Clay Mineralogy

- Clay is a particle SIZE
- Predominant make-up is SECONDARY minerals

Minerals can be crystalline or amorphous.

Example: SiO_2

crystalline QUARTZ (SiO_2): resistant to weathering

Amorphous silica (SiO_2): 10x more soluble

1. Silicate Clays (crystalline)
2. Sesquioxide/oxidic clays
3. Amorphous clays (non-crystalline)

1. Silicate Clays (aluminosilicates)

Micelle: particle of silicate clay

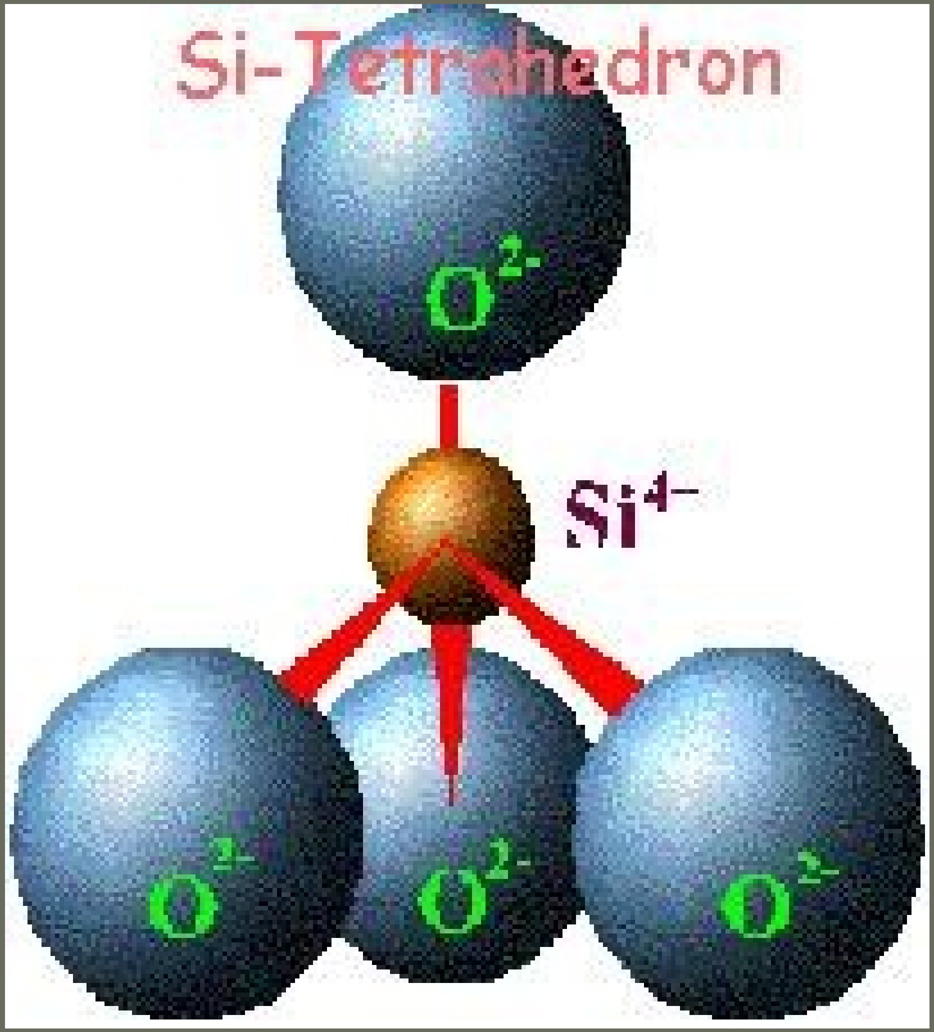
Composed of tetrahedral and octahedral "sandwiches"

Tetrahedron: central cation (Si^{+4}, Al^{+3}) surrounded by 4 oxygens

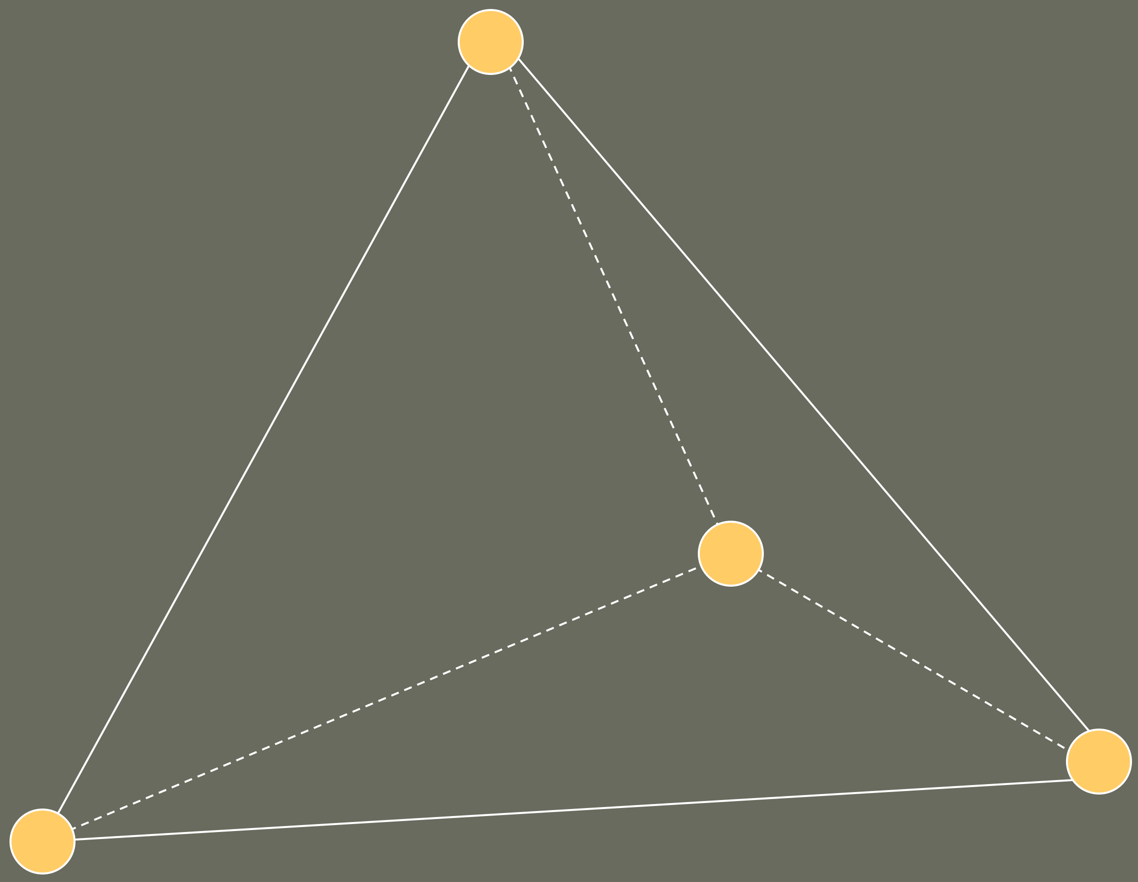
Octahedron: central cation (Al^{+3},Fe^{+2}, Mg^{+2}) surrounded by 6 oxygens (or hydroxyls)

