Types of Soil Colloids

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

Non-crystalline Silicate Clays

Allophane and Imogolite

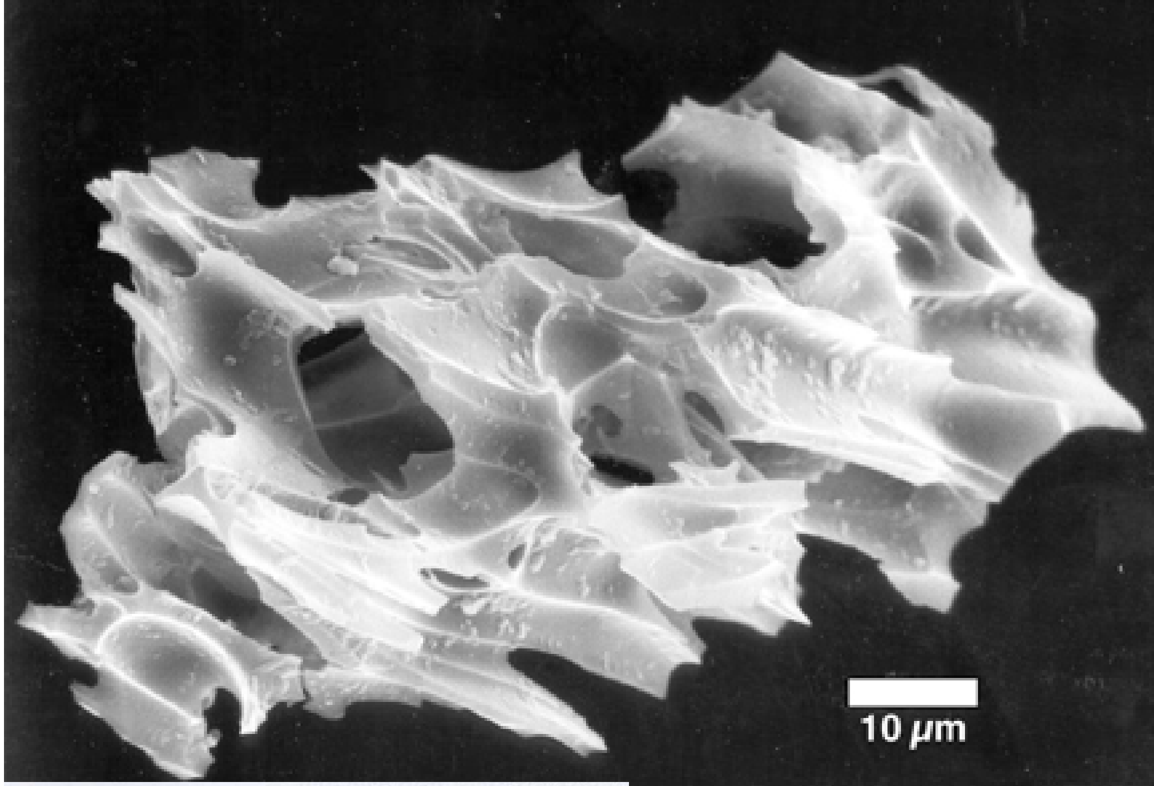
1. Volcanic ash is chemically/mineralogically distinct from most other soil parent materials.
2. Composed largely of vitric or glassy materials containing varying amounts of Al and Si.
3. It lacks a well-defined crystal structure (i.e., amorphous) and is quite soluble.

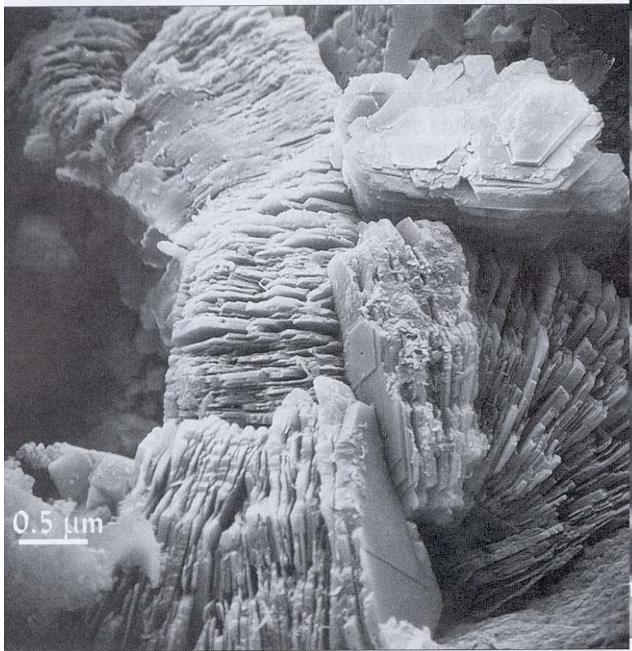
Allophane and Imogolite are common early-stage residual weathering products of volcanic glass and both have poorly-ordered structures.

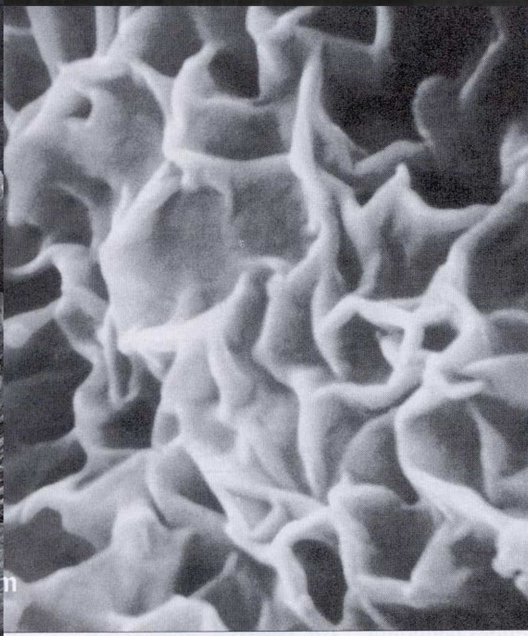
Allophane forms inside glass fragments where Si concentration and pH are high and has a characteristic spherule shape.

Imogolite tends to form on the exterior of glass fragments under conditions of lower pH and Si concentration, and has a characteristic thread-like morphology.


M
F
.2
1
.4
.5
2
.6
3
1
.2
4
.4
5
.6


10 μm


0.5 μm


m

Iron and Aluminum oxides

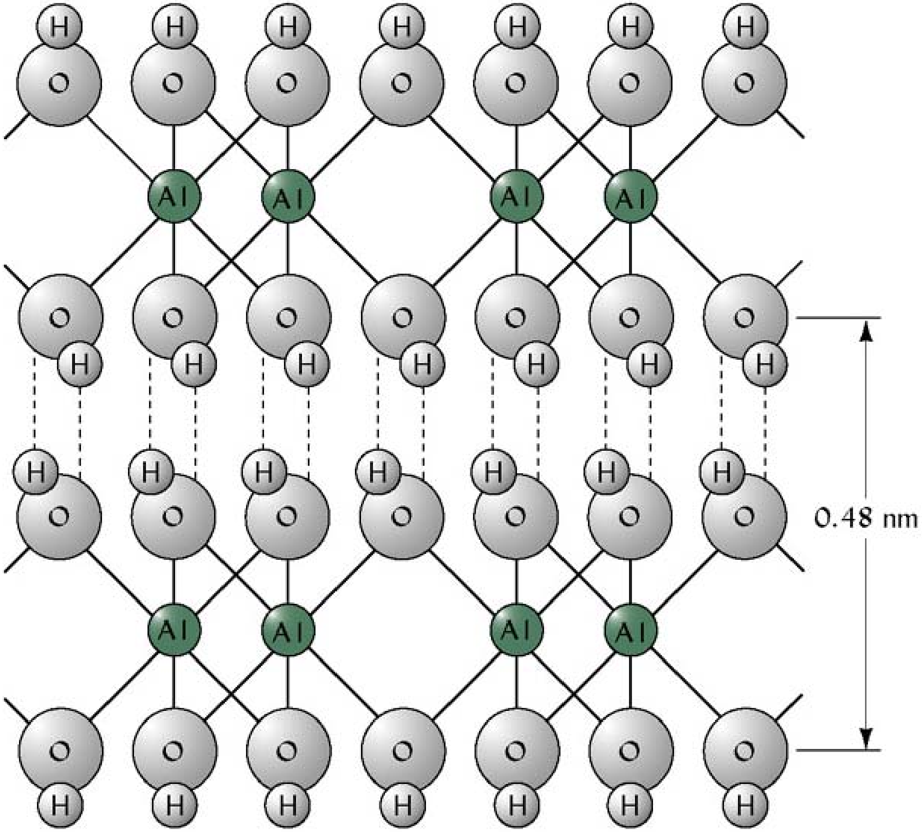
Sesquioxides

Dominantly gibbsite (Al-oxide) and goethite (Fe-oxide)

