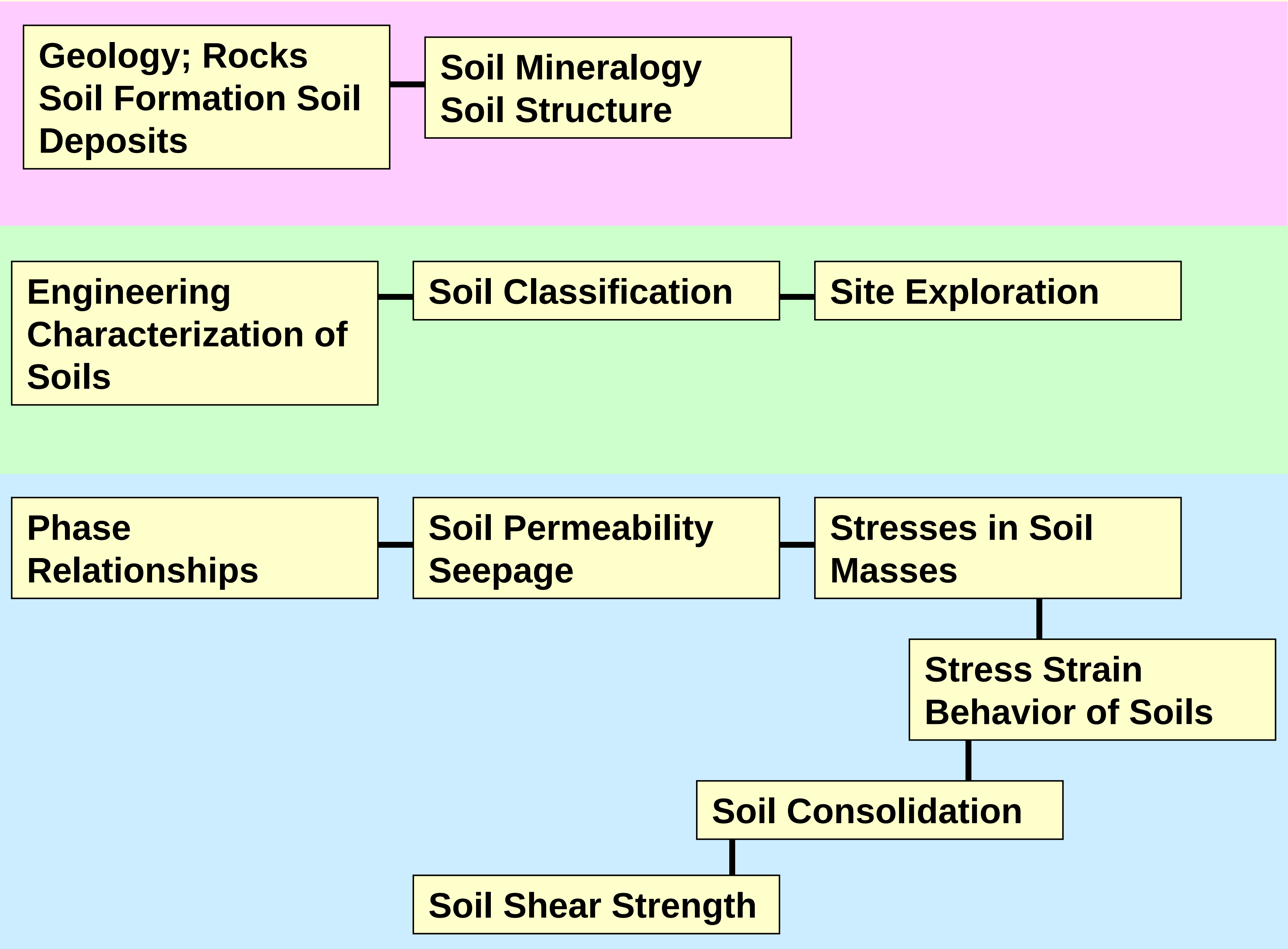

Geology; Rocks Soil Formation Soil Deposits
Soil Mineralogy Soil Structure
Engineering Characterization of Soils
Soil Classification
Site Exploration
Phase Relationships
Soil Permeability Seepage
Stresses in Soil Masses
Stress Strain Behavior of Soils
Soil Consolidation
Soil Shear Strength

Engineering Characterization of Soils

<u>Soil Properties that Control its Engineering Behavior</u>

- Particle Size
  - Sieve Analysis
  - Hydrometer Analysis

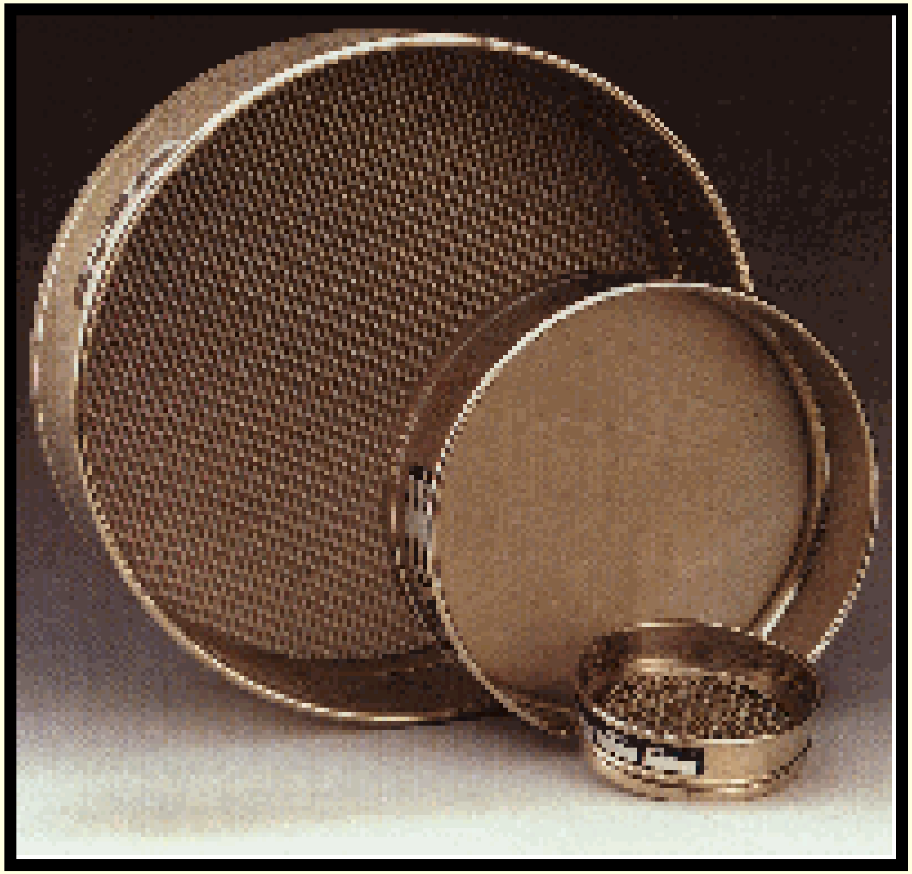
coarse-grained

- Particle/Grain Size Distribution
- Particle Shapes (?)

