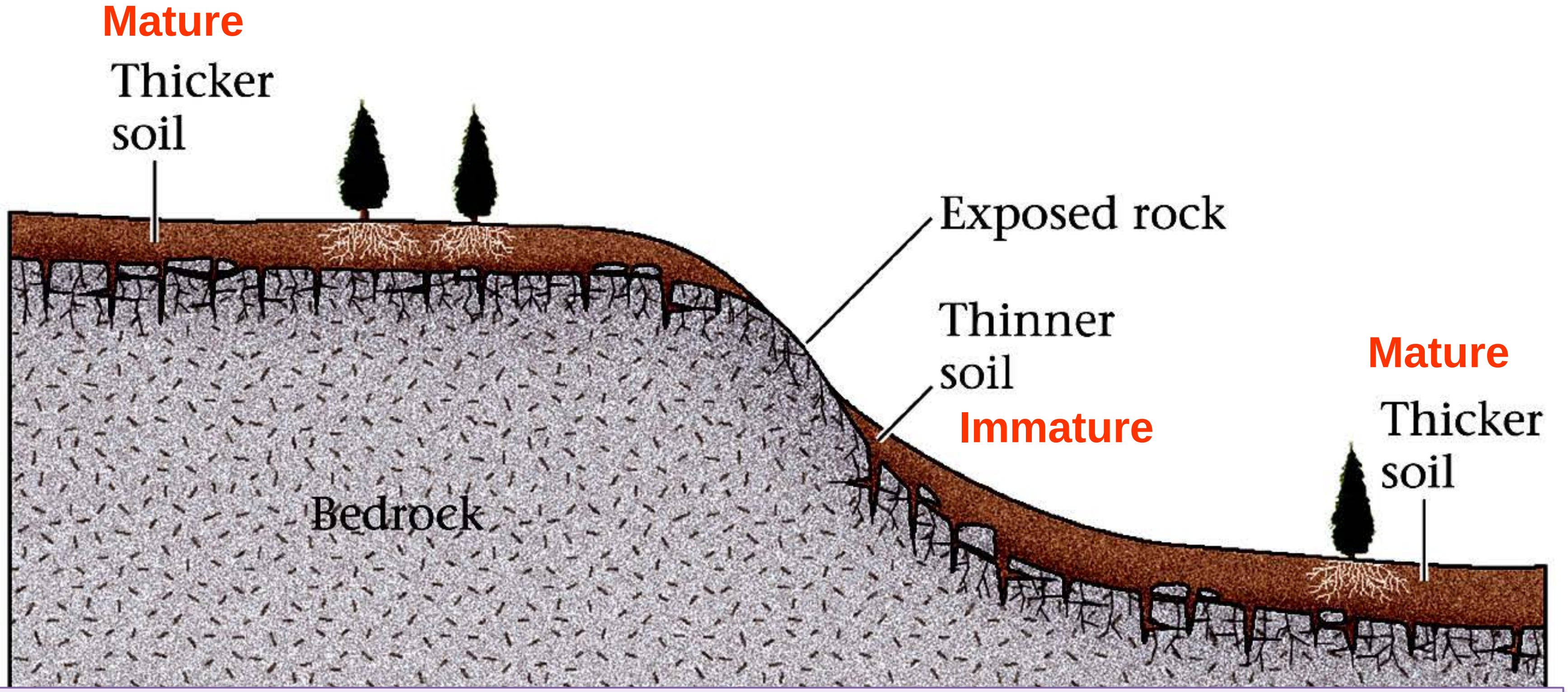
E horizon, a soil level that has undergone substantial leaching but has not yet mixed with organic matter.

B horizon (or *subsoil*) often referred to as **the *zone of accumulation***. The O, A, E and B horizons together constitute the **solum**, or "true soil".

C horizon, a layer characterized by partially altered parent material and little if any organic matter. While the parent rock may be so dramatically altered in the solum that its original character is not recognizable, it is easily identifiable in the C horizon. Below the C horizon, the **R horizon** corresponds to the unaltered bedrock.