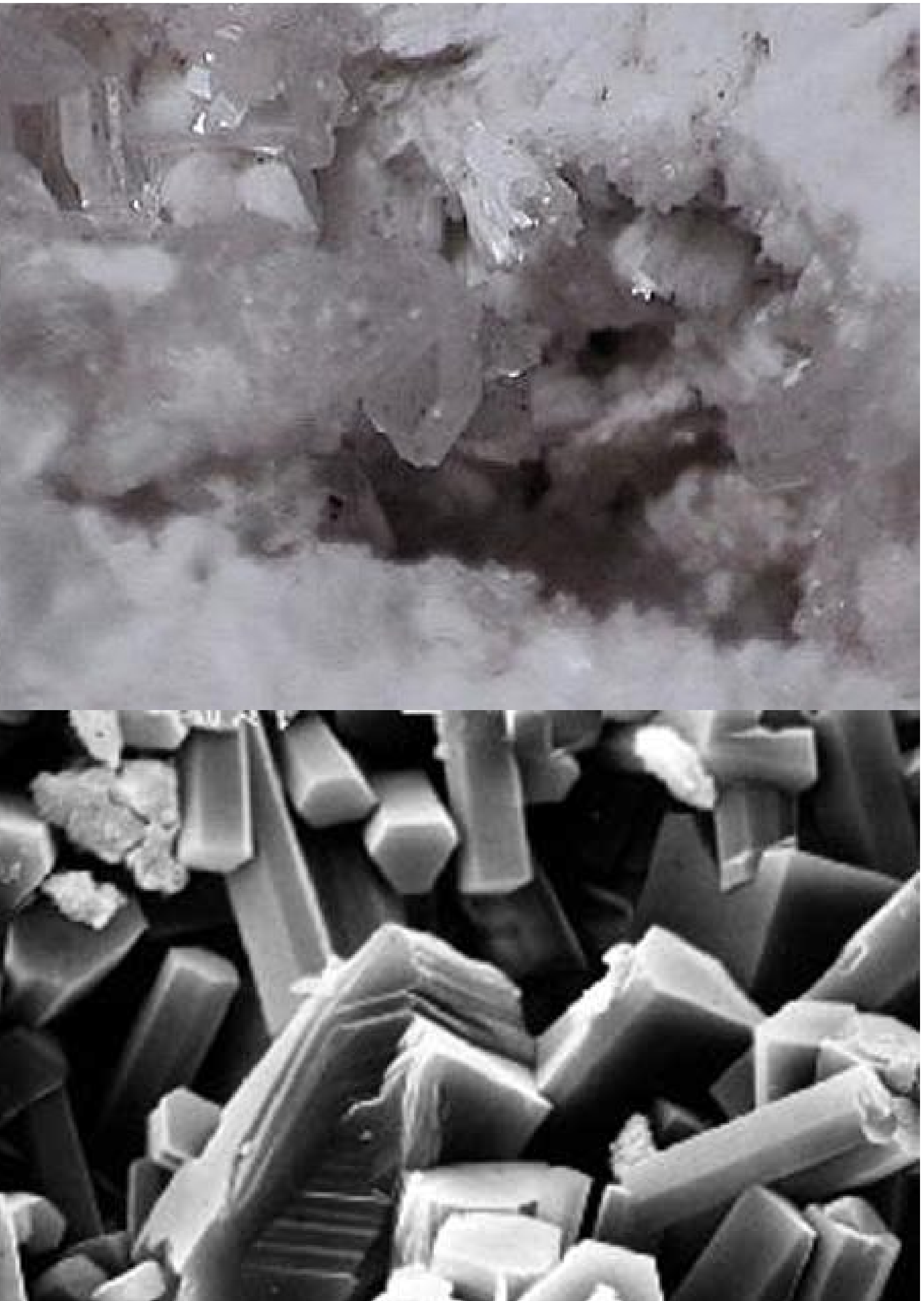
1. Found in many soils
2. Especially important in highly weathered soils of warm humid regions
3. Consist of mainly either Fe or Al atoms coordinated with O atoms
    - the O atoms often associated with H ions to make hydroxyl groups
4. Some, such as gibbsite (Al-oxide) and goethite (Fe-oxide), form crystalline sheets
5. Others form amorphous coatings on soil particles

Because of surface plane of covalently bonded hydroxyls gives these colloids the capacity to strongly adsorb certain anions

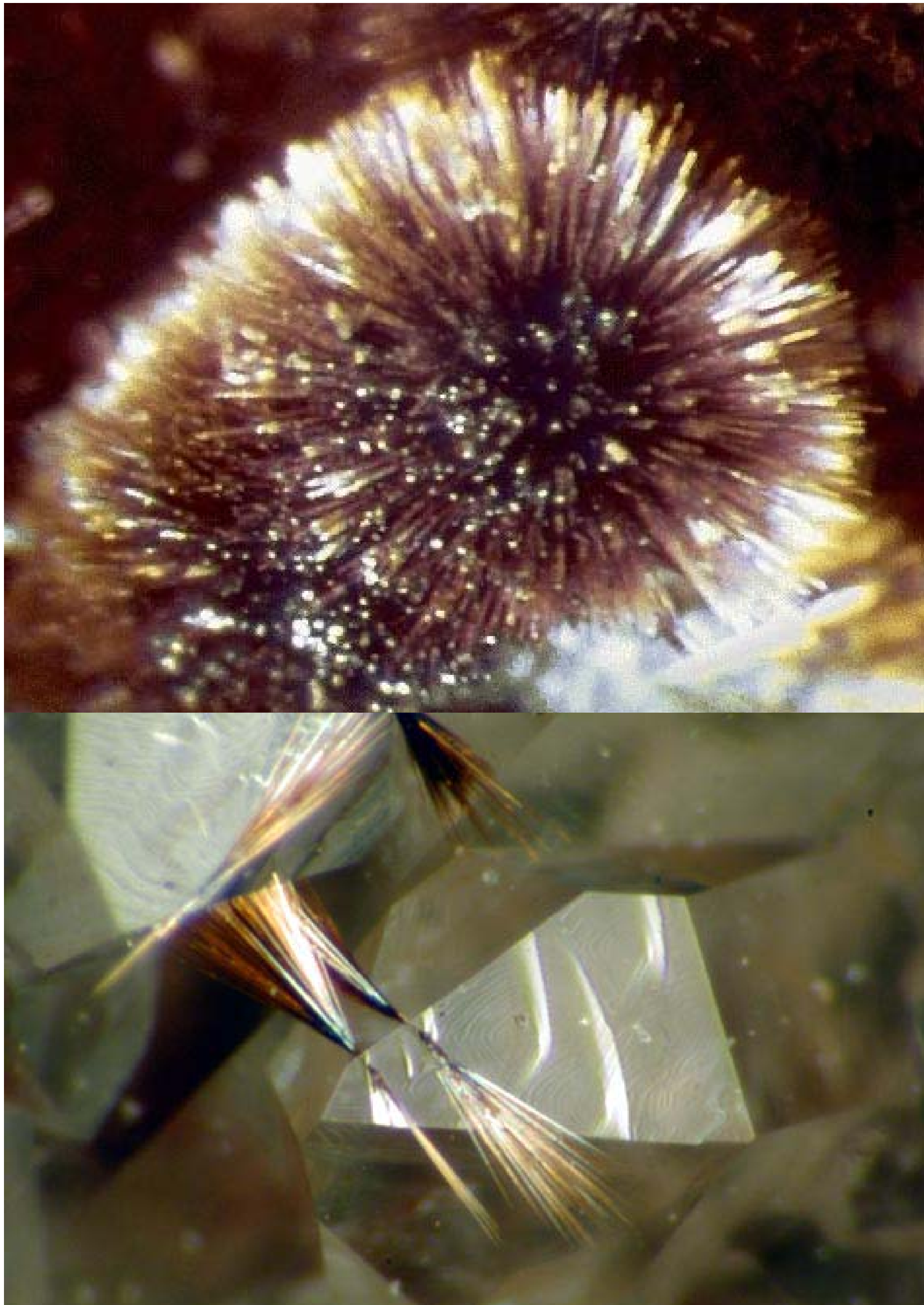
Because of surface plane of covalently bonded hydroxyls gives these colloids the capacity to strongly adsorb certain anions



Gibbsite (Al-oxide)



Goethite (Fe-oxide)

