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ASAC 1101 : FUNDAMENTALS OF SOIL SCIENCE (2+1)

Level : B.Sc (Ag), I semester

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SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

**M.S.SWAMINATHAN SCHOOL OF AGRICULTURE,CUTM,
PARLAKHEMUNDI**

Topic

Soil colloids

Secondary or silicate clay minerals

Concepts Covered:

- Soil colloids and their types**
- Silicate clays**
- Basic structure of silicate clays**
- Types of crystalline silicate clays**
- X-ray diffraction analysis**

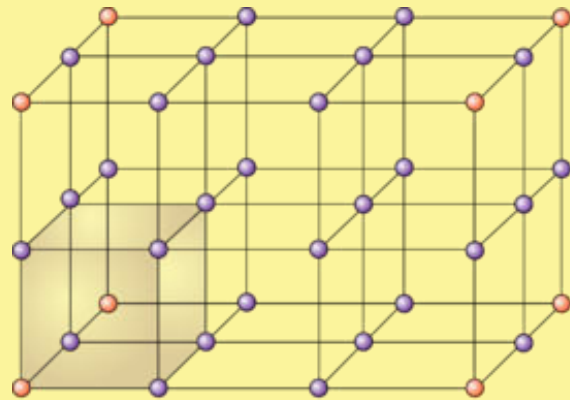
Soil colloids

- ❑ **Colloid** – a two phase system where one finely divided phase is dispersed in another phase
- ❑ **Example:** solid in liquid – clay in water
liquid in gas – clouds in atmosphere
- ❑ Soil particles < **2 μ m** are called soil colloids
- ❑ Includes the combined clay and humus fraction
- ❑ **Chemically active** and greatly impact ecosystem functions

Properties of soil colloids

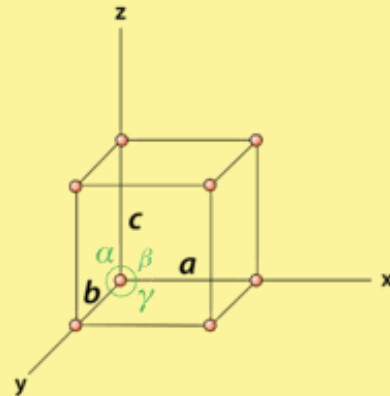
- ❑ **Extremely small size**
- ❑ **Very high surface area**
- ❑ **Have charges (predominantly negative charge)**
- ❑ **Adsorption of cations and anions**
 - colloids form an ionic double layer – an inner anionic(or cationic) layer with adsorbed outer cationic (or anionic) layer**
- ❑ **Adsorption of water**
 - causes ‘shrinking and swelling’ of clay**

Unit cell



Crystal Lattice

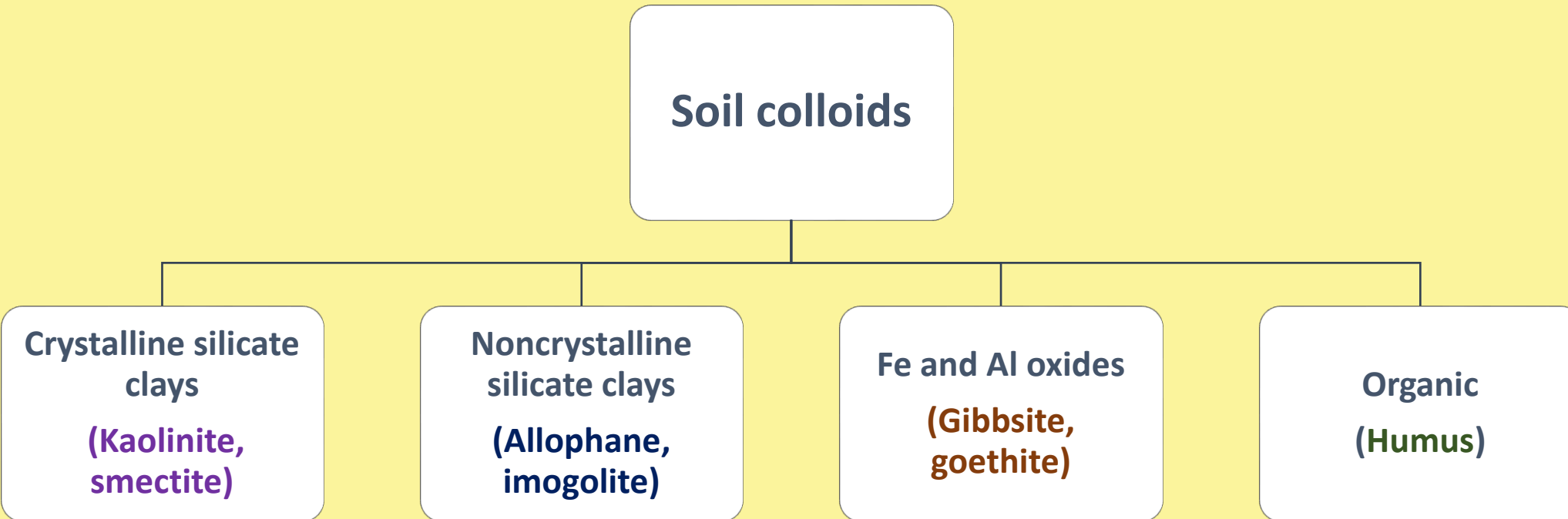
Christopher Auyeung



Unit Cell

- Simplest repeating unit in a crystal is called unit cell
- It repeats itself in 3 dimension to form the crystal lattice
- The basal spacing plays a fundamental role in the identification of clay mineral species by X-ray diffraction

Types of soil colloids



Crystalline silicate clays

- ❑ Has a layered structure with two to four sheets per layer
- ❑ Predominantly 'negative charged'
- ❑ Have diverse properties



Kaolinite

Noncrystalline silicate clays

- ❑ Do not have an ordered, crystalline structure
- ❑ Have high amounts of both positive and negative charge
- ❑ High water holding capacities and low stickiness



Allophane

Iron and aluminium oxides

- ❑ Found usually in highly weathered soils
- ❑ May be crystalline or amorphous
- ❑ Low plasticity and stickiness



goethite



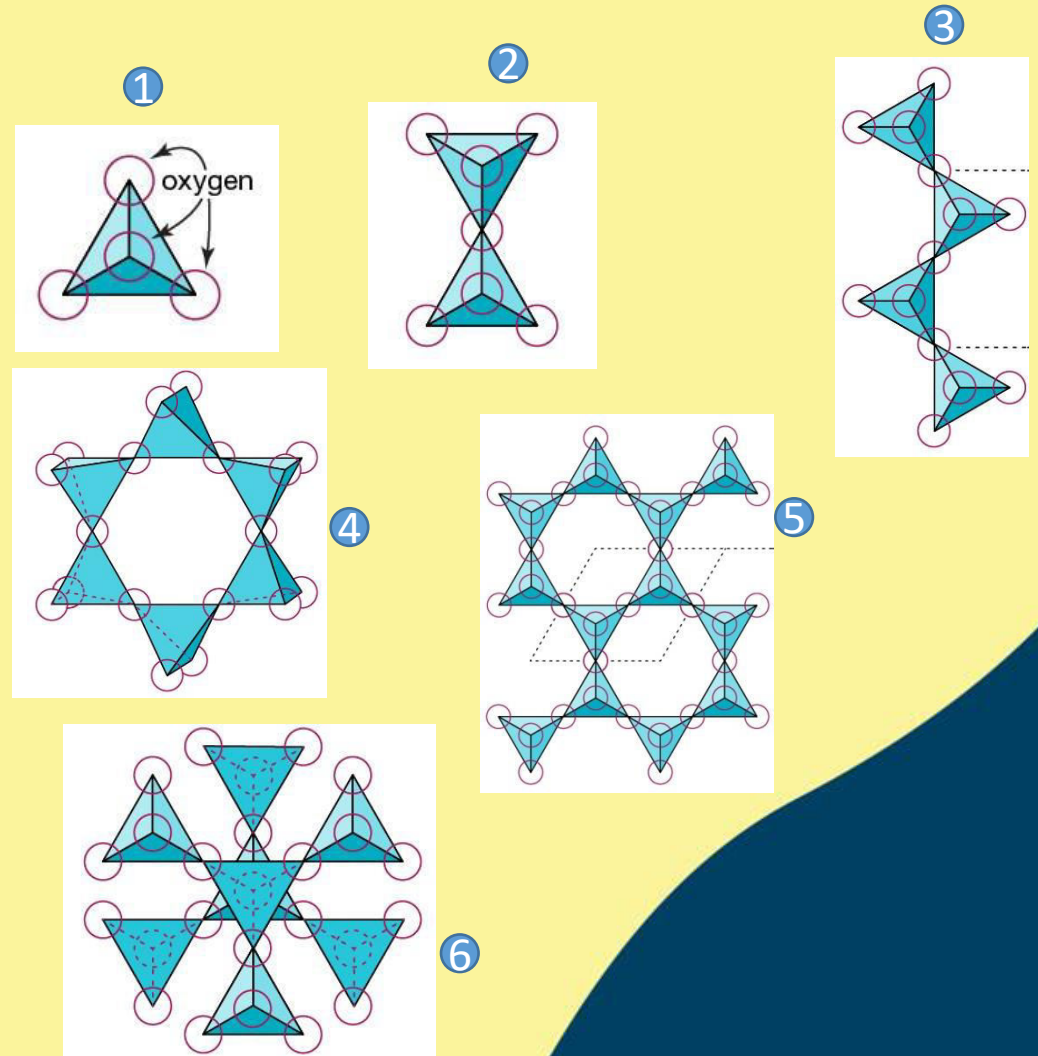
gibbsite

Organic(humus)