fine-grained

- Soil Plasticity

Particle Size; Standard Sieve Sizes

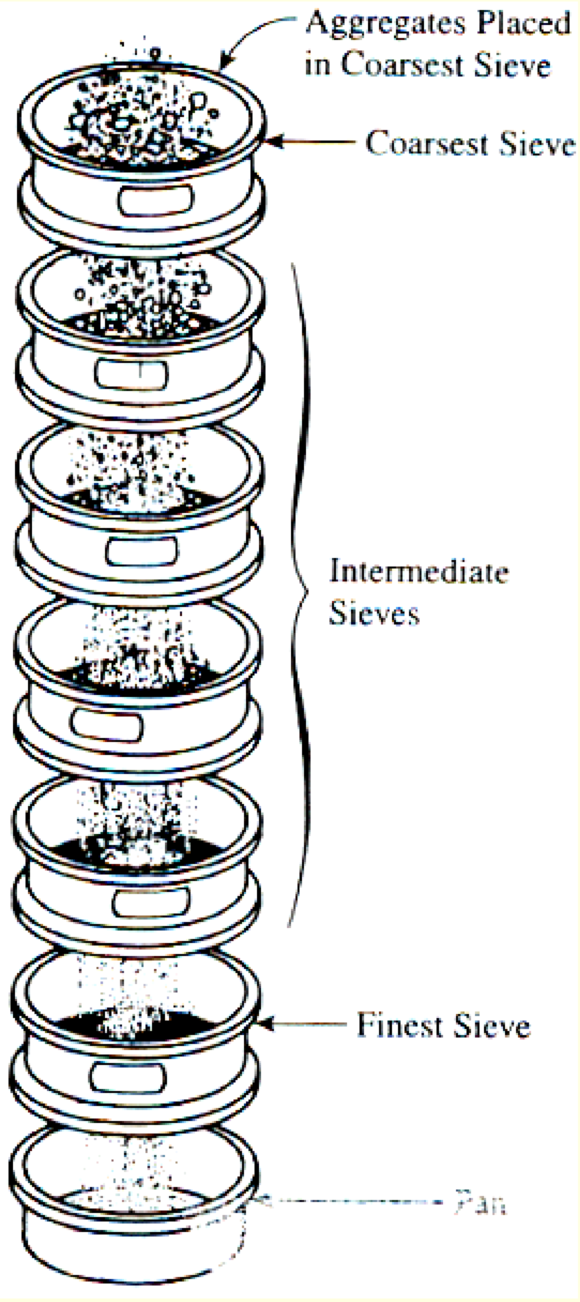


ASTM Particle Size Classification

Sieve Size		Particle Diameter		Soil Classification	
Passes	Retained on	(in)	(mm)		
	12 in	> 12	> 350	Boulder	Rock Fragments
12 in	3 in	3 - 12	75.0 - 350	Cobble	
3 in	3/4 in	0.75 - 3	19.0 - 75.0	Coarse gravel	Soil
3/4 in	#4	0.19 - 0.75	4.75 - 19.0	Fine gravel	
#4	#10	0.079 - 0.19	2.00 - 4.75	Coarse sand	
#10	#40	0.016 - 0.079	0.425 - 2.00	Medium sand	
#40	#200	0.0029 - 0.016	0.075 - 0.425	Fine sand	
#200		< 0.0029	< 0.075	Fines (silt + clay)	

Sieve Analysis (Mechanical Analysis)

- This procedure is suitable for coarse grained soils
- See next slide for ASTM Standard Sieves
- No.10 sieve .... Has 10 apertures per linear inch



ASTM Standard Sieves

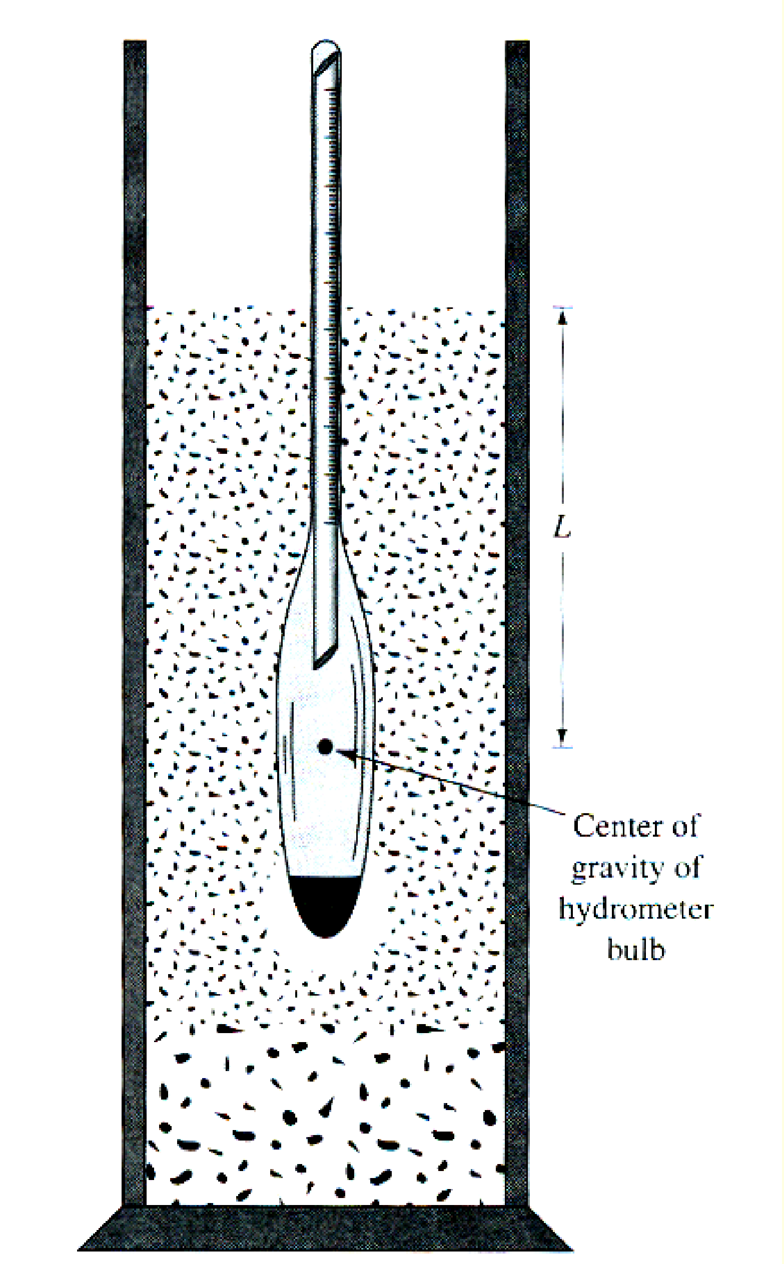
Sieve Identification	Opening Size (in)	Opening Size (mm)
3 inch	3.00	76.2
2 inch	2.00	50.8
1½ inch	1.50	38.1
1 inch	1.00	25.4
3/4 inch	0.75	19.0
3/8 inch	0.375	9.52
#4	0.187	4.75
#8	0.0929	2.36
#10	0.0787	2.00

Sieve Identification	Opening Size (in)	Opening Size (mm)
#16	0.0465	1.18
#20	0.0335	0.850
#30	0.0236	0.600
#40	0.0167	0.425
#50	0.0118	0.300
#60	0.00984	0.250
#100	0.00591	0.150
#140	0.00417	0.106
#200	0.00295	0.075