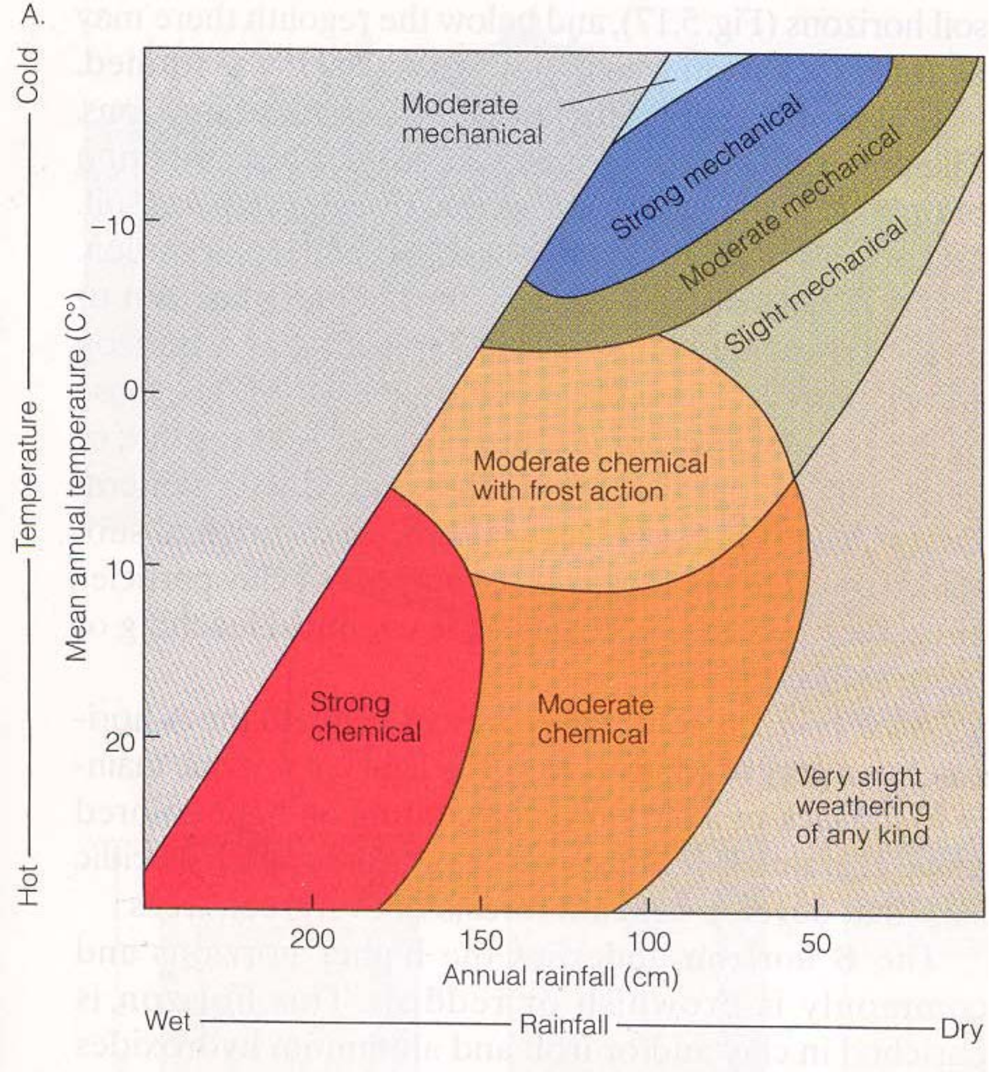
Mature and immature soils

The boundaries between soil horizons may be very sharp, or the horizons may blend gradually from one to another. Some soils lack horizons altogether, such as immature soils (time, slope).



Soil development depends on climate (rainfall and temperature), vegetation, pH, oxygen content, time, topography and composition of the bedrock. For example, an O horizon (organic matter) forms only where the rate of production of plant debris exceeds the rate at which it is decomposed (tropical rainforests, swamps).

Influence of climate on weathering



From: Skinner and Porter (1999) The Dynamic Earth

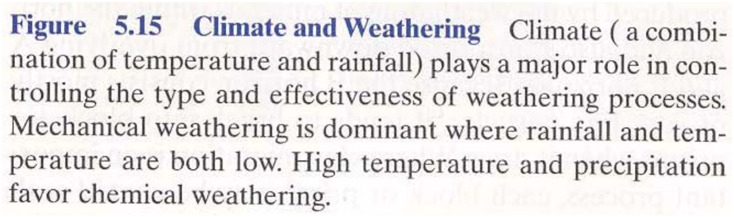


Figure 5.15 Climate and Weathering Climate (a combination of temperature and rainfall) plays a major role in controlling the type and effectiveness of weathering processes. Mechanical weathering is dominant where rainfall and temperature are both low. High temperature and precipitation favor chemical weathering.

The most important factor in the development of soil profiles is **climate, and more specifically, the temperature and the amount of meteoric precipitation or rainfall**.
Moisture and heat promote chemical reactions.
Not surprisingly, weathering is most intense and generally extends to greater depths in a warm moist climate than in a dry cold one.

Influence of climate on soil development

(variations in the type and thickness of soils as a function of latitude)

