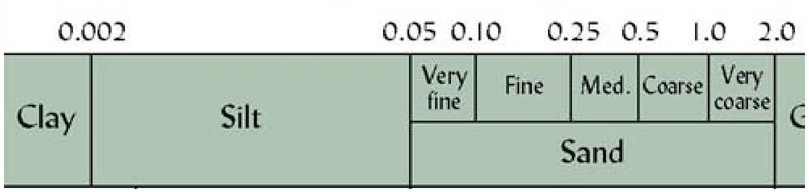
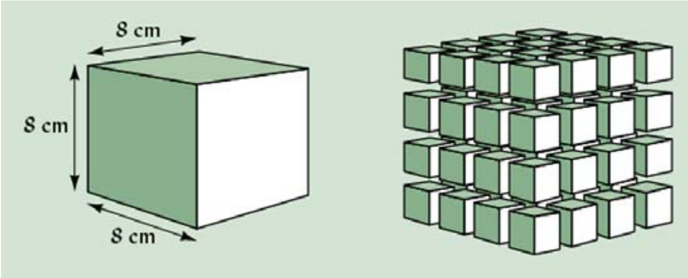
# The Colloid Fraction of Soil

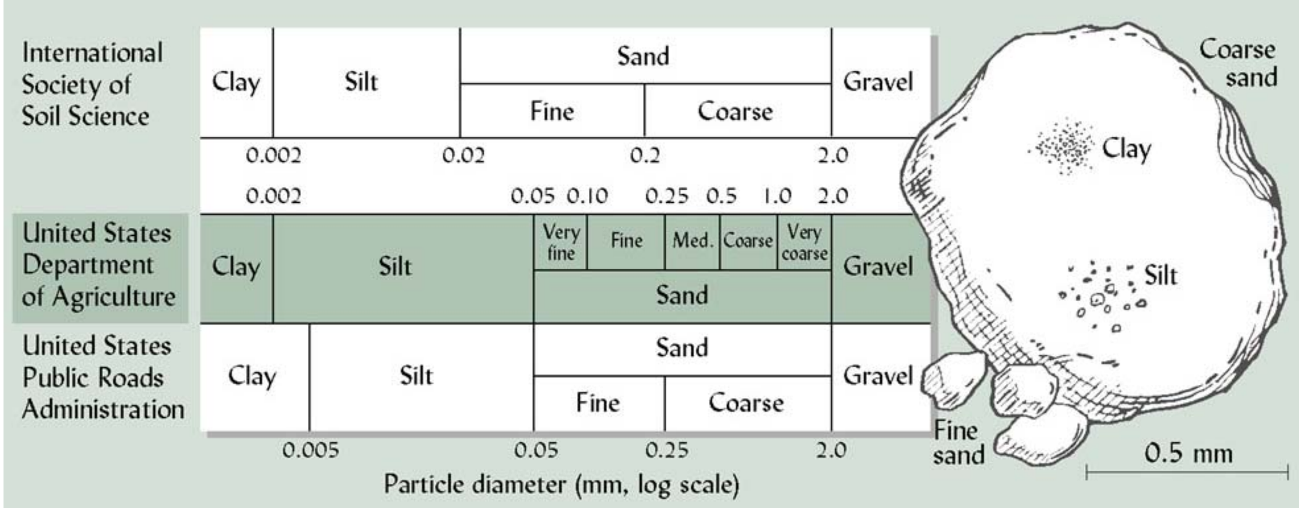
- Size – 1 μm in size (2 μm?)

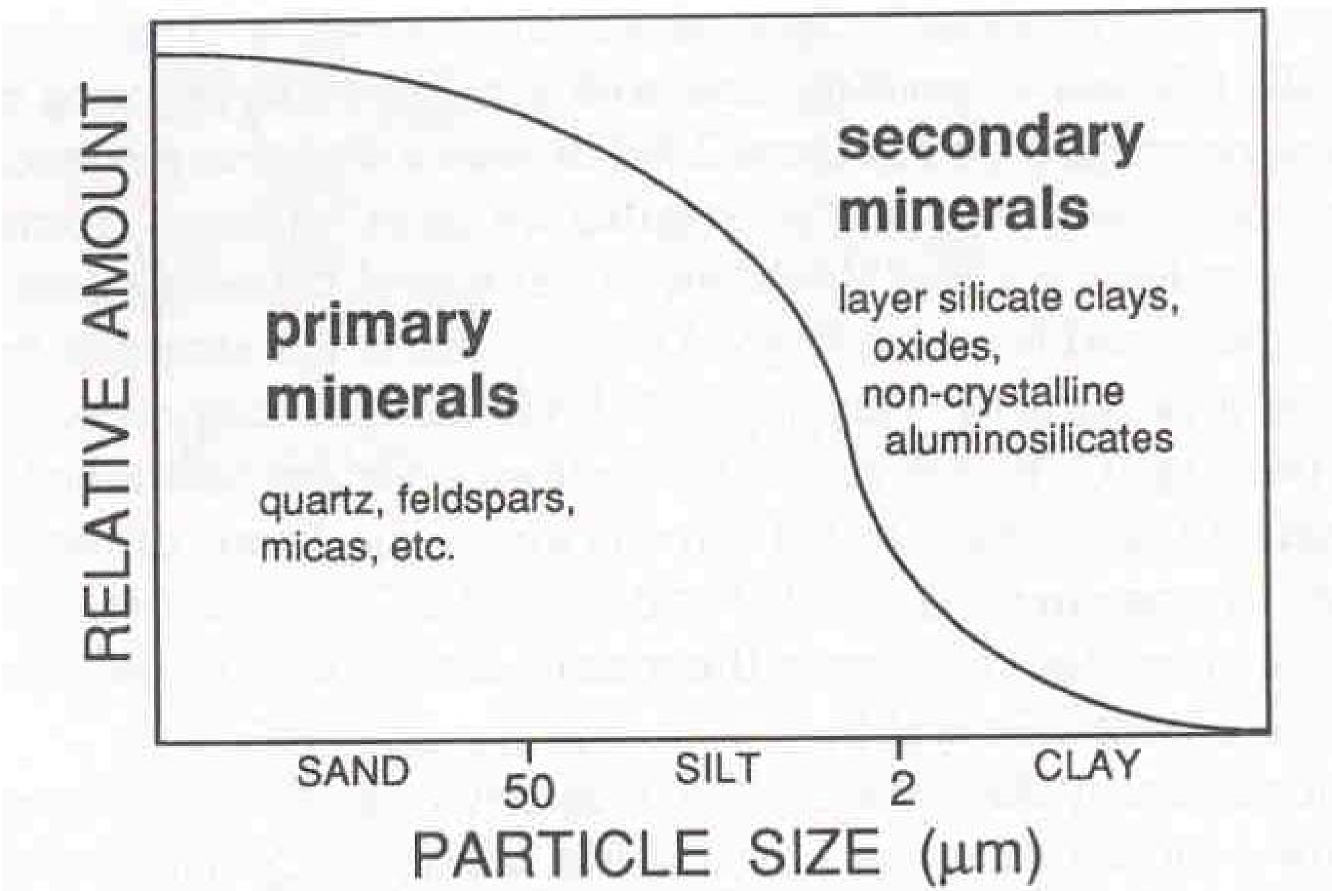


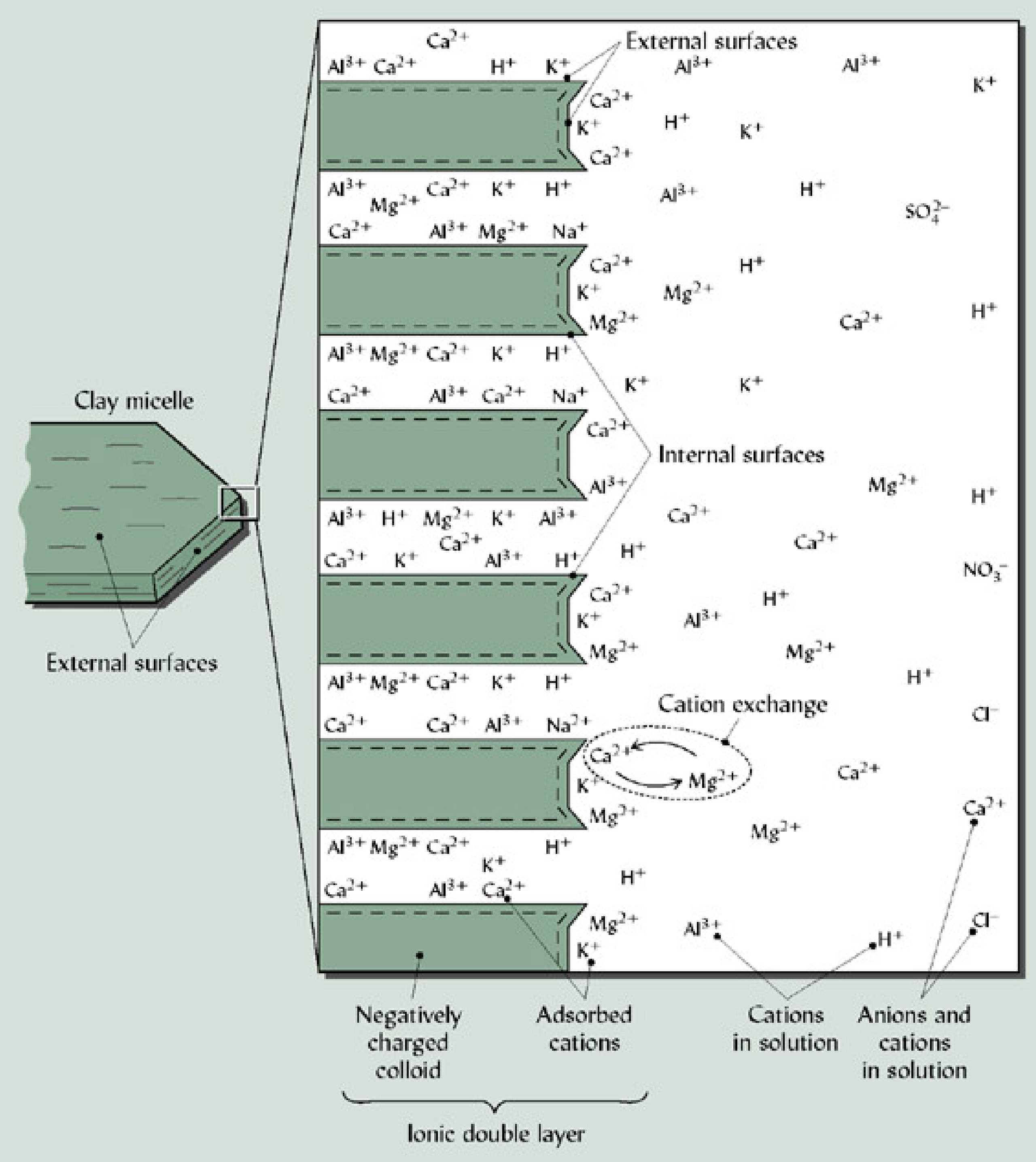

- Surface Area




- Surface Charge (generally negative)
- Cation (and Anion) Adsorption


International Society of Soil Science
Clay
Silt
Sand
Fine
Coarse
Gravel
0.002
0.02
0.2
2.0
0.002
0.05 0.10
0.25 0.5
1.0 2.0
United States Department of Agriculture
Clay
Silt
Very fine
Fine
Med.
Coarse
Very coarse
Sand
Gravel
United States Public Roads Administration
Clay
Silt
Sand
Fine
Coarse
Gravel
0.005
0.05
0.25
2.0
Particle diameter (mm, log scale)
Coarse sand
Clay
Silt
Fine sand
0.5 mm


RELATIVE AMOUNT
primary minerals
quartz, feldspars, micas, etc.
secondary minerals
layer silicate clays, oxides, non-crystalline aluminosilicates
SAND
50
SILT
2
CLAY
PARTICLE SIZE (μm)


Clay micelle
External surfaces
External surfaces
Internal surfaces
Cation exchange
Negatively charged colloid
Adsorbed cations
Cations in solution
Anions and cations in solution
Ionic double layer

# Types of Soil Colloids

- Crystalline silicate clays
  - Phylosilicates → tetrahedral and octahedral crystal sheets
- Non-crystalline silicate clays (Andisols)
  - Dominately amorphous clays (allophane and imogolite)
- Iron and aluminum oxides (Oxisols & …)
  - Dominately gibbsite (Al-oxide) and goethite (Fe-oxide)
- Organic (humus) colloids (Histosols &…)
  - Non-crystalline colloids dominated by long C-chain molecules

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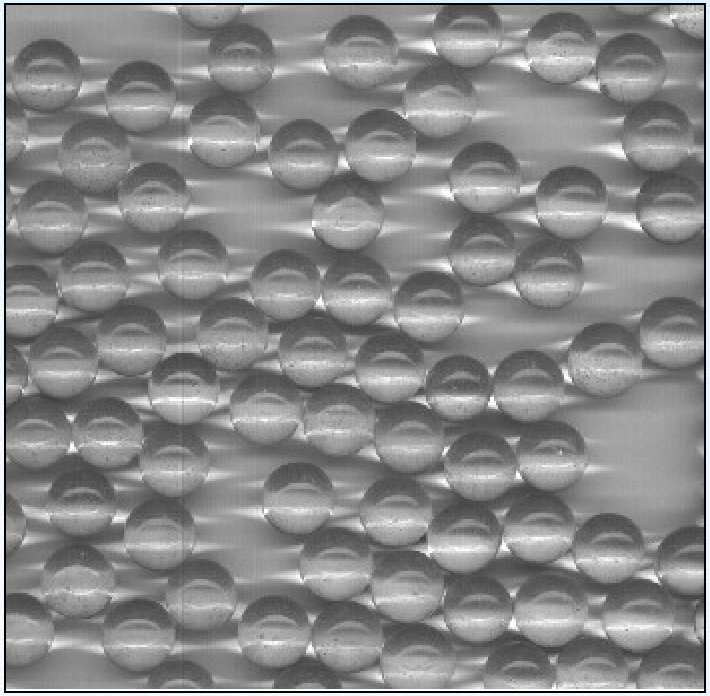
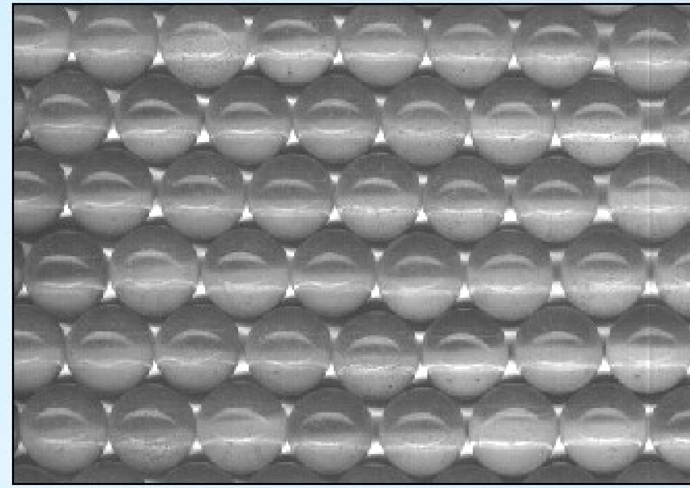


- Ions dissolved in magma or water move rapidly
- No regular pattern



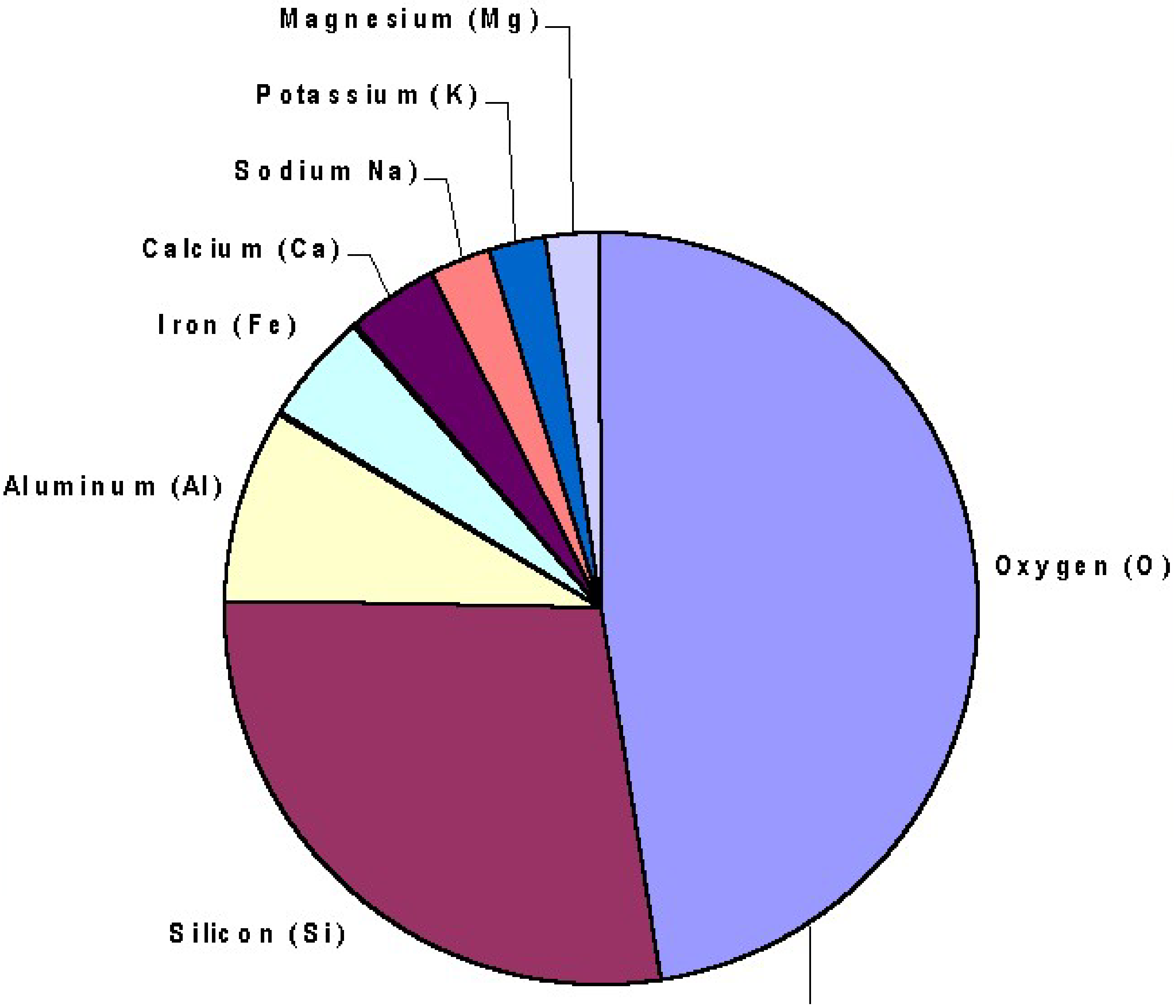
- Ions “frozen” in solid crystal have symmetrical repeating pattern