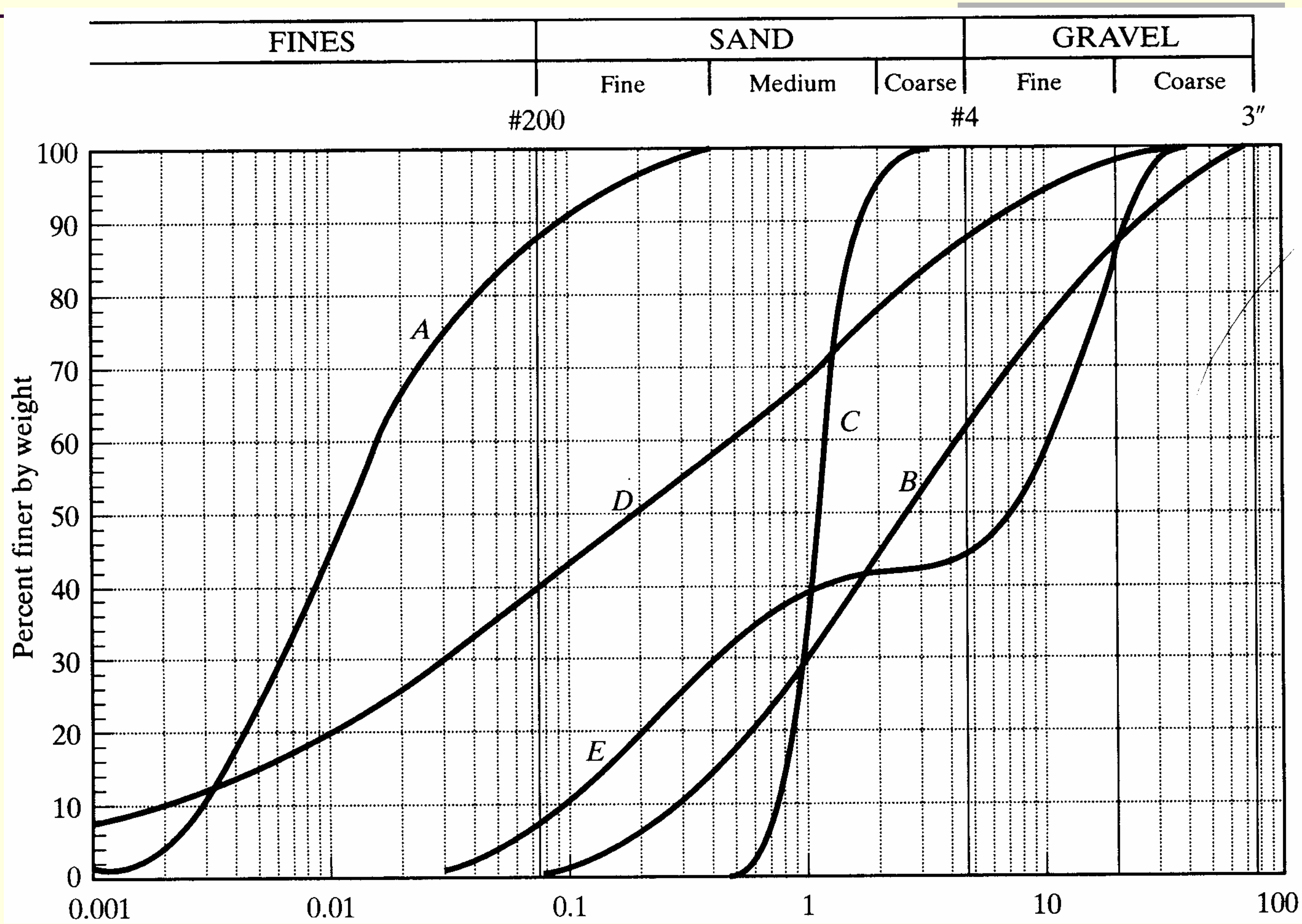
Hydrometer Analysis

- Also called Sedimentation Analysis
- Stoke's Law

$$v = \frac{D^2 \gamma_w (G_s - G_L)}{18\eta}$$



Grain Size Distribution Curves



Terminology

- C….. Poorly-graded soil
- D …. Well-graded soil
- E …. Gap-graded soil
- D_{10}, D_{30}, D_{60} = ??
- Coefficient of Uniformity, $C_u = D_{60}/D_{10}$
- Coefficient of Curvature,

$$C_c = (D_{30})^2/(D_{10})(D_{60})$$

Particle Distribution Calculations Example

TABLE 2–3
Sieve Analysis Data for Example 2–1

(1) Sieve Number	(2) Sieve Opening (mm)	(3) Weight Retained (g)	(4) Percentage Retained	(5) Cumulative Percentage Retained	(6) Percentage Passing
¾ in.	19.0	0	0	0	100
⅜ in.	9.50	158	7.9	7.9	92.1
No. 4	4.75	308	15.4	23.3	76.7
No. 10	2.00	608	30.4	53.7	46.3
No. 40	0.425	652	32.6	86.3	13.7
No. 100	0.150	224	11.2	97.5	2.5
No. 200	0.075	42	2.1	99.6	0.4
Pan	—	8	0.4	100.0	—

Required

A grain-size distribution curve for this soil sample.

Solution

To plot the gradation curve, one must first calculate the percentage retained on each sieve, the cumulative percentage retained, and the percentage passing through each sieve, then tabulate the results, as shown in Table 2–3.

Total sample weight = 2000 g

1. The percentage retained on each sieve is obtained by dividing the weight retained on each sieve by the total sample weight. Thus,

$$\text{Percentage retained on } 3/4\text{-in. sieve} = \frac{0\text{ g}}{2000\text{ g}} \times 100\% = 0\%$$

$$\text{Percentage retained on } 3/8\text{-in. sieve} = \frac{158\text{ g}}{2000\text{ g}} \times 100\% = 7.9\%$$

$$\text{Percentage retained on No. 4 sieve} = \frac{308\text{ g}}{2000\text{ g}} \times 100\% = 15.4\% \qquad \text{etc.}$$

Therefore,

$$\text{Column (4)} = \frac{\text{Column (3)}}{\text{Total sample weight}} \times 100\%$$

2. The cumulative percentage retained on each sieve is obtained by summing the percentage retained on all coarser sieves. Thus,

Cumulative percentage retained on ¾-in. sieve = 0%
Cumulative percentage retained on ⅜-in. sieve = 0% + 7.9% = 7.9%
Cumulative percentage retained on No. 4 sieve = 7.9% + 15.4% = 23.3%
Cumulative percentage retained on No. 10 sieve = 23.3% + 30.4% = 53.7% etc.

3. The percentage passing through each sieve is obtained by subtracting from 100% the cumulative percentage retained on the sieves. Thus,

Percentage passing through ¾-in. sieve = 100% − 0% = 100%
Percentage passing through ⅜-in. sieve = 100% − 7.9% = 92.1%
Percentage passing through No. 4 sieve = 100% − 23.3% = 76.7% etc.

Therefore, column (6) = 100% − column (5).

4. Upon completion of these calculations, the grain-size distribution curve is obtained by plotting column (2), sieve opening (mm), versus column (6), percentage passing through, on semilog paper. The percentage passing is always plotted as the ordinate on the arithmetic scale and the sieve opening as the abscissa on the log scale (see Fig. 2–2).

