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Origin of Clay Minerals

The contact of rocks and water produces clays, either at or near the surface of the earth" (from Velde, 1995).

Rock + Water → Clay

For example,

The CO_2 gas can dissolve in water and form carbonic acid, which will become hydrogen ions H^+ and bicarbonate ions, and make water slightly acidic.

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

The acidic water will react with the rock surfaces and tend to dissolve the K ion and silica from the feldspar. Finally, the feldspar is transformed into kaolinite.

Feldspar + hydrogen ions+water → clay (kaolinite) + cations, dissolved silica

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

- Note that the hydrogen ion displaces the cations.
- The alternation of feldspar into kaolinite is very common in the decomposed granite.

- The clay minerals are common in the filling materials of joints and faults (fault gouge, seam) in the rock mass.

Clay Mineral:

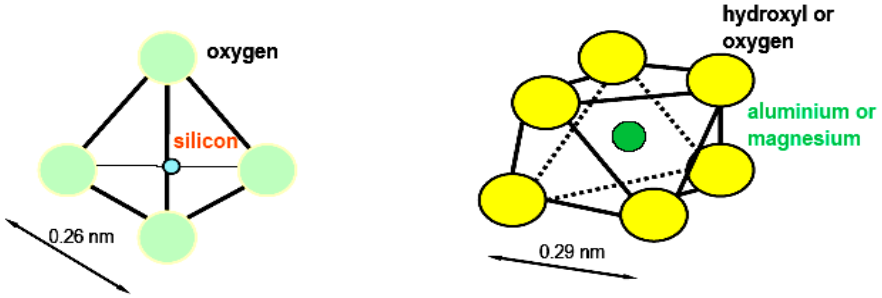
1. Possess the tendency to develop plasticity when mixed with water.
2. More than 90% of soils in the world are silicate minerals.

Two basic minerals:

1. silicon Oxygen tetrahedron (SiO_4)
2. Aluminum Magnesium octahedron $Al_2(OH)_3$,$Mg_2(OH)_3$

Basic Structural Units

Clay minerals are made of two distinct structural units.

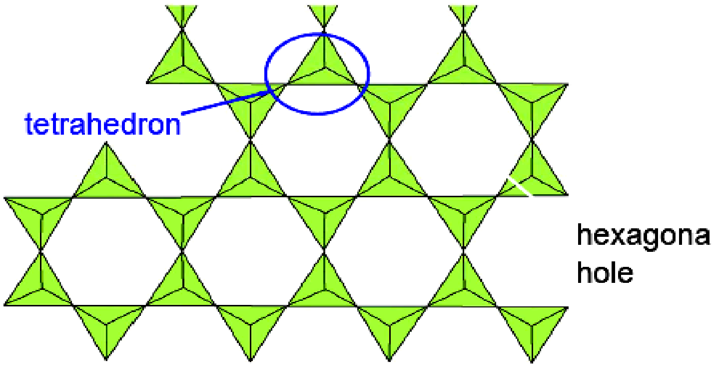


Silicon tetrahedron **Aluminium Octahedron**

$(Si_2O_{10})^{-4}$ Replace four Oxygen with hydroxyls or combine with positive union

Tetrahedral Sheet

Several tetrahedrons joined together form a tetrahedral sheet.



Tetrahedron
Plural: Tetrahedral

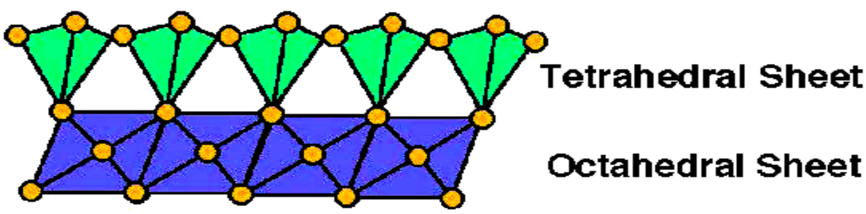
For simplicity, let's represent silica **tetrahedral sheet** by:

and alumina **octahedral sheet** by:

Different Clay Minerals

Different combinations of tetrahedral and octahedral sheets form different clay minerals:

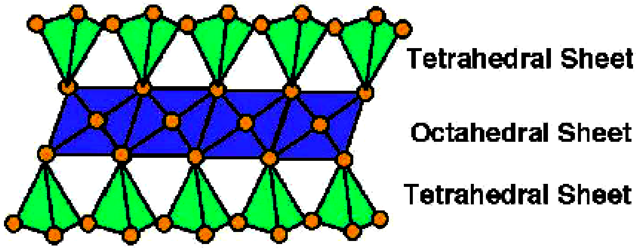
<u>1:1 Clay Mineral</u> (e.g., kaolinite, halloysite):



Different Clay Minerals

Different combinations of tetrahedral and octahedral sheets form different clay minerals:

<u>2:1 Clay Mineral</u> (e.g., montmorillonite, illite)



Unit-Summary

Silica sheet (tips up) **or** (tips down)

Octahedral sheet **(Various cations in octahedral coordination)**

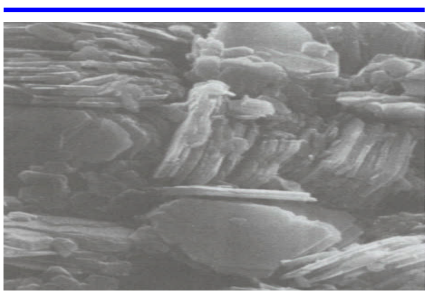
Gibbsite sheet G **(Octahedral sheet cations are mainly aluminum)**

Brucite sheet B **(Octahedral sheet cations are mainly magnesium)**

Kaolinite

- $Si_4Al_4O_{10}(OH)_8$. Platy shape
- The bonding between layers are van der Waals forces and hydrogen bonds (strong bonding).
- There is no interlayer swelling
- Width: 0.1~ 4μm, Thickness: 0.05~2 μm

17 μm



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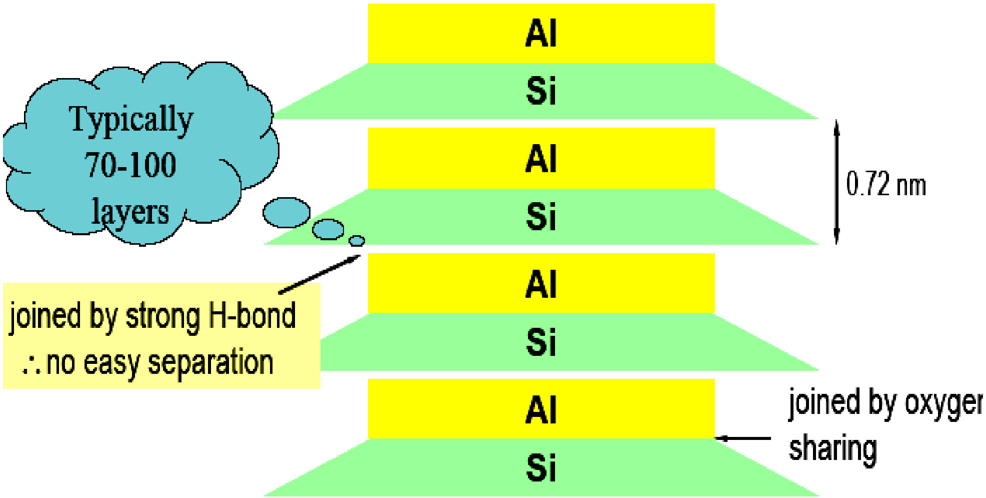
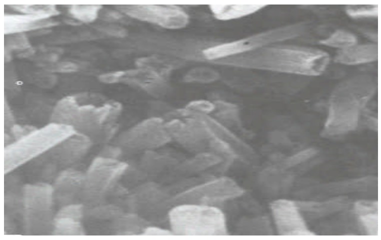
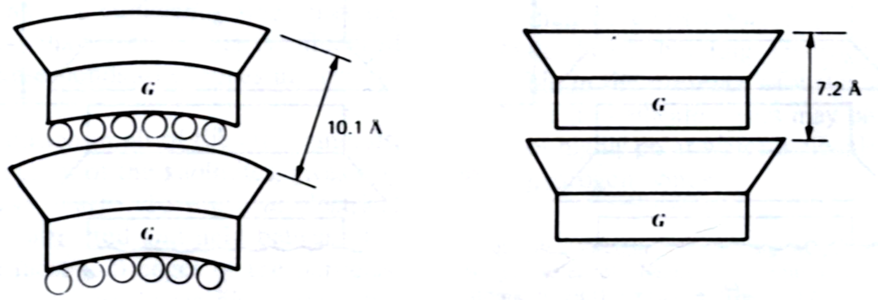