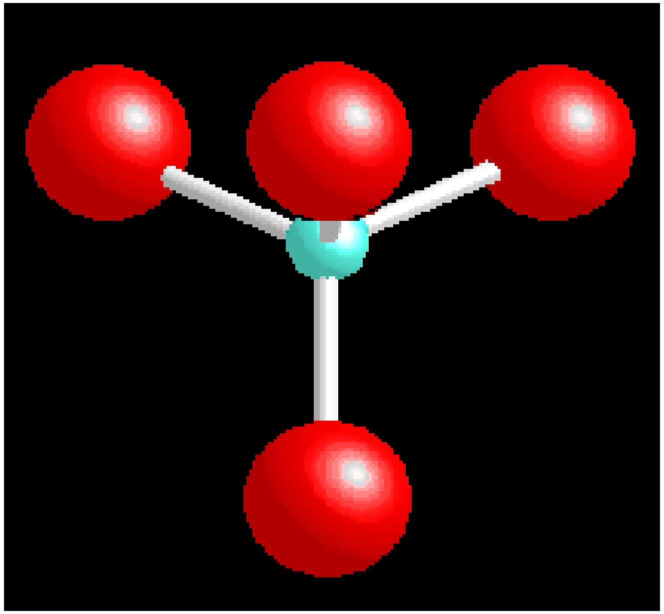
# Chemical Weathering

Process that changes minerals from their original composition to a new composition by:

- Hydrolysis – addition of a $H^+$ to the structure
- Hydration – addition of a water molecule
- Oxidation / Reduction – gain or loss of an electron
- Dissolution / Carbonation – $H^+$ from $H_2CO_3$

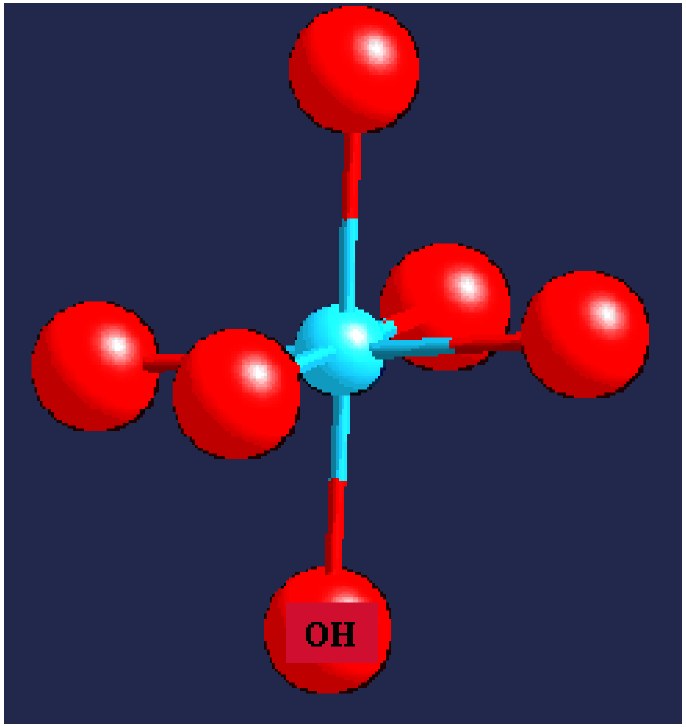
# Composition of the Earth's Crust

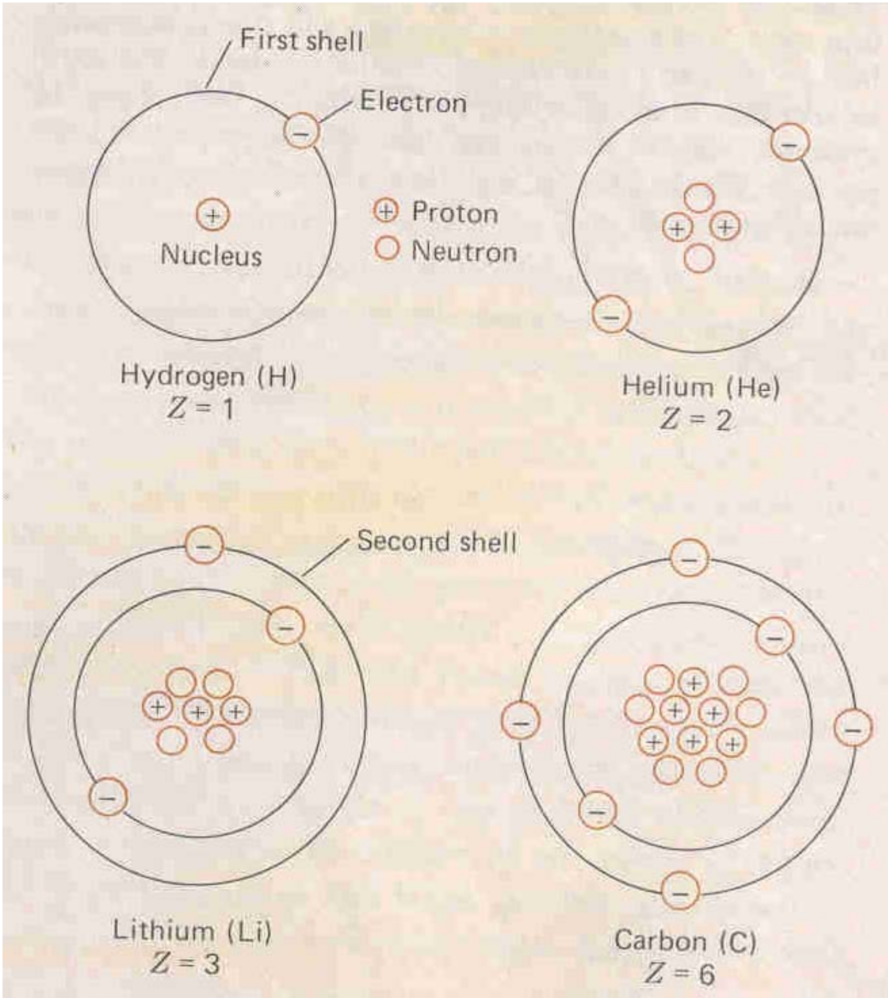




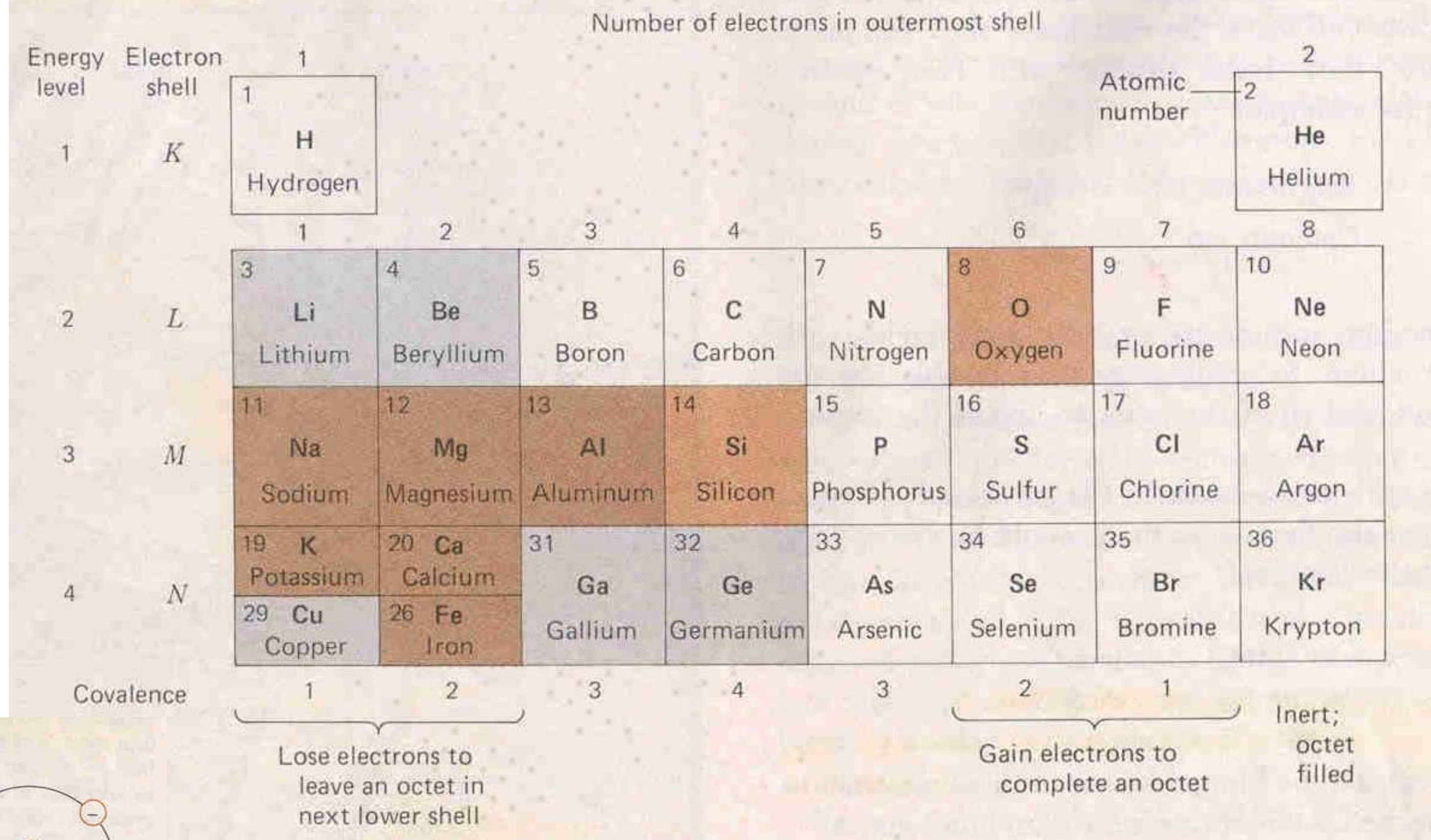
Tetrahedra - Si

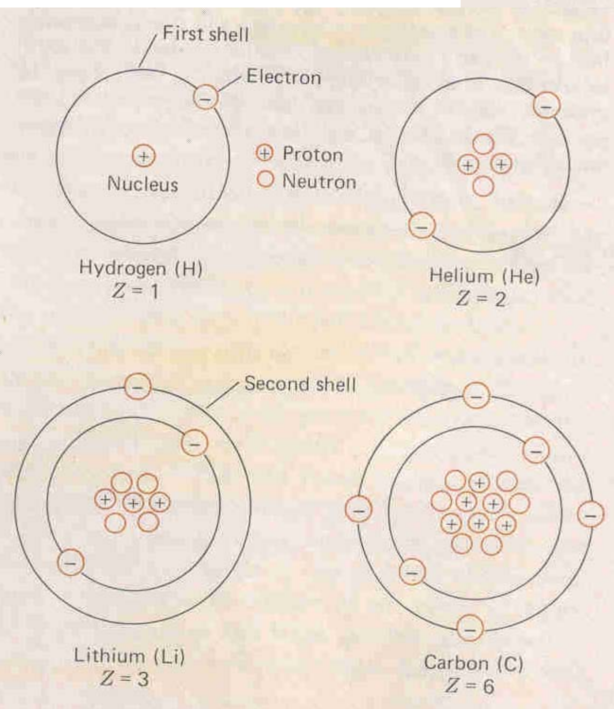
Octahedra – Al or Mg



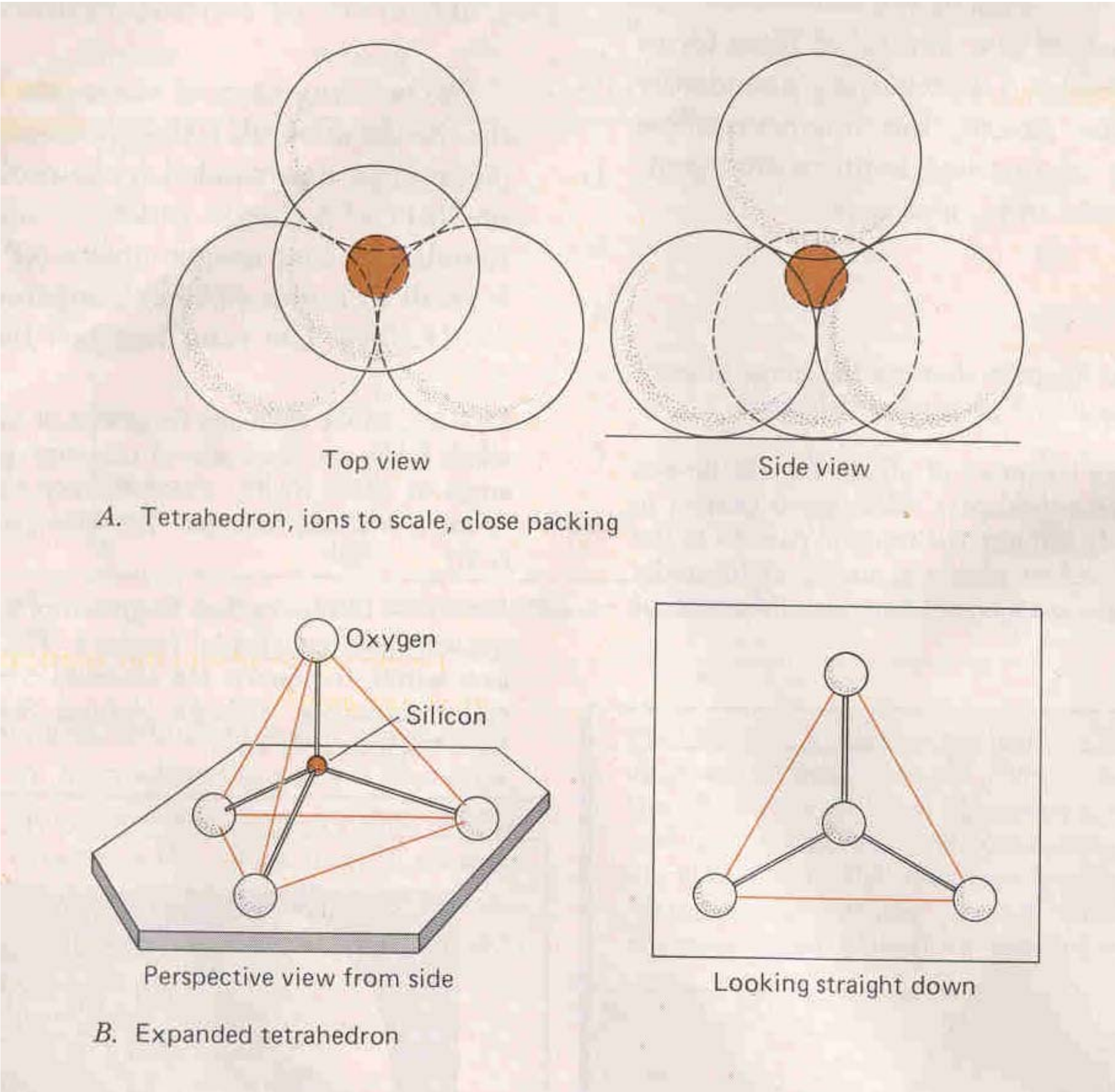



| Energy level | # of electrons needed to fill shell |
|---|---|
| 1 | 2 |
| 2 | 8 |
| 3 | 8 |
| 4 | 8 |
| 5 | 8 |



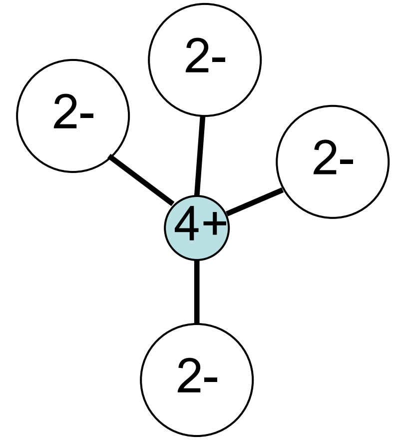




| Energy level | # of electrons needed to fill shell |
|---|---|
| 1 | 2 |
| 2 | 8 |
| 3 | 8 |
| 4 | 8 |
| 5 | 8 |