1.Silicate Clays

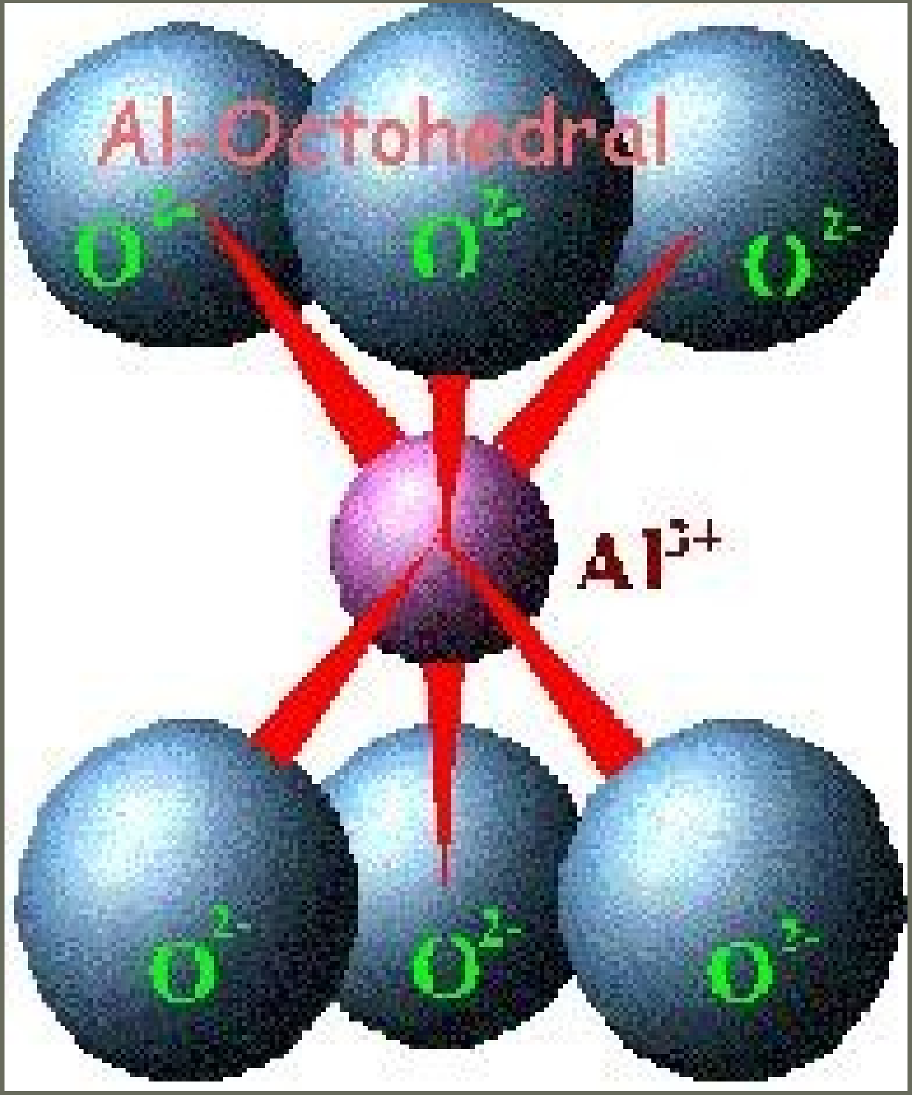
tetrahedron



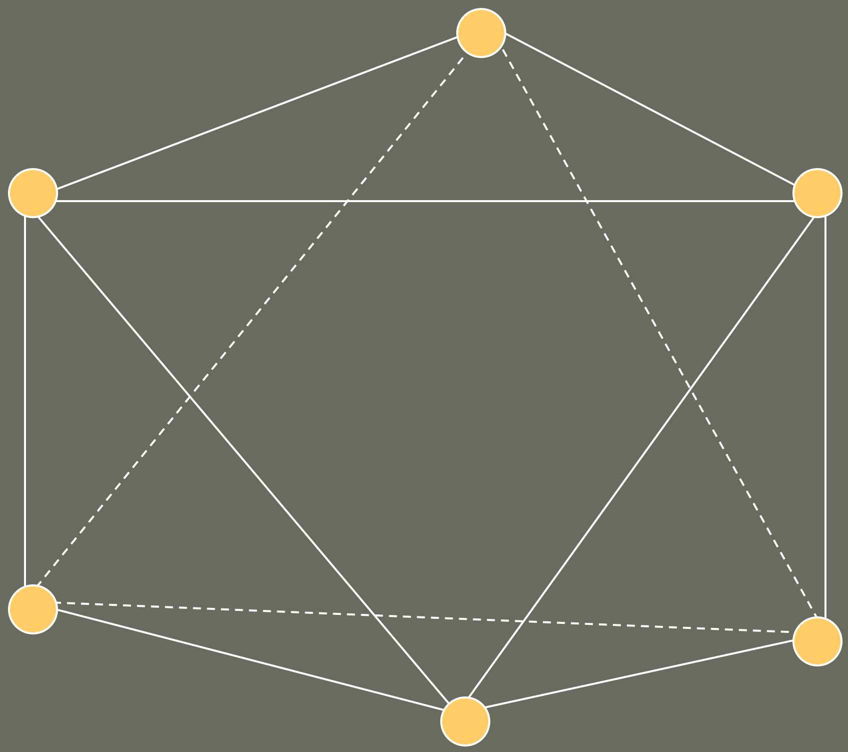
1.Silicate Clays



octahedron



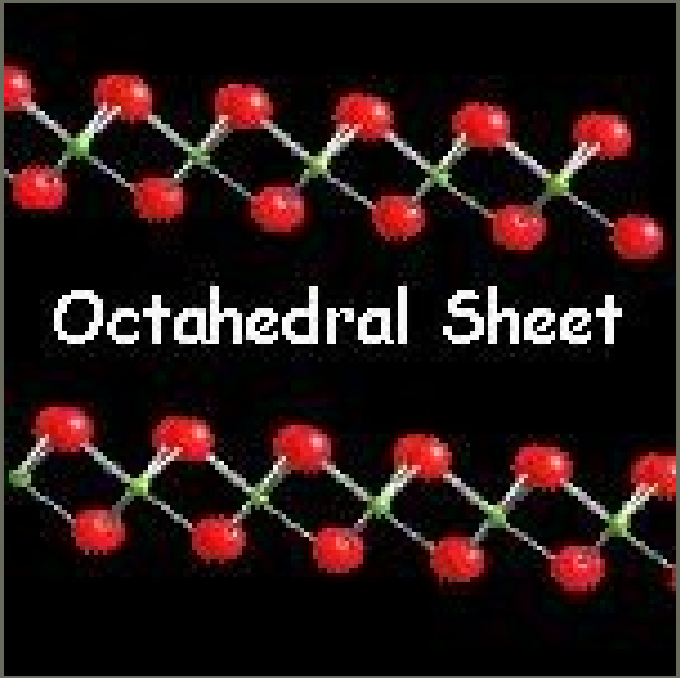
1.Silicate Clays



Tetrahedral sheets

Connected tetrahedra, sharing oxygens

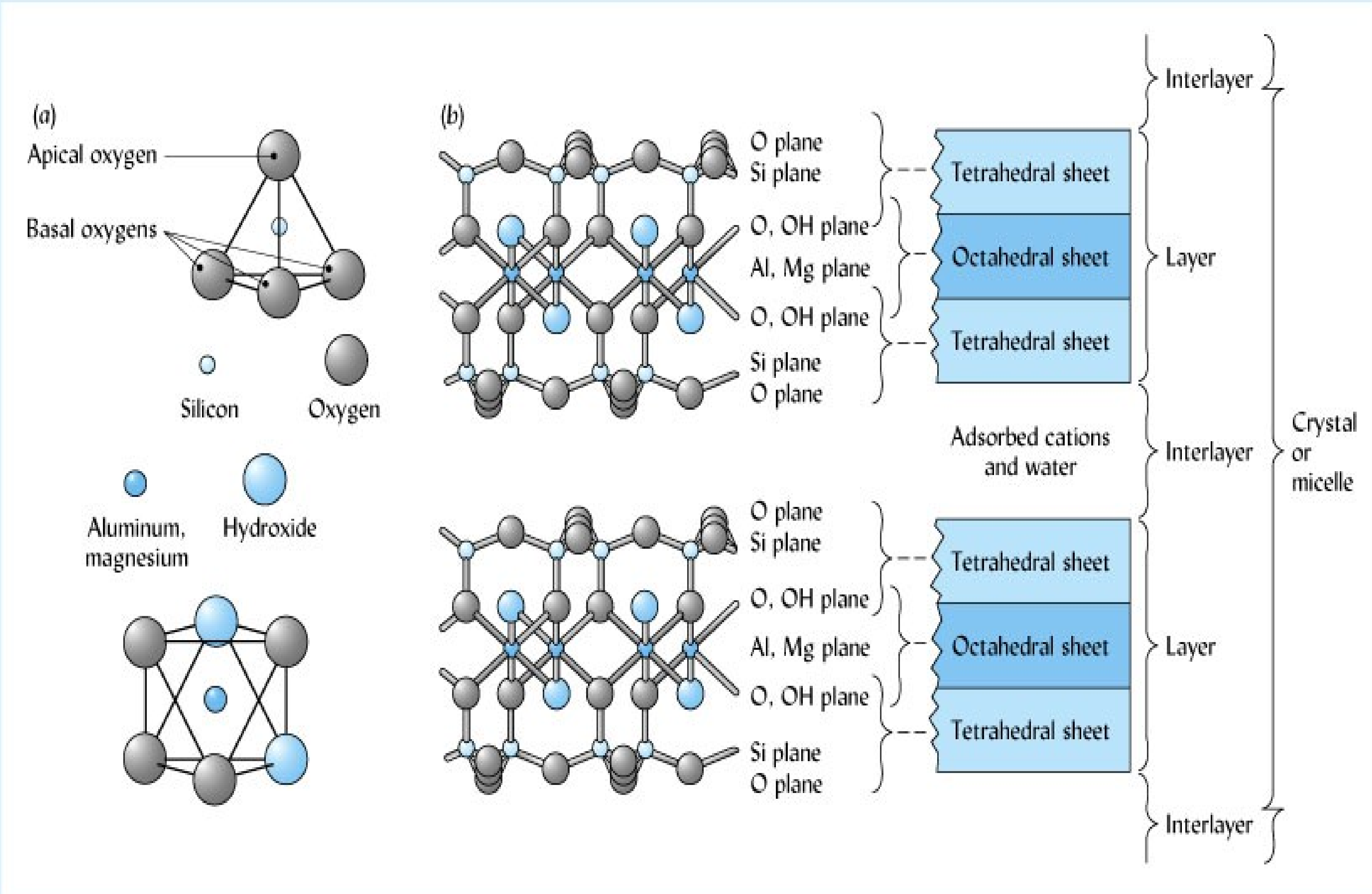
Octahedral sheets



Connected octahedra, sharing oxygens or hydroxyls

- 1000s of tetrahedra and octahedra connect in clay minerals to give:
  - Planes of Si, Al, Mg
  - Planes of Oxygen, hydroxyl groups