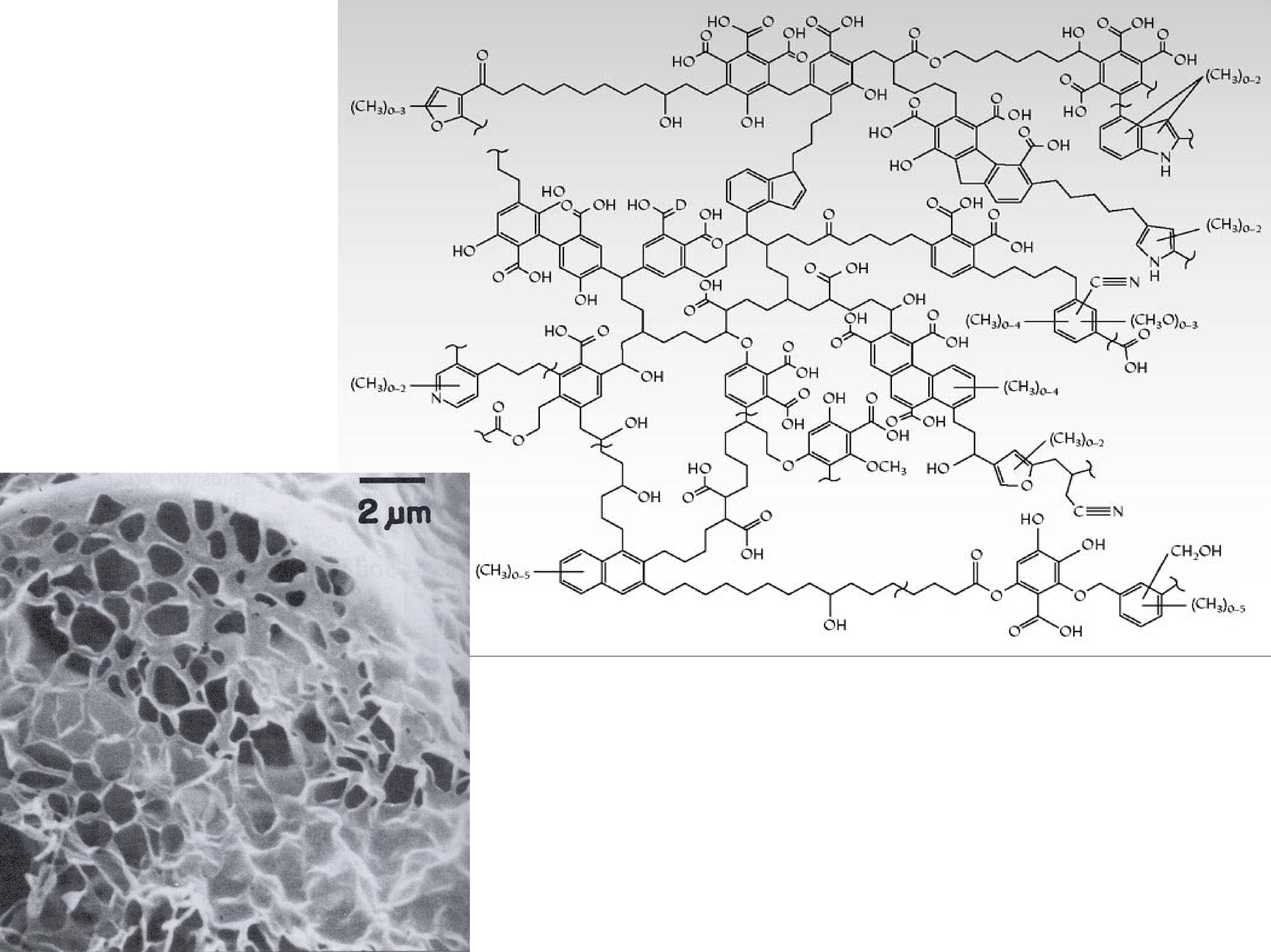


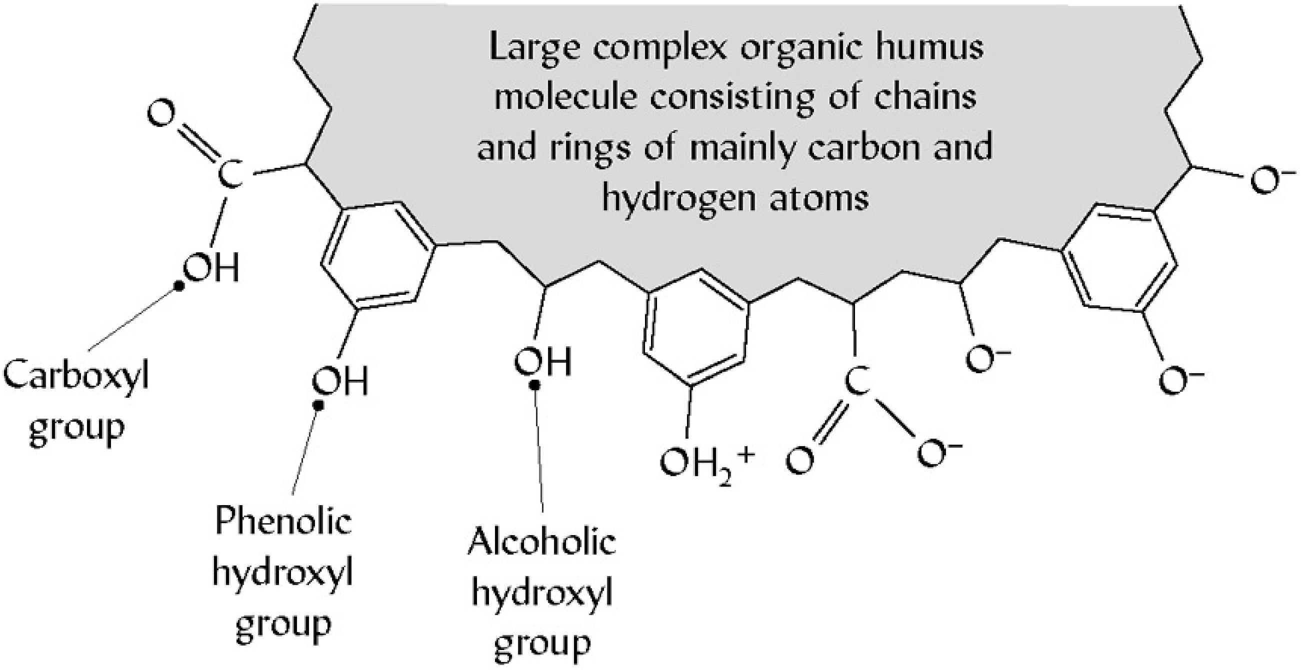
amorphous coatings on soil particles

Organic (humus) colloids

Non-crystalline colloids dominated by long C-chain molecules

1. Important in nearly all soils
2. They are not mineral or crystalline in nature
3. Consist of long convoluted chains and rings of **Carbon** bonded to Hydrogen, Oxygen and Nitrogen
4. Very high capacity to adsorb water
5. Have high amounts of both positive and negative charges, but **net charge is always negative**


(CH₃)₀₋₃
(CH₃)₀₋₂
(CH₃)₀₋₂
(CH₃)₀₋₄
(CH₃O)₀₋₃
(CH₃)₀₋₂
(CH₃)₀₋₄
(CH₃)₀₋₂
OCH₃
(CH₃)₀₋₅
CH₂OH
(CH₃)₀₋₅
2 μm


Large complex organic humus molecule consisting of chains and rings of mainly carbon and hydrogen atoms
O
C
OH
Carboxyl group
OH
Phenolic hydroxyl group
OH
Alcoholic hydroxyl group
OH2+
C
O
O−
O−
O−
O−

Types of Soil Colloids

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  - Dominantly gibbsite (Al-oxide) and goethite (Fe-oxide)
- Organic (humus) colloids
  - Non-crystalline colloids dominated by long C-chain molecules

TABLE 8.3 Prominent Occurrence of Clay Minerals in Different Soil Orders in the United States and Typical Locations for These Soils

Soil order[a]	*General weathering intensity*	*Typical location in U.S.*	*Fe, Al oxides*	*Kaolinite*	*Smectite*	*Fine-grained mica*	*Vermiculite*	*Chlorite*	*Intergrades*
Aridisols	Low	Dry areas			XX	XX		X	X
Vertisols[b]	↑	Alabama, Texas			XXX				X
Mollisols		Kansas, Iowa		X	XX	X	X	X	X
Alfisols		Ohio, New York		X	X	X	X	X	X
Spodosols		New England	X	X					
Ultisols	↓	Southeast	XX	XXX			X	X	X
Oxisols	High	Hawaii, Puerto Rico	XX	XXX					

[a] See Chapter 3 for soil descriptions.