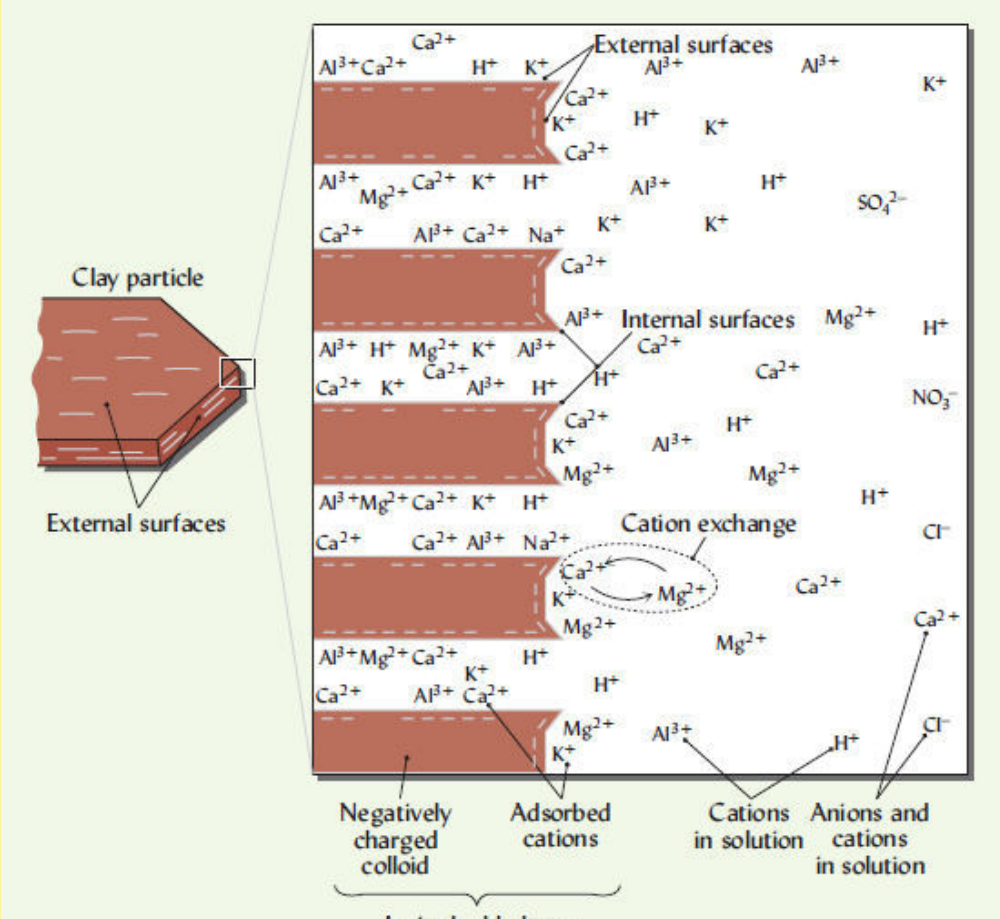
- ❑ Smallest of all soil colloids
- ❑ Made up of partially decomposed cell walls and biomolecules
- ❑ Very high water adsorbing capacity
- ❑ Net charge of humus is always negative

Silicate clays

1. Nesosilicates—Separate SiO_4 tetrahedra
2. Sorosilicates—Two or more linked tetrahedra (Si_2O_7 , Si_5O_{16})
3. Inosilicates—Single or double chains of tetrahedra (SiO_3 , Si_4O_{11})
4. Cyclosilicates—Closed rings or double rings of tetrahedra (SiO_3 , Si_2O_5)
5. Phyllosilicates—Sheets of tetrahedra (Si_2O_5)
6. Tectosilicates—Framework of tetrahedra (SiO_2)

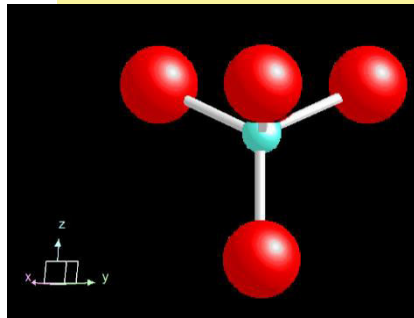
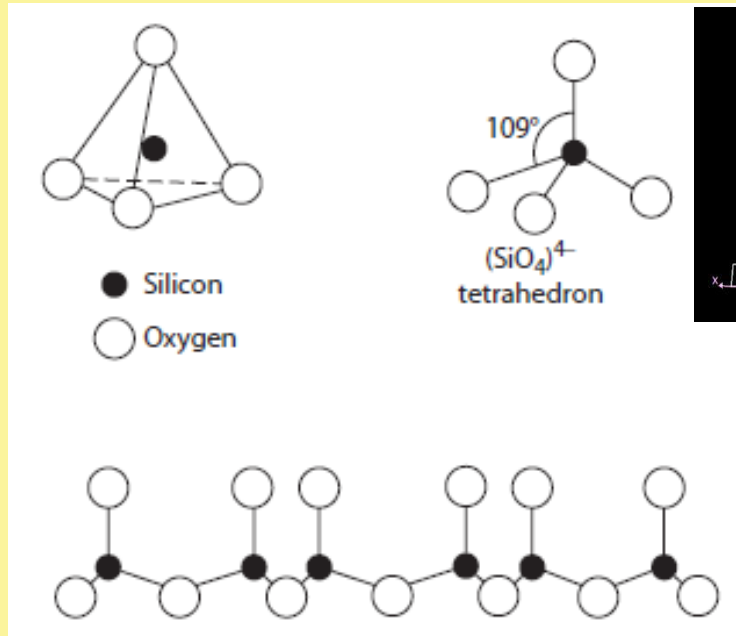


A silicate clay crystal

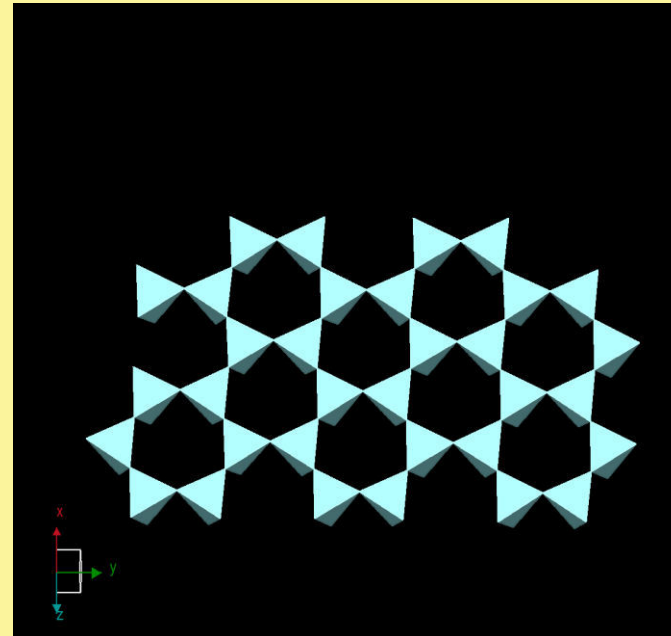


Basic structure of silicate clays

Silica tetrahedron

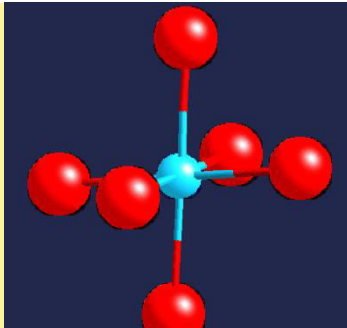
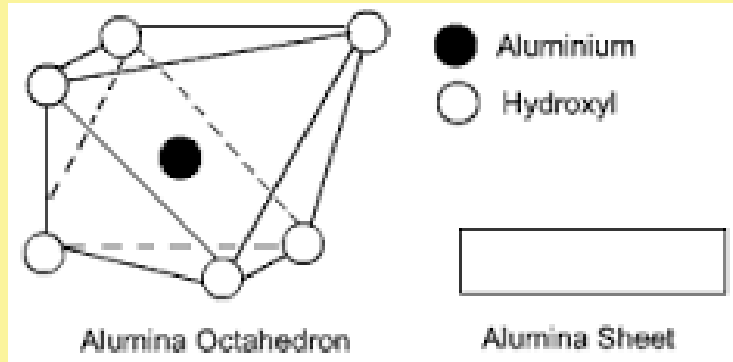