- Sheets combine to form layers
- Layers are separated by interlayer space
  - Water, adsorbed cations

1.Silicate Clays



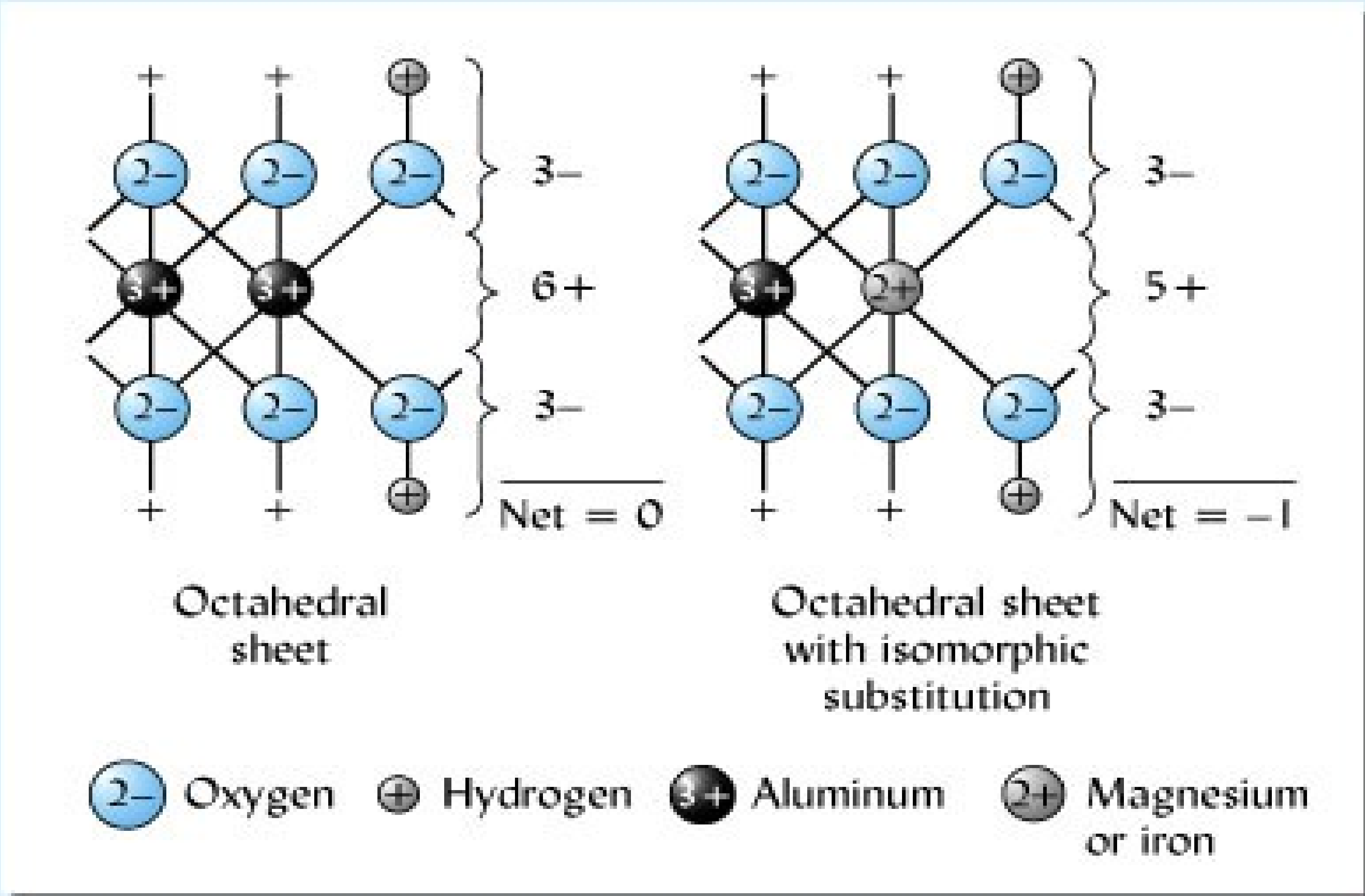
Isomorphous substitution

Lower charge cations replace higher charge cations as central cation

- E.g., Mg^{+2} replaces Al^{+3}

- leaves net negative charge

1.Silicate Clays



Different types of silicate clays are composed of sandwiches (combinations) of layers with various substances in their interlayer space.