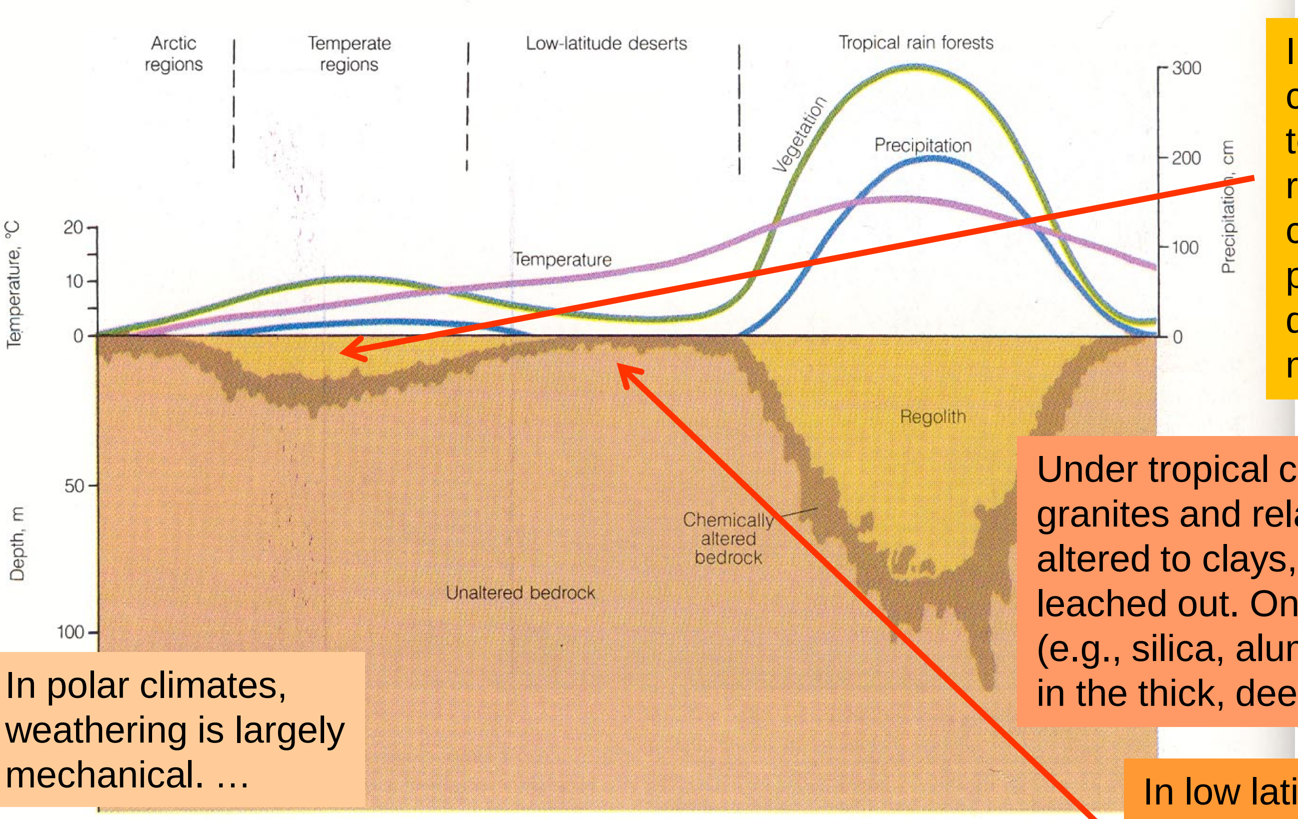


FIGURE 9.11
The type and extent of weathering vary with climate because of the combined effects of precipitation, temperature, and vegetation. Weathering is most pronounced in the tropics, where precipitation, temperature, and vegetation reach a maximum. Conversely, a minimum of weathering is found in deserts and polar regions where these factors are minimal. *(After N. M. Strakov, 1967,* Principles of Lithogenesis, *vol. 1, trans. J. P. Fitzemms. Edinburgh: Oliver and Boyd.)*

In temperate regions, the climate ranges from sub-humid to sub-arid, and temperatures range from cold to warm. Both chemical and mechanical processes operate, and the soil develops to depths of several meters.

Under tropical conditions, the feldspars in granites and related rocks are completely altered to clays, and all soluble minerals are leached out. Only the most insoluble materials (e.g., silica, aluminium and iron oxides) remain in the thick, deep soil → infertile soils