Tetrahedral sheet

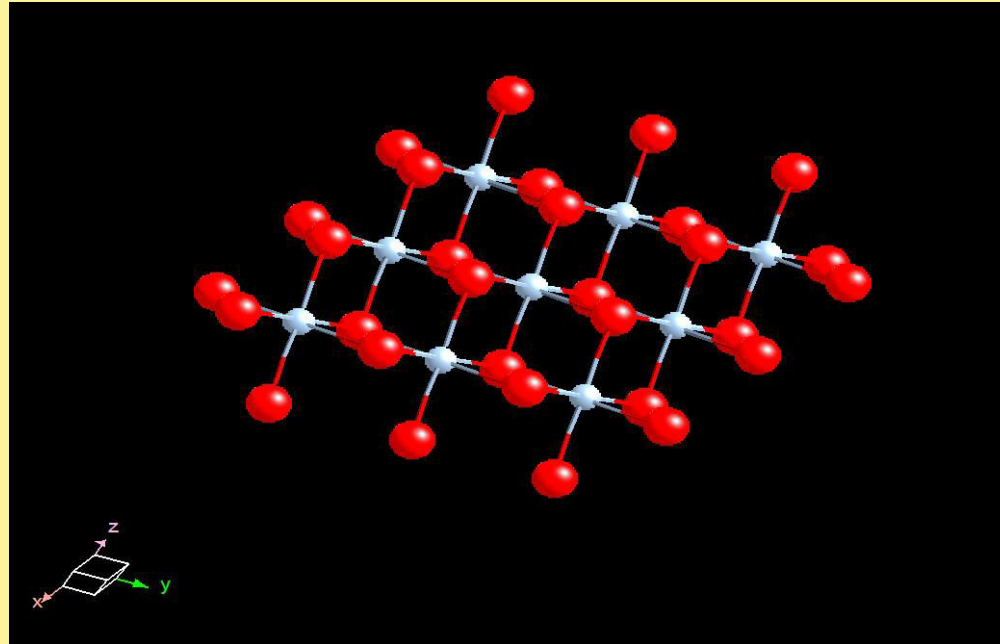


Basic structure of silicate clays

Alumina octahedron

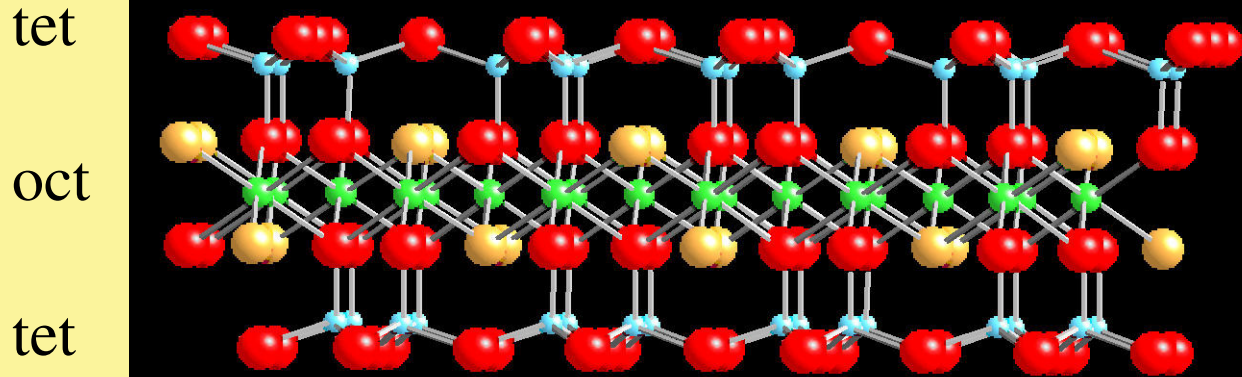


Octahedral sheet



Octahedral-tetrahedral linkage

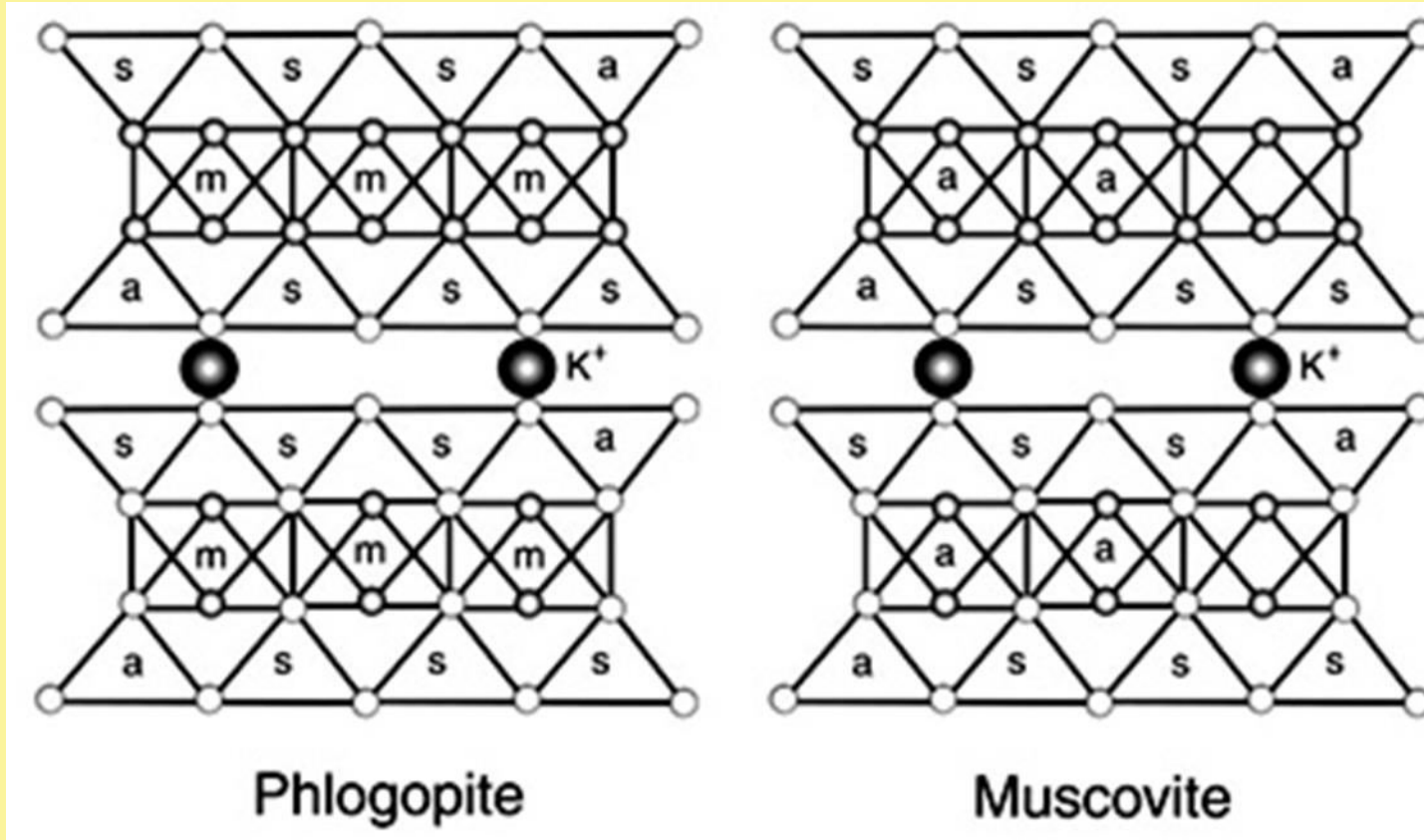
Talc (2:1 trioctahedral mineral)



Shorthand notation



Trioctahedral vs dioctahedral mineral

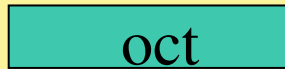


Classification

T:O
(class)
octahedra

trioctahedral

dioctahedral



brucite

gibbsite

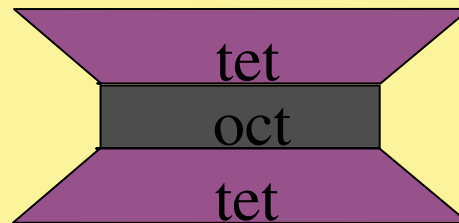
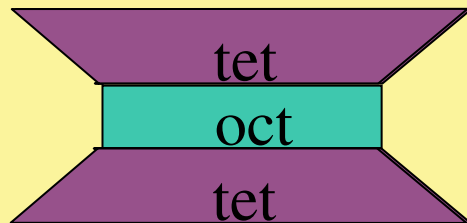
1:1