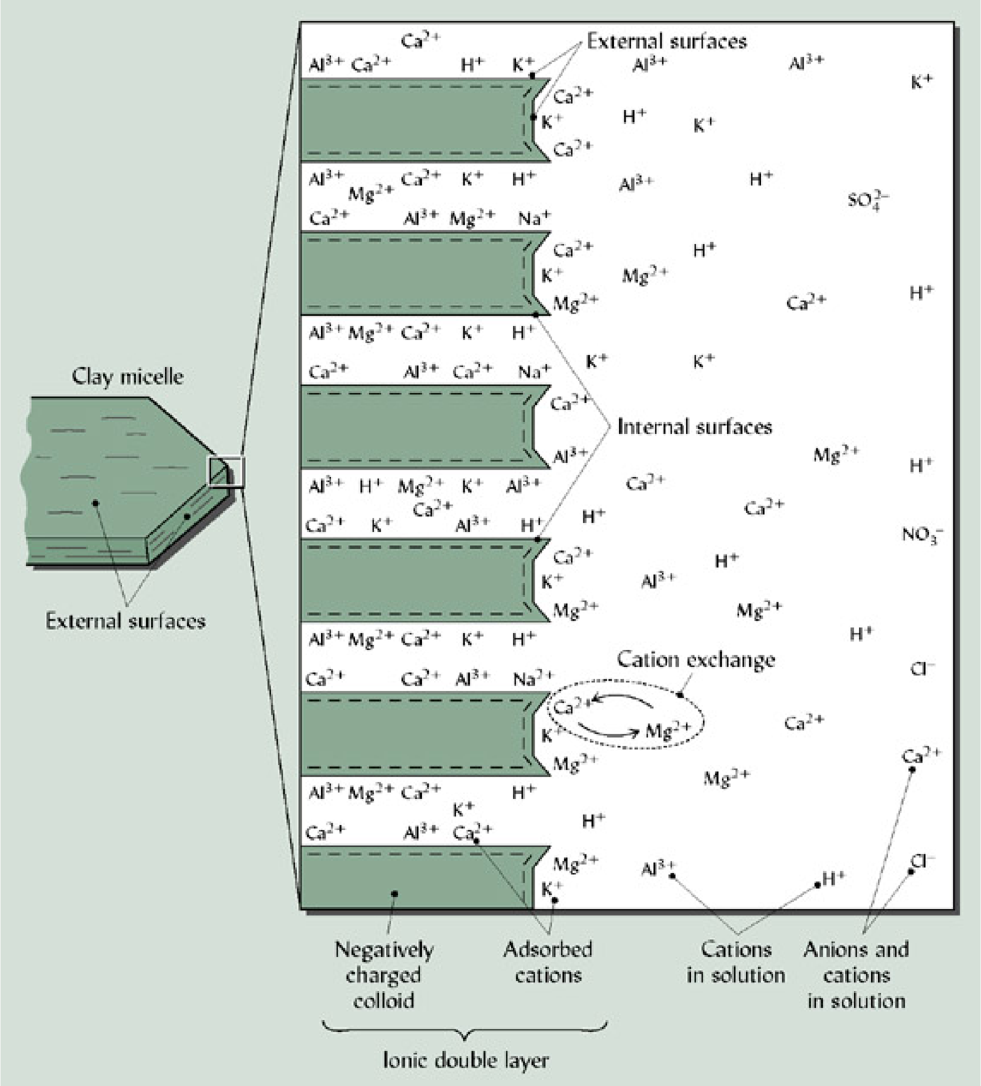
[b] By definition these soils have swelling-type clays, which account for the dominance of smectites.

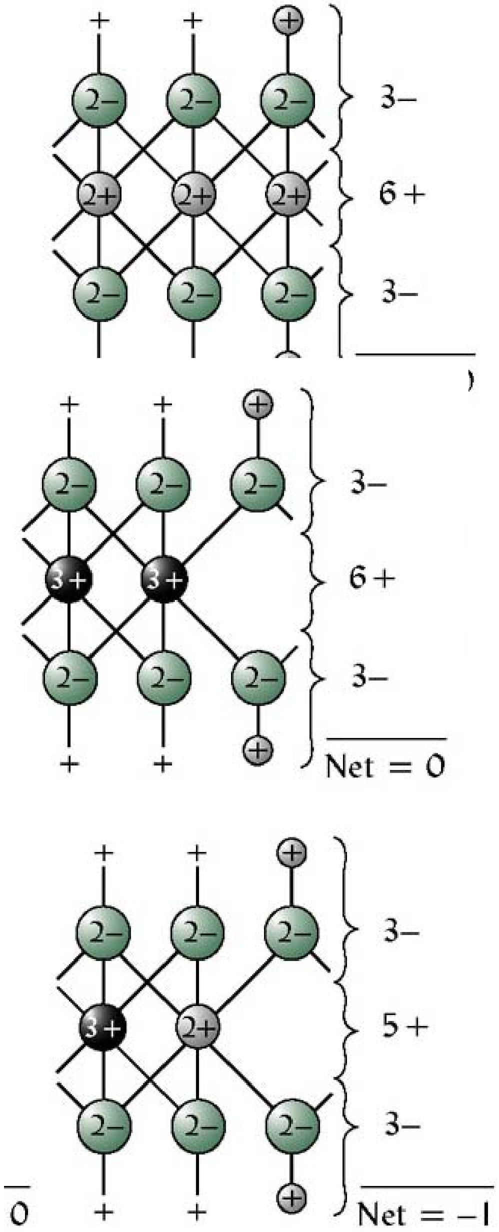
Sources of Charges on Soil Colloids

- Constant Charge (structural)
  - through Isomorphic substitution
  - both negative and positive charges
  - predominately positive
- Variable or pH-Dependent Charge
  - both negative and positive charges
  - primarily associated with hydroxyl (OH) groups
  - Source of charge on humus, Fe & Al oxides, allophane and some phylosilicates.

Adsorption vs. Absorption

Surface bonding vs. internal structure





Cation vs. Anion

Ion: a particle that is electrically charged
an atom or a molecule that has lost or gained one or more electrons…

Cation is a positively charged ion

Anion is a negatively charged ion

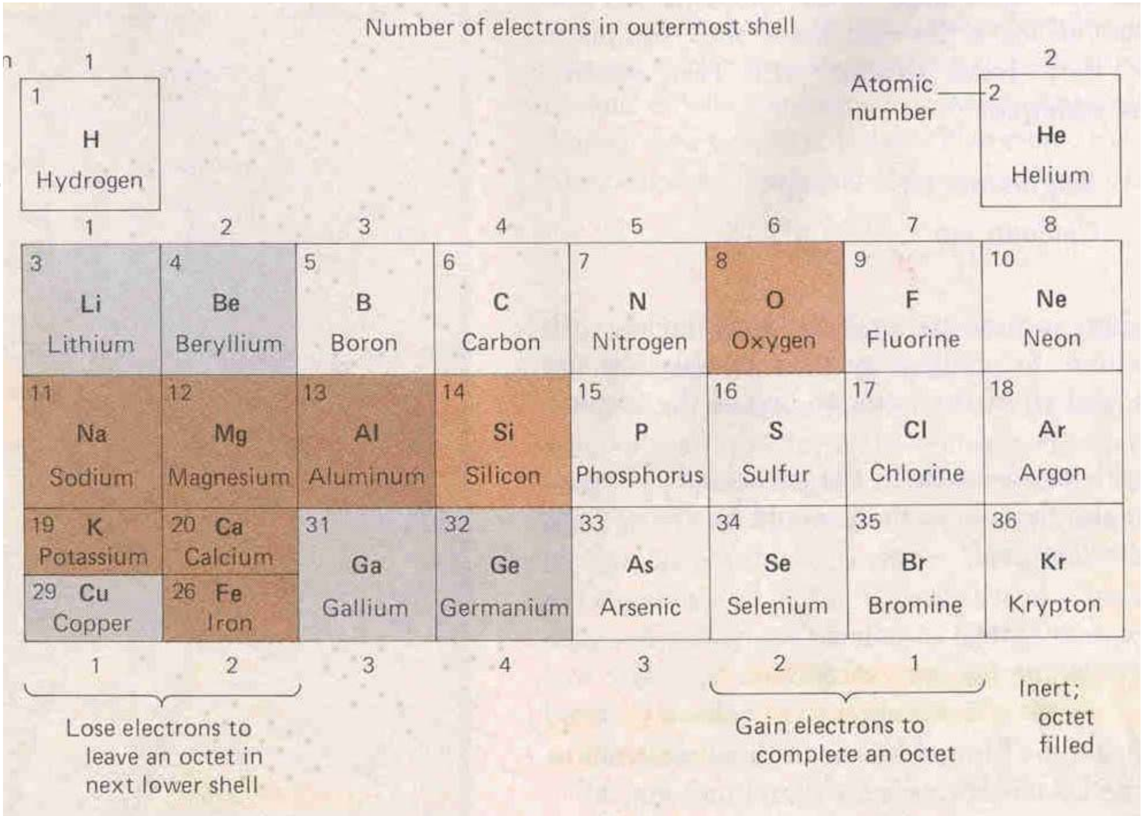
for example:

Cations

Na^{1+}, Ca^{2+}, Al^{3+} or Si^{4+}

Anions

Cl^{1-}, O^{2-} or S^{2-}



Number of electrons in outermost shell

1							2
1 H Hydrogen						Atomic number — 2	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 29 Cu Copper	20 Ca Calcium 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

Constant Charge (structural)