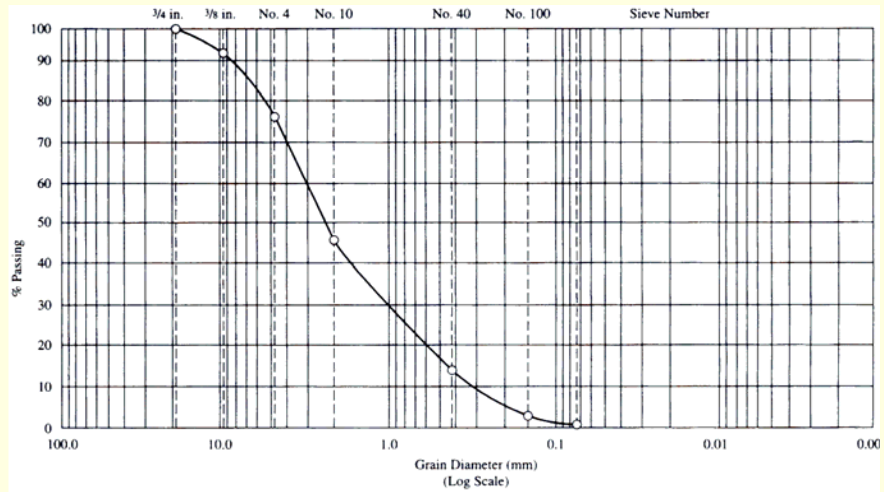
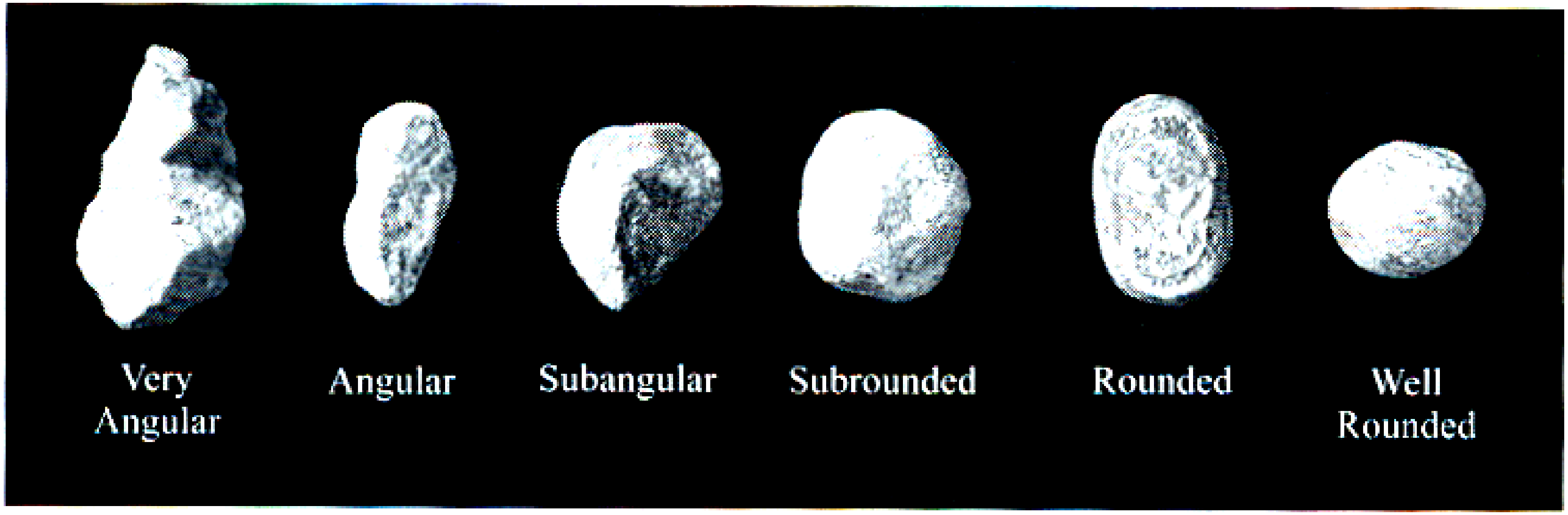


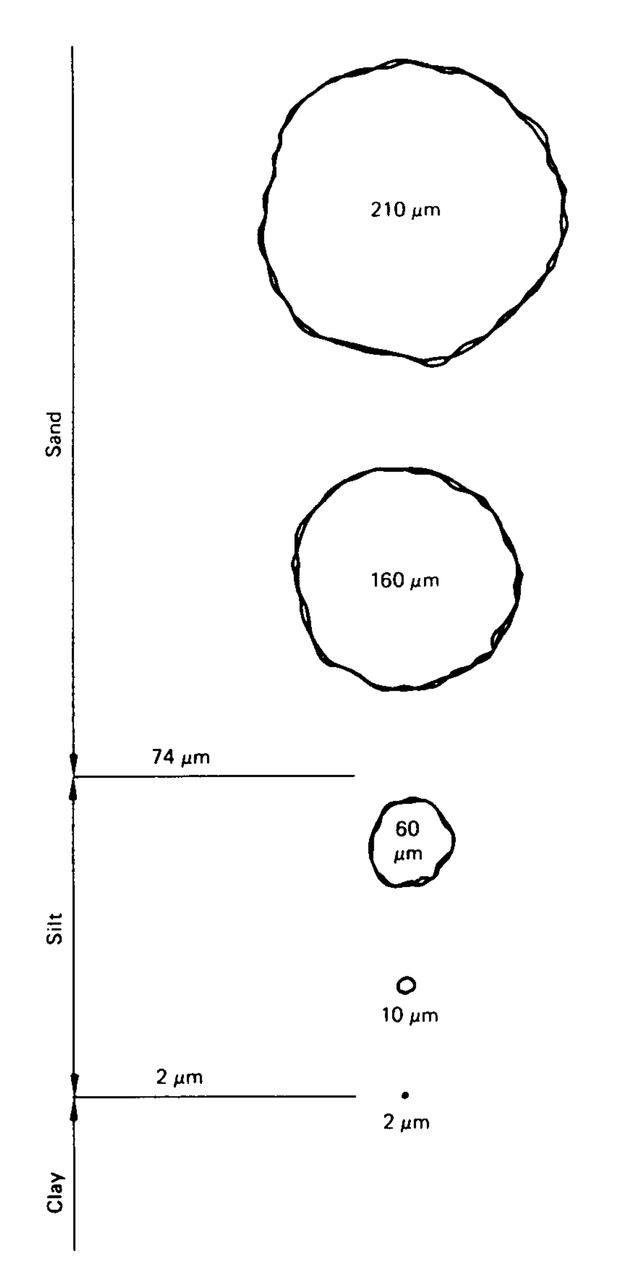
FIGURE 2–2 Grain-size distribution curve for Example 2–1.

Particle Shapes



Clay Formation

- Clay particles < 2 μm
- Compared to Sands and Silts, clay size particles have undergone a lot more "chemical weathering"!