serpentine

kaolinite

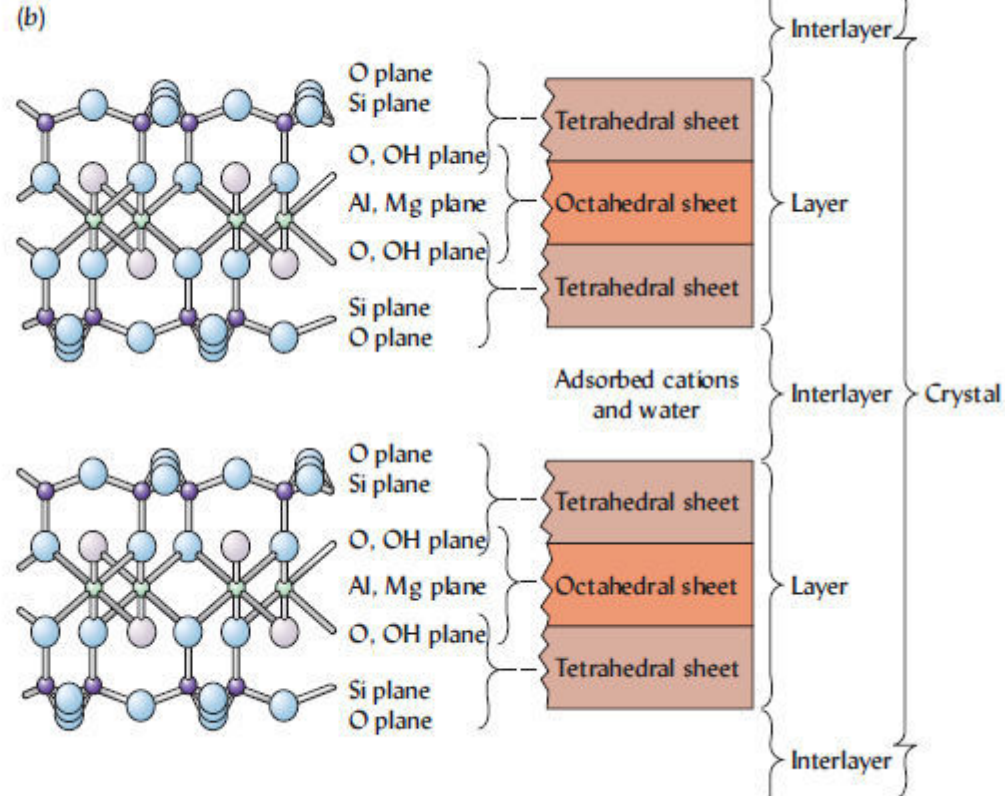
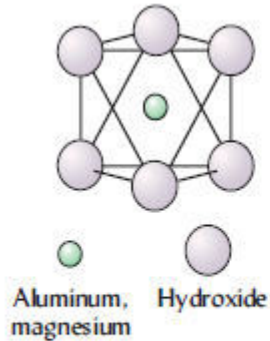
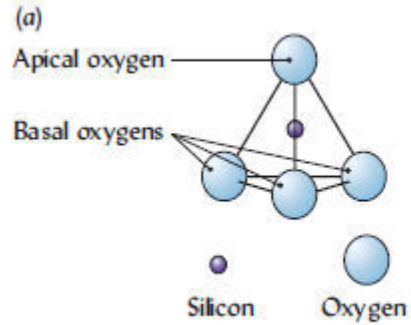
2:1



pyrophyllite

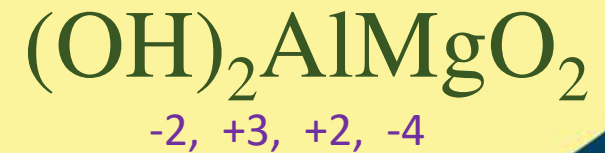
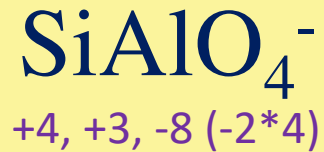
talc

Relationship between planes, sheets and layers



Sources of charges

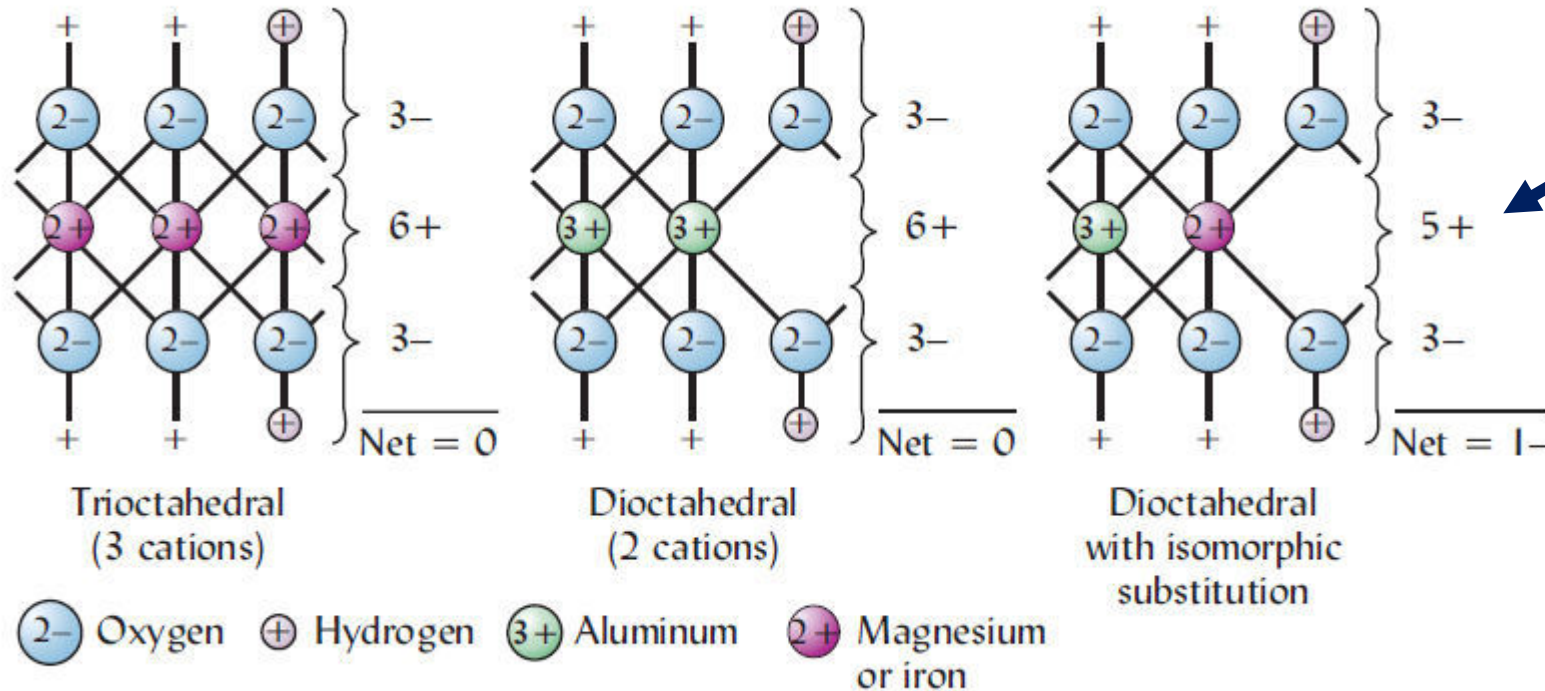
- Isomorphous substitution
- One element fills the position of another element having similar size



Tetrahedral

Octahedral

Sources of charges



Ion	Radius, nm (10^{-9} m)	Found in
Si ⁴⁺	0.042	Tetrahedral sheet
Al ³⁺	0.051	
Fe ³⁺	0.064	Octahedral sheet
Mg ²⁺	0.066	
Zn ²⁺	0.074	Exchange or interlayer sites
Fe ²⁺	0.076	
Na ⁺	0.095	
Ca ²⁺	0.099	Both sheets
K ⁺	0.133	
O ²⁻	0.140	
OH ⁻	0.155	

Basis for distinguishing crystalline silicate clays

- ❑ Based on numbers & combinations of structural units
 - ❑ tetrahedral and octahedral sheets
 - ❑ *planes combined → sheets combined → layers → crystals*
- ❑ Two general categories: 1:1, 2:1
 - ❑ 2:1 types: expanding & nonexpanding
 - ❑ *also "2:1:1" → Chlorites*
- ❑ Number of cations in octahedral sheet
 - ❑ *tri- vs. di-octahedra*
- ❑ Size and location of layer charge
- ❑ Type of bonding between layers :
 - ❑ *Strong: ionic > H-bonding > van der Waals :Weak*
- ❑ Absence or presence of a cation interlayer
 - ❑ *fine grained micas*