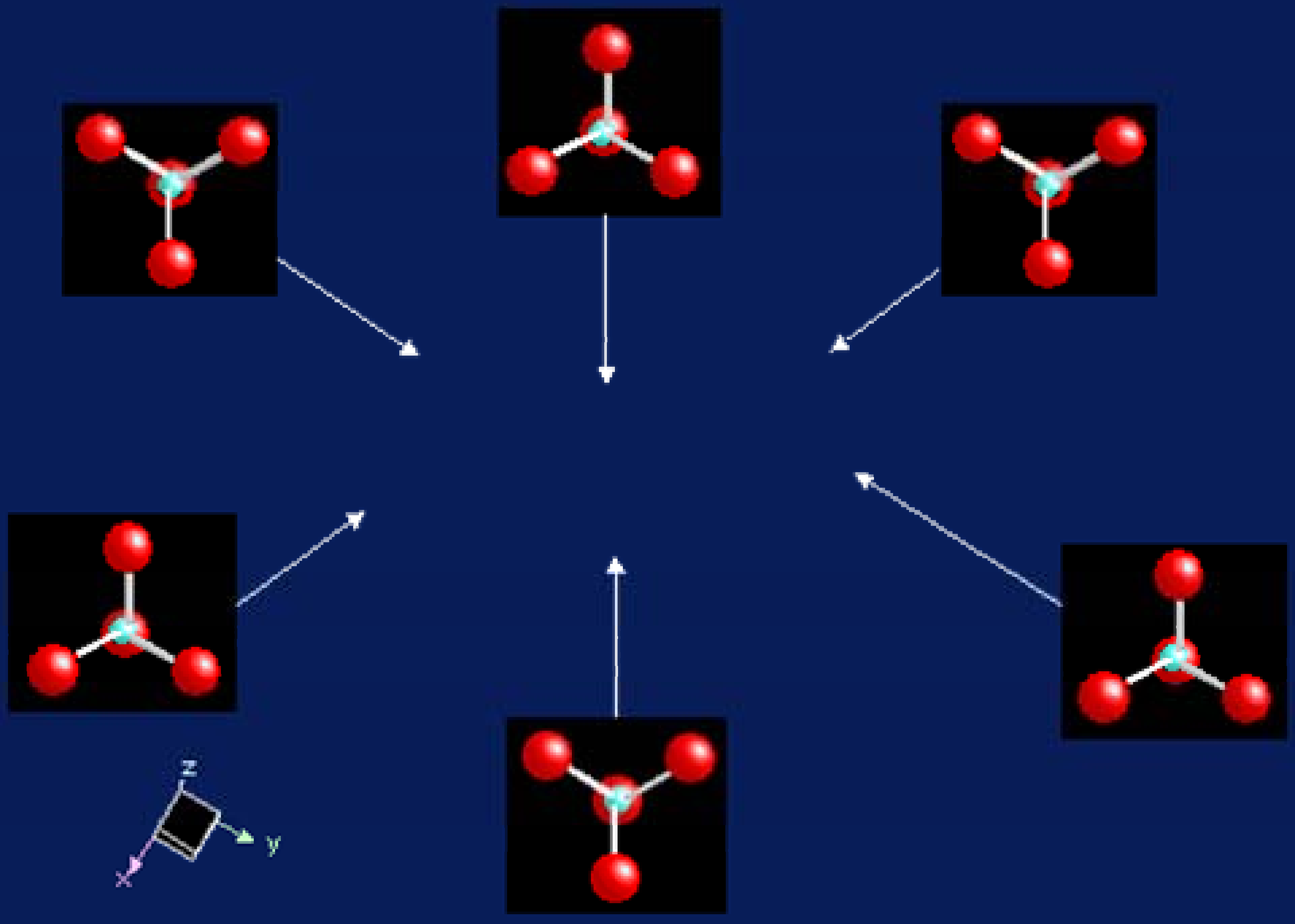



*A.* Tetrahedron, ions to scale, close packing

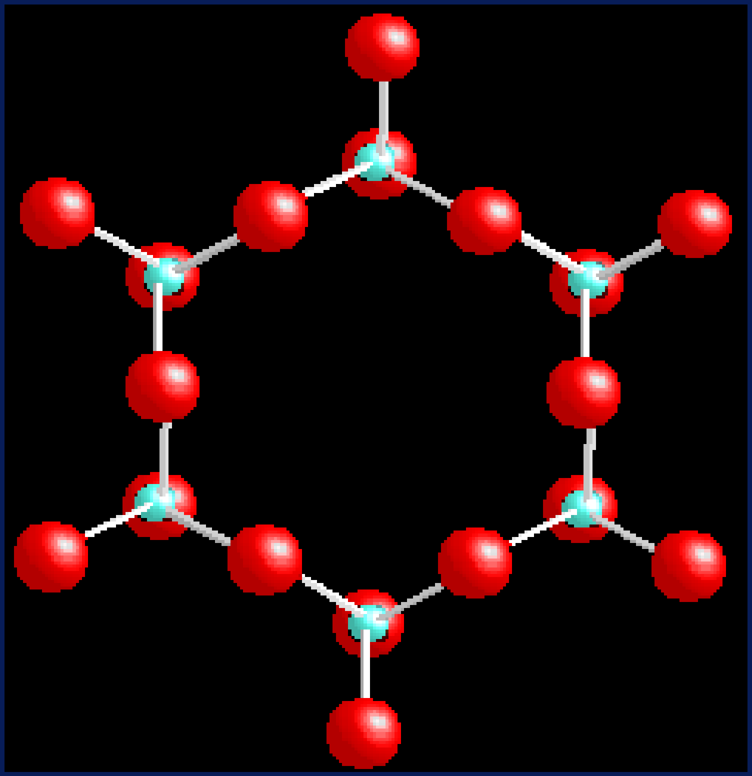
*B.* Expanded tetrahedron



# CONNECT THE TETRAHEDRA

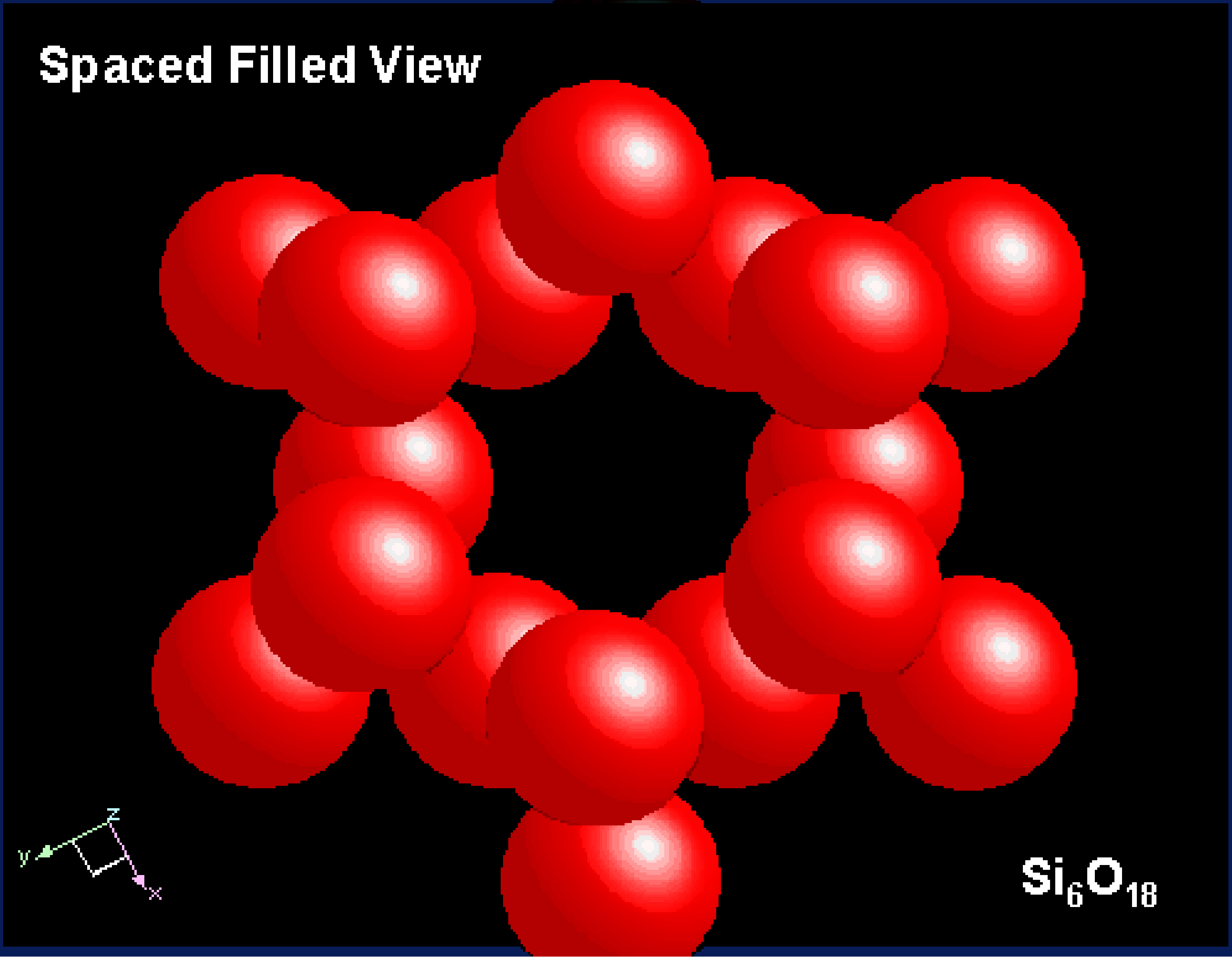


# SILICA TETRAHEDRAL RING

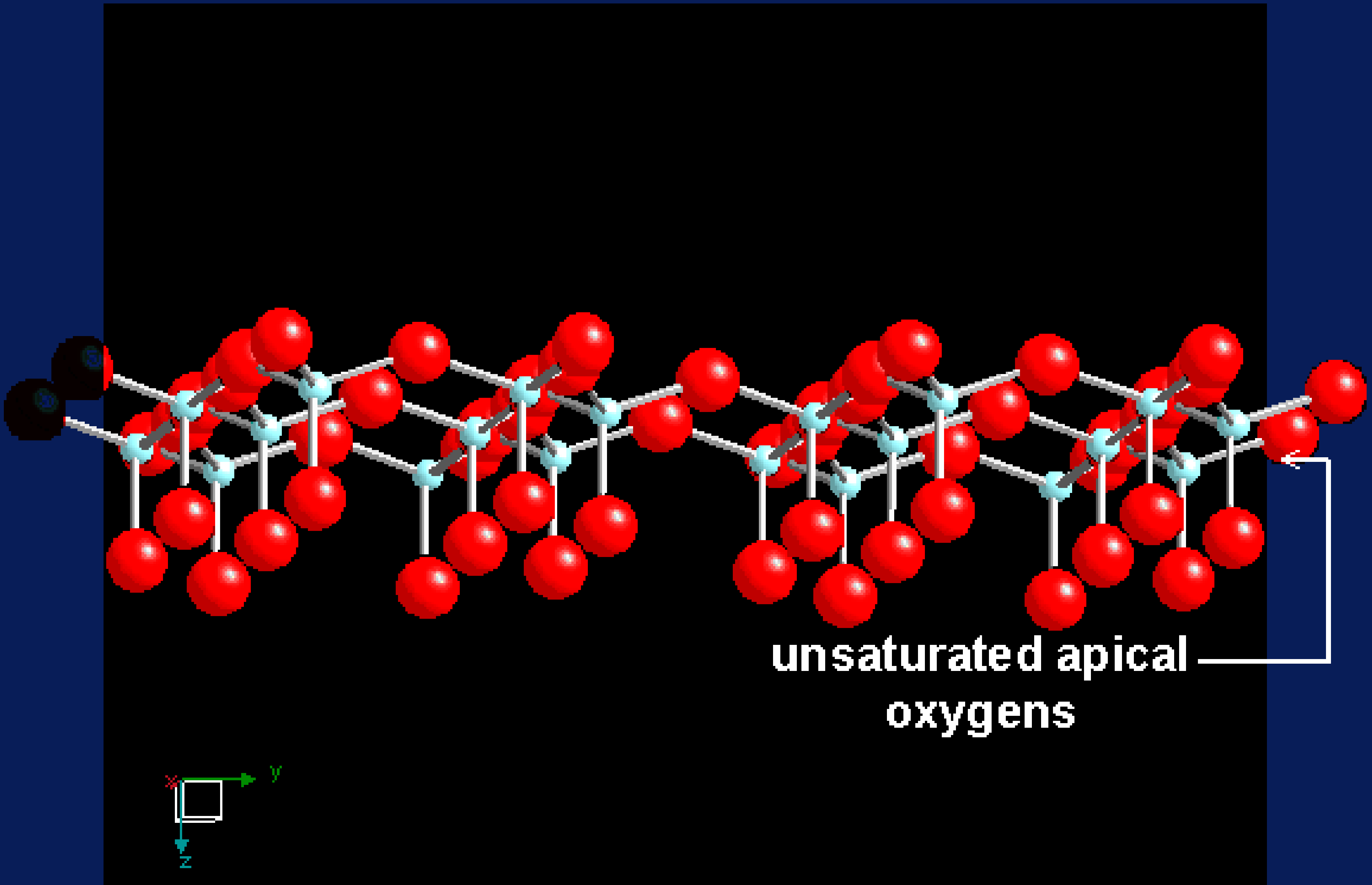


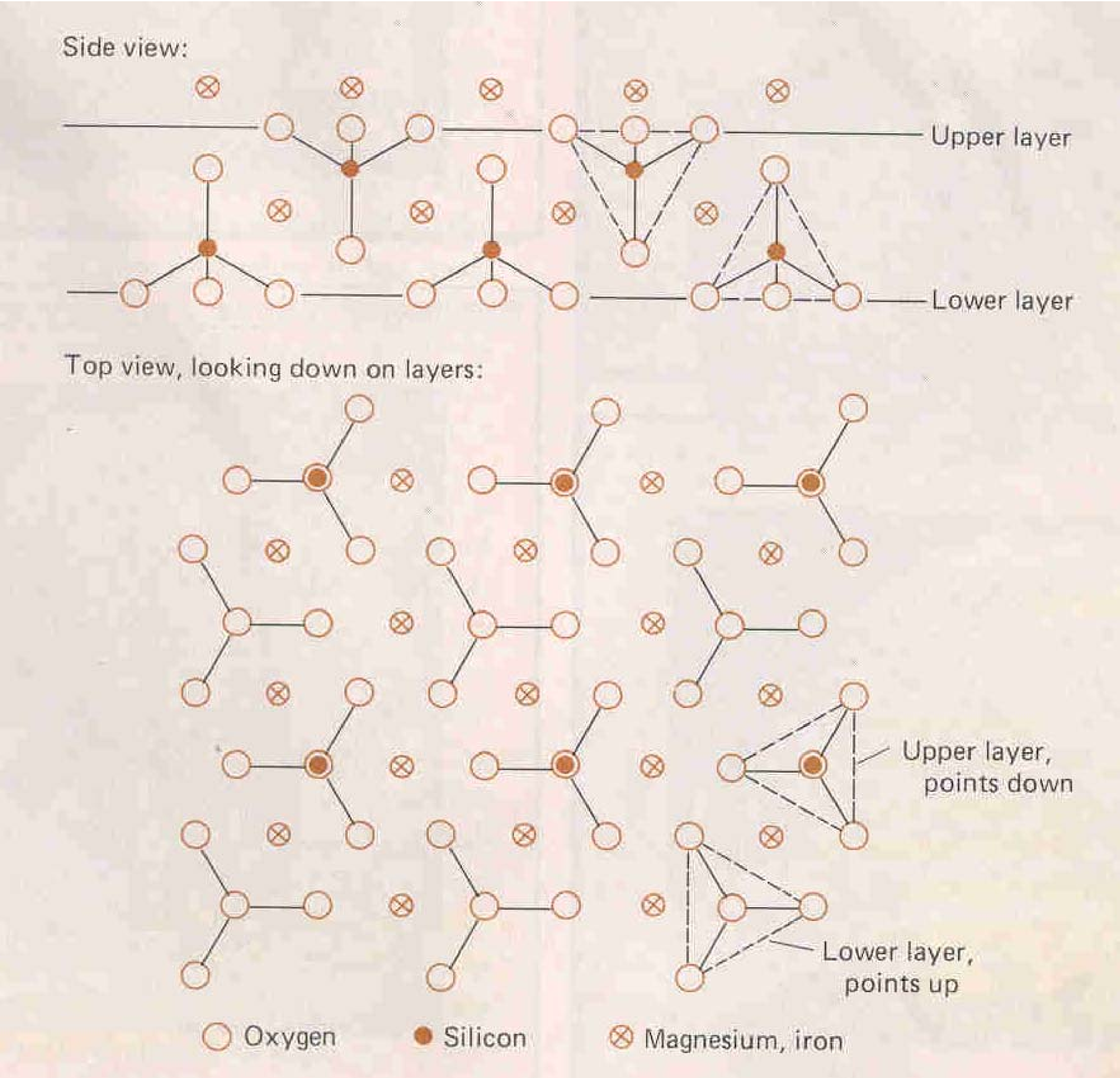
$Si_6O_{18}$

# SILICA TETRAHEDRAL RING



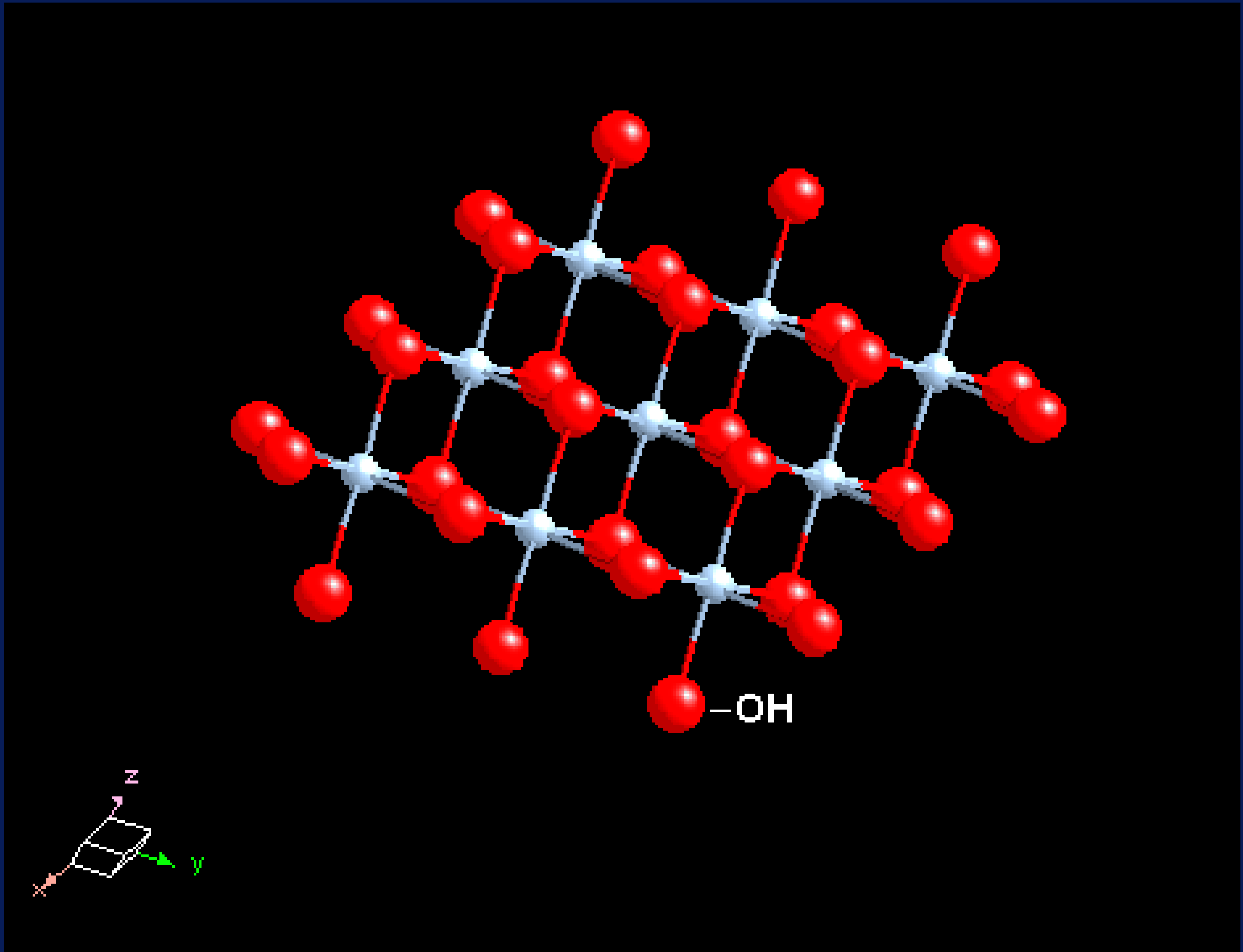
# TETRAHEDRAL SHEET





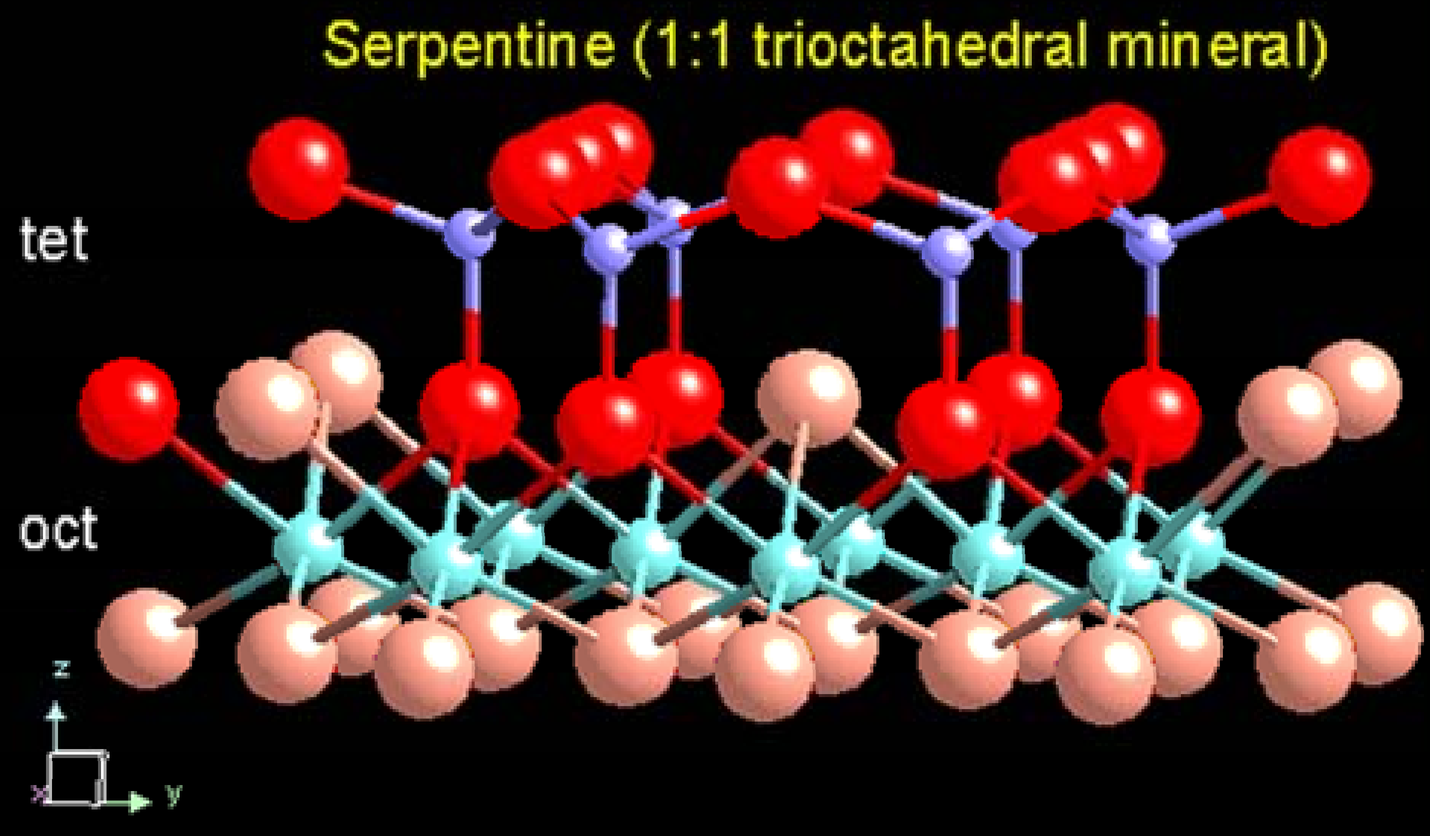
Side view:
Upper layer
Lower layer
Top view, looking down on layers:
Upper layer,
points down
Lower layer,
points up
Oxygen
Silicon
Magnesium, iron

# OCTAHEDRAL SHEET



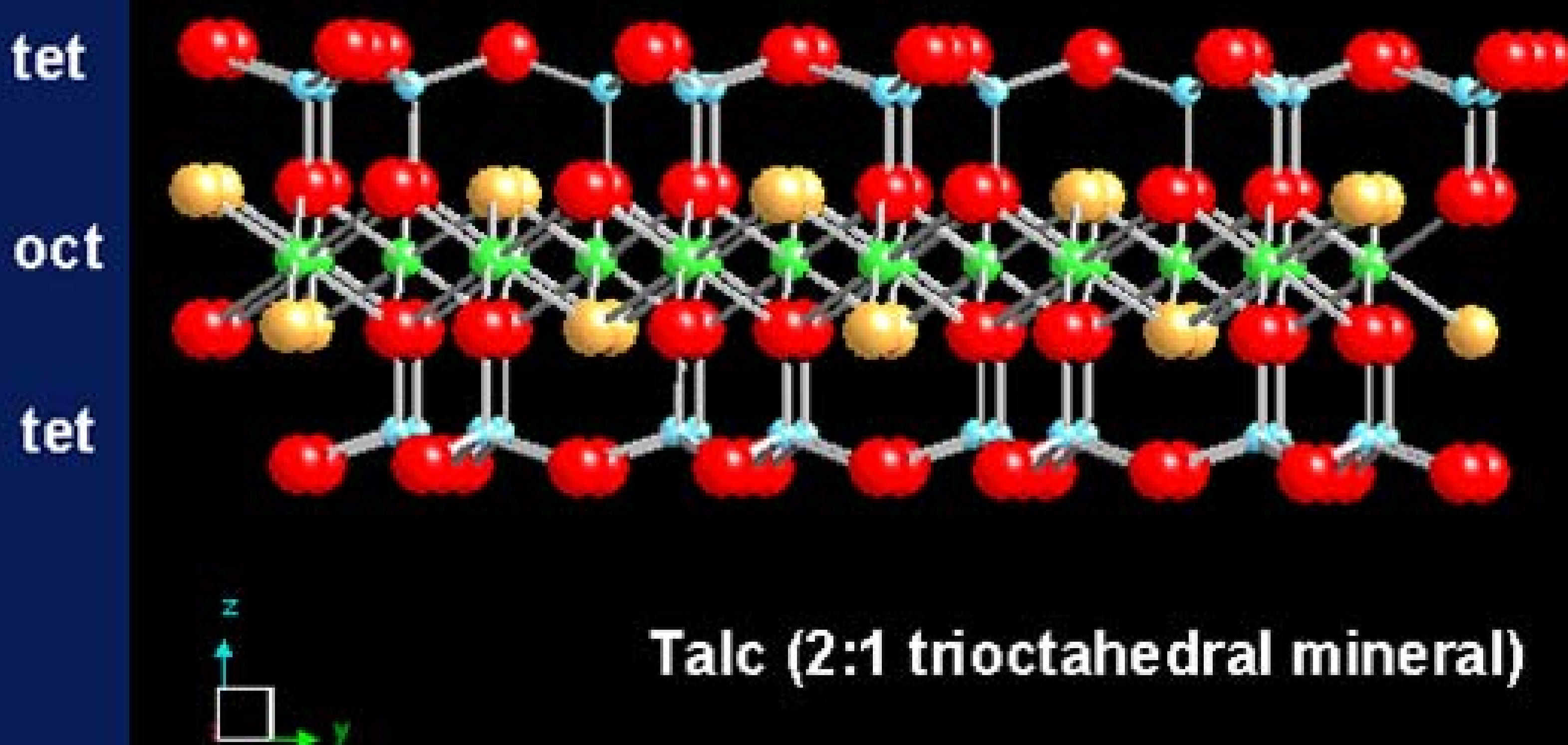
# OCTAHEDRAL-TETRAHEDRAL LINKAGE

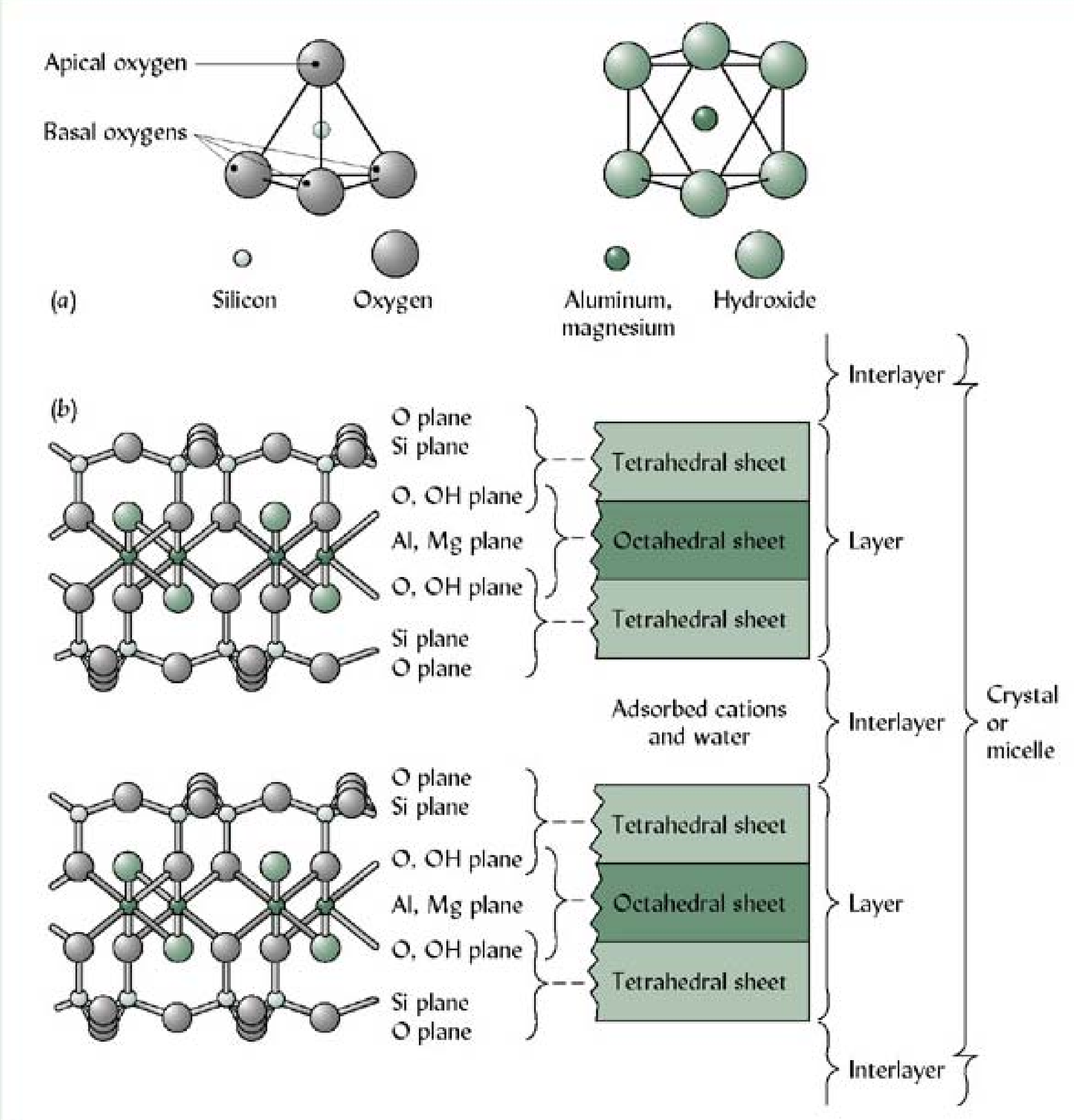
Sharing of Apical Oxygens in Tetrahdral Sheet
with Hydroxyls of Octahedral Sheet

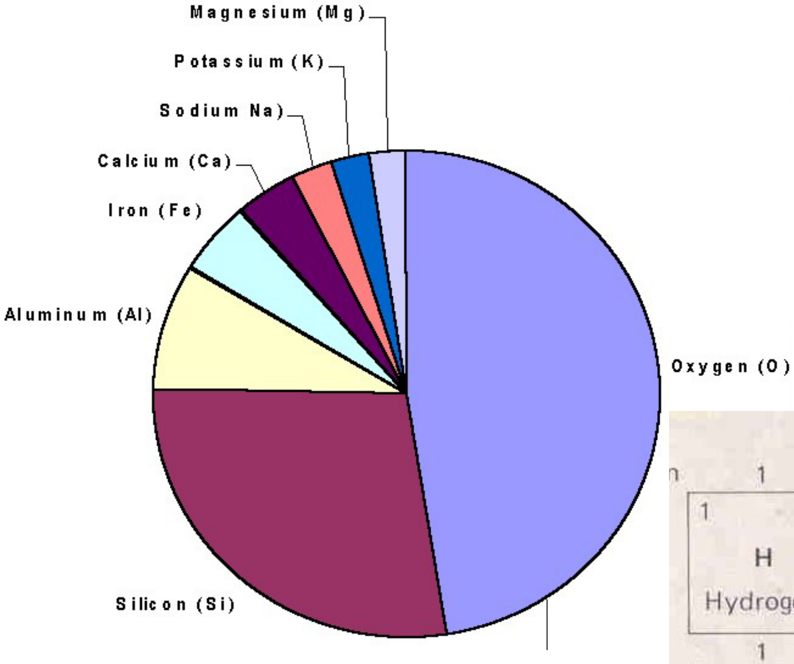


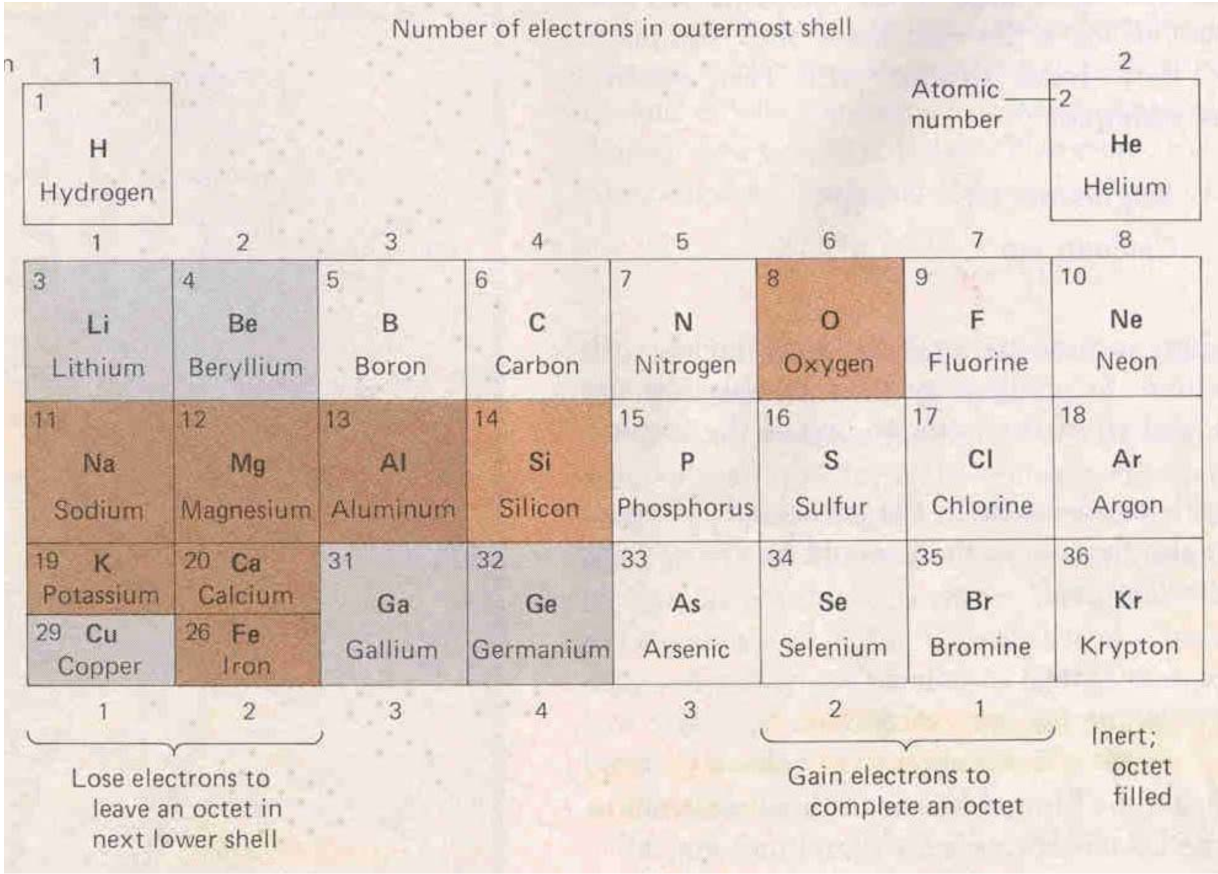
# OCTAHEDRAL-TETRAHEDRAL LINKAGE

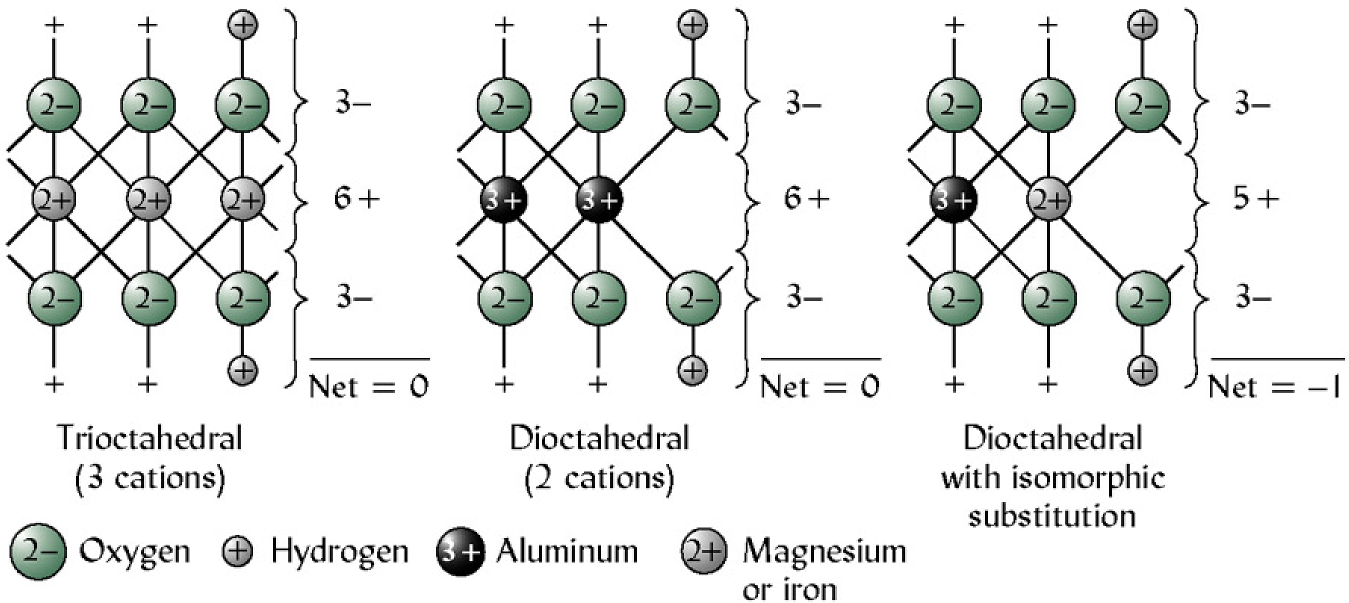
Sharing of Apical Oxygens in Tetrahdral Sheet
with Hydroxyls of Two Octahedral Sheets