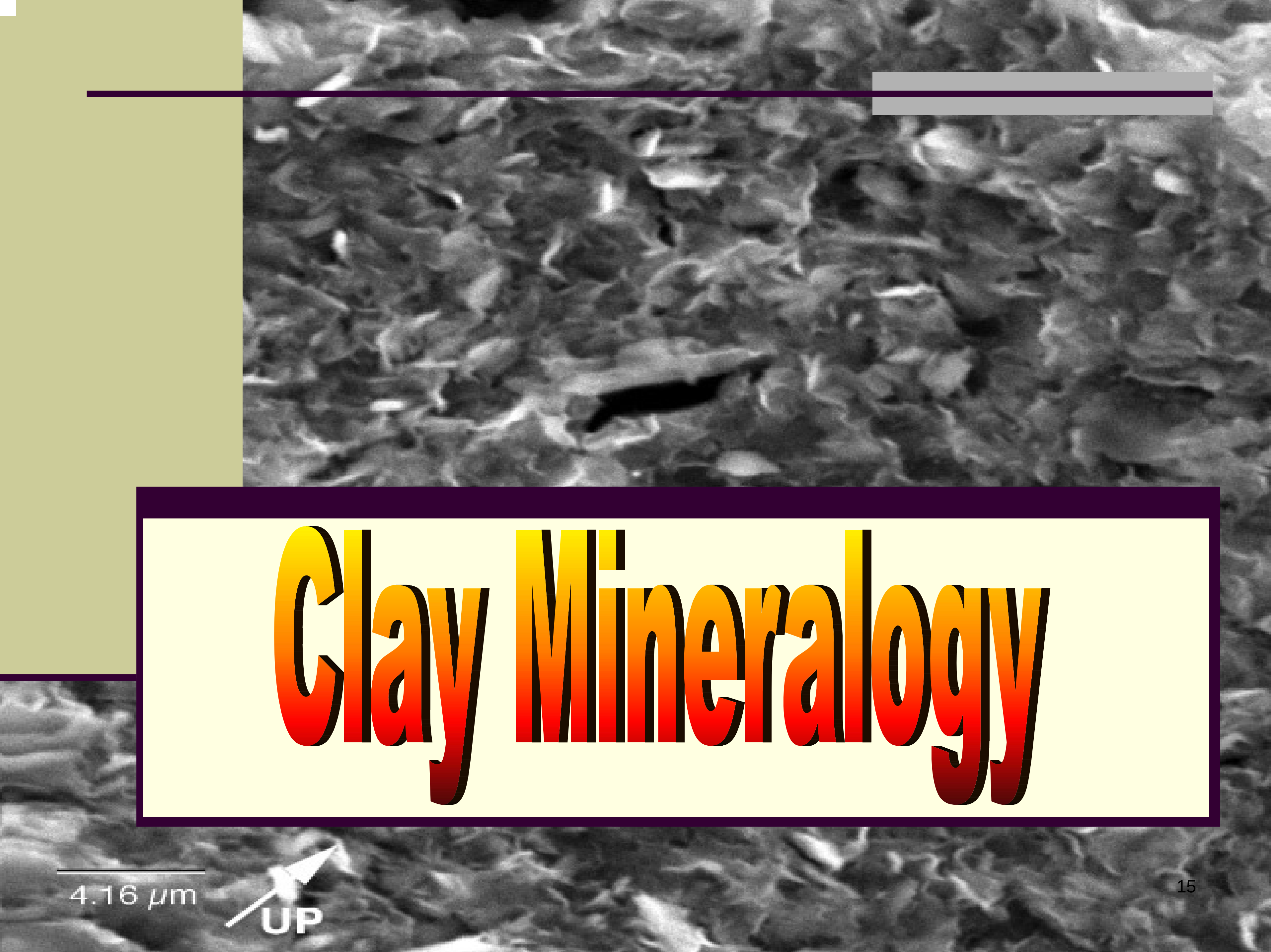
Clay vs. Sand/Silt

- Clay particles are generally more platy in shape (sand more equi-dimensional)
- Clay particles carry surface charge
- Amount of surface charge depends on type of clay minerals
- Surface charges that exist on clay particles have major influence on their behavior (for e.g. plasticity)

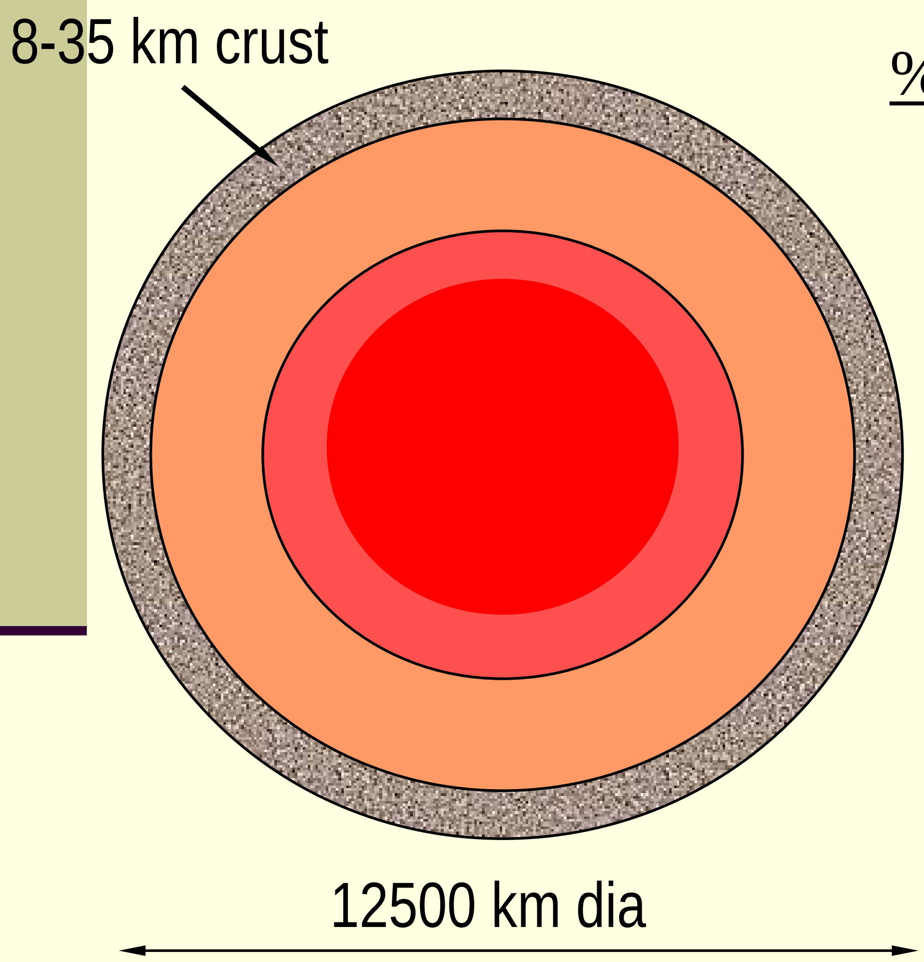
Clay Minerals

- Kaolinite family
  - Kaolinite (ceramic industry, paper, paint, pharmaceutical)
- Smectite family
  - Montmorillonite (weathered volcanic ash, Wyoming Bentonite, highly expansive, used in drilling mud)
- Illite family

Clay Mineralogy



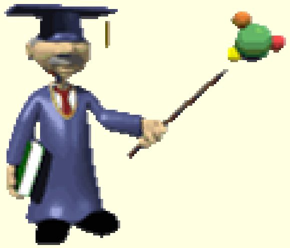
Elements of Earth

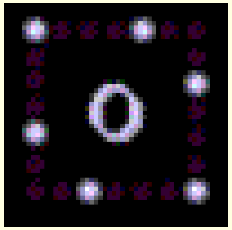


<u>% by weight in **crust**</u>

O	= 49.2	82.4% (O + Si + Al)
Si	= 25.7	
Al	= 7.5	
Fe	= 4.7	
Ca	= 3.4	
Na	= 2.6	
K	= 2.4	
Mg	= 1.9	
other	= 2.6	