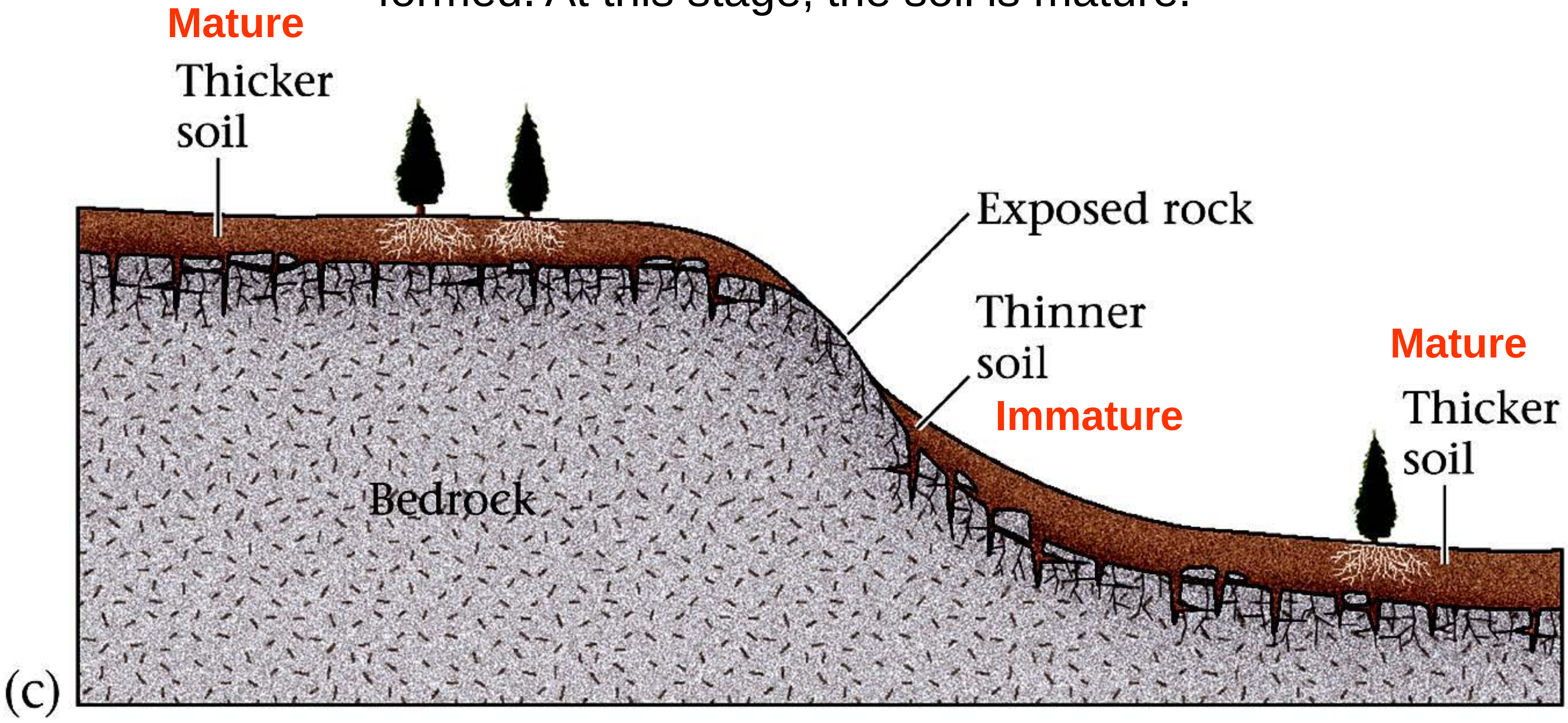
In low latitude deserts, chemical weathering is minimal because of the lack of precipitation. The soil is thin, and exposures of fresh, unaltered bedrock are abundant. Mechanical weathering is more evident.

In polar climates, weathering is largely mechanical. …

From: Hamblin (1994) Introduction to Physical Geology

Mature and immature soils

Given the dominant influence of climate, soils within a climatic zone will have similar profiles, regardless of the composition of the bedrock from which they formed. At this stage, the soil is mature.



The time required to convert an immature soil to a mature soil varies with the type of bedrock and climate but is probably measured in hundreds if not thousands of years.