Mineralogical organization of silicate clays

□ Two main groups of crystalline clays

▪ 1:1 silicate clays

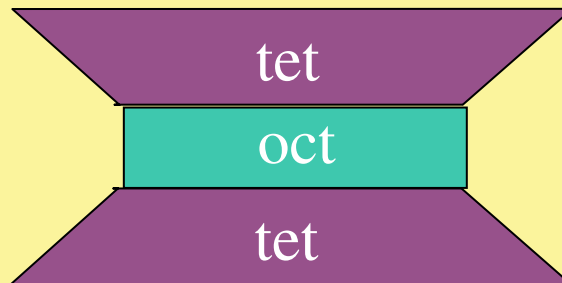
1 octahedral 1 tetrahedral

▪ 2:1 silicate clays

1 octahedral sandwiched between 2 tetrahedral



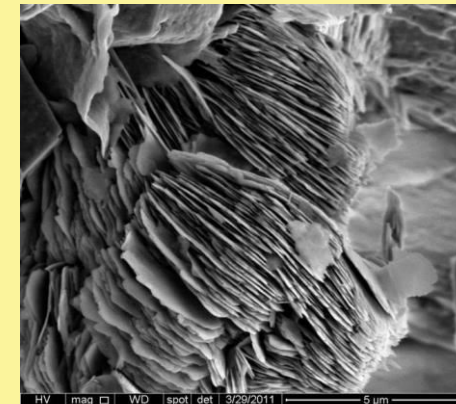
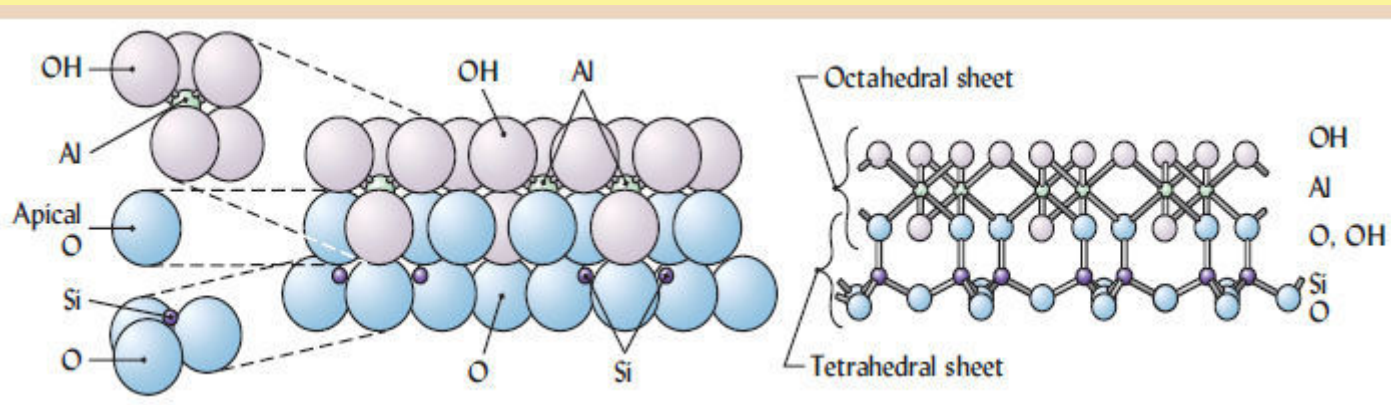
1:1



2:1

1:1 silicate clay

- Layer consists of 1 tetrahedral and 1 octahedral sheet held together by apical oxygen atom
- Kaolinite – most common 1:1 silicate clay
- Synthesized under equal concentrations of Al^{3+} and Si^{4+}



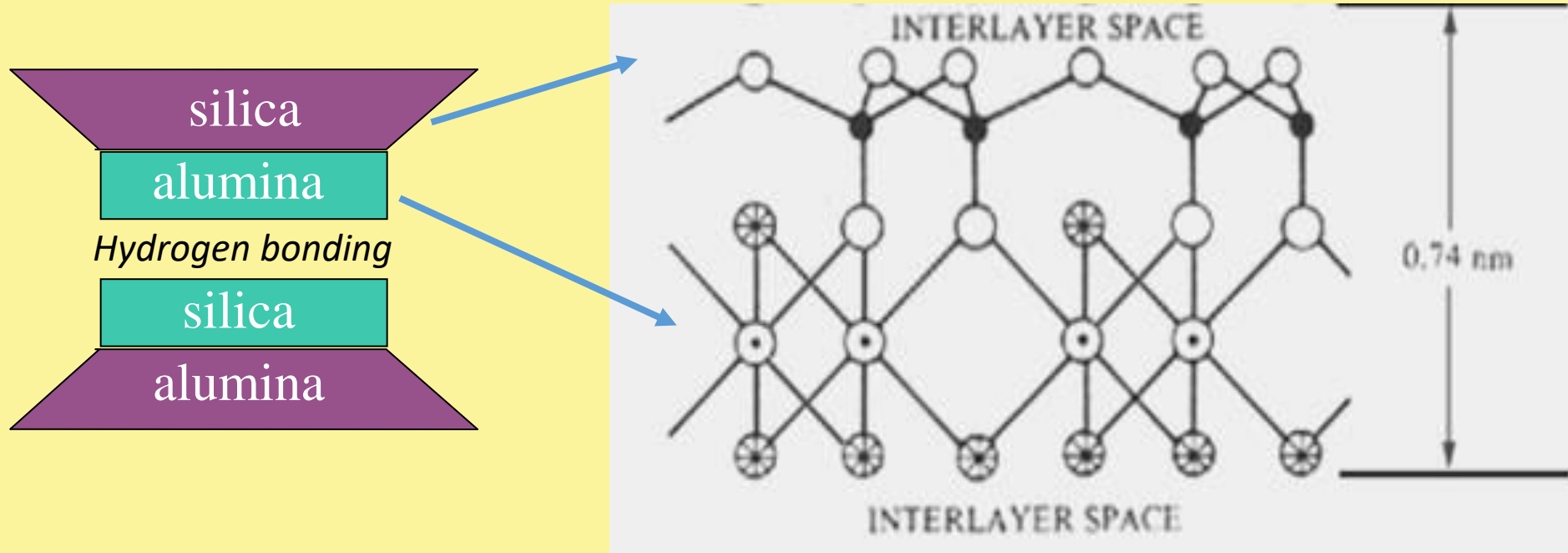
kaolinite

Kaolinite

- ❑ 1:1 clay
- ❑ Little or no isomorphous substitution
- ❑ 'Nutrient poor'
- ❑ No 'shrink swell' because of hydrogen bonding between adjacent layers
- ❑ A product of acid weathering



Kaolinite



Less cation exchange capacity owing to hydrogen bonding
Relatively less plasticity, stickiness and cohesion

2:1 clays

- ❑ Two silica tetrahedral sheets linked to one octahedral sheet
- ❑ Four major groups of 2:1 clays
 - ❑ Expanding clay
 - ❑ Smectite
 - ❑ Vermiculite
 - ❑ Non expanding clay
 - ❑ Fine grained mica
 - ❑ Chlorite

Smectite

- ❑ Have high isomorphous substitution
- ❑ Mostly negatively charged
- ❑ Subject to **shrinking and swelling** (owing to loosely bound oxygen-oxygen or oxygen-cation bonding)
- ❑ High plasticity, stickiness and cohesion (owing to high expansion)

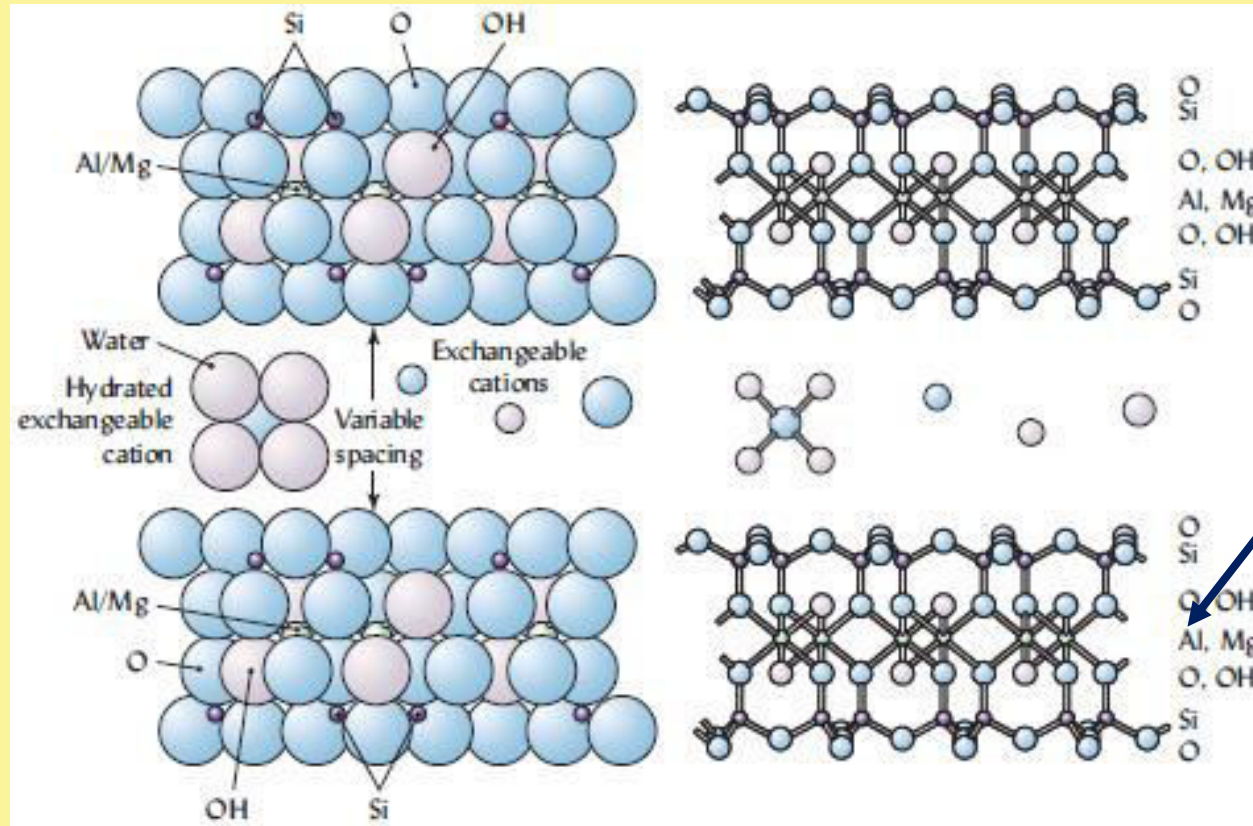
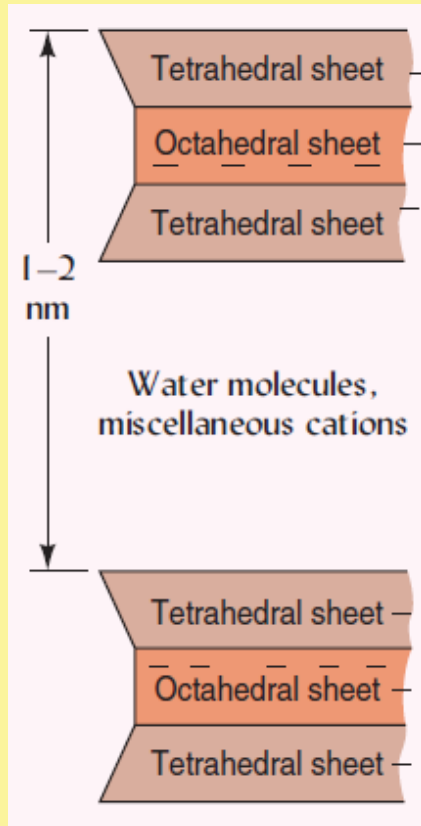
Montmorillonite(a 2:1 smectite)