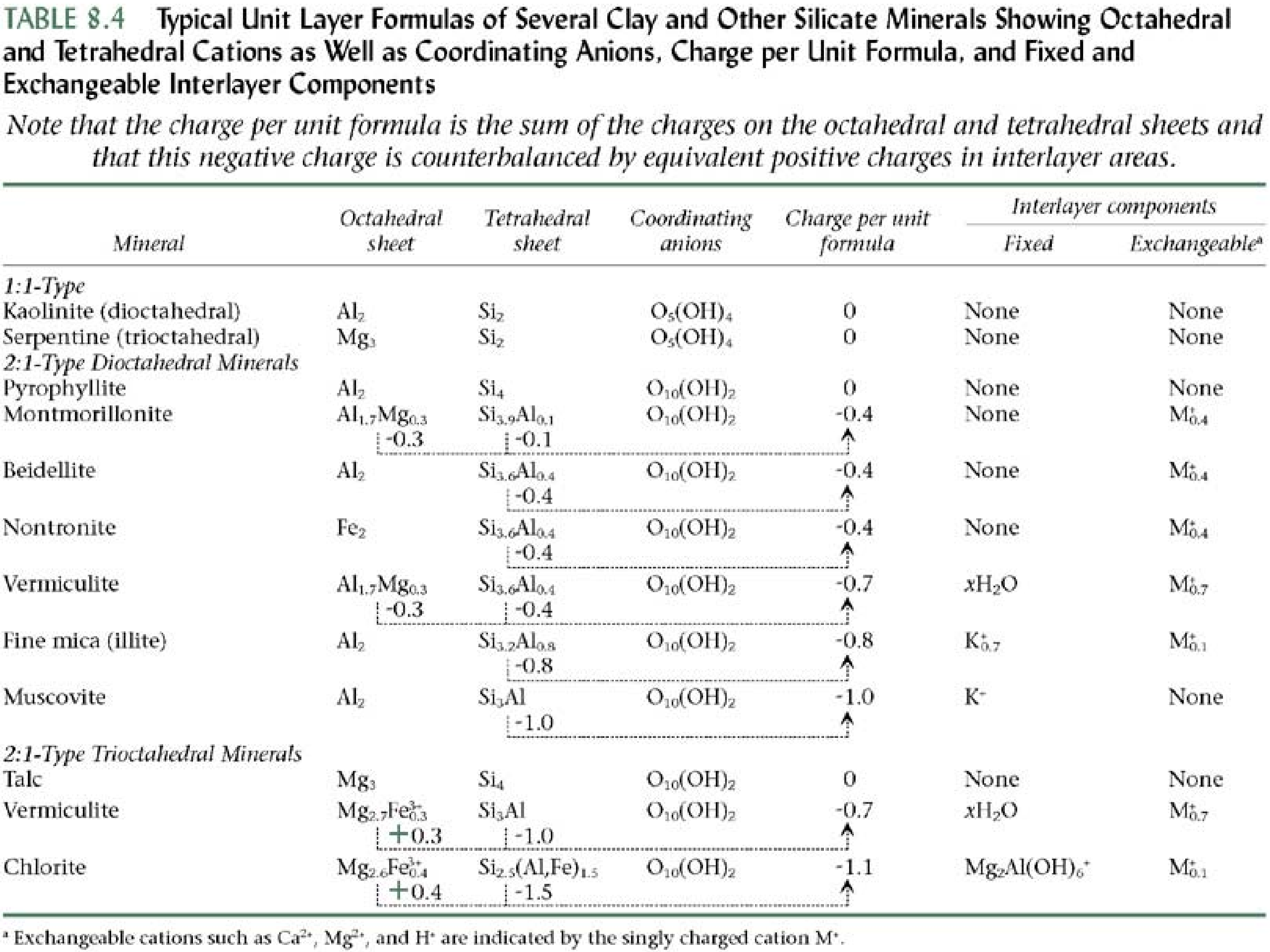
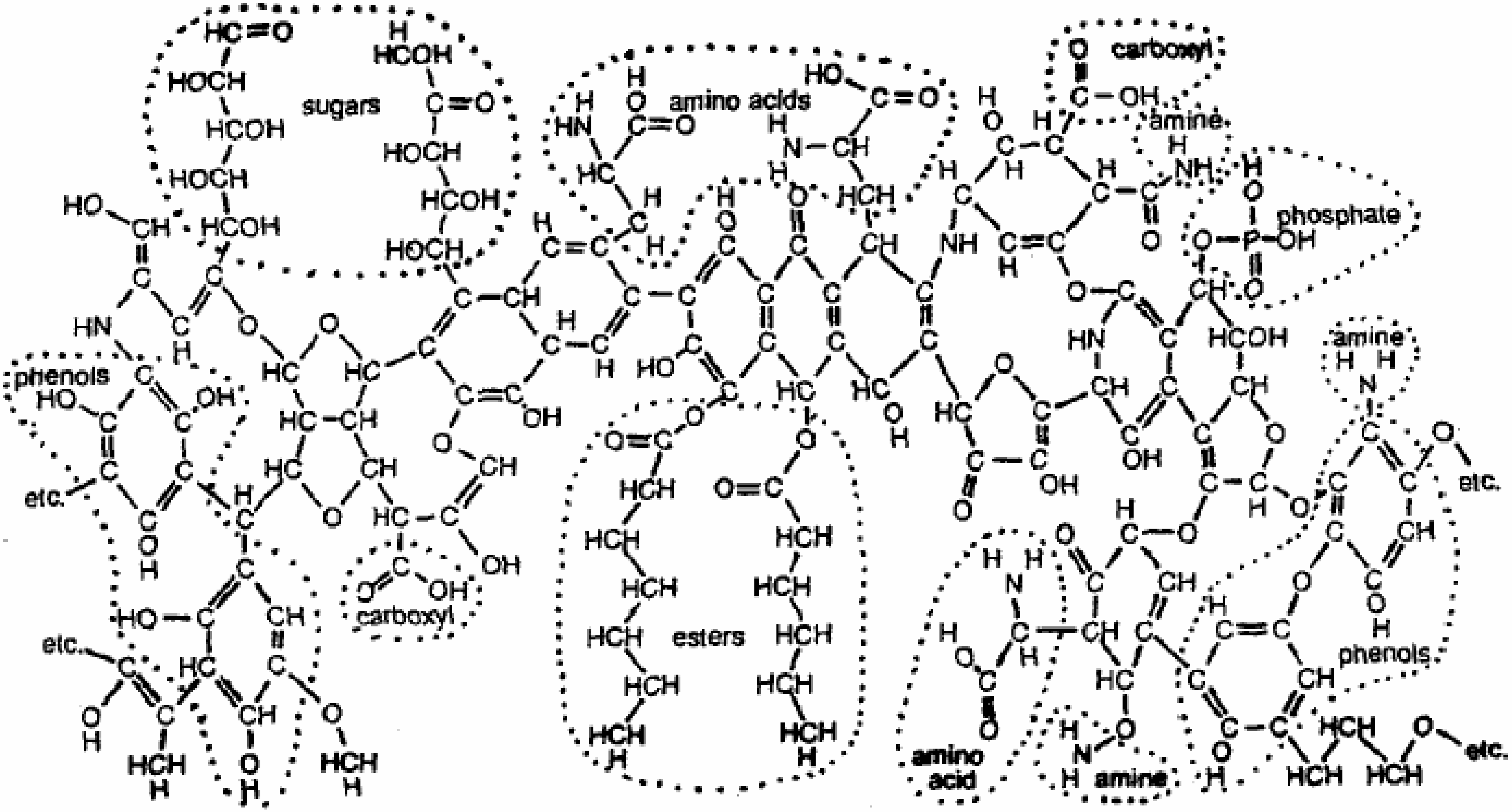


TABLE 8.4 Typical Unit Layer Formulas of Several Clay and Other Silicate Minerals Showing Octahedral and Tetrahedral Cations as Well as Coordinating Anions, Charge per Unit Formula, and Fixed and Exchangeable Interlayer Components

Note that the charge per unit formula is the sum of the charges on the octahedral and tetrahedral sheets and that this negative charge is counterbalanced by equivalent positive charges in interlayer areas.