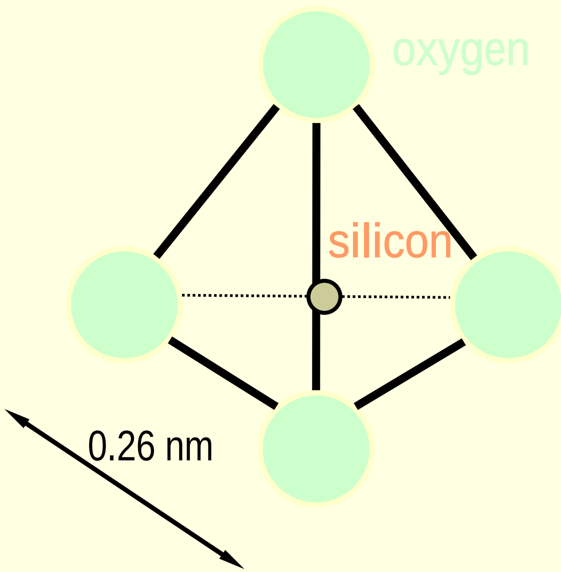
Atomic Structure



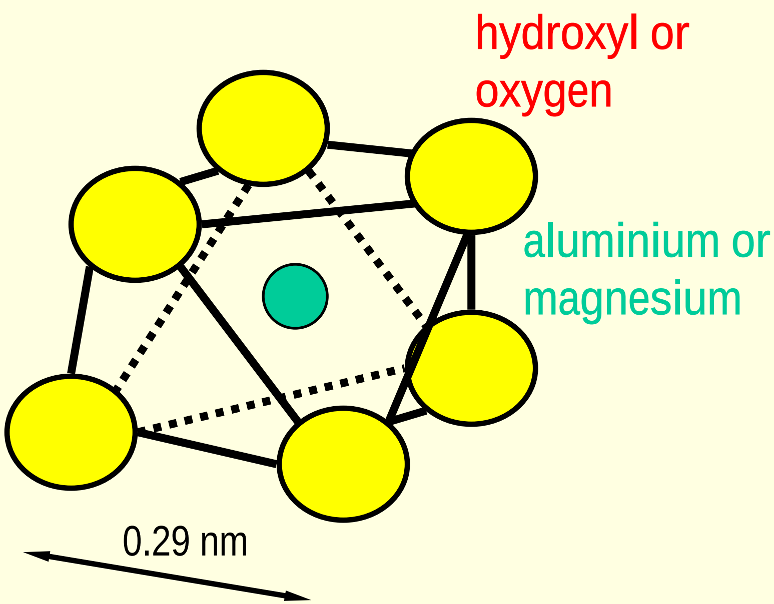


Basic Structural Units

Clay minerals are made of two distinct structural units.



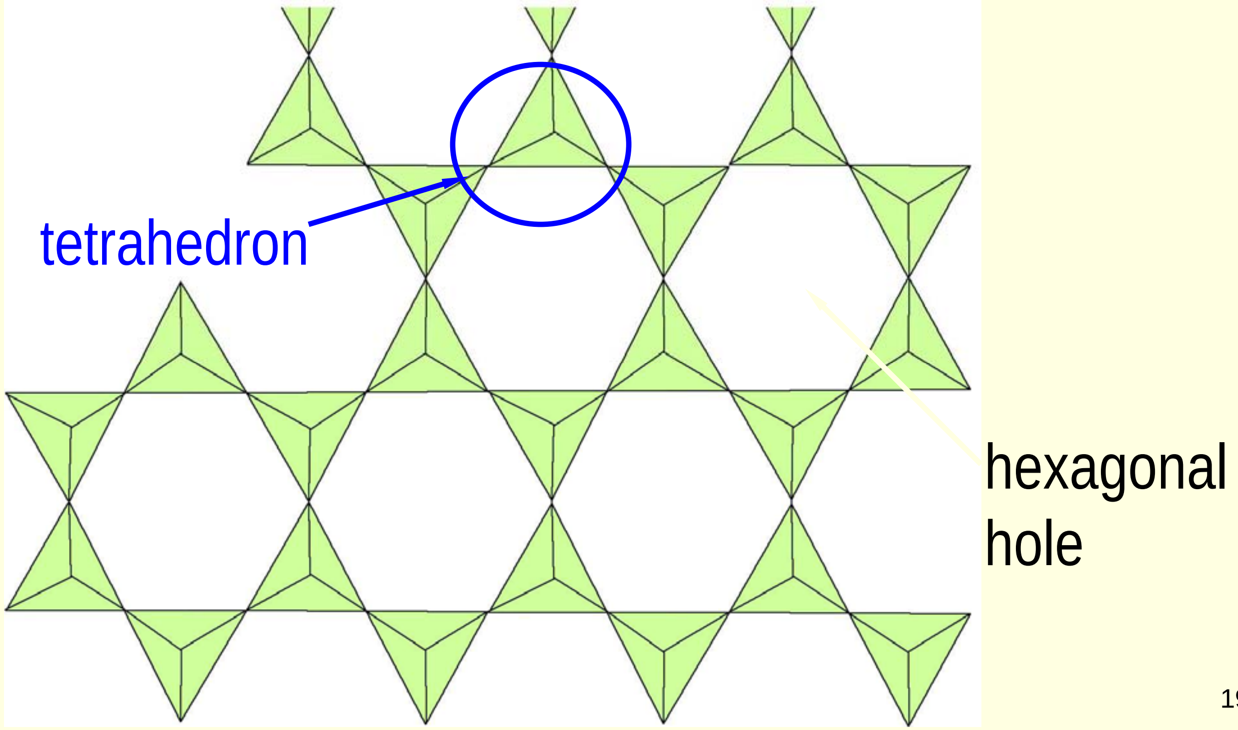
<u>Silicon tetrahedron</u>



<u>Aluminium Octahedron</u>

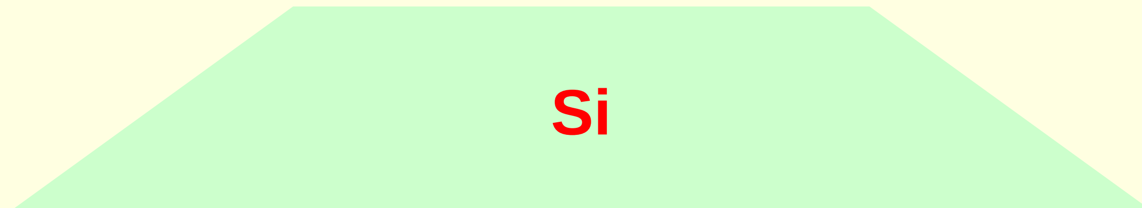
Tetrahedral Sheet

Several tetrahedrons joined together form a tetrahedral sheet.

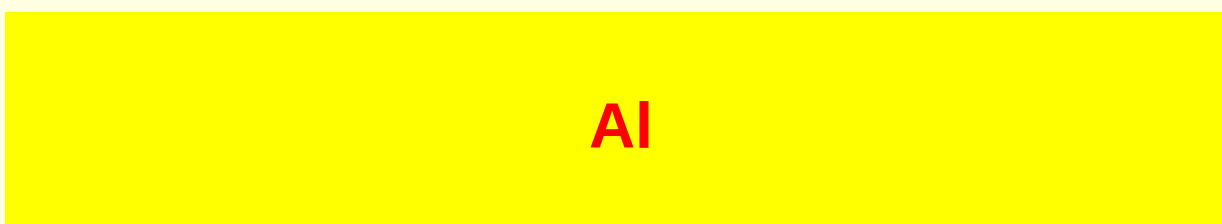


Tetrahedral & Octahedral Sheets

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



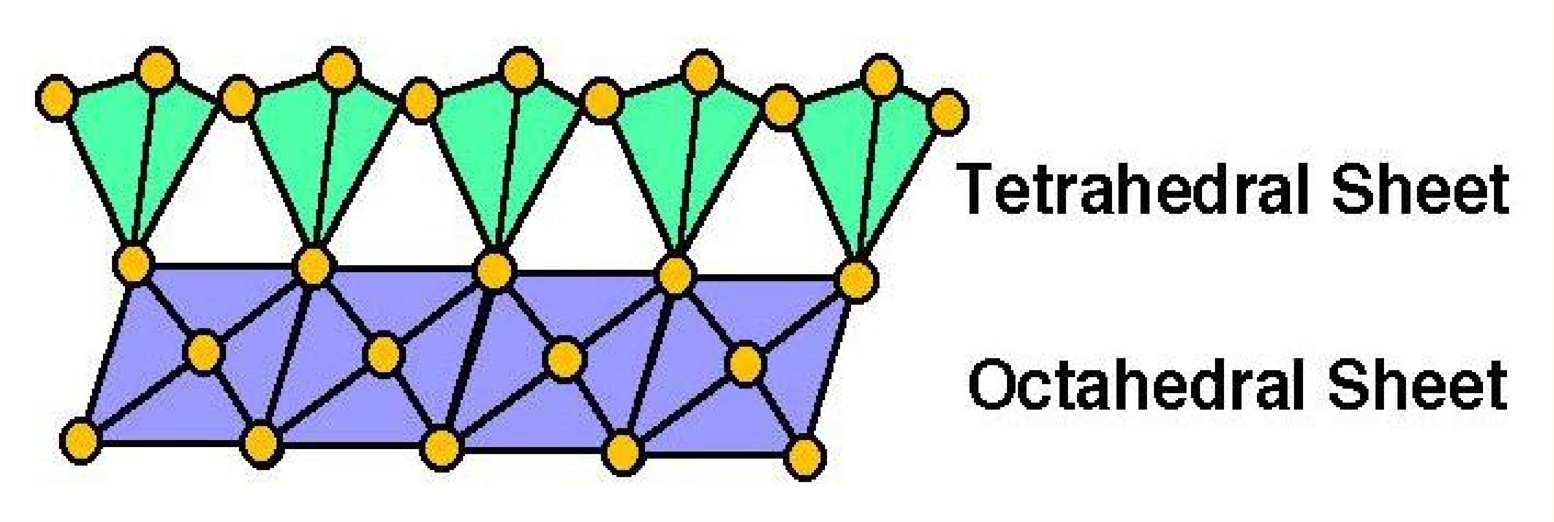
and alumina **octahedral sheet** by:



Different Clay Minerals

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

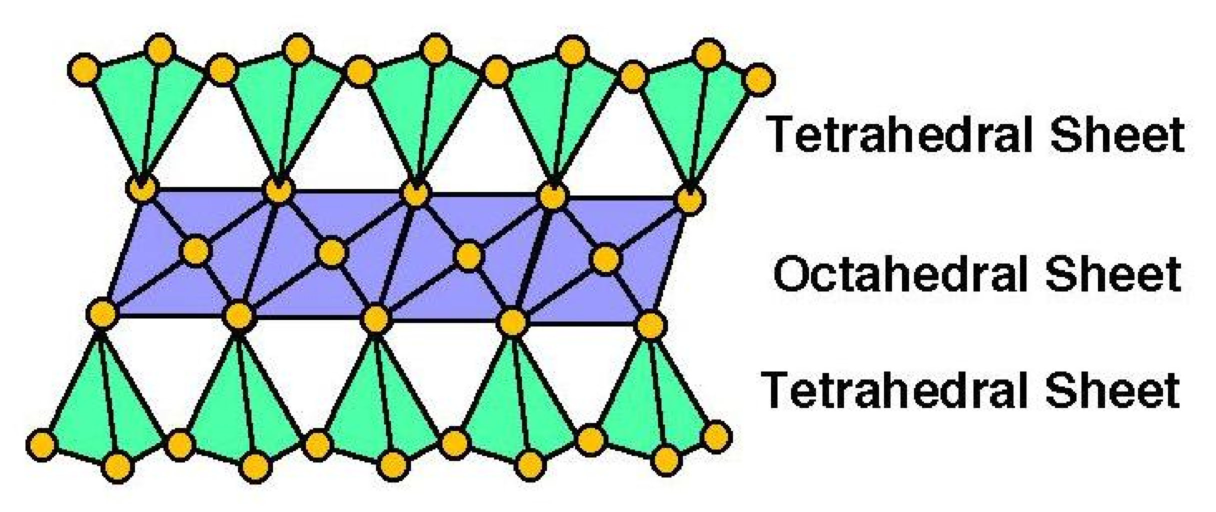
<u>1:1 Clay Mineral</u> (e.g., kaolinite, halloysite):



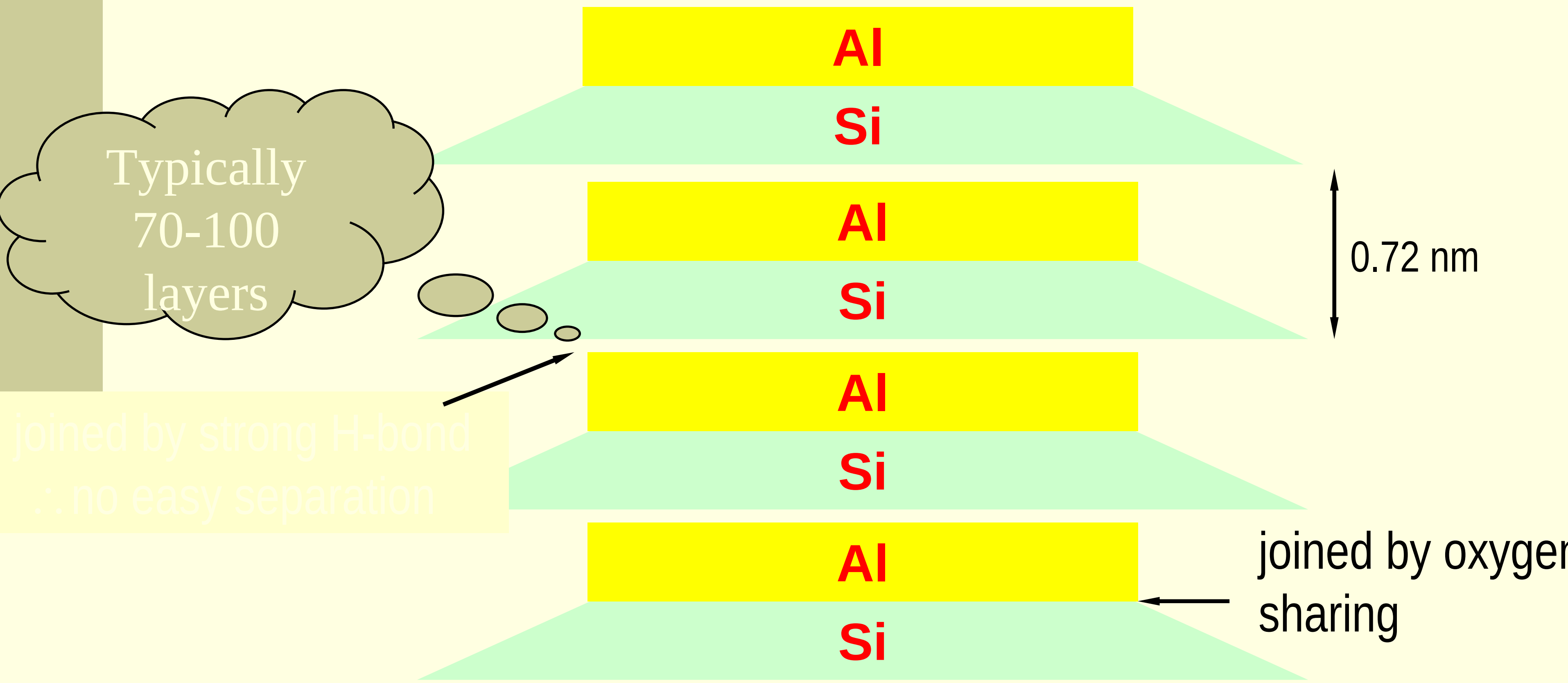
Different Clay Minerals

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

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



Kaolinite


Al
Si
Al
Si
Al
Si
Al
Si
Typically 70-100 layers
0.72 nm
joined by strong H-bond
∴ no easy separation
joined by oxygen sharing