Apical oxygen
Basal oxygens
(a)
Silicon
Oxygen
Aluminum, magnesium
Hydroxide
(b)
Interlayer
O plane
Si plane
Tetrahedral sheet
O, OH plane
Al, Mg plane
Octahedral sheet
Layer
O, OH plane
Tetrahedral sheet
Si plane
O plane
Adsorbed cations and water
Interlayer
Crystal or micelle
O plane
Si plane
Tetrahedral sheet
O, OH plane
Al, Mg plane
Octahedral sheet
Layer
O, OH plane
Tetrahedral sheet
Si plane
O plane
Interlayer


Magnesium (Mg)
Potassium (K)
Sodium Na)
Calcium (Ca)
Iron (Fe)
Aluminum (Al)
Oxygen (O)
Silicon (Si)


Number of electrons in outermost shell
1
2
Atomic number
1 H Hydrogen
2 He Helium
1 2 3 4 5 6 7 8
3 Li Lithium
4 Be Beryllium
5 B Boron
6 C Carbon
7 N Nitrogen
8 O Oxygen
9 F Fluorine
10 Ne Neon
11 Na Sodium
12 Mg Magnesium
13 Al Aluminum
14 Si Silicon
15 P Phosphorus
16 S Sulfur
17 Cl Chlorine
18 Ar Argon
19 K Potassium
20 Ca Calcium
29 Cu Copper
26 Fe Iron
31 Ga Gallium
32 Ge Germanium
33 As Arsenic
34 Se Selenium
35 Br Bromine
36 Kr Krypton
1 2 3 4 3 2 1
Lose electrons to leave an octet in next lower shell
Gain electrons to complete an octet
Inert; octet filled



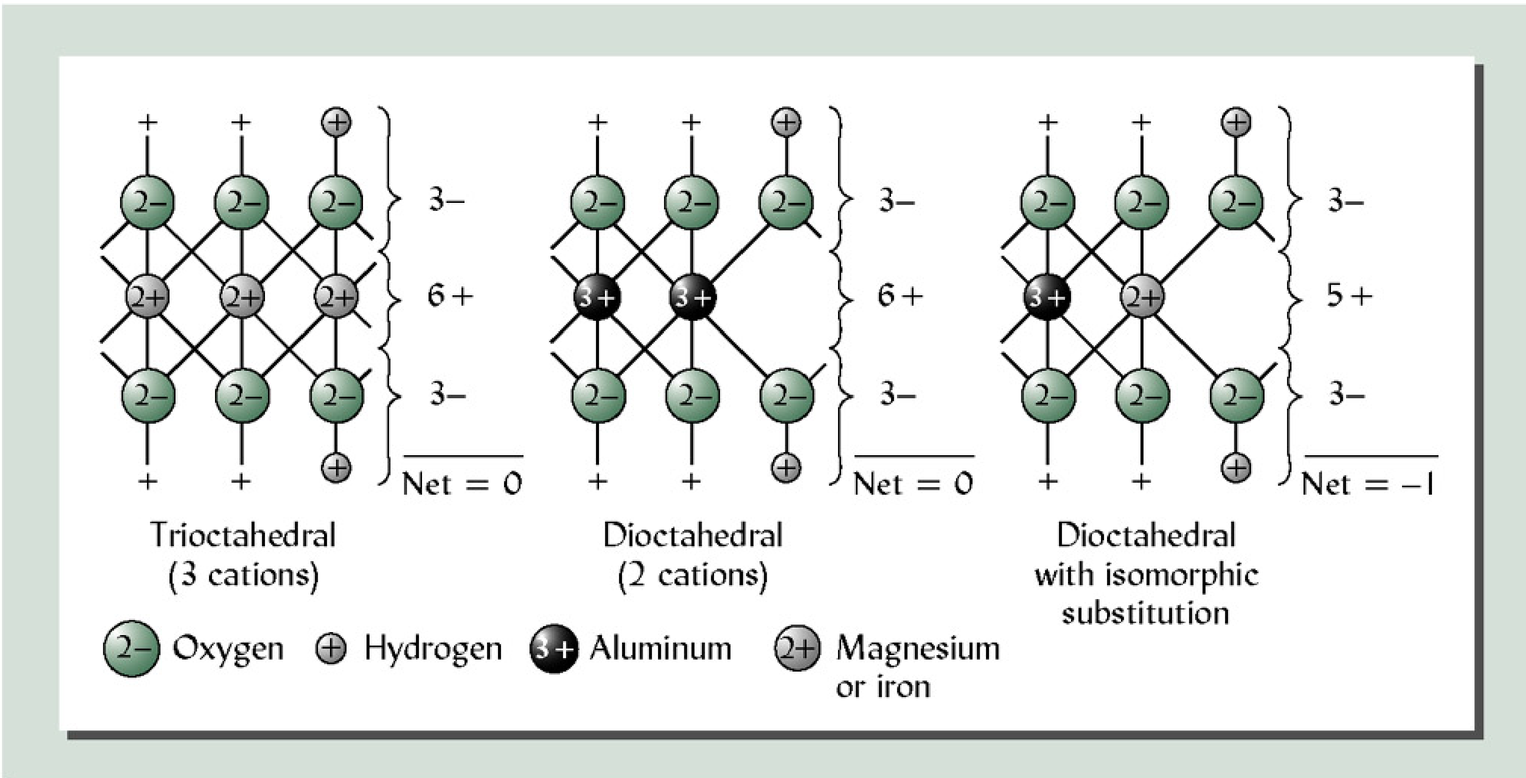
3–
6 +
3–
Net = 0
Trioctahedral
(3 cations)
3–
6 +
3–
Net = 0
Dioctahedral
(2 cations)
3–
5 +
3–
Net = –1
Dioctahedral
with isomorphic
substitution
Oxygen
Hydrogen
Aluminum
Magnesium
or iron

## TABLE 8.2 Ionic Radii of Elements Found in Silicate Clays and an Indication of Which Are Found in the Tetrahedral and Octahedral Sheets

*Note that Al, Fe, O, and OH can fit in either.*

| *Ion* | *Radius, nm*[a] | *Found in* |
|---|---|---|
| $Si^{4+}$ | 0.042 | Tetrahedral sheet ($Si^{4+}$, $Al^{3+}$, $Fe^{3+}$) |
| $Al^{3+}$ | 0.051 | Octahedral sheet ($Al^{3+}$ to $Fe^{2+}$) |
| $Fe^{3+}$ | 0.064 | Exchange sites ($Al^{3+}$ to $K^{+}$) |
| $Mg^{2+}$ | 0.066 | |
| $Zn^{2+}$ | 0.074 | |
| $Fe^{2+}$ | 0.070 | |
| $Na^{+}$ | 0.097 | |
| $Ca^{2+}$ | 0.099 | |
| $K^{+}$ | 0.133 | |
| $O^{2-}$ | 0.140 | Both sheets |
| $OH^{-}$ | 0.155 | Both sheets |

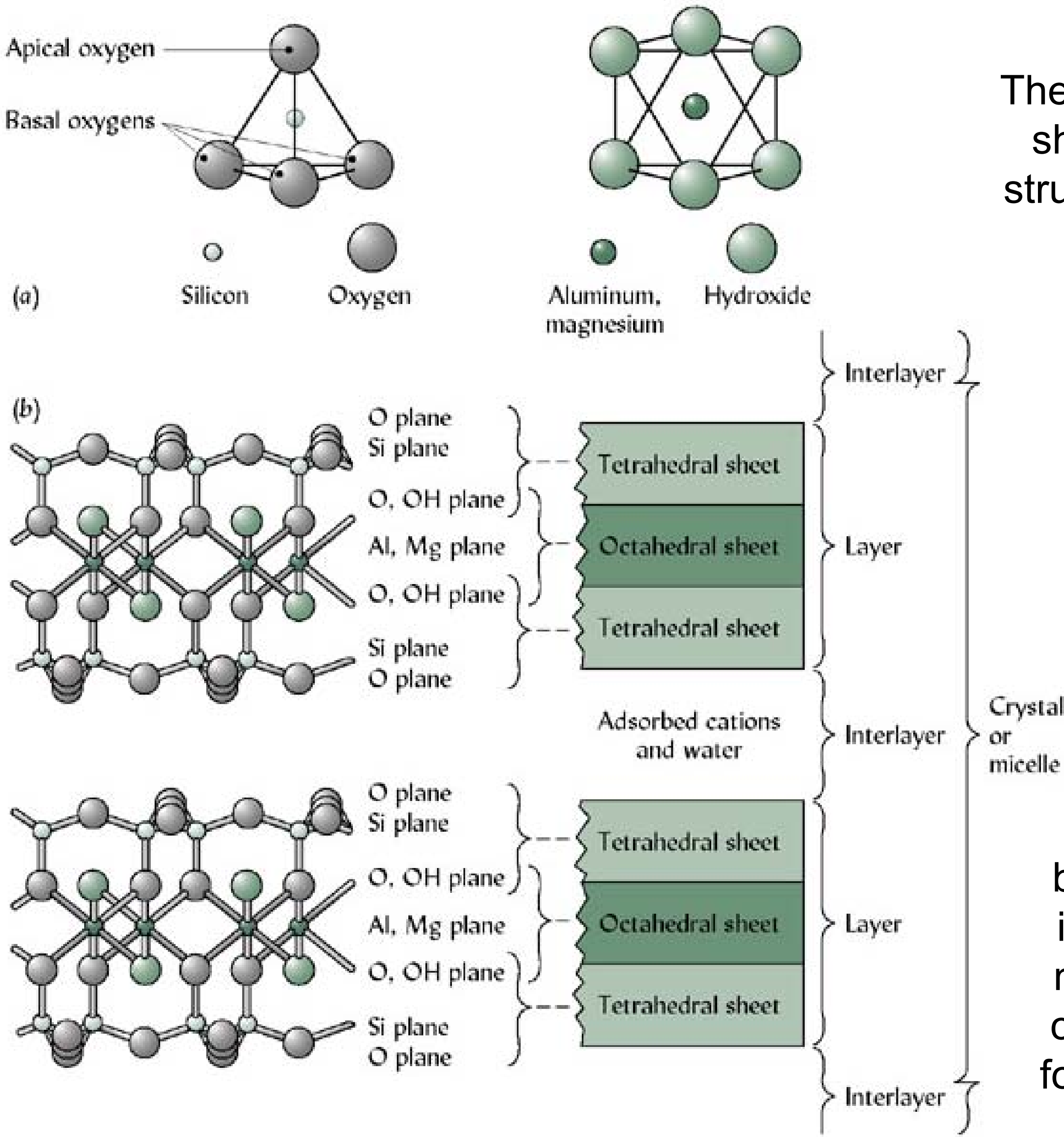
[a] 1 nm = $10^{-9}$m.



3–
6+
3–
Net = 0
Trioctahedral
(3 cations)
3–
6+
3–
Net = 0
Dioctahedral
(2 cations)
3–
5+
3–
Net = –1
Dioctahedral
with isomorphic
substitution
Oxygen
Hydrogen
Aluminum
Magnesium
or iron

# Isomorphous Substitution

- In the tetrahedra, $Al^{3+}$ ions substitute for $Si^{4+}$ ions
- In the octahedra, $Fe^{2+}$, $Mg^{2+}$ ions substitute for $Al^{3+}$ or $Fe^{3+}$
- This leaves some of the negative charge unbalanced
- $K^+$, $Na^+$, $Ca^{2+}$, $Mg^{2+}$ and other ions can be absorbed on the edges and between sheets to restore charge balance



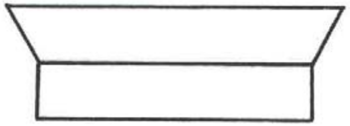

The tetrahedral and octahedral sheets are the fundamental structural units of silicate clays

2 to 4 sheets can be stacked in sandwich-like arrangements (called layers) bound together by the sharing of oxygen atoms

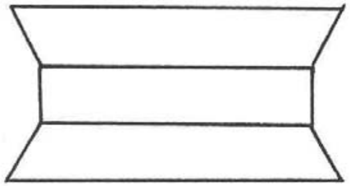
The interlayer zones, binding the layers together is largely controlled by the nature of atom and charge combinations of the sheets forming the individual layers

## Silicate Clays
### Main groups:

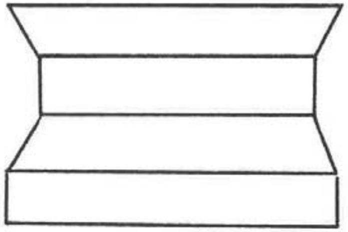
1-to-1 silica sheet + alumina sheet = layer
(tetrahedral) (octahedral)



2-to-1 silica + alumina + silica = layer
(Mg, Fe)