U.S. Soil Classification

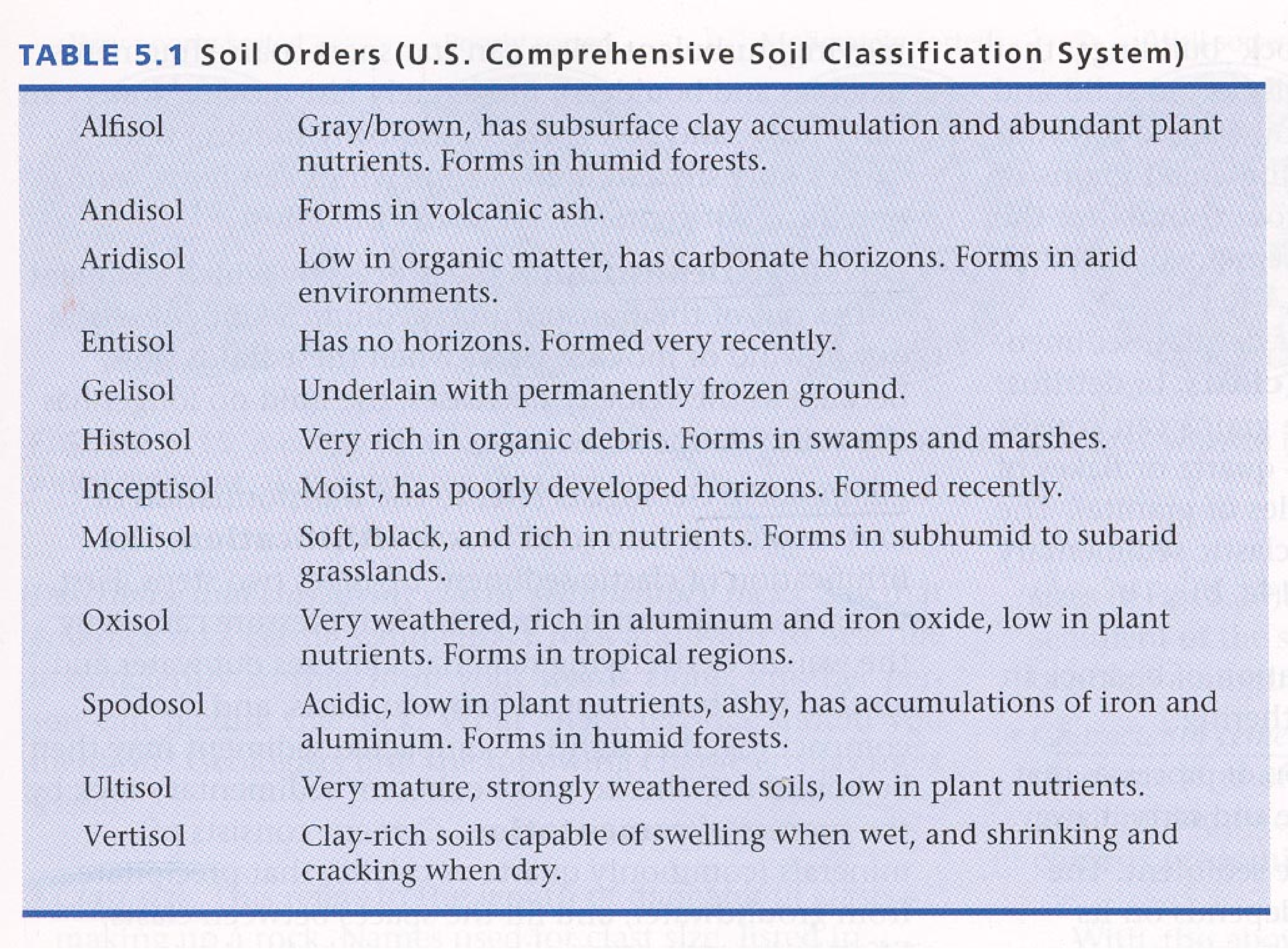


TABLE 5.1 Soil Orders (U.S. Comprehensive Soil Classification System)

Alfisol	Gray/brown, has subsurface clay accumulation and abundant plant nutrients. Forms in humid forests.
Andisol	Forms in volcanic ash.
Aridisol	Low in organic matter, has carbonate horizons. Forms in arid environments.
Entisol	Has no horizons. Formed very recently.
Gelisol	Underlain with permanently frozen ground.
Histosol	Very rich in organic debris. Forms in swamps and marshes.
Inceptisol	Moist, has poorly developed horizons. Formed recently.
Mollisol	Soft, black, and rich in nutrients. Forms in subhumid to subarid grasslands.
Oxisol	Very weathered, rich in aluminum and iron oxide, low in plant nutrients. Forms in tropical regions.
Spodosol	Acidic, low in plant nutrients, ashy, has accumulations of iron and aluminum. Forms in humid forests.
Ultisol	Very mature, strongly weathered soils, low in plant nutrients.
Vertisol	Clay-rich soils capable of swelling when wet, and shrinking and cracking when dry.