- ❑ Layer charge originates from the substitution of Mg^{2+} for Al^{3+} in the octahedral sheet
- ❑ 'nutrient rich'
- ❑ Very high shrink-swell capacity
- ❑ Unstable under low pH and high moisture

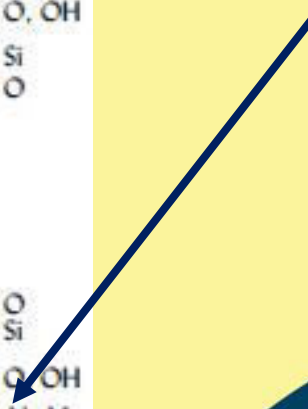


Rob Lavinsky

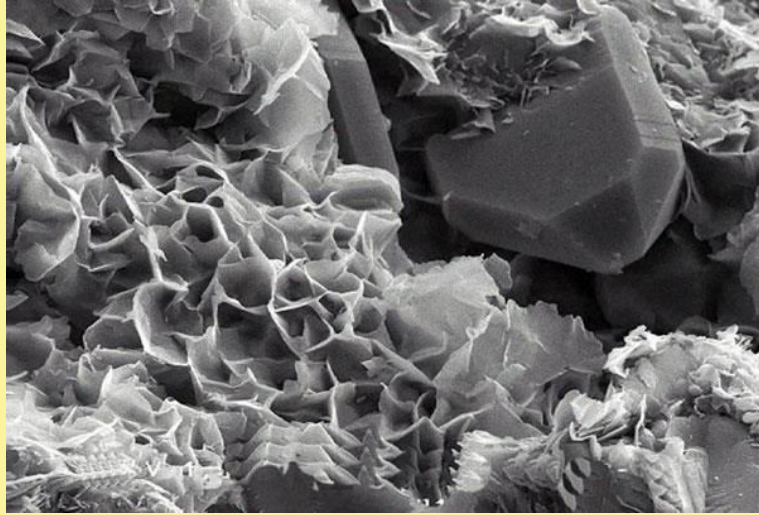
Structure of montmorillonite



Isomorphous substitution occurs here



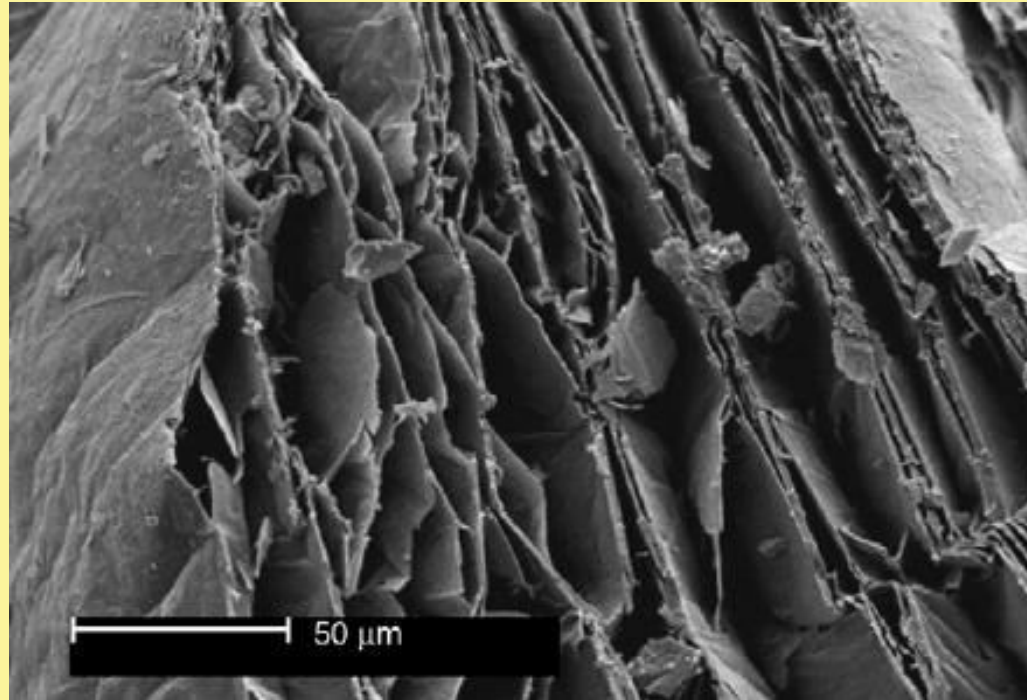
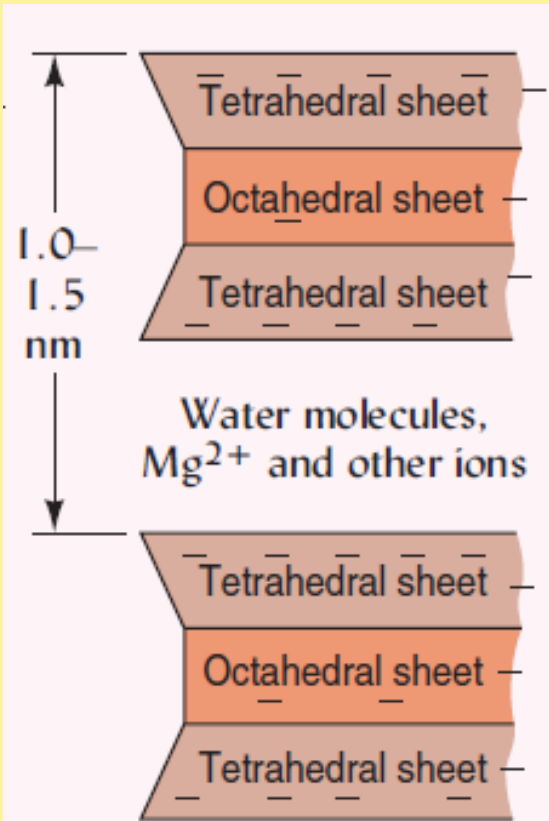
Montmorillonite



Vermiculite

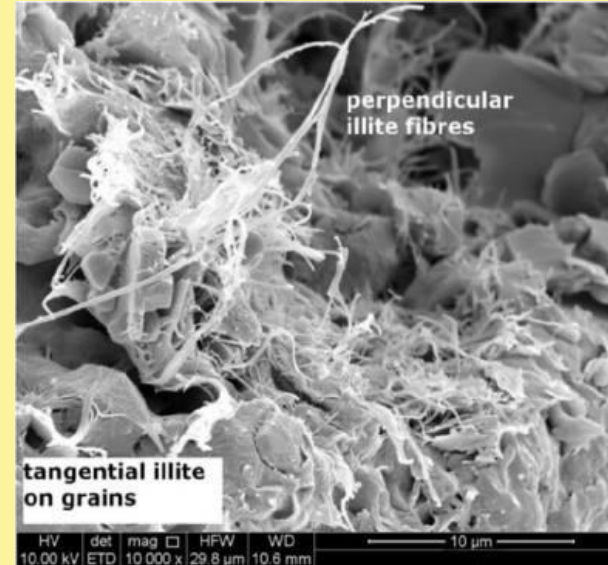
- Weathered mica products where the K^+ ions between the molecular sheets are replaced by Mg^{2+} ions
- Have the **highest Cation Exchange Capacity (CEC)** of all clays
- Less swelling capacity than smectites but more than kaolinite
- 'nutrient rich'
- Stable under low pH