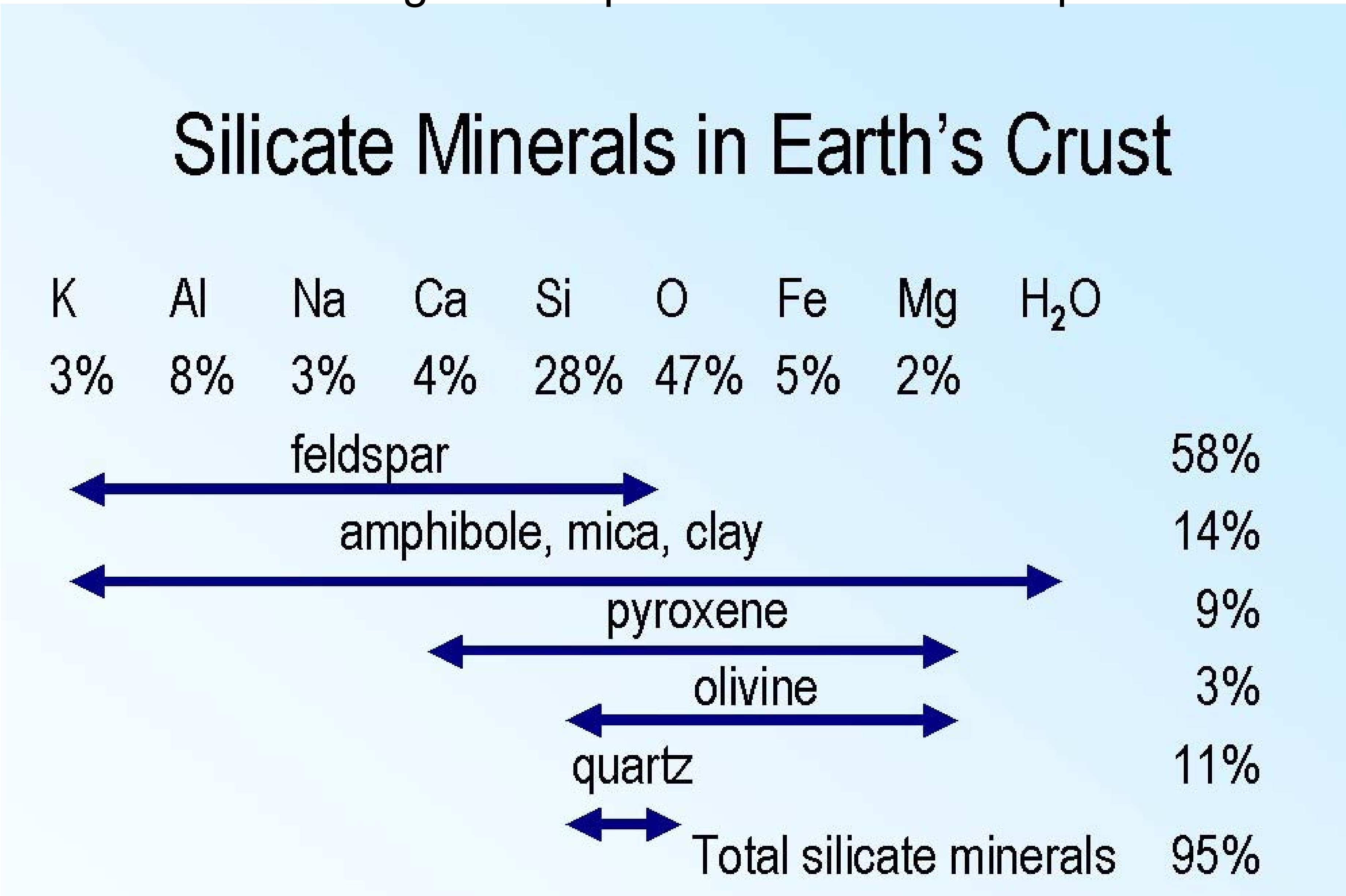


2-to-1-to-1
silica + alumina + silica + magnesia = layer

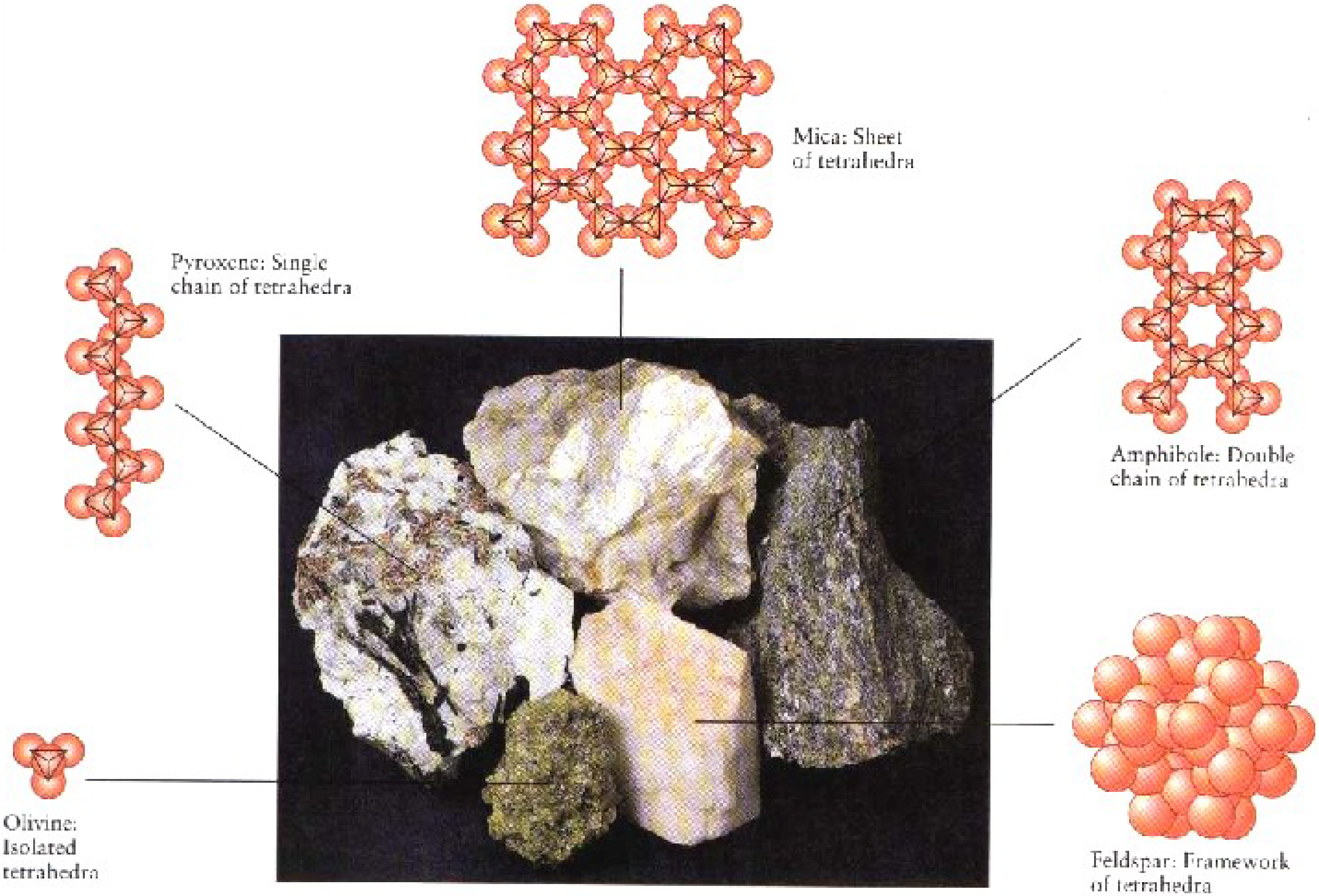


All are based on the layer (sheet) silicate

# Chemical Weathering: Process that changes minerals from their original composition to a new composition

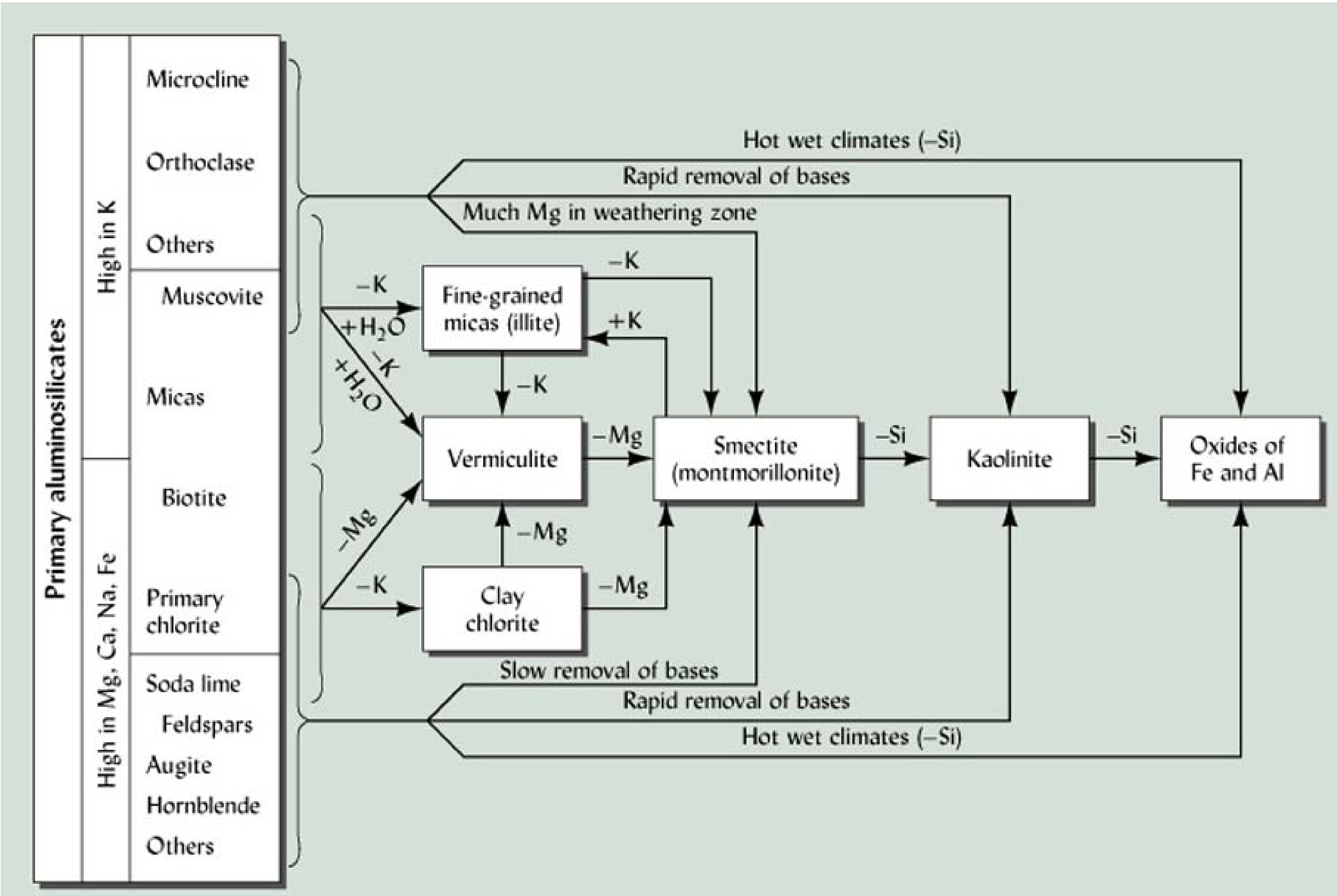


# Linked $SiO_4$ tetrahedra form structural backbone for silicate mineral groups



Secondary phylosilicate mineral formation is not always from scratch, but is generally in a dynamic interaction with chemical weathering – ie transformation

Alteration versus Recrystallization



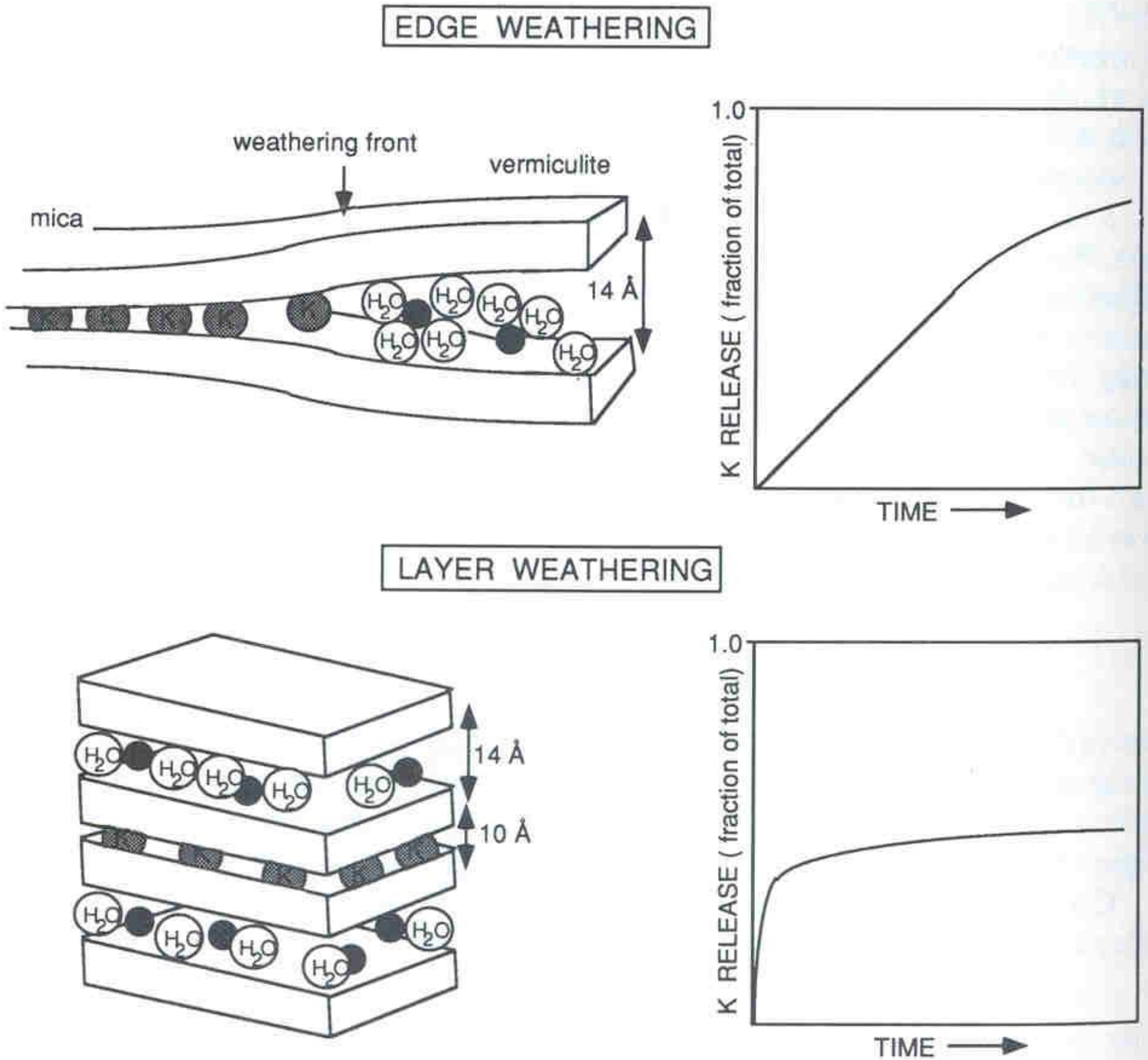
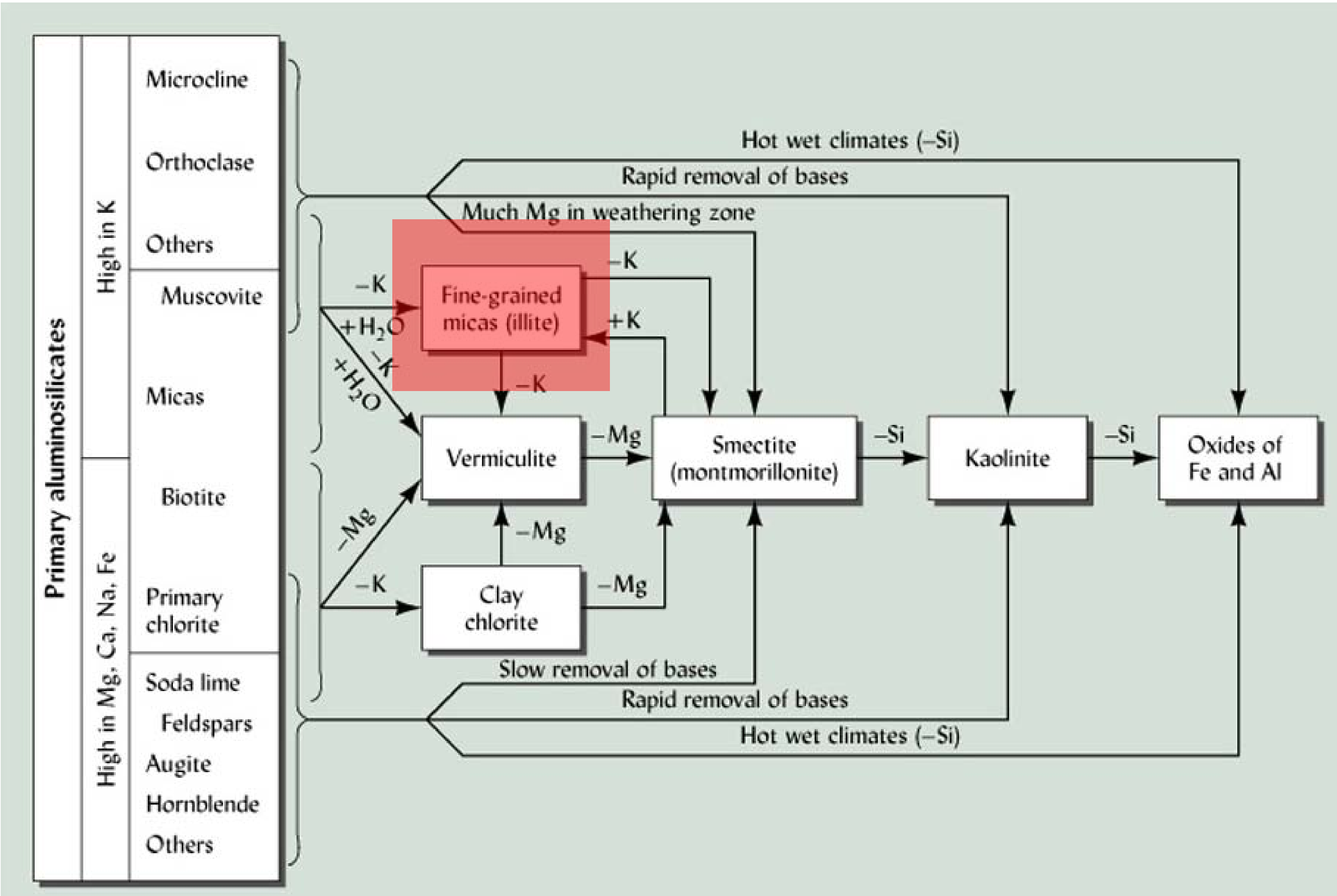
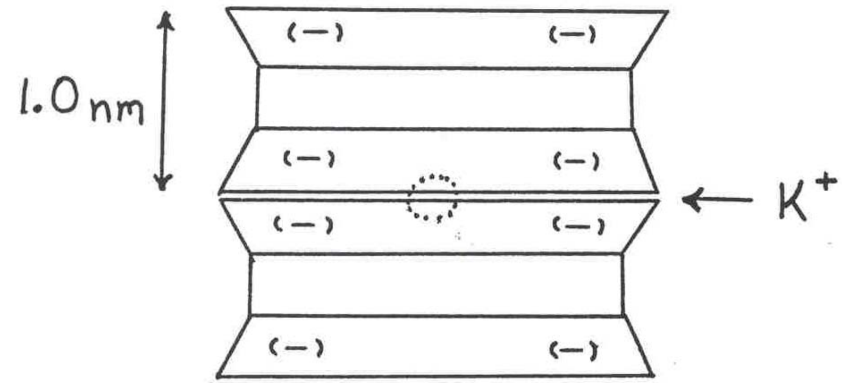


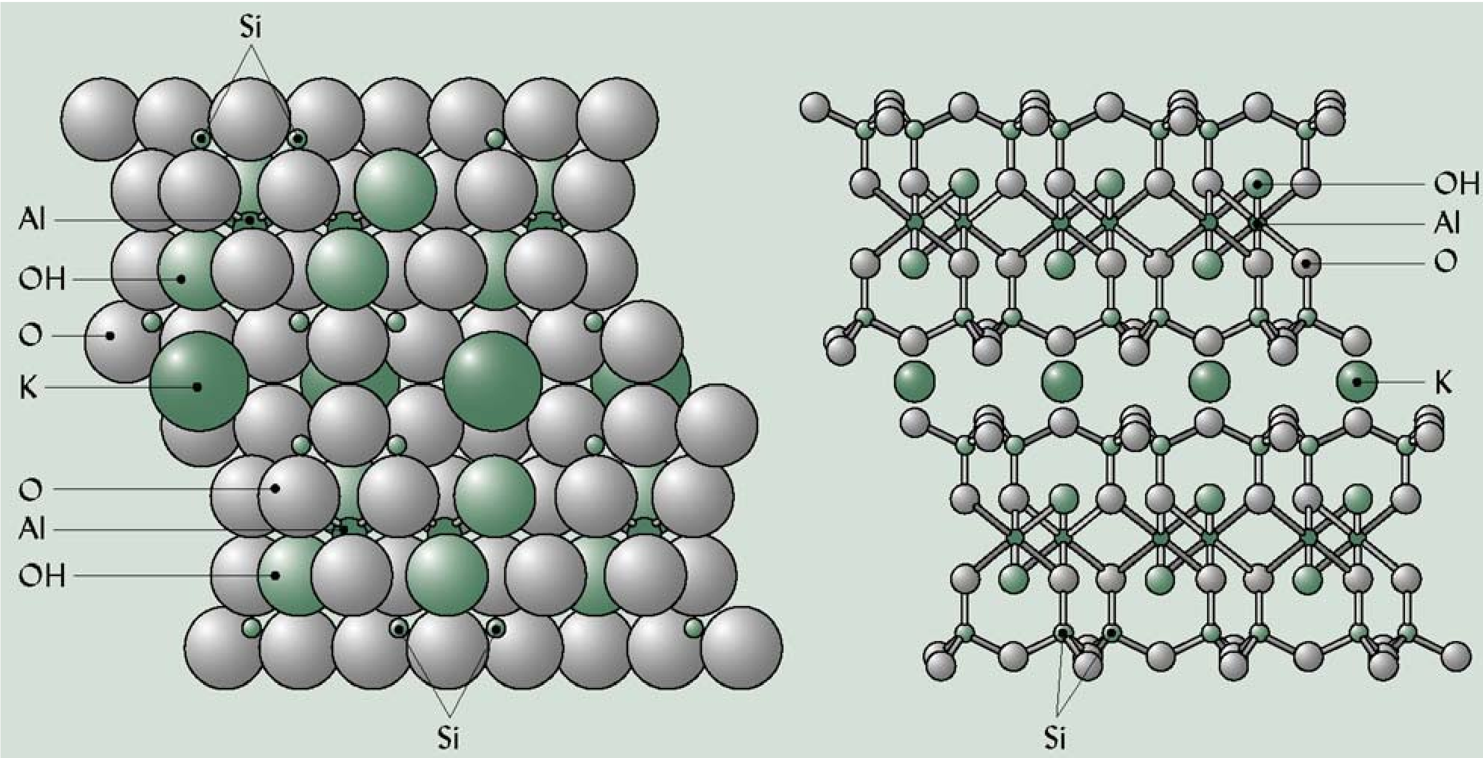

**Figure 6.4.** Schematic picture of edge weathering of large mica particles and layer weathering of small mica particles.