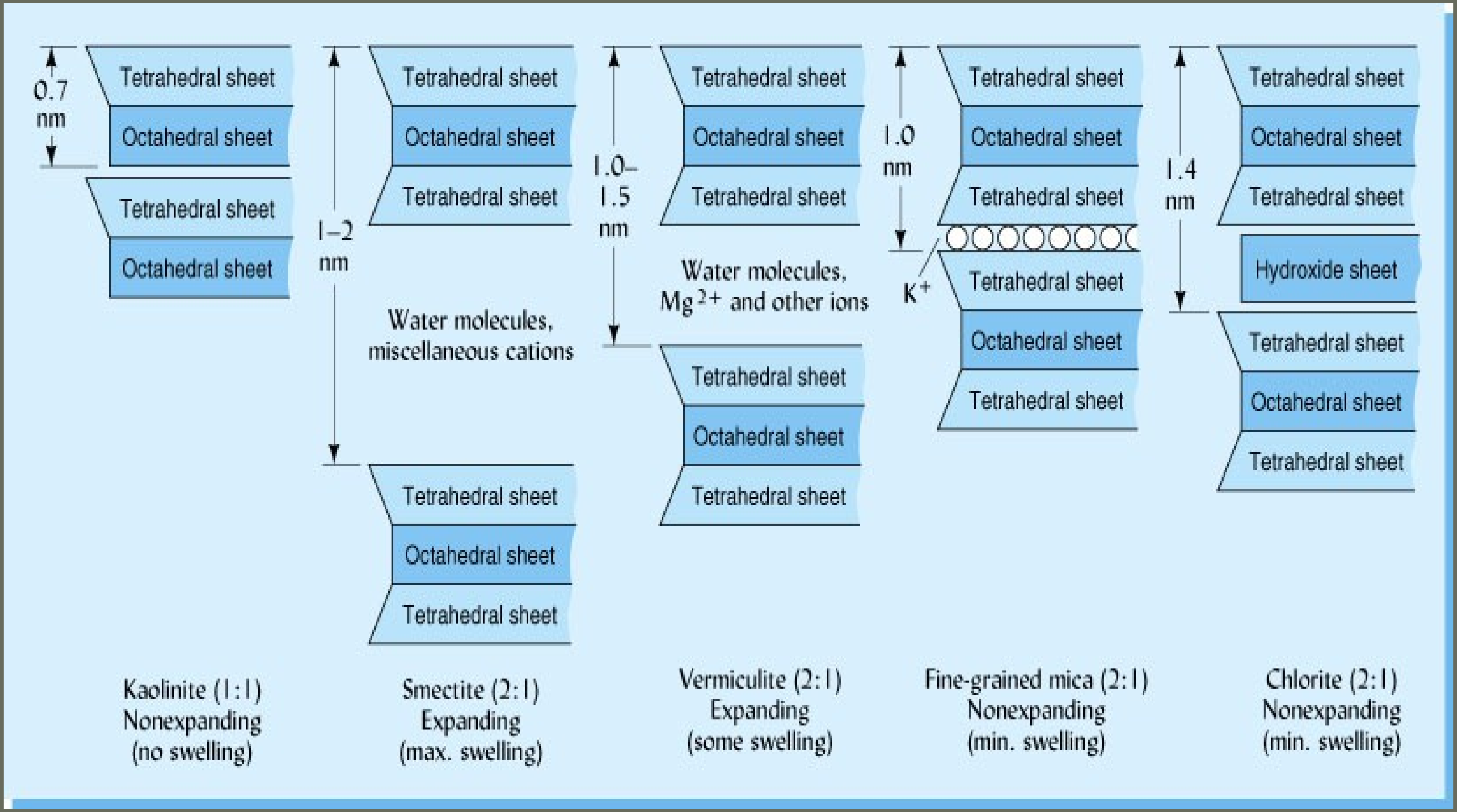
2:1 two tetrahedral sheets to one octahedral sheet

1:1 one tetrahedron sheet to one octahedral sheet

a. Kaolinite

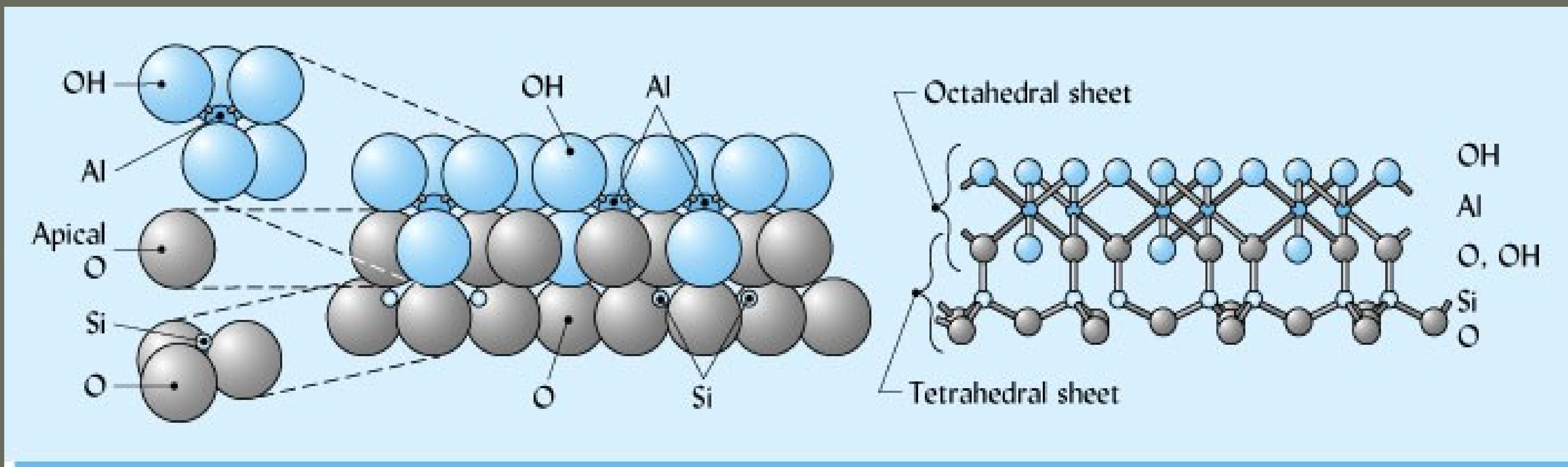
- 1:1
- Hydrogen bonds in interlayer space
  - strong
- Nonexpandable
- Low CEC
- Particles can grow very large (0.2 – 2 μm)
- Effective surface area = 10 – 30 m^2/g
  - External surface only