Halloysite

- $Si_4Al_4O_{10}(OH)_8 \cdot 4H_2O$
- A single layer of water between unit layers.
- The basal spacing is 10.1 Å for hydrated halloysite and 7.2 Å for dehydrated halloysite.
- If the temperature is over 50 °C or the relative humidity is lower than 50%, the hydrated halloysite will lose its interlayer water (Irfan, 1966). Note that this process is **irreversible** and will affect the results of soil classifications (GSD and Atterberg limits) and compaction tests.
- There is no interlayer swelling.
- Tubular shape while it is hydrated.

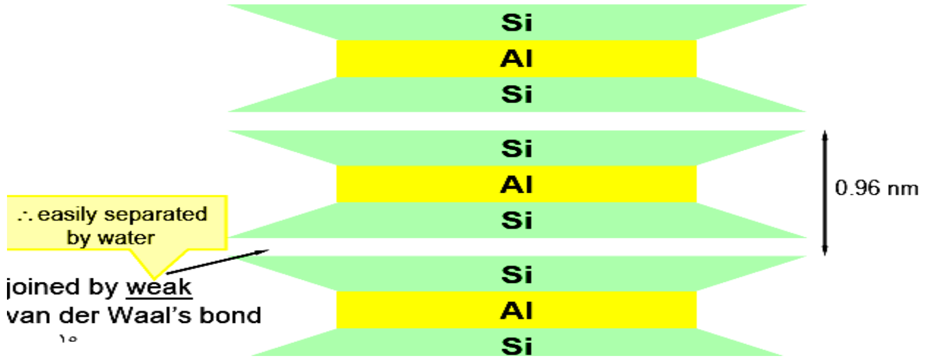


2 μm



Montmorillonite

- also called **smectite**; expands on contact with water



- A highly reactive (expansive) clay
- $(OH)_4Al_4Si_8O_{20}.nH_2O$

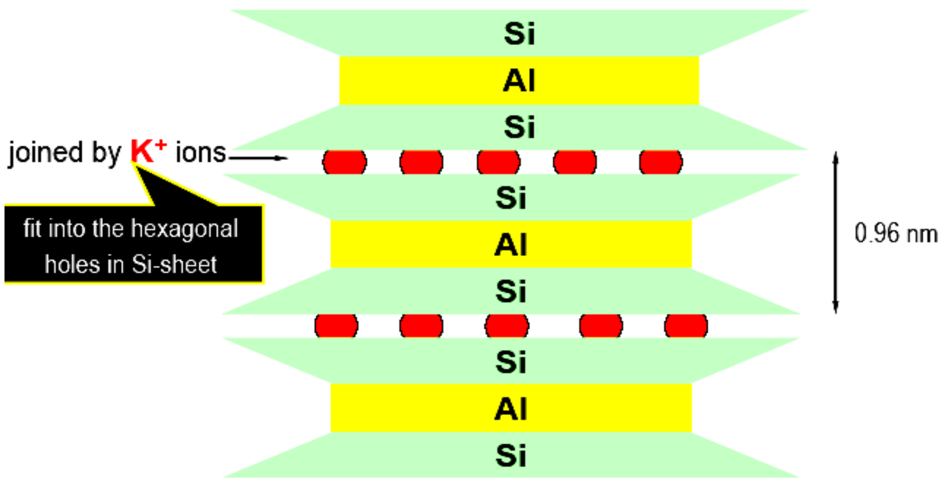
swells on contact with water

high affinity to water

Bentonite

- montmorillonite family
- used as drilling mud, in slurry trench walls, stopping leaks