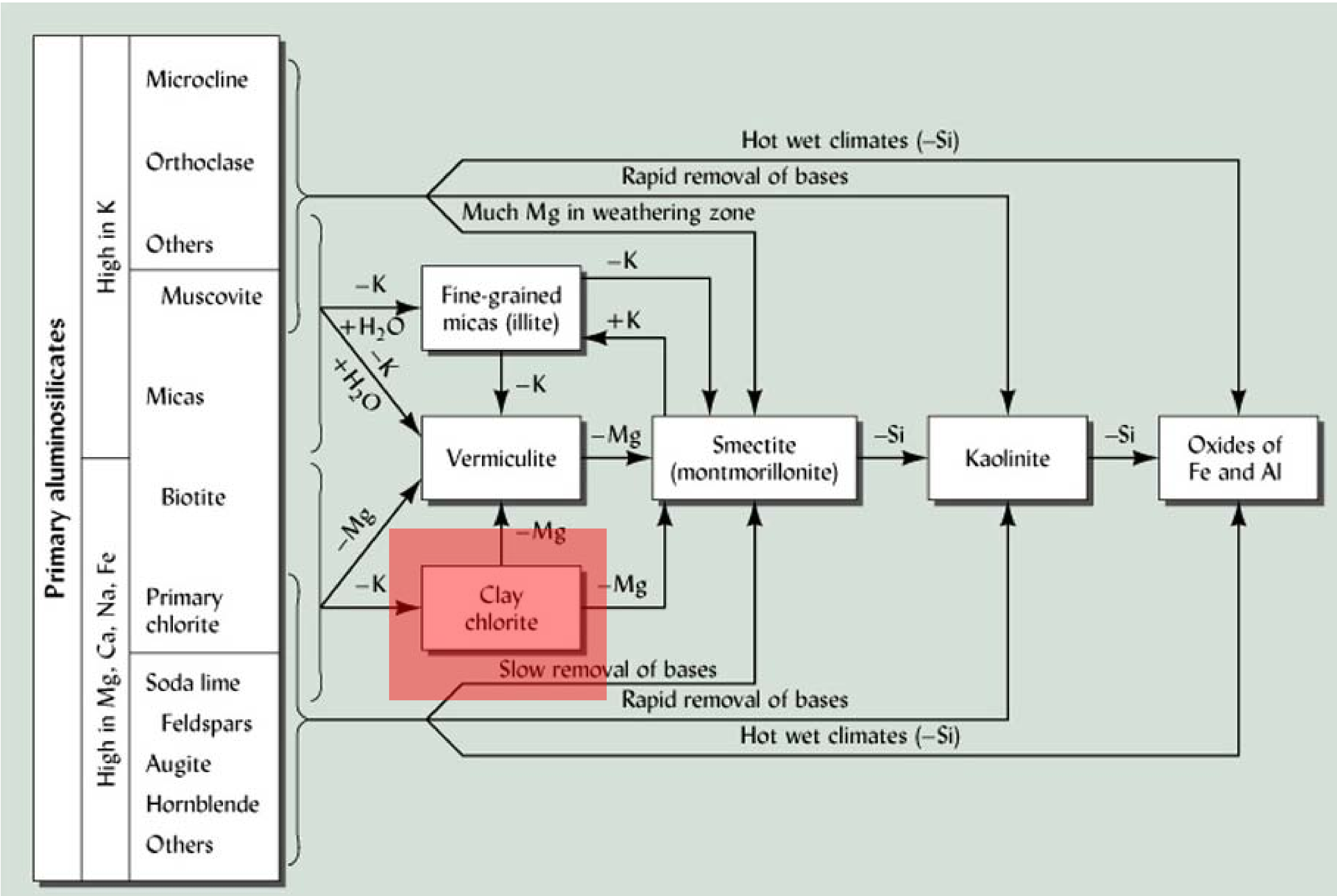

Primary aluminosilicates
High in K
High in Mg, Ca, Na, Fe
Microcline
Orthoclase
Others
Muscovite
Micas
Biotite
Primary chlorite
Soda lime
Feldspars
Augite
Hornblende
Others
Hot wet climates (–Si)
Rapid removal of bases
Much Mg in weathering zone
–K
+H2O
Fine-grained micas (illite)
–K
+K
–K
+H2O
–K
Vermiculite
–Mg
Smectite (montmorillonite)
–Si
Kaolinite
–Si
Oxides of Fe and Al
–Mg
–Mg
–K
Clay chlorite
–Mg
Slow removal of bases
Rapid removal of bases
Hot wet climates (–Si)

# Illite

- **2-to-1, non-expanding clay mineral**
- **often called "hydrous mica"**
- **interlayer K+ (as in mica) prevents swelling**




Primary aluminosilicates
High in K
High in Mg, Ca, Na, Fe
Microcline
Orthoclase
Others
Muscovite
Micas
Biotite
Primary chlorite
Soda lime
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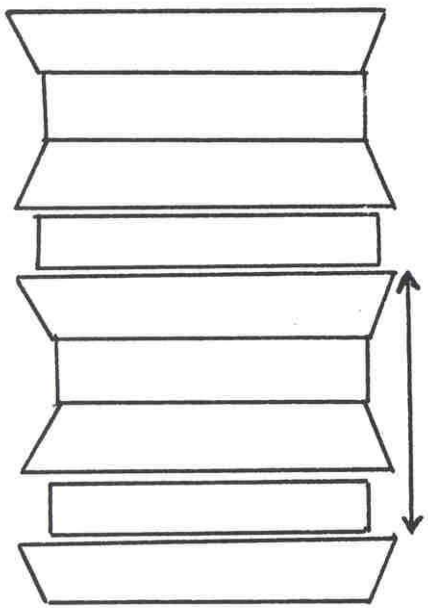
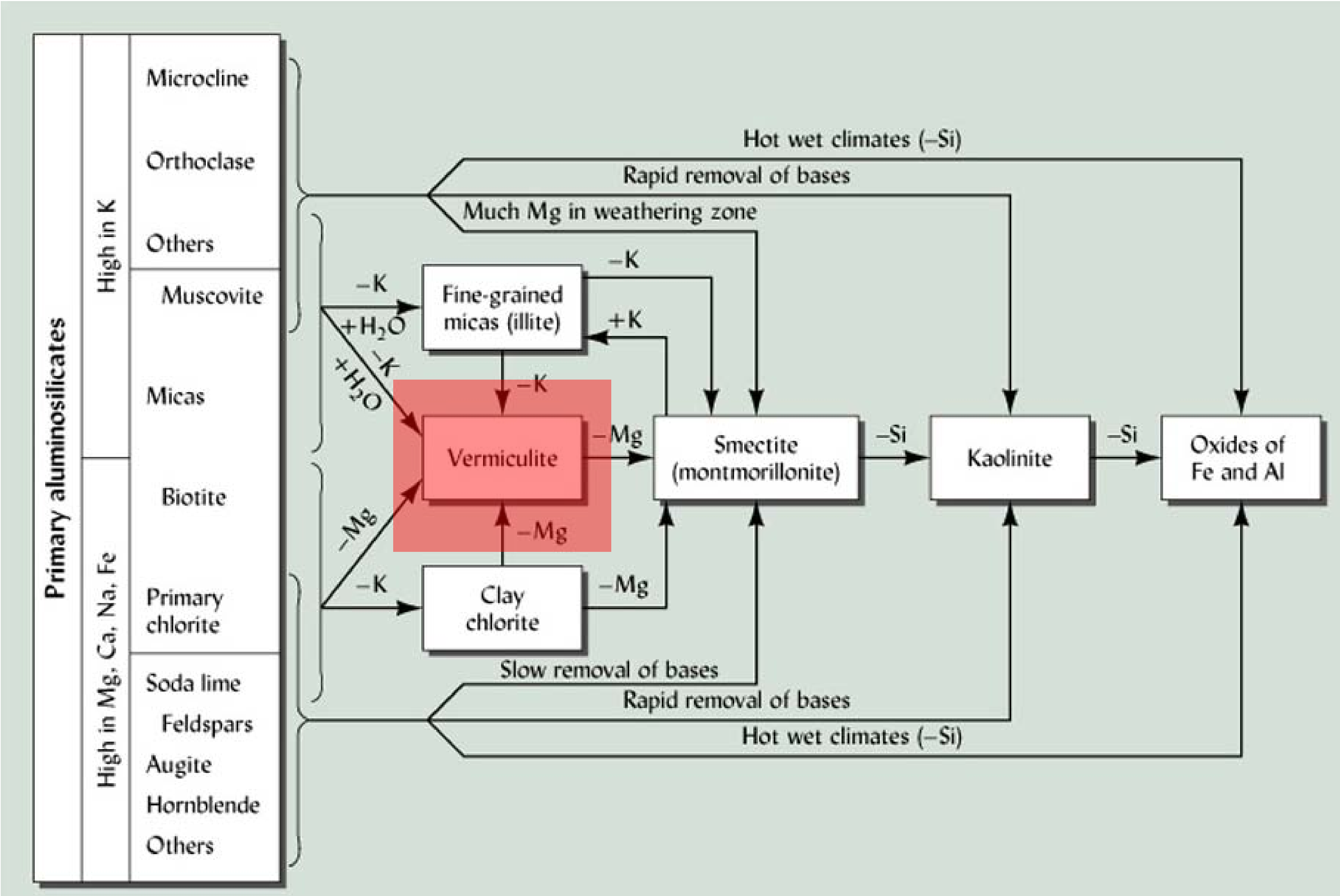
Augite
Hornblende
Others
Hot wet climates (–Si)
Rapid removal of bases
Much Mg in weathering zone
–K
+H2O
–K
+H2O
Fine-grained micas (illite)
–K
+K
–K
Vermiculite
–Mg
Smectite (montmorillonite)
–Si
Kaolinite
–Si
Oxides of Fe and Al
–Mg
–K
–Mg
Clay chlorite
–Mg
Slow removal of bases
Rapid removal of bases
Hot wet climates (–Si)

## Chlorite:

2-to-1-to-1, non-expanding clay mineral
like vermiculite, but has positively charged Mg hydroxide sheet replacing exchange cations between 2-to-1 sheets: $[Mg_5Al(OH)_{12}+]$



1.4 nm



Primary aluminosilicates
High in K
High in Mg, Ca, Na, Fe
Microcline
Orthoclase
Others
Muscovite
Micas
Biotite
Primary chlorite
Soda lime
Feldspars
Augite
Hornblende
Others
Hot wet climates (–Si)
Rapid removal of bases
Much Mg in weathering zone
–K
+$H_2O$
–K
+$H_2O$
Fine-grained micas (illite)
–K
+K
–K
Vermiculite
–Mg
–Mg
–Mg
–K
Clay chlorite
–Mg
Smectite (montmorillonite)
–Si
Kaolinite
–Si
Oxides of Fe and Al
Slow removal of bases
Rapid removal of bases
Hot wet climates (–Si)

**Vermiculite:**

- important 2-to-1 clay mineral in soils

- structurally similar to smectites with 3 differences:

  1. most or all of isomorphous substitution is tetrahedral

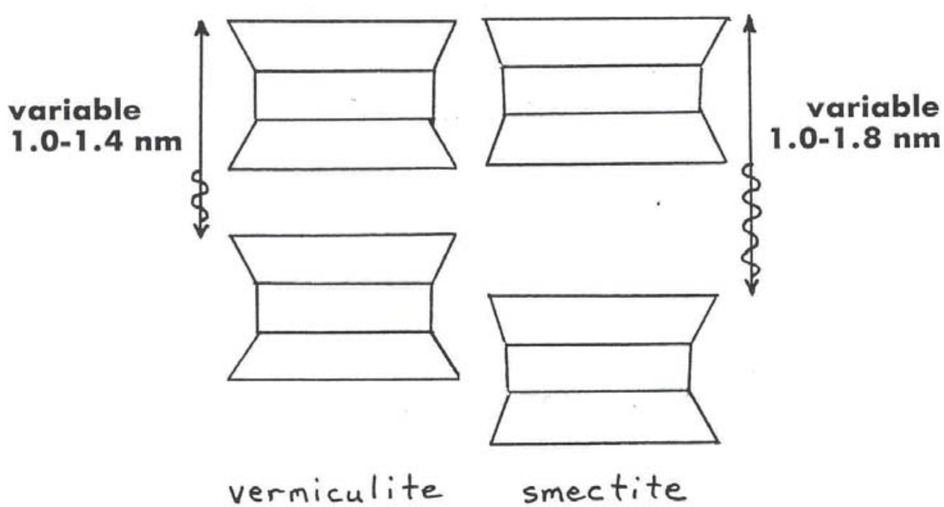
  2. isomorphous substitution is greater
     - $Al^{3}$ for $Si^{4+}$ (tet.)
     - $Fe^{3+}$, $Fe^{2+}$, $Mg^{2+}$ for $Al^{3+}$ (oct.)

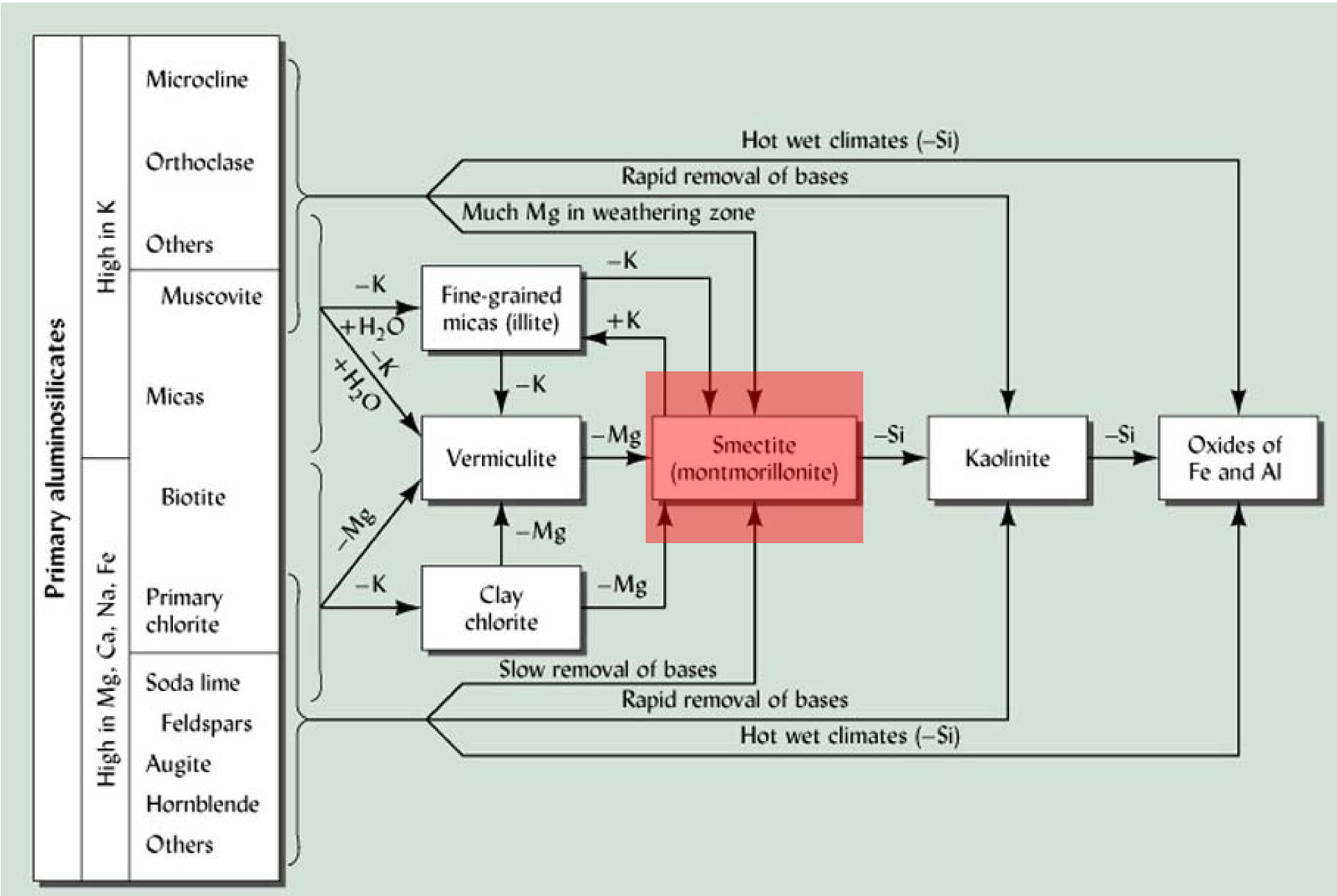
  3. $Mg^{2+}$ is the usual exchangeable cation

- result of these differences:

  1. swelling in water limited to 1.4 nm

  2. larger capacity for adsorption of exchangeable cations than smectites



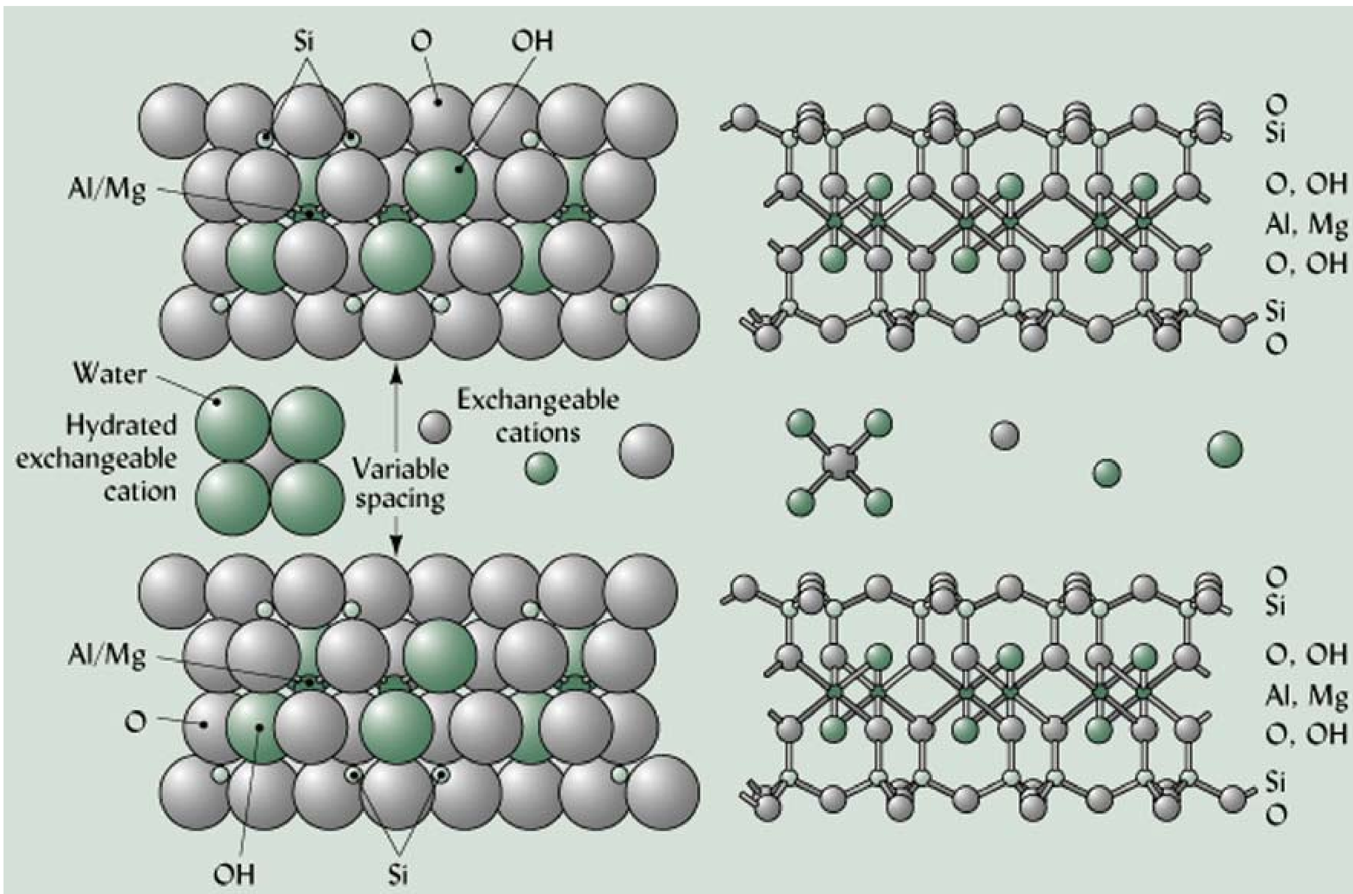


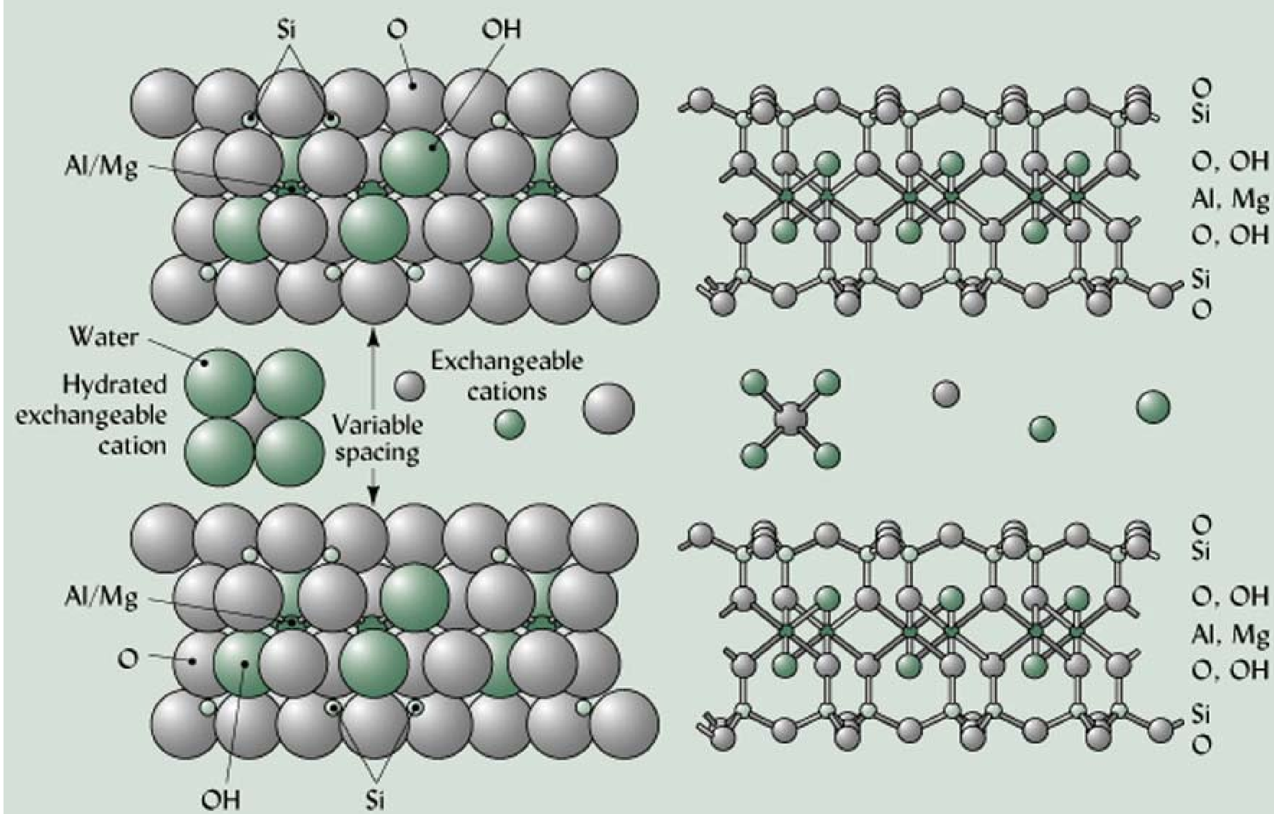
Primary aluminosilicates
High in K
Microcline
Orthoclase
Others
Muscovite
Micas
High in Mg, Ca, Na, Fe
Biotite
Primary chlorite
Soda lime
Feldspars
Augite
Hornblende
Others
Hot wet climates (–Si)
Rapid removal of bases
Much Mg in weathering zone
–K
+H$_2$O
–K
+H$_2$O
Fine-grained micas (illite)
–K
+K
–K
Vermiculite
–Mg
Smectite (montmorillonite)
–Si
Kaolinite
–Si
Oxides of Fe and Al
–Mg
–Mg
–K
Clay chlorite
–Mg
Slow removal of bases
Rapid removal of bases
Hot wet climates (–Si)

**Smectites (a family of minerals):**

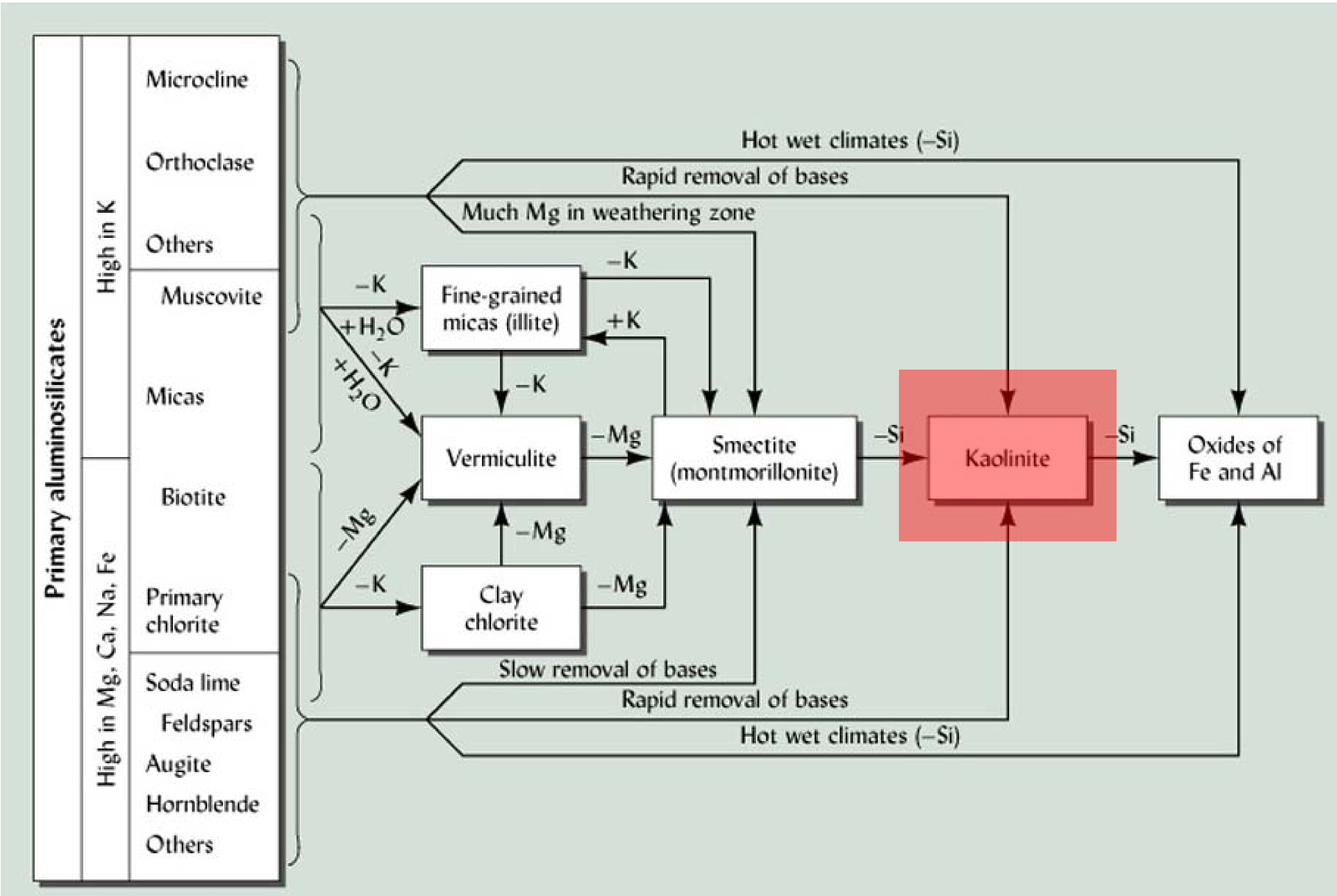
sheets held together at apical oxygen ions

- **important 2-to-1 clay minerals in soils**
- **each layer has octahedral sheet sandwiched between two tetrahedral sheets**
- **formula of unit cell is variable, but many common smectites are based on pyrophyllite:**






- able to expand in water, increasing size of unit cell & amount of adsorbed water
- shrink/swell behavior is related to the loss or gain of water in the interlayer space
- adsorbed water (n $H_2O$) is associated with exchangeable cations
- huge surface area due to exposed interlayer surface (800 $m^2/g$)



Primary aluminosilicates
High in K
Microcline
Orthoclase
Others
Muscovite
Micas
High in Mg, Ca, Na, Fe
Biotite
Primary chlorite
Soda lime
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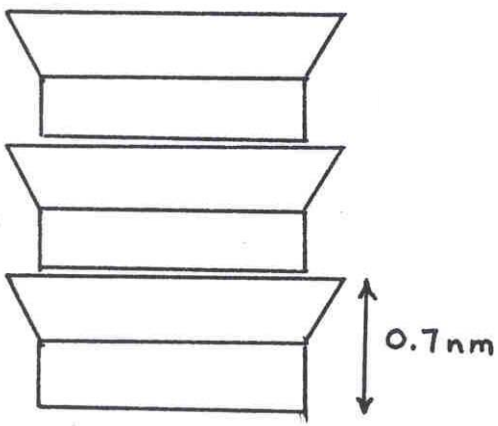
–Si
Kaolinite
–Si
Oxides of Fe and Al
–Mg
–Mg
–K
Clay chlorite
–Mg
Slow removal of bases
Rapid removal of bases
Hot wet climates (–Si)

**Kaolinite:**

- most important 1-to-1 mineral in soil
- formula shows 1:1 silica/alumina ratio

$Al_4Si_4O_{10}(OH)_8$ (unit cell)

**UNIT CELL =** minimum unit which can be repeated to form the crystal structure



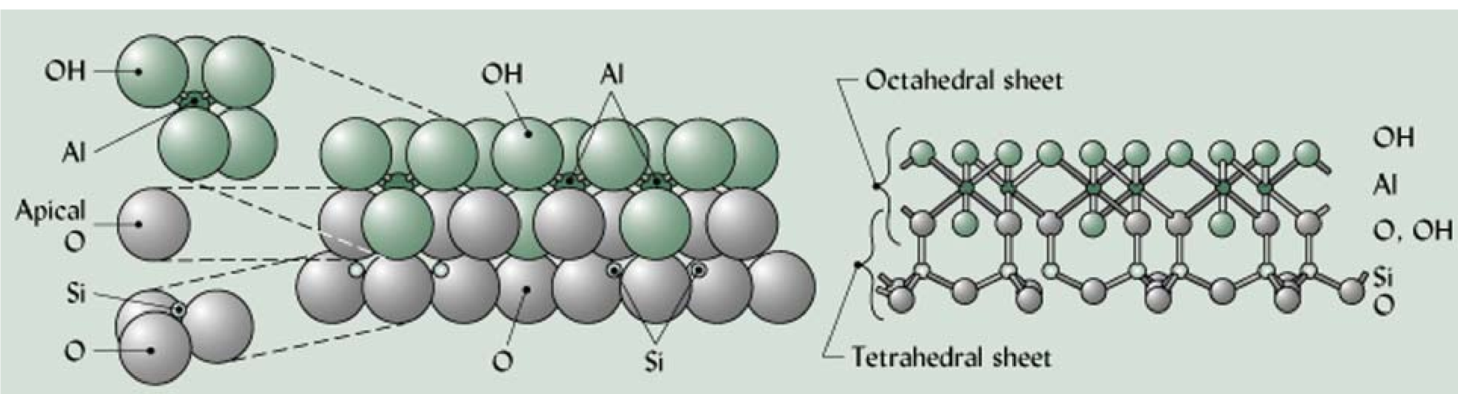

each layer (unit cell) is 0.7 nm thick

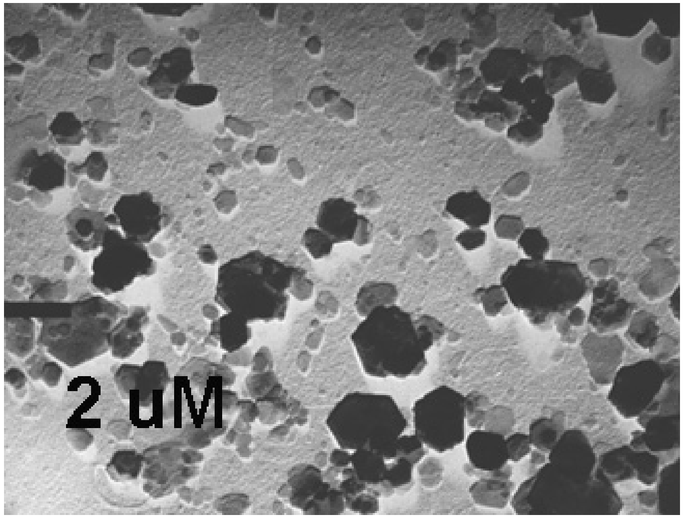
takes 3,000 layers to form a .002 mm thick clay particle

hydrogen bonds hold layers together (hydroxyl contacts oxygen on adjacent layer)

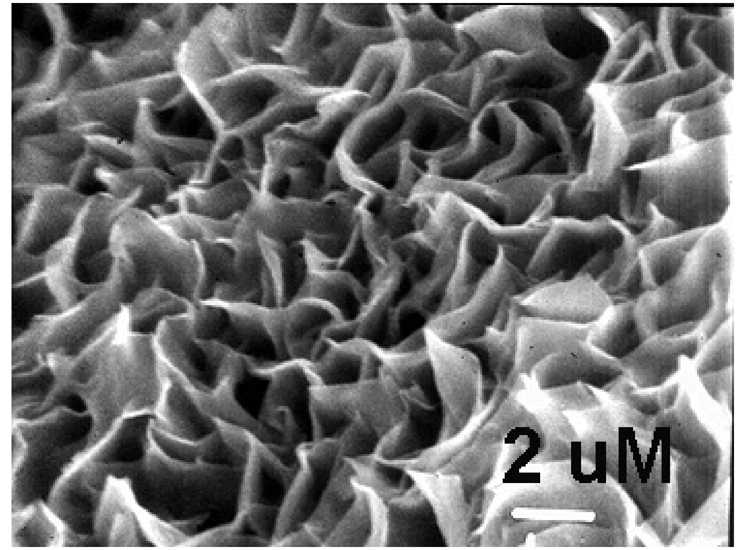
non-expanding in water

little ability to retain cations

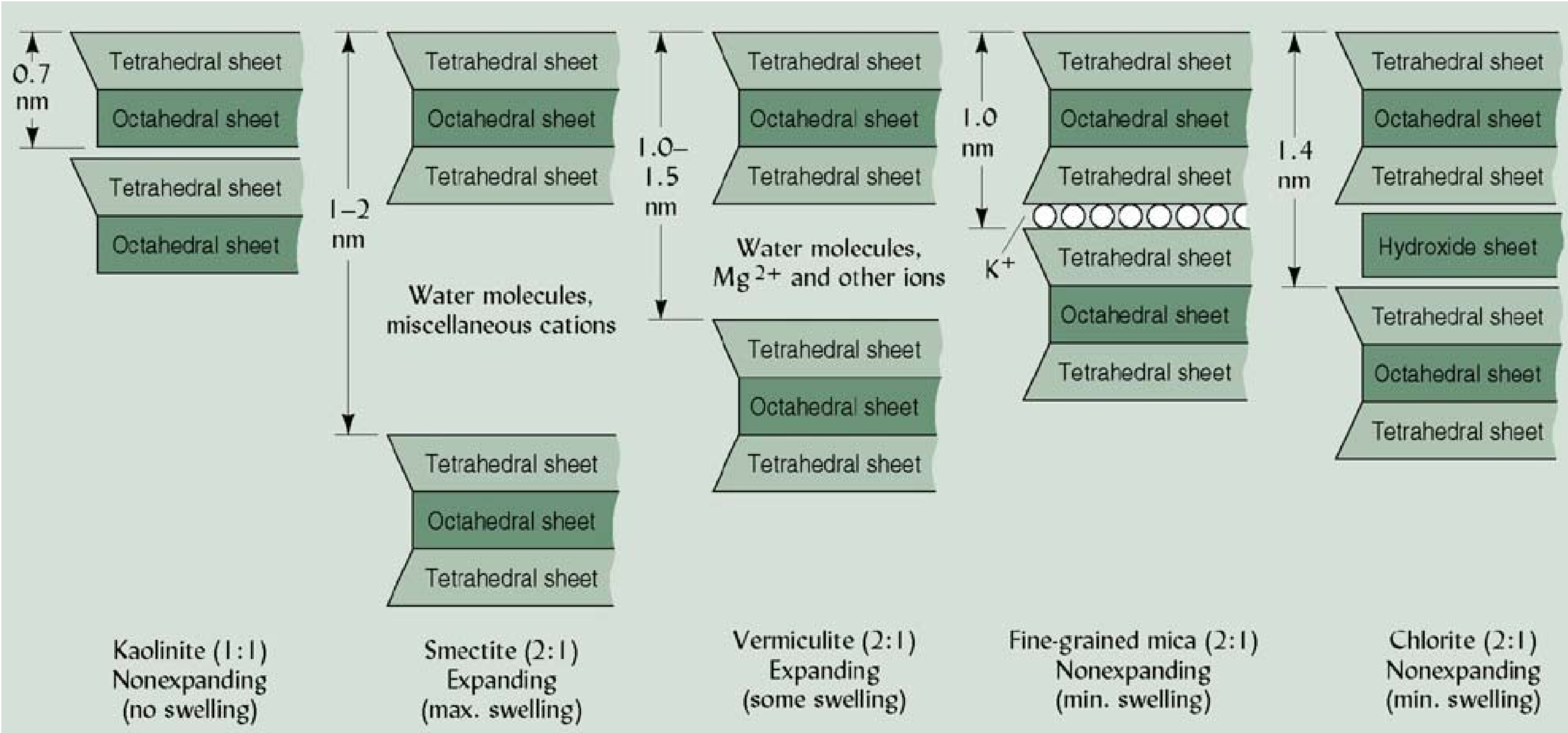





1: 1 kaolinite




2:1 smectite



0.7 nm
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Octahedral sheet
Kaolinite (1:1)
Nonexpanding
(no swelling)
1–2 nm
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Water molecules,
miscellaneous cations
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Smectite (2:1)
Expanding
(max. swelling)
1.0–1.5 nm
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Water molecules,
Mg 2+ and other ions
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Vermiculite (2:1)
Expanding
(some swelling)
1.0 nm
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
K+
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Fine-grained mica (2:1)
Nonexpanding
(min. swelling)
1.4 nm
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Hydroxide sheet
Tetrahedral sheet
Octahedral sheet
Tetrahedral sheet
Chlorite (2:1)
Nonexpanding
(min. swelling)