Structure of a vermiculite



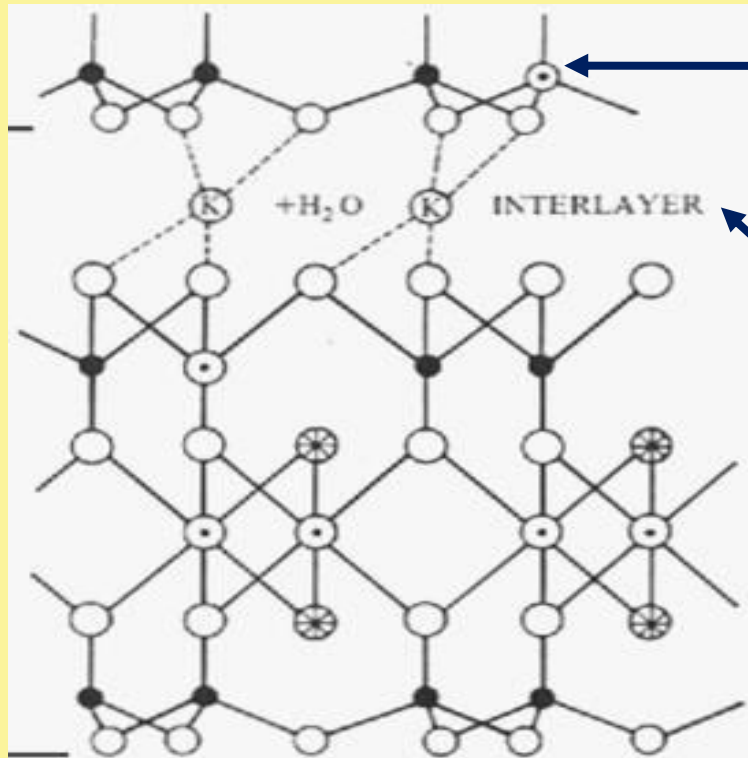
Mica group

- Si^{4+} in tetrahedral is replaced by Al^{3+}
- High net negative charge
- K^+ ions adsorbed in interlayer
- Non-expansive
- Fairly 'nutrient poor'



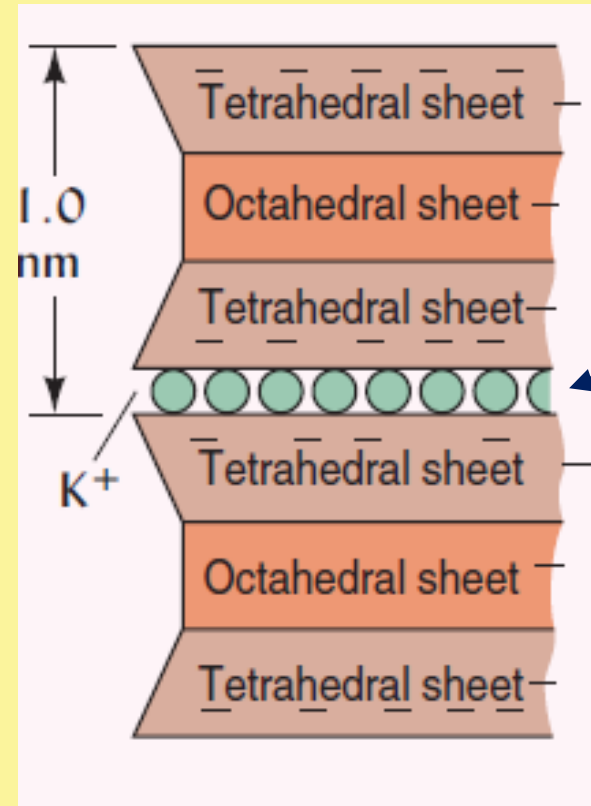
Illite

Illite (2:1, fine grained mica)



Isomorphous substitution

K⁺ in interlayer

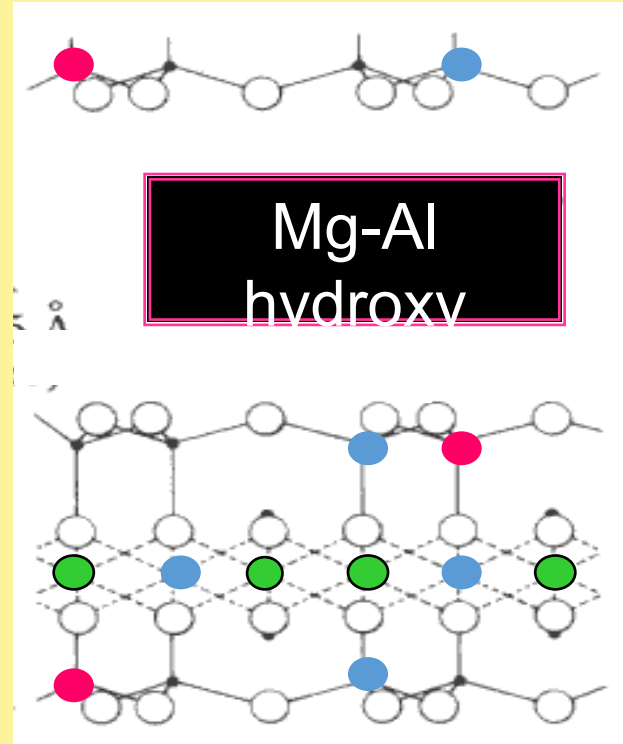
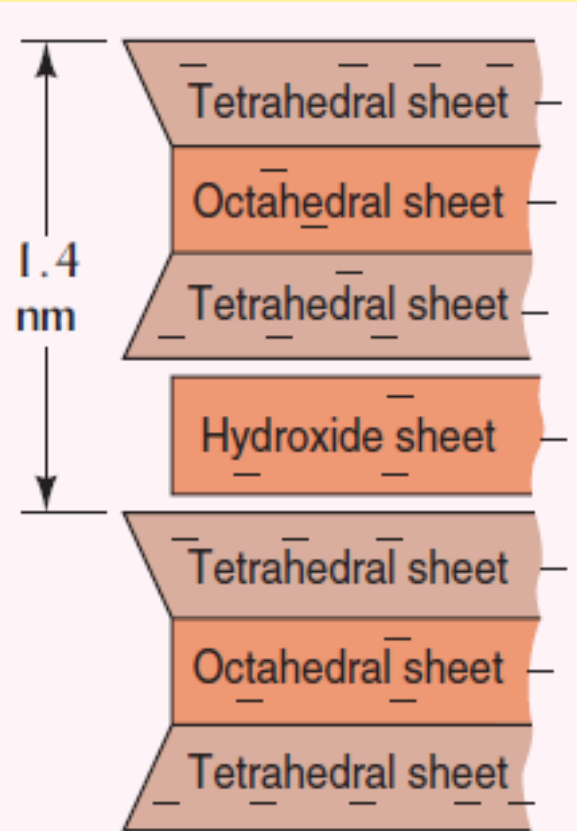


K⁺ tightly bound

Chlorite

- ❑ Iron or magnesium occupy the octahedral sheets
- ❑ **Hydroxy octahedral sheet** in the interlayer space
- ❑ Restricted swelling (due to locked interlayer structure)
- ❑ 'Nutrient poor'
- ❑ Common in sedimentary rocks and the soils derived from them

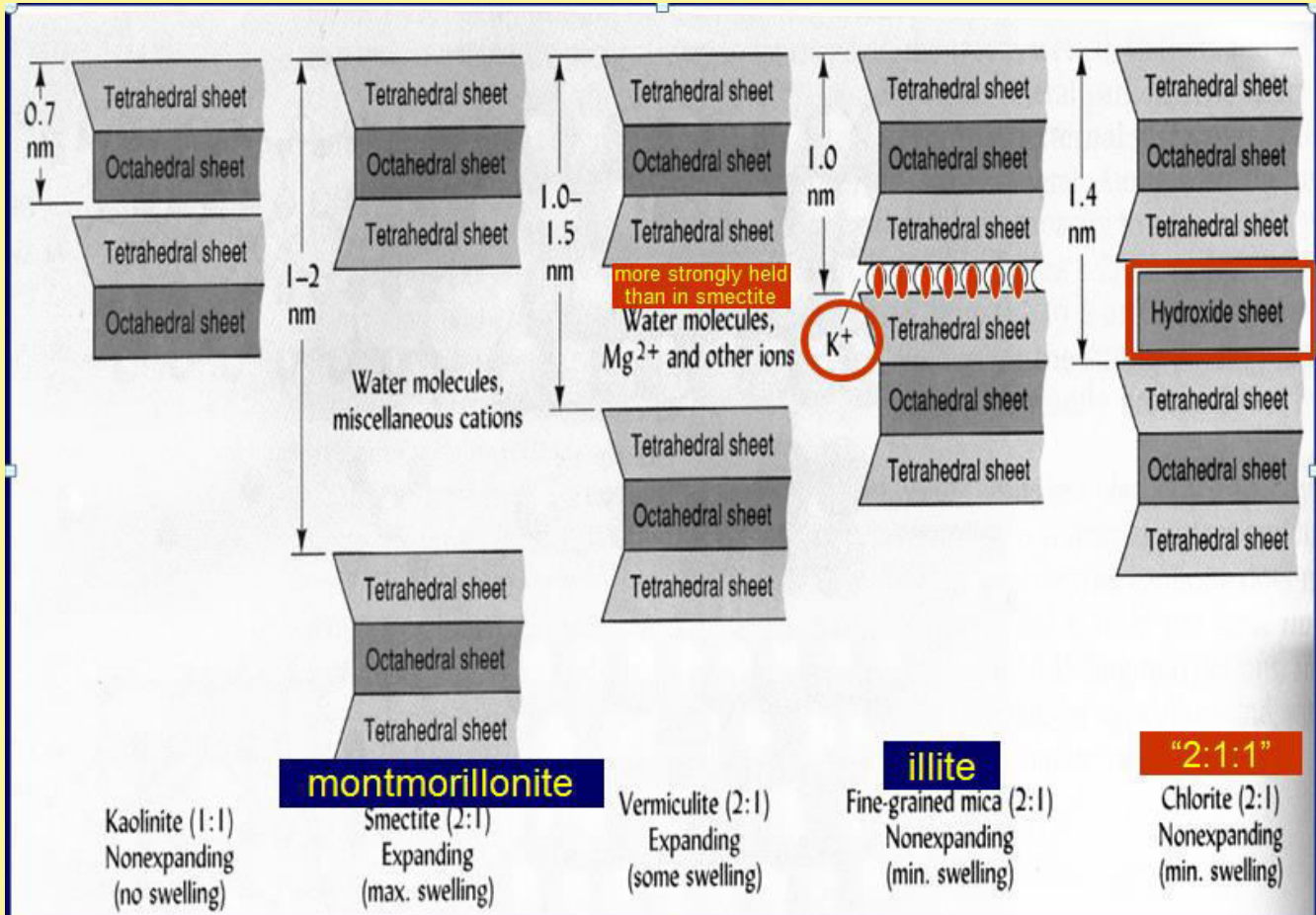
Chlorite (2:1:1 clay)