Simplified soil classification

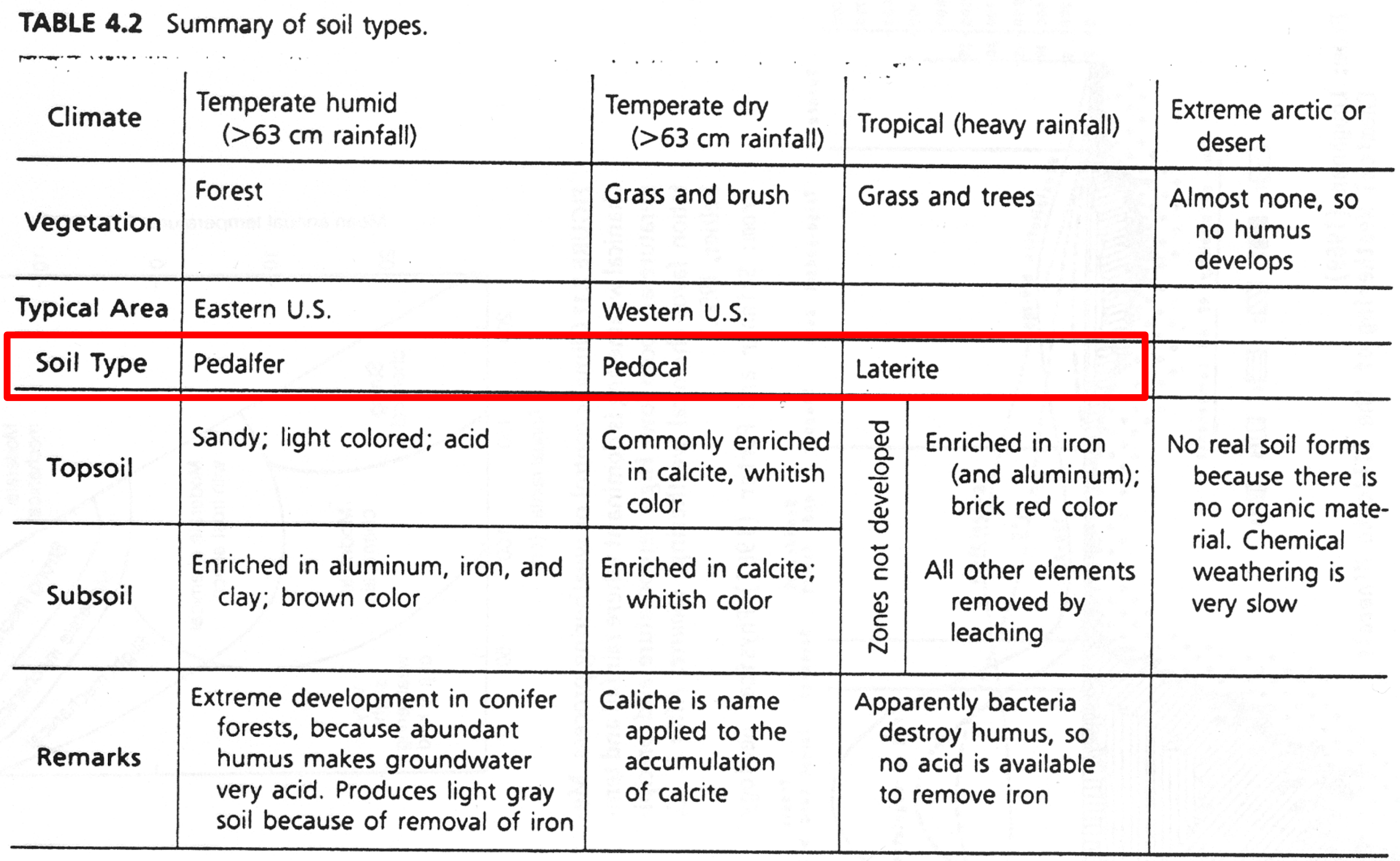
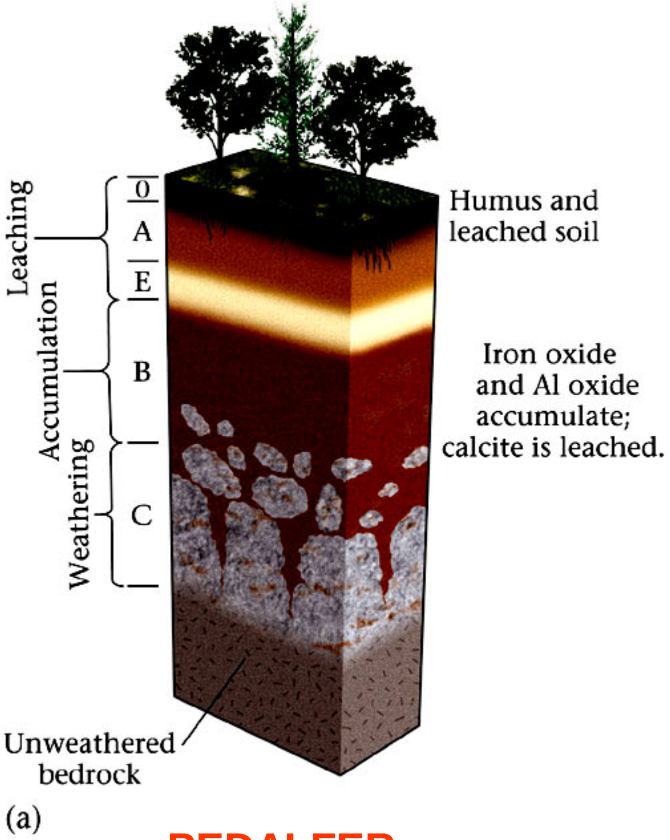


TABLE 4.2 Summary of soil types.

Climate	Temperate humid (>63 cm rainfall)	Temperate dry (>63 cm rainfall)	Tropical (heavy rainfall)	Extreme arctic or desert
Vegetation	Forest	Grass and brush	Grass and trees	Almost none, so no humus develops
Typical Area	Eastern U.S.	Western U.S.		
Soil Type	Pedalfer	Pedocal	Laterite	
Topsoil	Sandy; light colored; acid	Commonly enriched in calcite, whitish color	Zones not developed Enriched in iron (and aluminum); brick red color	No real soil forms because there is no organic material. Chemical weathering is very slow
Subsoil	Enriched in aluminum, iron, and clay; brown color	Enriched in calcite; whitish color	All other elements removed by leaching	
Remarks	Extreme development in conifer forests, because abundant humus makes groundwater very acid. Produces light gray soil because of removal of iron	Caliche is name applied to the accumulation of calcite	Apparently bacteria destroy humus, so no acid is available to remove iron	