Illite



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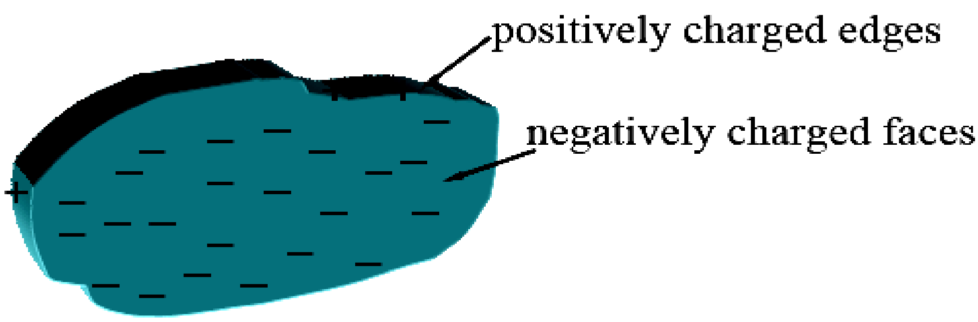
<u>Clay Minerals :</u> are complex aluminum silicates composed of two basic units , silica and alumina ,they possess the tendency to develop plasticity when mixed with water.

<u>Nature of water in clay</u>

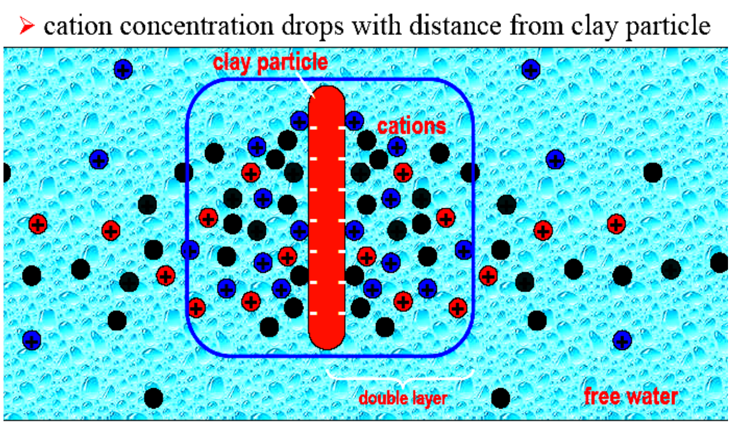
- shape of a clay particle is plately.
- The net charge at the face of clay particle is (-ve).
- There are (+ve) charge at edges of a clay particle.
- There are (+ve) ions (cautions) from salts in water, also the water molecules are dipolar or dipoles.



Clay Particle with Net negative Charge

<u>Exchangeable Ions</u> : a soil particle in nature attracts ions to neutralize its net charge, these ions are weakly held on the particle surface and can be replaced by other ions.
Al^{+3} >ca^{+2} >Mg^{+2} >NH_4^{+} >K^{+}>H^{+} >Na^{+} >Li^{+}

Cation Concentration in Water



<u>Double Layer</u>: describes *<u>all the water</u>* hold to clay particle by attractive force.

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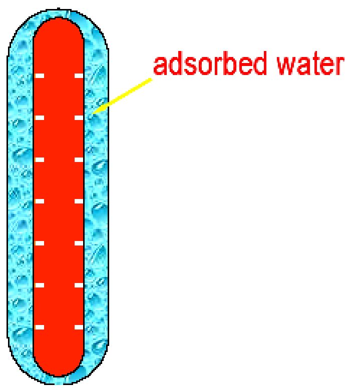
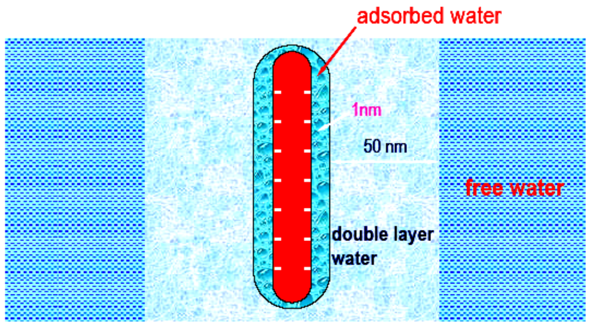
Adsorbed water: the *innermost* layer of double layer water which is held very strongly by clay.



Clay Particle in Water



Thickness of the double layer: the distance from the surface required to neutralize the net charge on the particle or the distance over which there is electrical potential.

4-1. Calculate the specific surface of a cube (1) 10 mm, (b) 1 mm, (c) 1 • m, and (d) 1 nm on a side. Calculate the specific surface in terms of both areas and m^2/kg. Assume for the latter case that • s = 2.65 Mg/m^3.