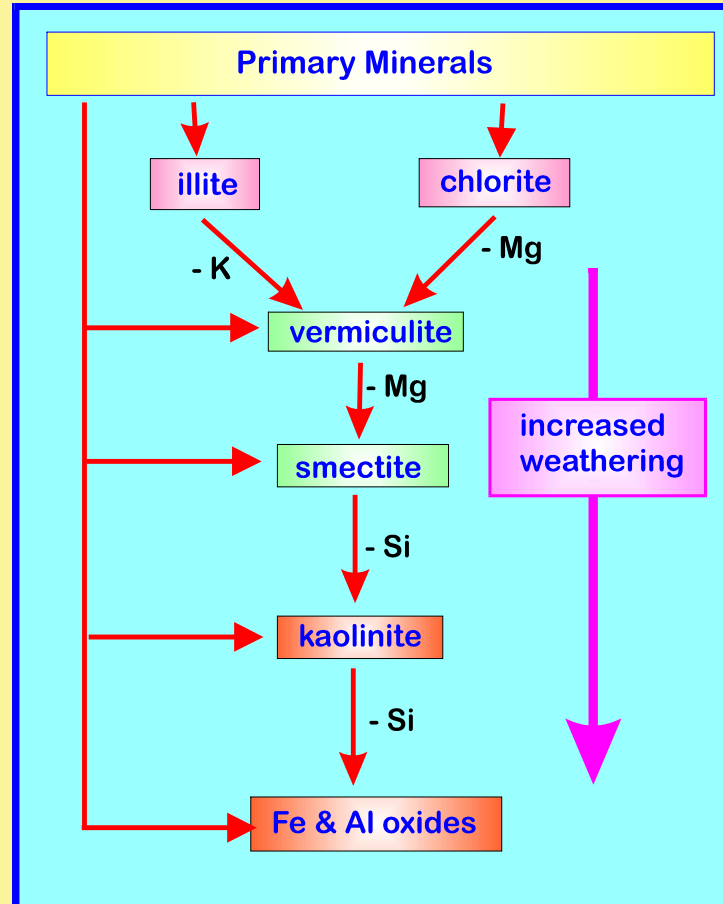
Locked structure
Low nutrient capacity

● = Al ● = Fe ● = Mg

Visual comparison



Clay mineralogy and weathering pattern

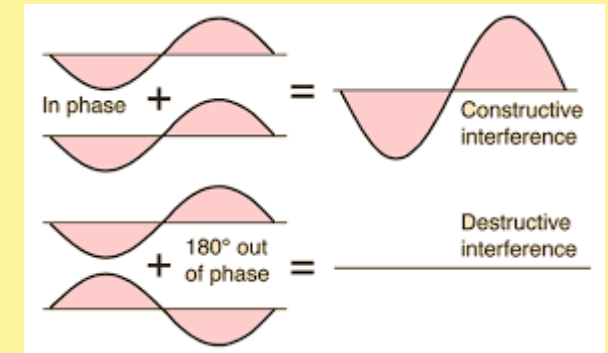
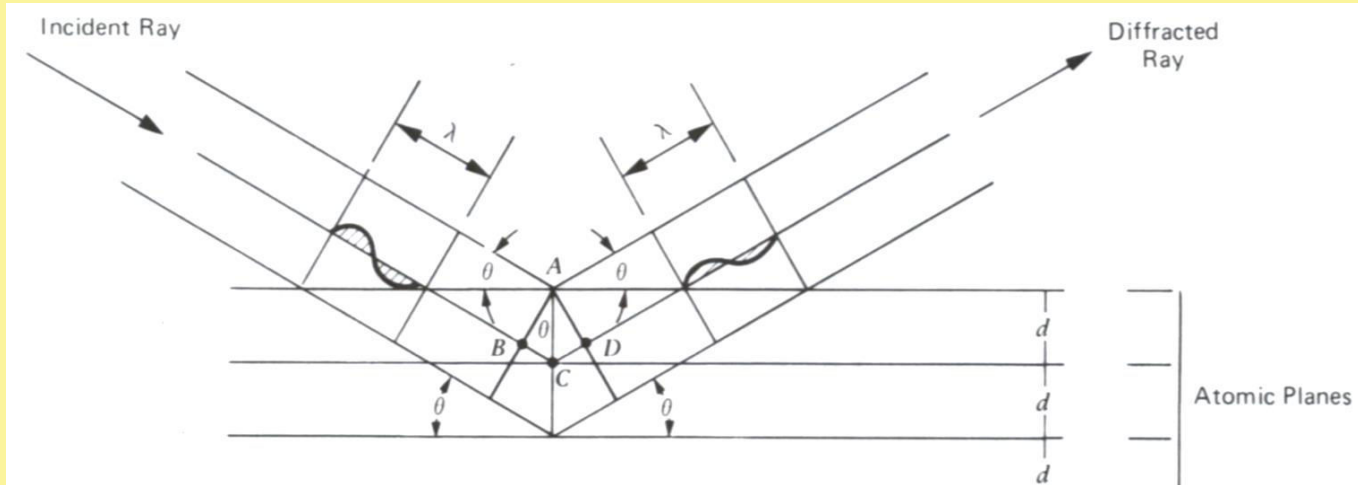


Young, weakly weathered

Intermediately weathered

Strongly weathered

X-ray diffraction analysis



<http://hyperphysics.phy-astr.gsu.edu>

- The distance of atomic planes d can be determined based on the Bragg's equation.

$$BC + CD = n\lambda, n\lambda = 2d \cdot \sin\theta, d = \frac{n\lambda}{2 \sin\theta}$$

where n is an integer and λ is the wavelength.

Bragg's law: The two rays will constructively interfere if the extra distance ray II travels is a whole number of wavelengths farther than what ray I travels.

- Different clays minerals have various basal spacing (atomic planes). For example, the basal spacing of kaolinite is 7.7 \AA

X-ray diffraction analysis

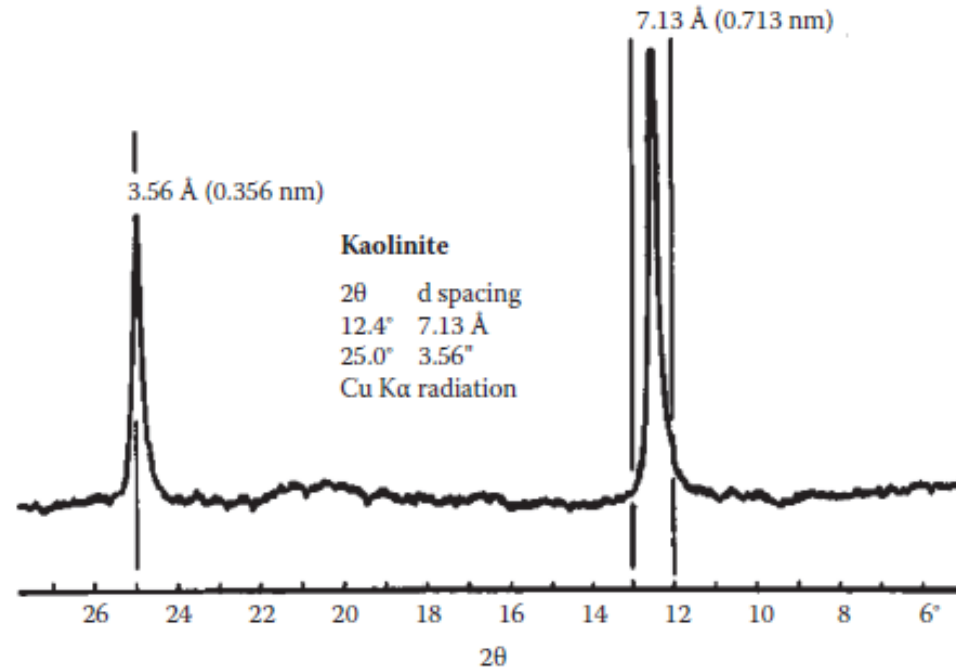


FIGURE 6.22 Interpretation and identification of kaolinite using its x-ray diffraction pattern. A first-order diffraction peak at 7.13 \AA (0.713 nm), together with a second-order peak at $3.56 (= 7.13/2) \text{ \AA}$, is diagnostic for the presence of kaolinite.

Reference:

- ❑ **The Nature and Properties of Soils by Nyle C. Brady and Ray R. Weil**