1.Silicate Clays



kaolinite

1.Silicate Clays



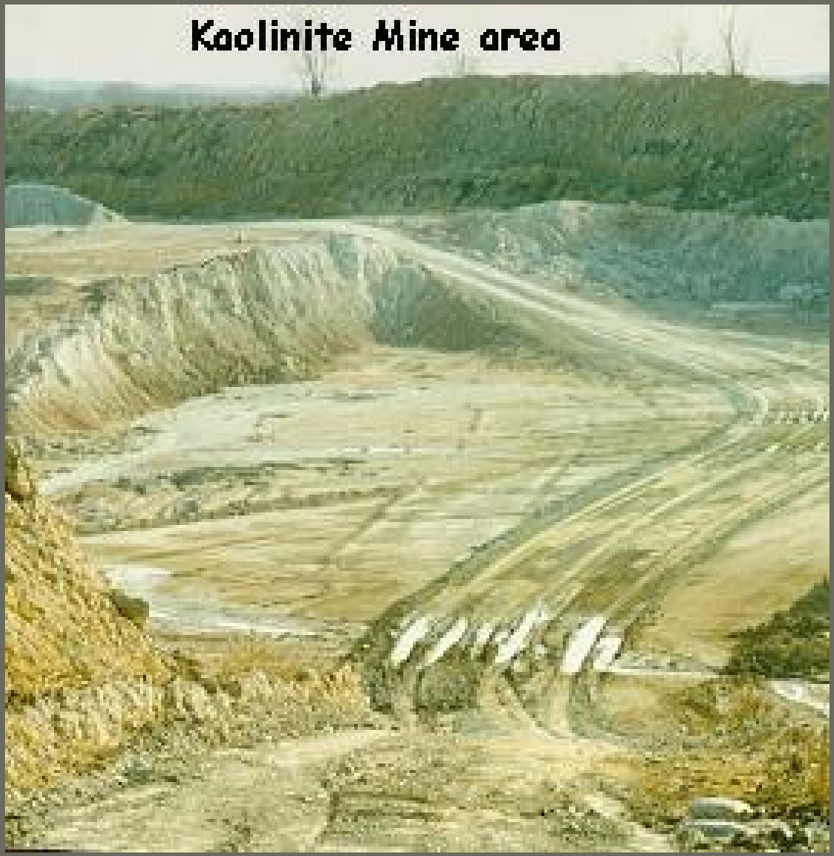
kaolinite

Kaolinite

- good road base
- good foundation
- good for pottery; China clay (porcelain)
- easy to cultivate, but need manure or fertilizer
- Dominant clay mineral in highly weathered soils

Kaolin mine, Bulgaria

Kaolinite mine, MN
(MN River Valley)



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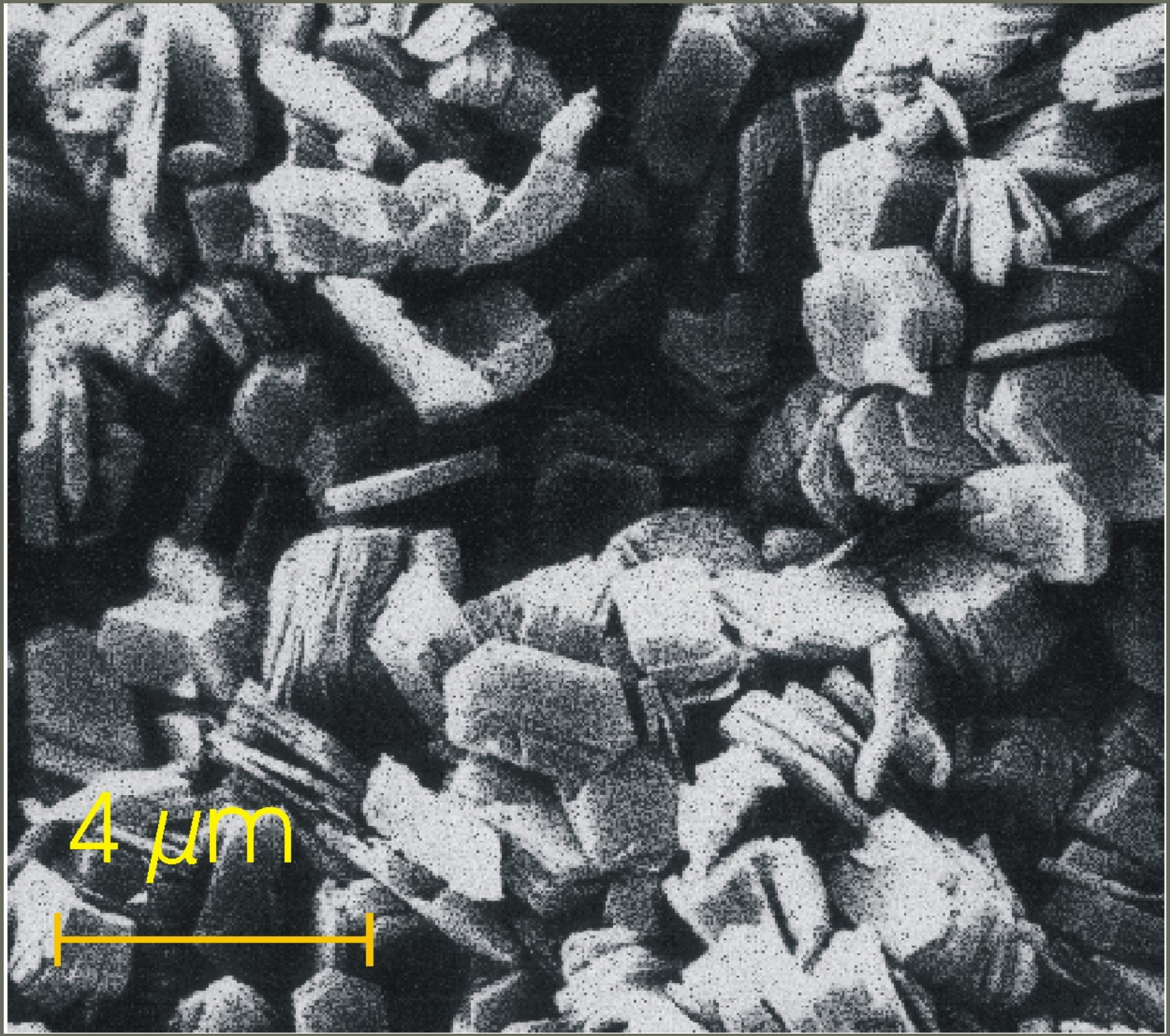
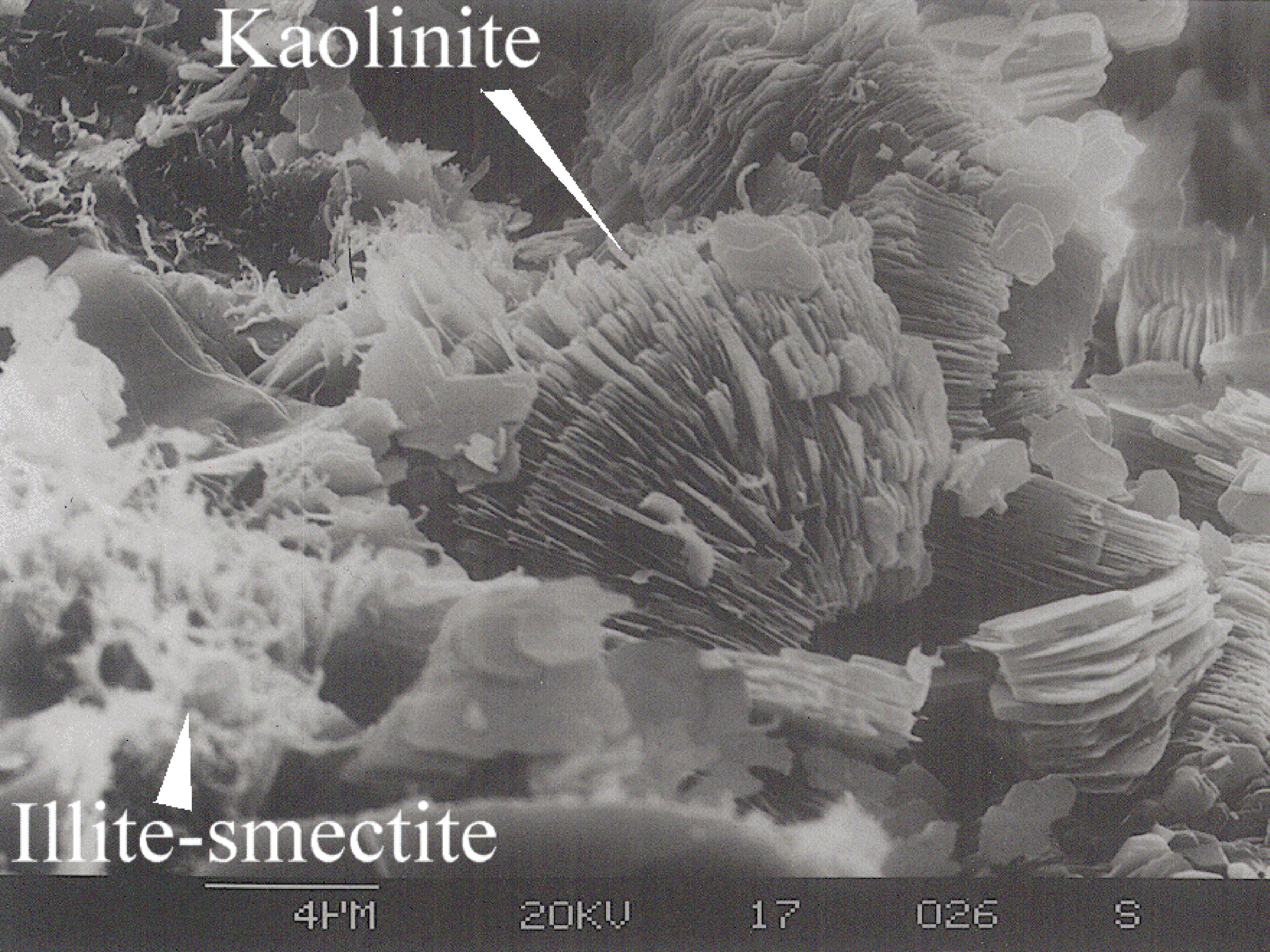
kaolinite