					Interlayer components	
Mineral	*Octahedral sheet*	*Tetrahedral sheet*	*Coordinating anions*	*Charge per unit formula*	*Fixed*	*Exchangeable*[a]
1:1-Type						
Kaolinite (dioctahedral)	Al_2	Si_2	$O_5(OH)_4$	0	None	None
Serpentine (trioctahedral)	Mg_3	Si_2	$O_5(OH)_4$	0	None	None
2:1-Type Dioctahedral Minerals						
Pyrophyllite	Al_2	Si_4	$O_{10}(OH)_2$	0	None	None
Montmorillonite	$Al_{1.7}Mg_{0.3}$ -0.3	$Si_{3.9}Al_{0.1}$ -0.1	$O_{10}(OH)_2$	-0.4	None	$M^+_{0.4}$
Beidellite	Al_2	$Si_{3.6}Al_{0.4}$ -0.4	$O_{10}(OH)_2$	-0.4	None	$M^+_{0.4}$
Nontronite	Fe_2	$Si_{3.6}Al_{0.4}$ -0.4	$O_{10}(OH)_2$	-0.4	None	$M^+_{0.4}$
Vermiculite	$Al_{1.7}Mg_{0.3}$ -0.3	$Si_{3.6}Al_{0.4}$ -0.4	$O_{10}(OH)_2$	-0.7	xH_2O	$M^+_{0.7}$
Fine mica (illite)	Al_2	$Si_{3.2}Al_{0.8}$ -0.8	$O_{10}(OH)_2$	-0.8	$K^+_{0.7}$	$M^+_{0.1}$
Muscovite	Al_2	Si_3Al -1.0	$O_{10}(OH)_2$	-1.0	K^+	None
2:1-Type Trioctahedral Minerals						
Talc	Mg_3	Si_4	$O_{10}(OH)_2$	0	None	None
Vermiculite	$Mg_{2.7}Fe^{3+}_{0.3}$ +0.3	Si_3Al -1.0	$O_{10}(OH)_2$	-0.7	xH_2O	$M^+_{0.7}$
Chlorite	$Mg_{2.6}Fe^{3+}_{0.4}$ +0.4	$Si_{2.5}(Al,Fe)_{1.5}$ -1.5	$O_{10}(OH)_2$	-1.1	$Mg_2Al(OH)_6^+$	$M^+_{0.1}$

[a] Exchangeable cations such as Ca^{2+}, Mg^{2+}, and H^+ are indicated by the singly charged cation M^+.

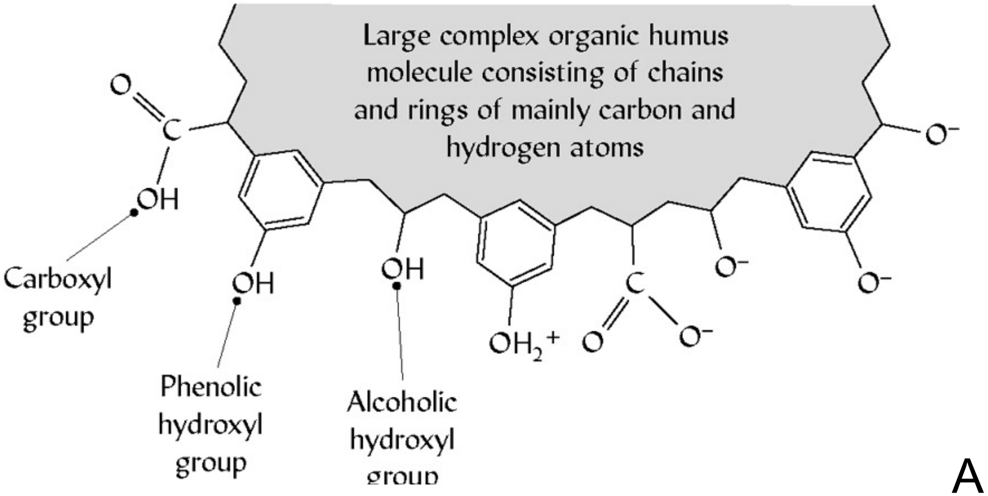

sugars
amino acids
carboxyl
amine
phosphate
phenols
amine
etc.
etc.
carboxyl
esters
etc.
phenols
etc.
amino acid
amine
etc.

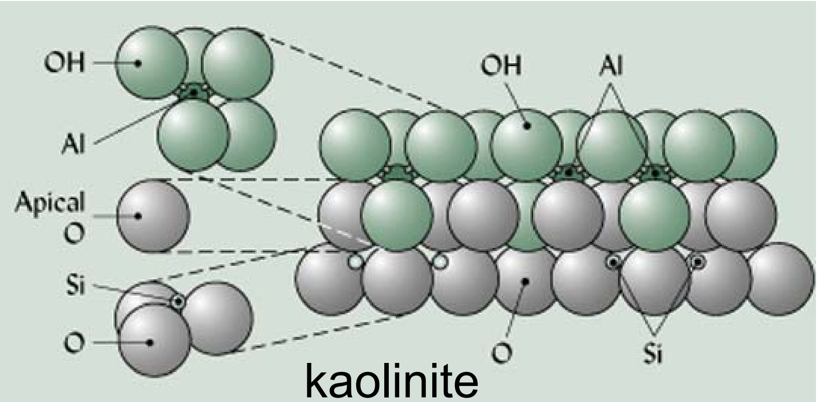
Sources of Charges on Soil Colloids

- Variable or pH-Dependent Charge
  - both negative and positive charges
  - primarily associated with hydroxyl (OH) groups
  - Source of charge on humus, Fe & Al oxides, allophane and some phylosilicates.

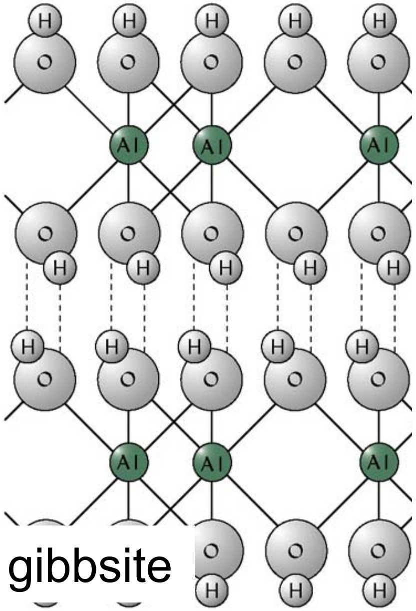
Variable or pH-Dependent Charge

via protonation / deprotonation of hydroxyl groups



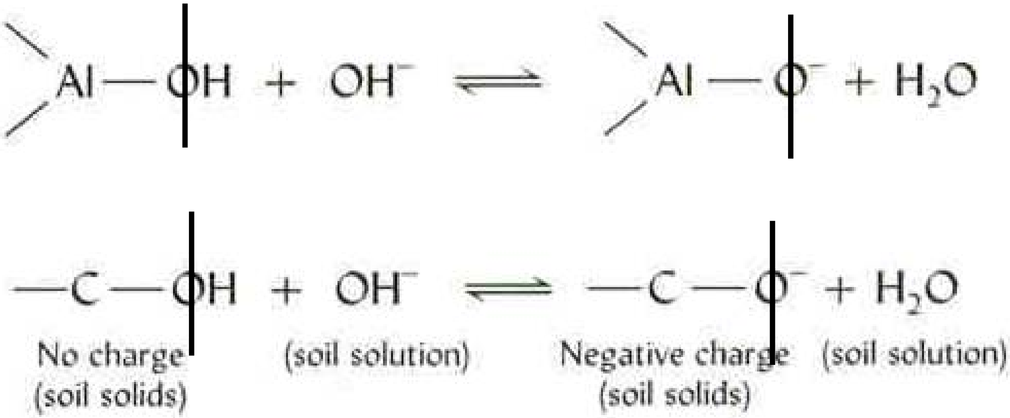


kaolinite



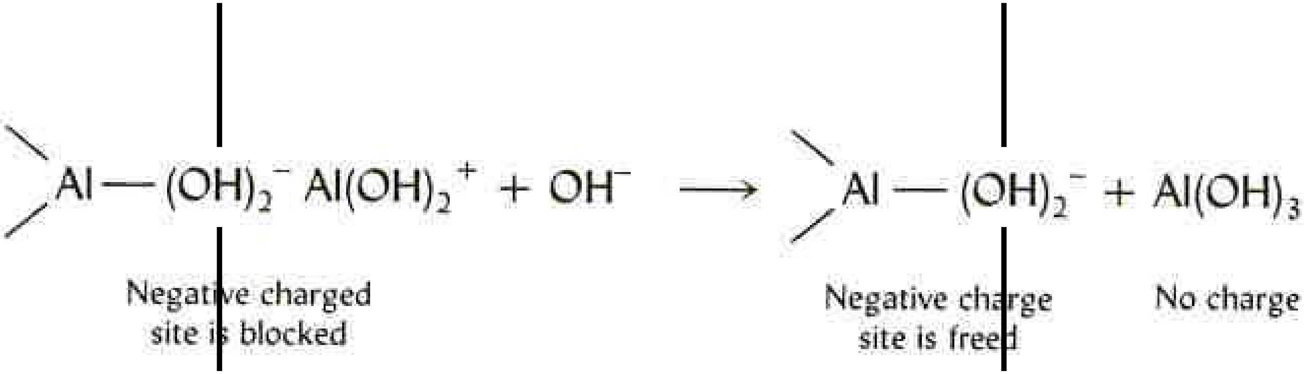
gibbsite

A negative charge comes with increasing pH



$$\text{Al—OH} + OH^- \rightleftharpoons \text{Al—O}^- + H_2O$$

$$\text{—C—OH} + OH^- \rightleftharpoons \text{—C—O}^- + H_2O$$



$$\mathrm{Al{-}(OH)_2^-\ Al(OH)_2^+ + OH^- \longrightarrow Al{-}(OH)_2^- + Al(OH)_3}$$