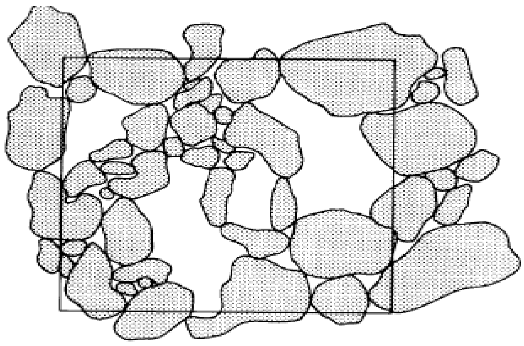
4-2. The values of e_{min} and e_{max} for a pure silica sand (• s = 2.65 Mg/m^3) were found to be 0.46 and 0.66 respectively. (a) what is the corresponding range in dry density? (b) If the in situ void ratio is 0.63, what is the density index?

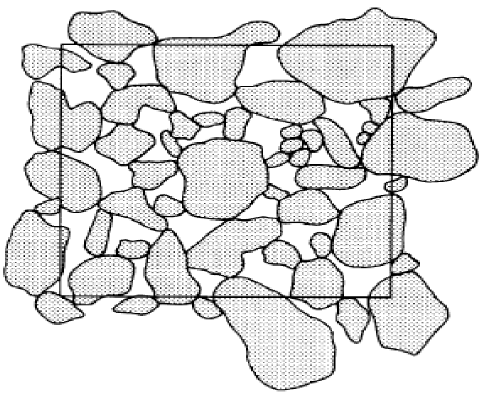
4-3. Describe briefly the crystalline or atomic structure of the following ten minerals. Also list any important distinguishing characteristics.

(a) Smecite; (b) Brucite; (c) Gibbsite
(d) Attapulgite (e) Bentonite (f) Allophane
(g) Halloysite (h) Ilite (i) Mica
(j) Chlorite

4-4. Which sheet, silica or alumina, would you wear to a fancy dress dance? Why?

4-5. Given the particles in the attached Figure, is it realistic to show that all the particles are in contact with each other for this given plane? Any given plane? Why?





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QUESTION 4-1

GIVEN: Cube; • ⇐ 2.65 Mg/m^3;

Find specific surface = surface area divide by volume

and specific surface = surface area divide by mass

(A) S = 10 MM

$$Specific\ Surface = \frac{6\ x\ 0.01^2}{0.01^3} = 0.6\ mm^{-1}$$

$$Aternately = \frac{0.6\ x\ 1000}{2.65\ x\ 1000} = 0.226\ \frac{m^2}{kg}$$

(B) S = 1 MM

$$Specific\ Surface = \frac{6\ x\ 0.001^2}{0.001^3} = 6.0\ mm^{-1}$$

$$Aternately = \frac{6.0\ x\ 1000}{2.65\ x\ 1000} = 2.26\ \frac{m^2}{kg}$$

(C) S = 1 • M

$$Specific\ Surface = \frac{6\ x\ 0.000001^2}{0.000001^3} = 6000\ mm^{-1}$$

$$Aternately = \frac{6000\ x\ 1000}{2.65\ x\ 1000} = 2260\ \frac{m^2}{kg}$$

(D) S = 1 NM

$$Specific\ Surface = \frac{6\ x\ 0.000000001^2}{0.000000001^3} = 6\ x\ 10^6\ mm^{-1}$$

$$Aternately = \frac{6\ x\ 10^6\ x\ 1000}{2.65\ x\ 1000} = 2.26\ x\ 10^6\ \frac{m^2}{kg}$$

QUESTION 4-2

$$Density = \frac{Mass}{Volume} = \frac{\rho_s}{1+e}$$

$$\therefore \rho_{max} = \frac{2.65}{1+e_{min}} = \frac{2.65}{1+0.46} = 1.82\ g/cm^3$$

$$\therefore \rho_{min} = \frac{2.65}{1+e_{max}} = \frac{2.65}{1+0.66} = 1.60\ g/cm^3$$

$$Relative\ Density = Density\ Index = D_r$$

$$= \frac{e_{max} - e_{field}}{e_{max} - e_{min}} = \frac{0.66 - 0.63}{0.66 - 0.46} = 0.15$$

or 15 %

QUESTION 4-3

(A) SMECTITE

Smectite also known as Montmorillenite is a 2:1 mineral composed of a repetition of one octahedral alumina (gibbsite) sheet sandwiched between two tetrahedral silica sheets (i.e. TOT). The ideal formula is $(OH)_4Si_8Al_4O_{20}$(interlayer)H_2O and the composition without the interlayer SiO_2, 66.7%; Al_2O_3, 28.3%; H_2O, 5%. The Silicon places in the tetrahedral sheets may be occupied by Aluminum. Similarly the Aluminum places may be occupied by Iron, Magnesium or both.