From: Lutgens and Tarbuck (1986) Essentials of Geology

Soil types

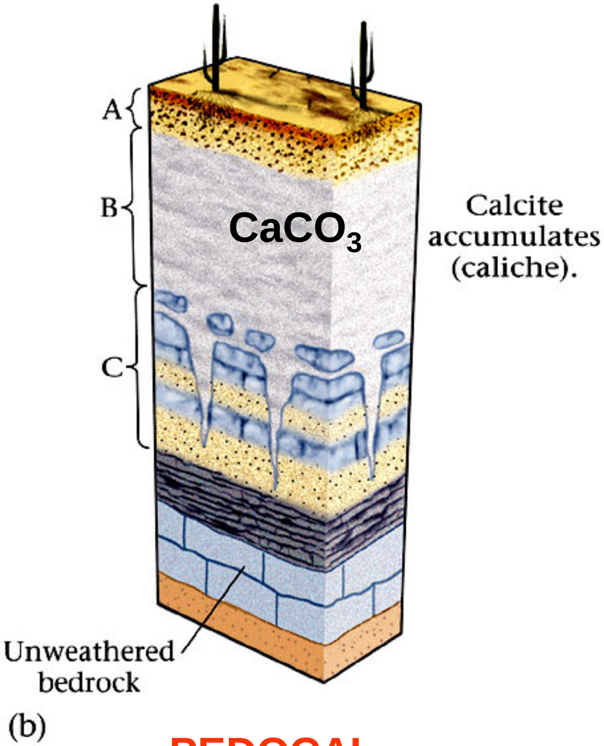


PEDALFER

PEDO{Al}{Fe}R

Pedalfer soils form generally on rocks covered by vegetation that receives a fair supply of rain. The rain is charged with CO_2 in the upper few centimetres of the humus-rich soil due to bacterial decomposition of plant material. This CO_2-charged water attacks the primary minerals of the rock releasing calcium, sodium, magnesium, as well as some potassium and silica to the solution. This soil is typically devoid of calcium carbonate and usually rich in aluminum (aluminosilicate hydrates) and iron (iron oxides). Ferric oxides and aluminium-rich clays are often concentrated in the B horizon, giving it a brown to red-brown colour.

Soil types



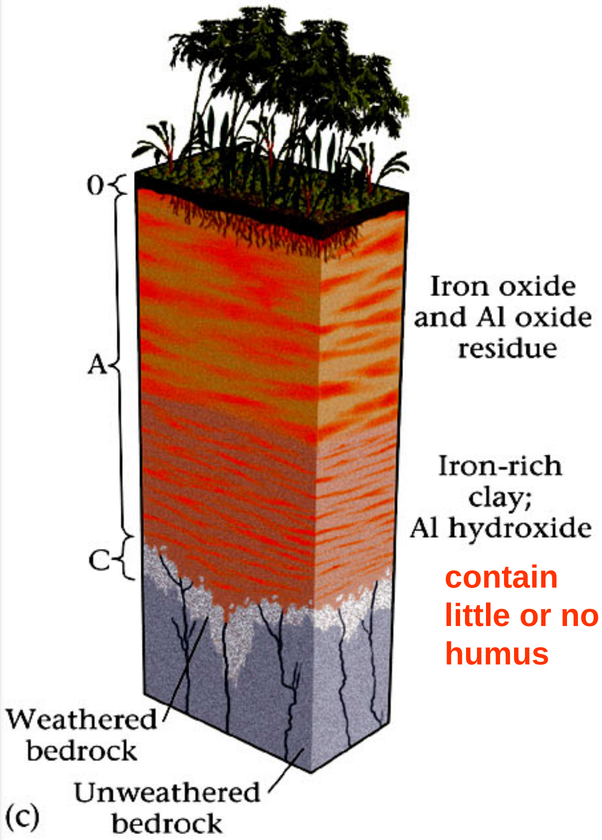
PEDOCAL

PEDO{Ca}{Al}

Pedocal soils form in areas of relatively low rainfall with brush or grass cover. The soils are often friable, are highly calcareous and contain montmorillonite as the primary clay mineral. Here, rainwater percolating through the soil often evaporates before it can remove soluble materials. The result in a whitish accumulation of calcium carbonate that forms nodules called **calcrete** or **caliche**. In general, the drier the climate, the closer the calcrete is to the ground surface.

Soil types

In regions of high rainfall, high temperature and sparse vegetation, as in many parts of the tropics (Africa), **laterites** may develop. Since chemical weathering is intense under such climatic conditions, these soils are usually deeper than soils developing over a similar period of time in mid-latitudes.
Not only does leaching remove the more soluble materials like calcium carbonate, but the great quantities of percolating water even dissolve much of the quartz, with the result that the weathered residue is rich in hydrated ferric and aluminium oxides which give characteristic colours to the soil.
Bacterial decomposition of organic matter is rapid in the tropics and laterites contain practically no humus. This fact, coupled with the highly leached and bricklike nature of these soils, make laterites poor for growing crops - infertile soils.