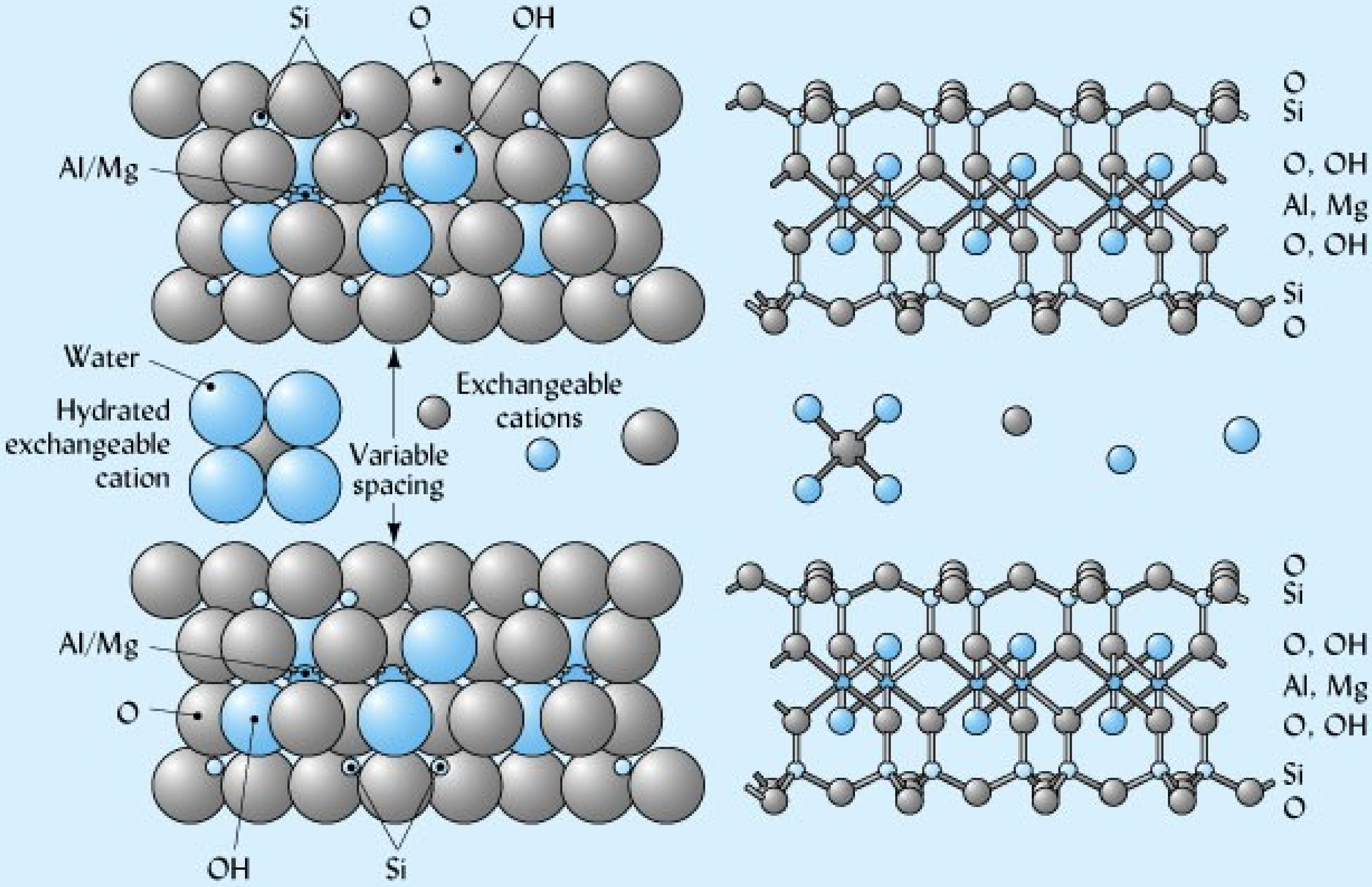



Kaolinite
Illite-smectite
4HM
20KV
17
026
S

b. Smectite

- 2:1
- Weathering product
- Always negative due to isomorphous substitution
- Layers weakly held together by weak O-O bonds or cation-O bonds
- Cations adsorbed in interlayer space
- Expandable
- High CEC