Between the adjacent (repetitive) terahedral sheets of two TOT units there is a weak bonding where water and exchangeaable ions can easily entre. This results in a high swell potential (or high attraction for water) for the smectite mineral. Another mineral with high swelling potential is Halloysite or Vermiculite.

(B) BRUCITE

Brucite is composed of single octahedral sheets where the anion (oxygen) postions are all occupied by hydroxils and the cation postions are occupied by Magnesium. Its ideal formula is $Mg_3(OH)_6$. Its importance is that of being a single layer mineral which in combinaton with tetrahedral sheets makes up the crystal structure of other minerals.

(C) GIBBSITE

Gibbsite like Brucite is a one layer mineral. This layer is octahedral where 1/3 of the cation positions are empty and the remaining 2/3 positions have Aluminum ions. Its ideal formula is $Al_2(OH)_6$

(D) ATTAPULGITE

Attapulgite has a chain silicate crystal structure. Chain silicates basic unit consists of rows of tetrahedrals each sharing two corners. This makes it look columnar. It is not a clay mineral and it is not a common clay constituent. The composition of an ideal cell is $(OH_2)_4(OH)_2Mg_5Si_8O_{20}.4H_2O$.

(E) BENTONITE

Bentonite is not a mineral but an altered volcanic ash. The dominant clay mineral in Bentonite is Sodium Montmorillenite. Bentonite expands its volume when placed in water (possibly to 1200% or more). It is used as a drilling fluid because of it increases the viscosity of a fluid to several times the viscosity of water.

(F) ALLOPHANE

Allophane is an amorphous or poorly crystallized alumino silicate. Even though it is poorly crytallized it is often classified as a clay mineral. Any amorphous clay is classified as allophane.

(G) HALLOYSITE

Halloysite exists with the crystal structure of Kaolinite (tetrahedral-Octahedral units bonded together by a hydrogen bond between the hydroxil ions). There are two forms of Halloysite. One with Kaolinite composition, $Al_4Si_4O_{10}(OH)_8$, and the other with the composition $Al_4Si_4O_{10}(OH)_8.4H_2O$. The second dehydrates to the first with the loss of interlayer water molecules. This all adds up to Hallosite being a clay mineral with swelling potential.

(H) ILLITE

Illite has the same TOT crystal structure as Montmorillite (i.e. a 2:1 mineral). The difference is that the hexagonal holes in the terahedral sheets are occupied with a Potasium ion bonding the layers together and preventing the formation of an interrlayer of water. Illite is a general term for the mica like clay minerals. The illites differ from the micas in having less substitution of Aluminum for Silicon. They contain more water and they have Potasium partly replaced by Calcium and Magnesium. Even though is a non-swelling clay Illites are chemically more active tham micas. Their ideal formula is $(OH)_4K_2(Al_2Si_6)AL_4O_{20}$.

(I) MICA

Mica is not a clay mineral but rather a clay soil constituent. Micas are a group of 2:1 minerals with interlayer cations and little or no exchangeable water in between. They consist of 2 tetradehal sheets with one octrahedral sheet sandwiched in between (i.e. TOT). Due to the strong bonding by ions Mica has no swell potential.

(J) CHLORITE

Chlorite like mica is a group of minerals. It is a 2:1:1 mineral and consists of a sequence of: a Silica sheet, an Alumina sheet, another Silica sheet, and either a Gibbsite sheet or a Brucite sheet making it sensitive to hydration. It has swell potential, but is much less active than montmorillonite.

QUESTION 4-4

Based on usage, Sillica in glass or Aluminum in foil the choice is ALUMINA.

Based on the drawings of the crystal lattices, a Sillica sheet has gaping hexagonal holes while a Alumina sheet has a densely packed structure providing better coverage. Again the choice is ALUMINA

QUESTION 4-5

Soil particles are highly irregular and three-dimensional in nature, it is unrealistic to show them all in contact in any one plane. The particles would need to be a bundle of rods, in which case they would be regular in a two-dimensional plane.