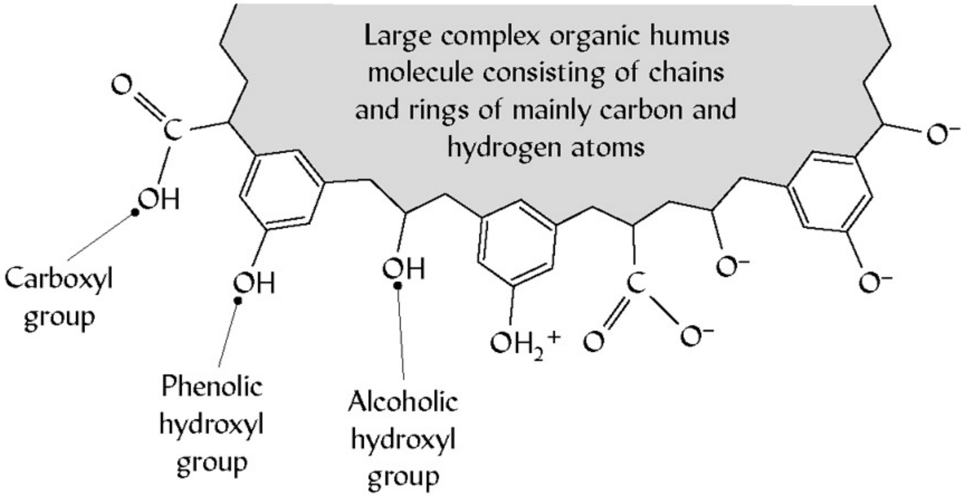
Negative charged site is blocked

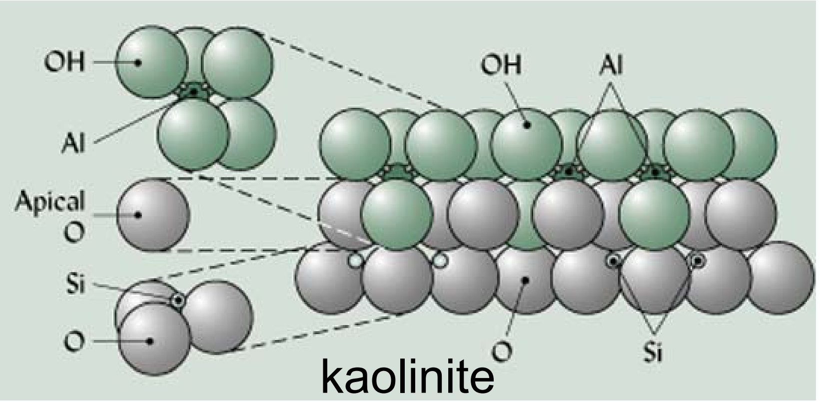
Negative charge site is freed

No charge

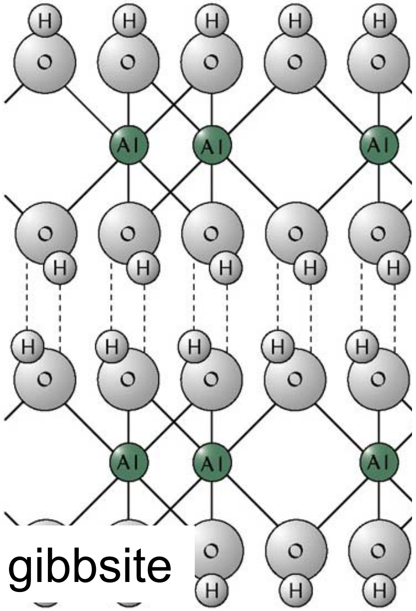
Variable or pH-Dependent Charge

via protonation / deprotonation of hydroxyl groups



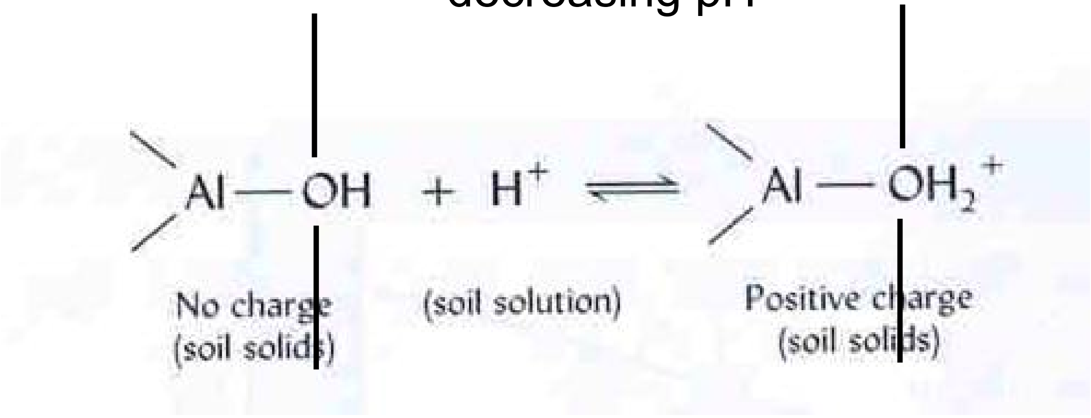


kaolinite



gibbsite

A positive charge comes with decreasing pH

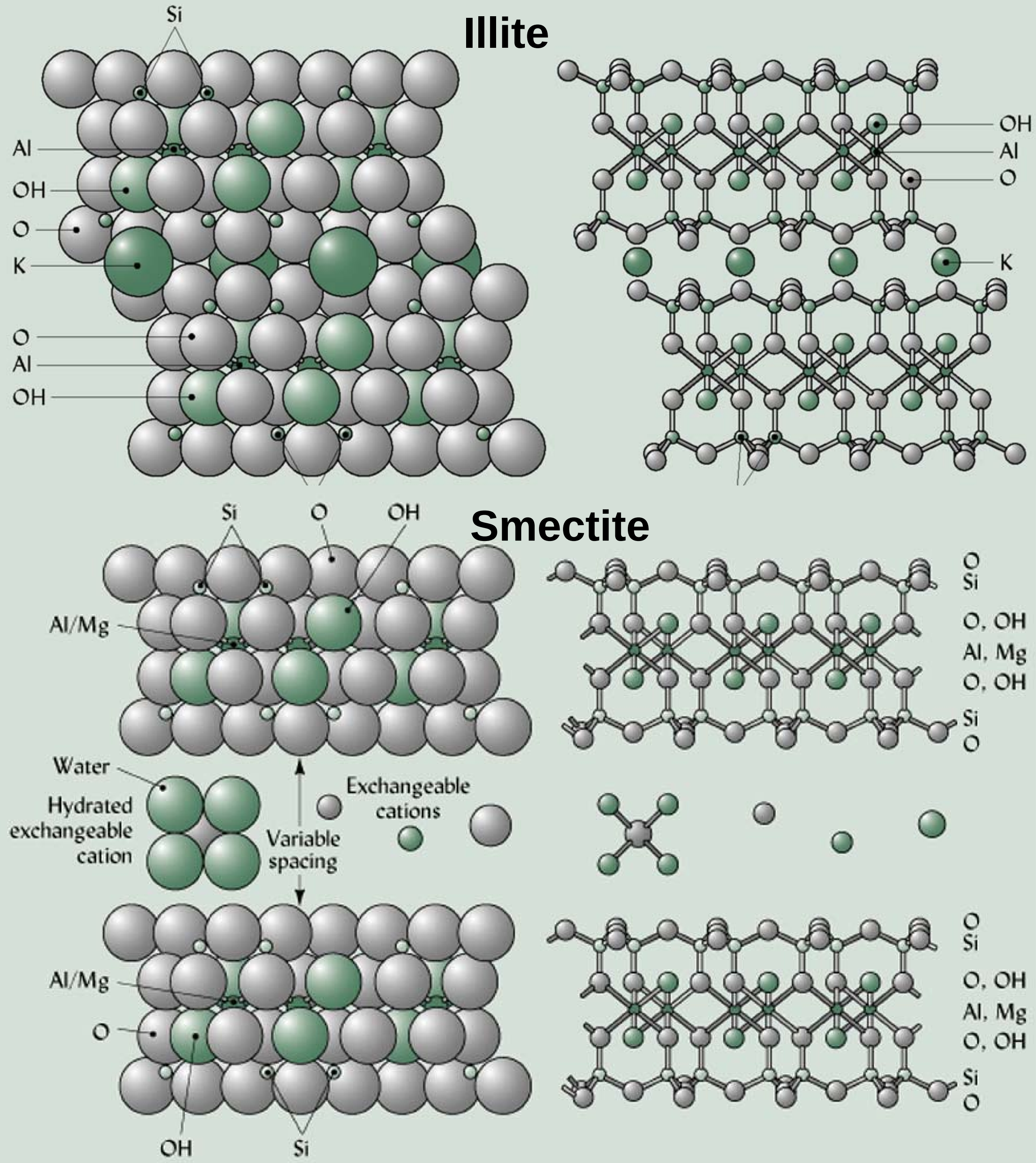


$$\text{Al—OH} + H^+ \rightleftharpoons \text{Al—OH}_2^+$$

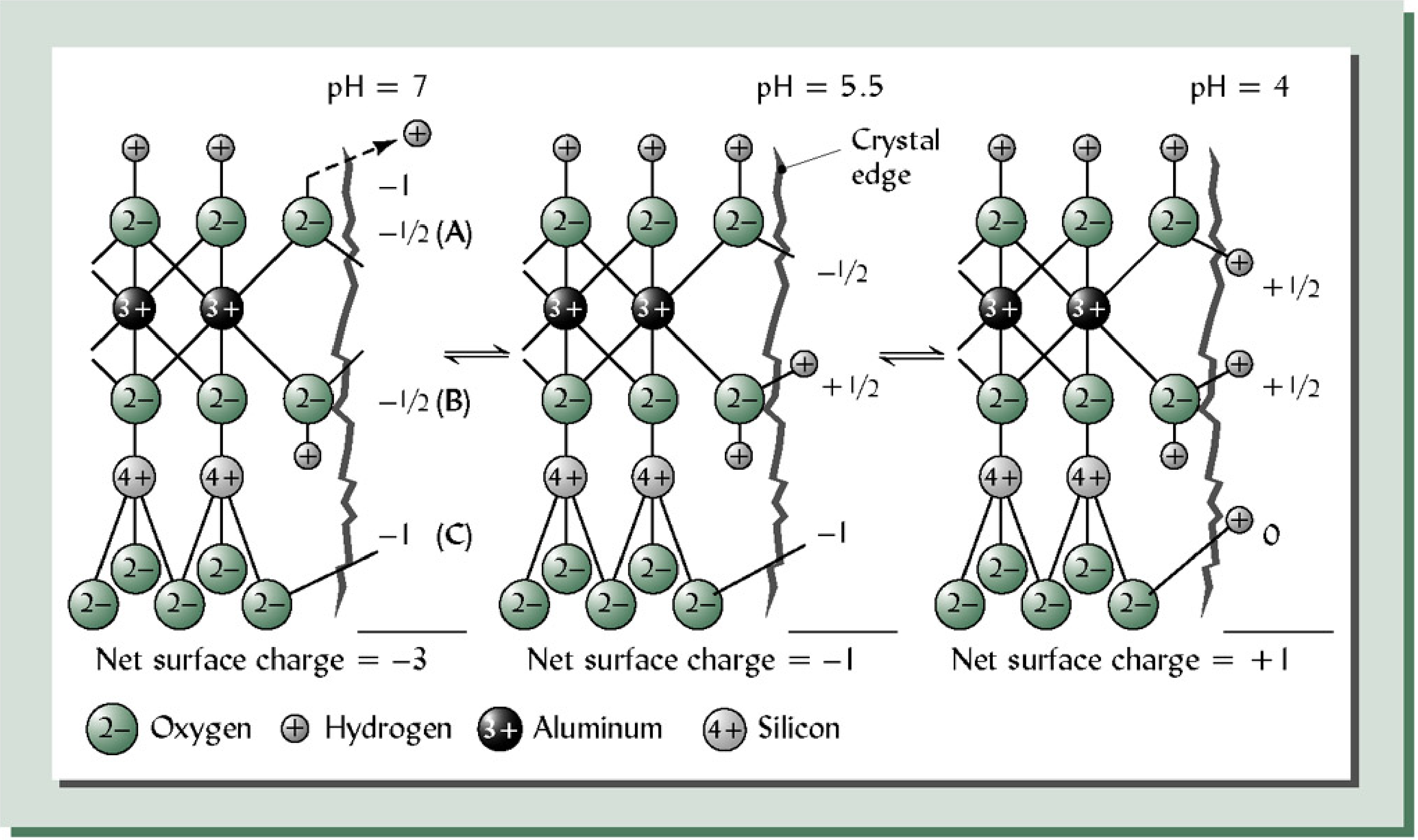