1.Silicate Clays



smectite

- ✓ Interlayer cations hold layers together

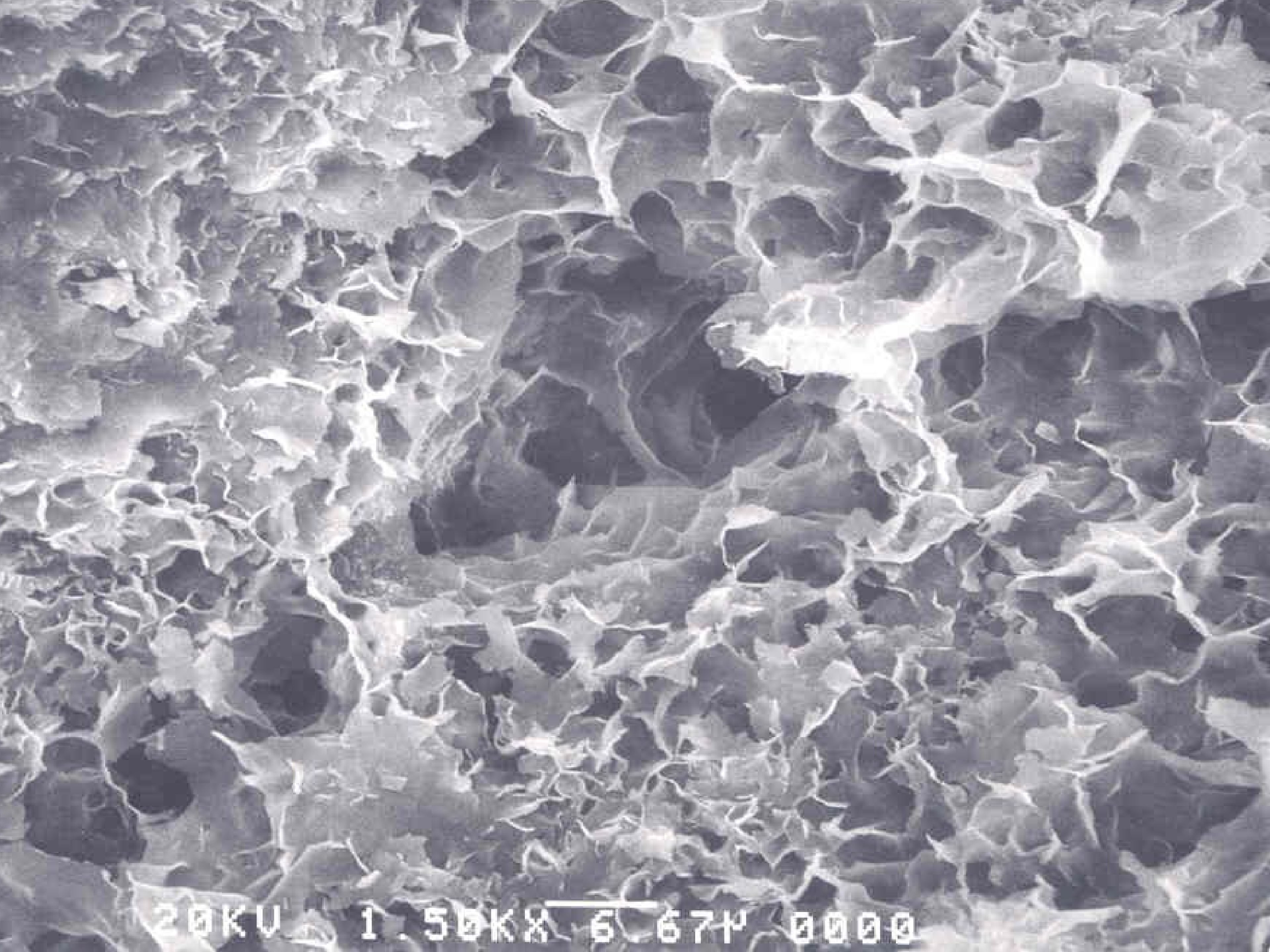
  In dry soils, bonding force is strong and hard clods form; deep cracks

  In wet soils, water is drawn into interlayer space and clay swells.

- ✓ Montmorillonite
- ✓ Vertisols
- ✓ Dominant clay mineral of most MN soils

smectite

- ✓ High effective surface area = 650 - 800 m^2/g
  - ✓ Internal surface area >> external
- ✓ Particles small
- ✓ Most expandable of all clays


20KV 1.50KX 6.67μ 0000

c. Fine-grained micas

- 2:1
- As mica crystallizes from magma:
  - Isomorphous substitution of Al^{+3} for Si^{+4} in tetrahedra
    - high net negative charge
- K^{+} ions in interlayer space
  - Strongly binds layers
- Non-expandable
- Illite
- Surface area 70 -175 m^2/g

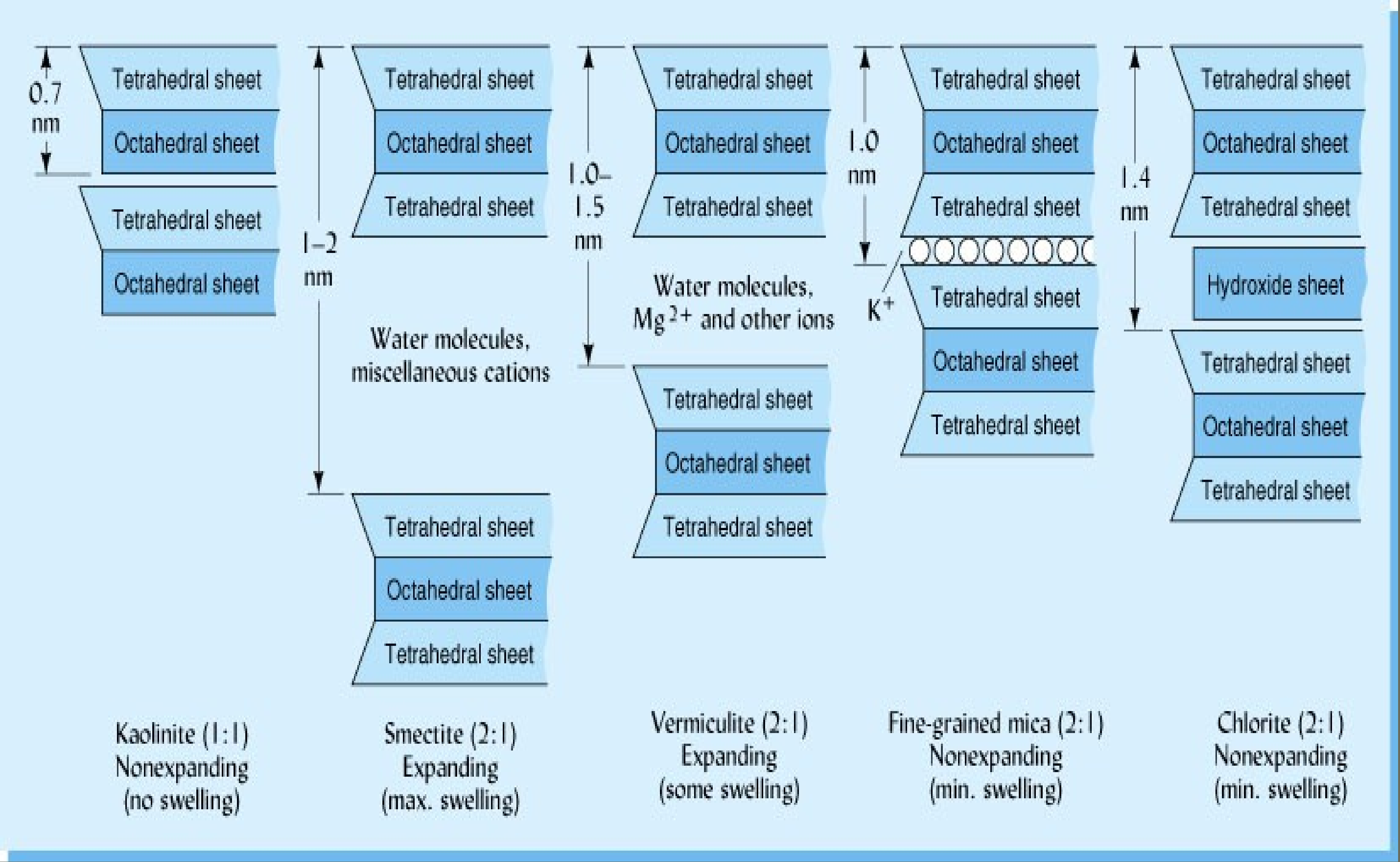
d. Vermiculite

- 2:1
- Forms from alteration of mica
  - Weathering removes some K+ ions
  - Replaced by hydrated cations in interlayer space
- Water molecules and cations bridge layers, so not as expandable as smectites

- ✓ Still have very high net negative charge
- ✓ High CEC (highest of all clays)
- ✓ Expandable
- ✓ Octahedral ions are Al, Mg, Fe
- ✓ Surface area 600 – 800 m^2/g
  - ✓ Internal >> external

e. Chlorite

- 2:1
- Central cations in octahedral sheets is Fe or Mg
- Interlayer space occupied by a stable, positively charged octahedral sheet
- Non-expandable
- 70 -100 m^2/g surface area



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)

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2. Sesquioxides / Oxidic Clays