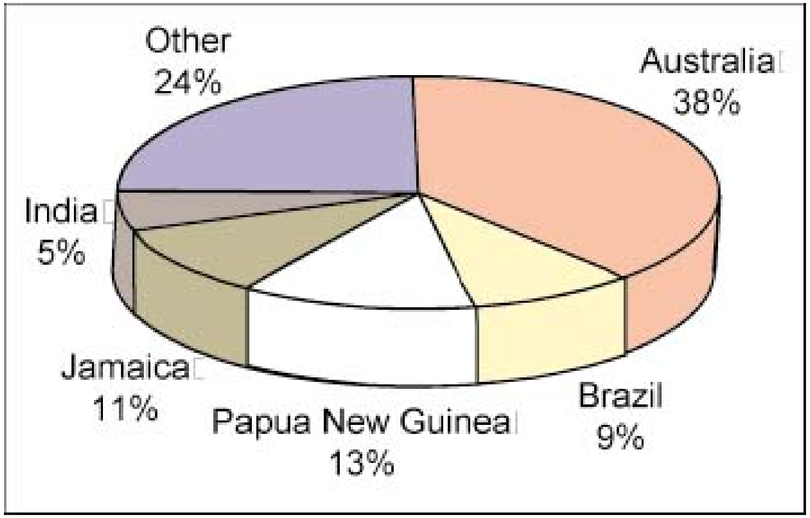


contain little or no humus

LATERITE

Laterite on Sulawesi Island, Indonesia

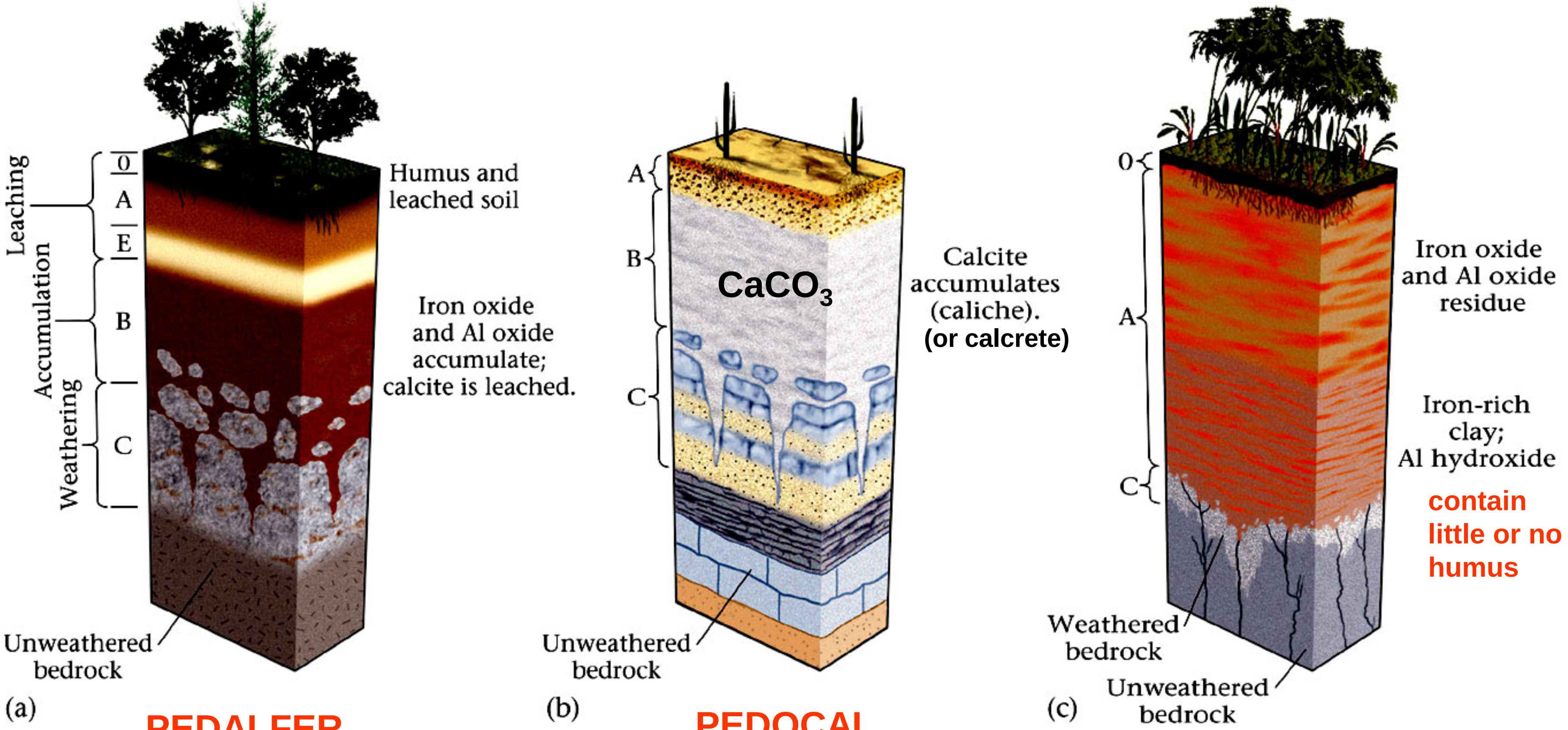
Bauxite:
primary ore of aluminum



World supply of bauxite

Soil types

(most of the soils of eastern North America and western Europe, north of the Alps, are pedalfers, whereas most of the soils of the Great Plains and the Southwest U.S. are pedocals.)



$CaCO_3$

(or calcrete)

contain little or no humus

PEDALFER

PEDO{Al}{Fe}R

PEDOCAL

PEDO{Ca}{Al}

LATERITE