Why is the pH dependent charge only associated with some phylosilicates?

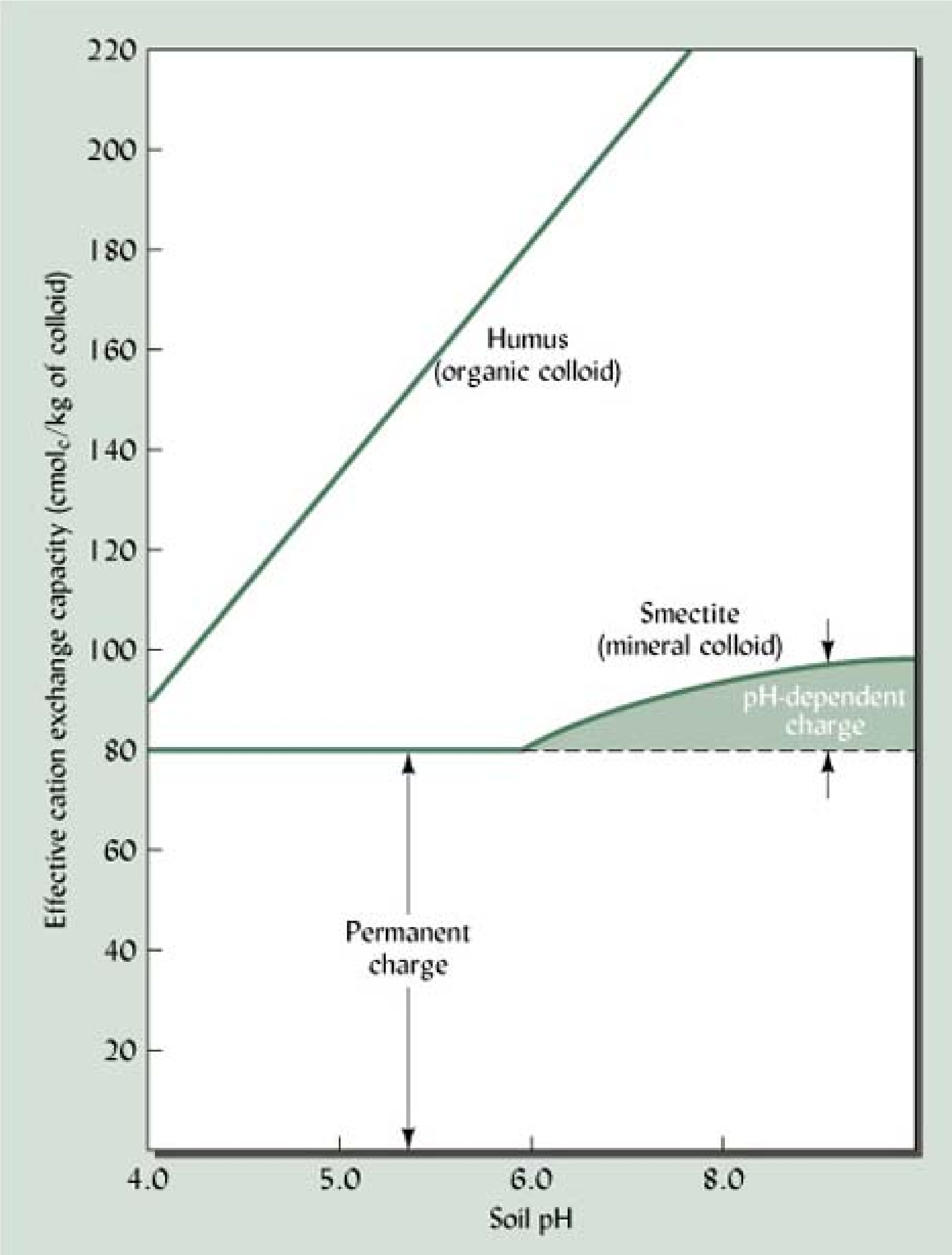
The charge is associated with the Hydroxyl groups (which is on the octahedral sheet of 1:1, 2:1 and 2:1:1 layers),

BUT is ONLY EXPOSED on the edge of phylosilicates and the face of 1:1 phylosilicates



The Real Edge Effect!




Effective cation exchange capacity ($cmol_c$/kg of colloid)
220
200
180
160
140
120
100
80
60
40
20
4.0
5.0
6.0
8.0
Soil pH
Humus
(organic colloid)
Smectite
(mineral colloid)
pH-dependent
charge
Permanent
charge