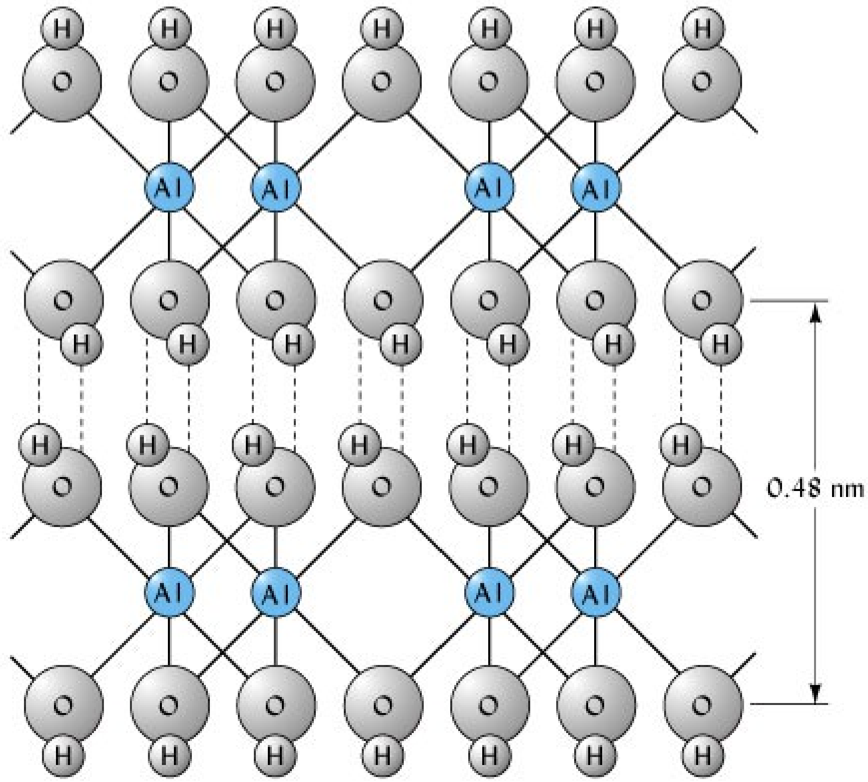
- Ultimate weathering products
  - Ultisols and Oxisols
- Very stable; persist indefinitely
- Yellow, red, brown
- Fe or Al as central cations
- Lack negative charge
  - Don't retain adsorbed cations
- Non-expandable
- Low CEC

Low fertility

- ✓ Often are net positive
- ✓ Often have enough Al or Mn to be toxic to plants
- ✓ High capacity to fix phosphorous so it is not available to plants
- ✓ Highly weathered so no more nutrients to release in weathering

Ultisol profile

- In heavily leached soils, sheets decompose into component Si tet. and Al oct.
  - Al oct. often weather into gibbsite $Al(OH)_3$



H
O
Al
0.48 nm

3. Amorphous (non-crystalline)

- silicates
- Allophane and imogolite
- Common in volcanic ash
- High internal negative charge
- High CEC
- High water-holding capacity
- Surface area 100 – 1000 m^2/g

Plasticity and Stickiness

	plasticity	stickiness
kaolinite	Low	Low
smectite	High	High
mica	Low	Low
vermiculite	High	High
chlorite	Low	Low
amorphous	High	Low
oxidic	Low	Low

"Activity" of silicate clays

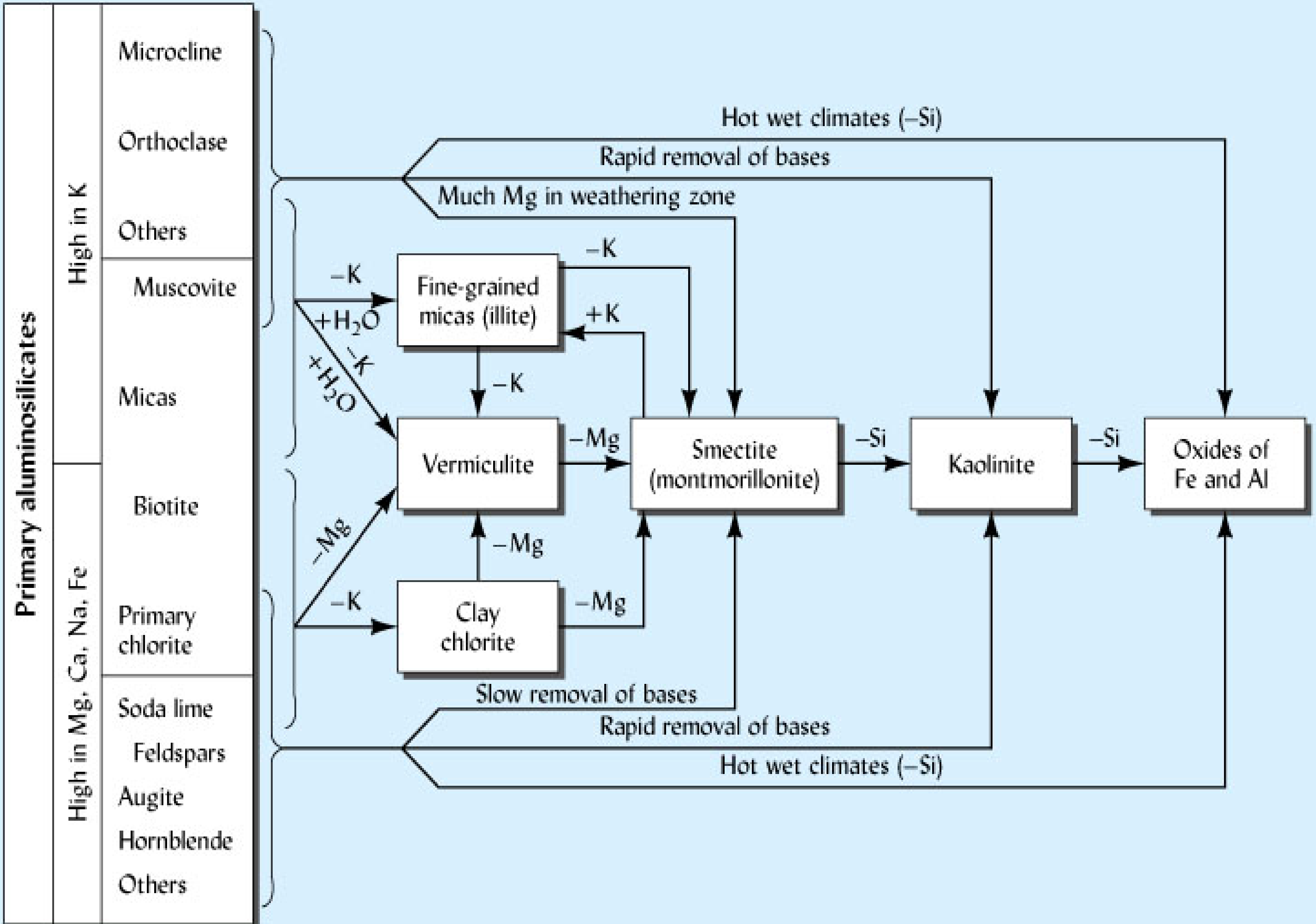
- refers to cation exchange capacity (CEC)
  - Ability to retain and supply nutrients
  - Fertility
- High activity clays:
  - Less weathered ; high effective surface area
  - smectite, vermiculite, mica (illite), chlorite
- Low activity clays:
  - More weathered; less effective surface area
  - kaolinite

Family description in taxonomy includes clay activity

- Example:
- "Fine-loamy, mixed, superactive, frigid Typic Hapludalfs"

What determines clay minerals in a given soil?

- ✓ Usually a mixture
- ✓ Climate
- ✓ Parent material
- ✓ Degree of weathering



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
–K
+H2O
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)

Generalized relationships:

Ultisols	Kaolinite, oxidic clays
Oxisols	
Alfisols	Mica, vermiculite, smectite
Mollisols	
Vertisols	
Andisols	Amorphous