Kaolinite

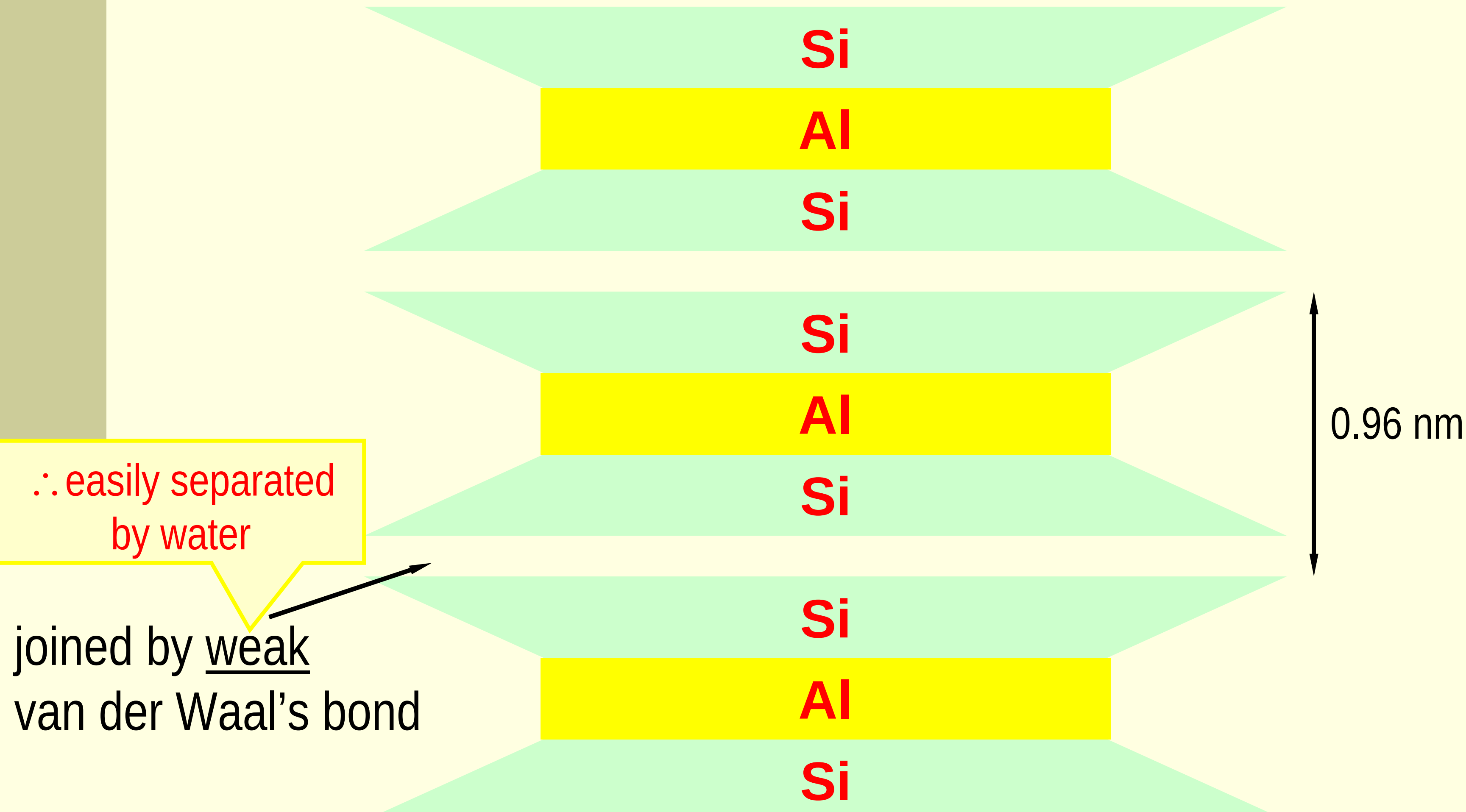
- used in paints, paper and in pottery and pharmaceutical industries
- $(OH)_8Al_4Si_4O_{10}$

Halloysite

- kaolinite family; hydrated and tubular structure
- $(OH)_8Al_4Si_4O_{10}.4H_2O$

Montmorillonite

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



Montmorillonite

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

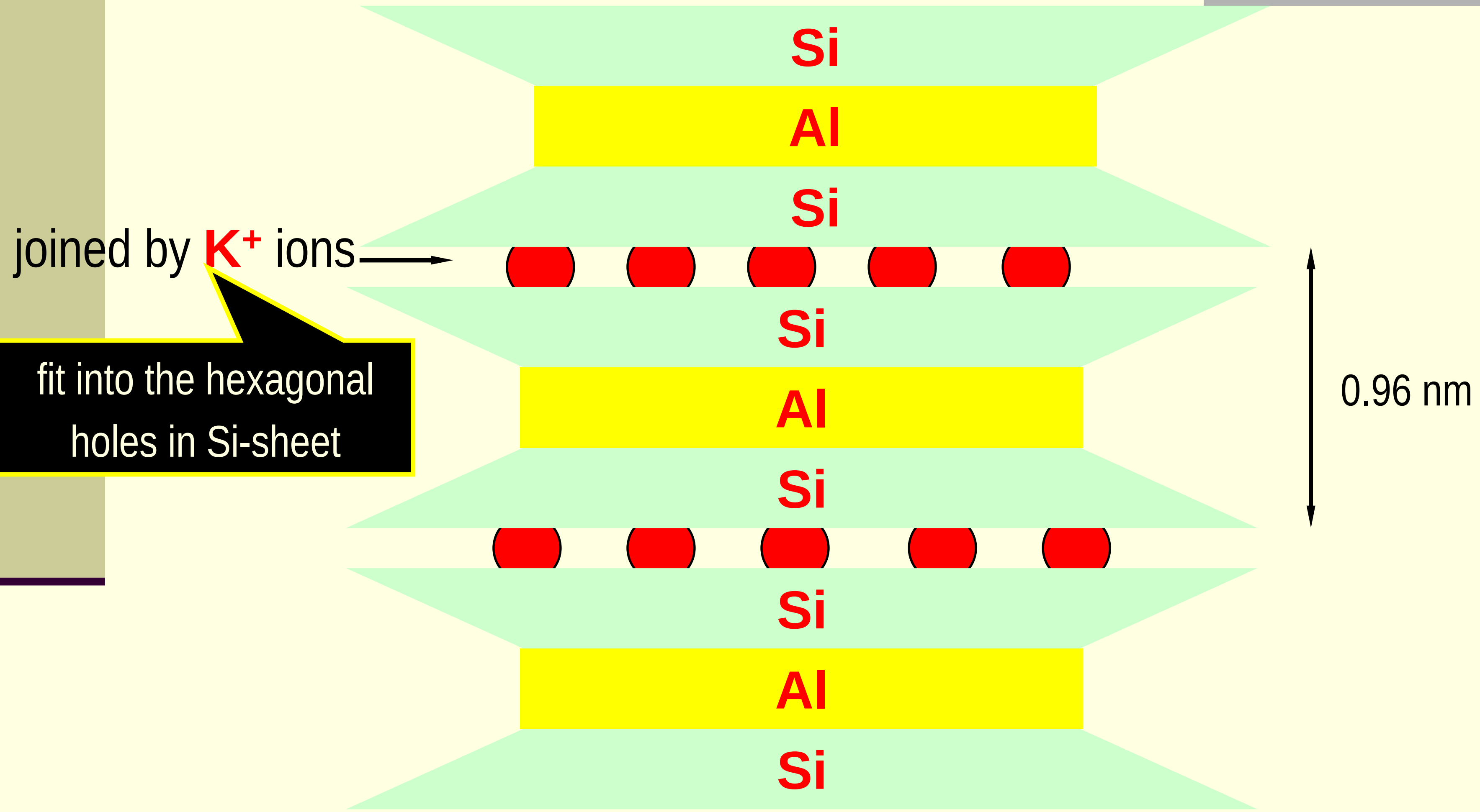
swells on contact with water

high affinity to water

Bentonite

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

Illite


Si
Al
Si
joined by K+ ions
Si
Al
Si
Si
Al
Si
0.96 nm
fit into the hexagonal holes in Si-sheet

Others…

Chlorite

- A 2:1:1 (???) mineral.

Si → 2, Al → 1, Al or Mg → 1

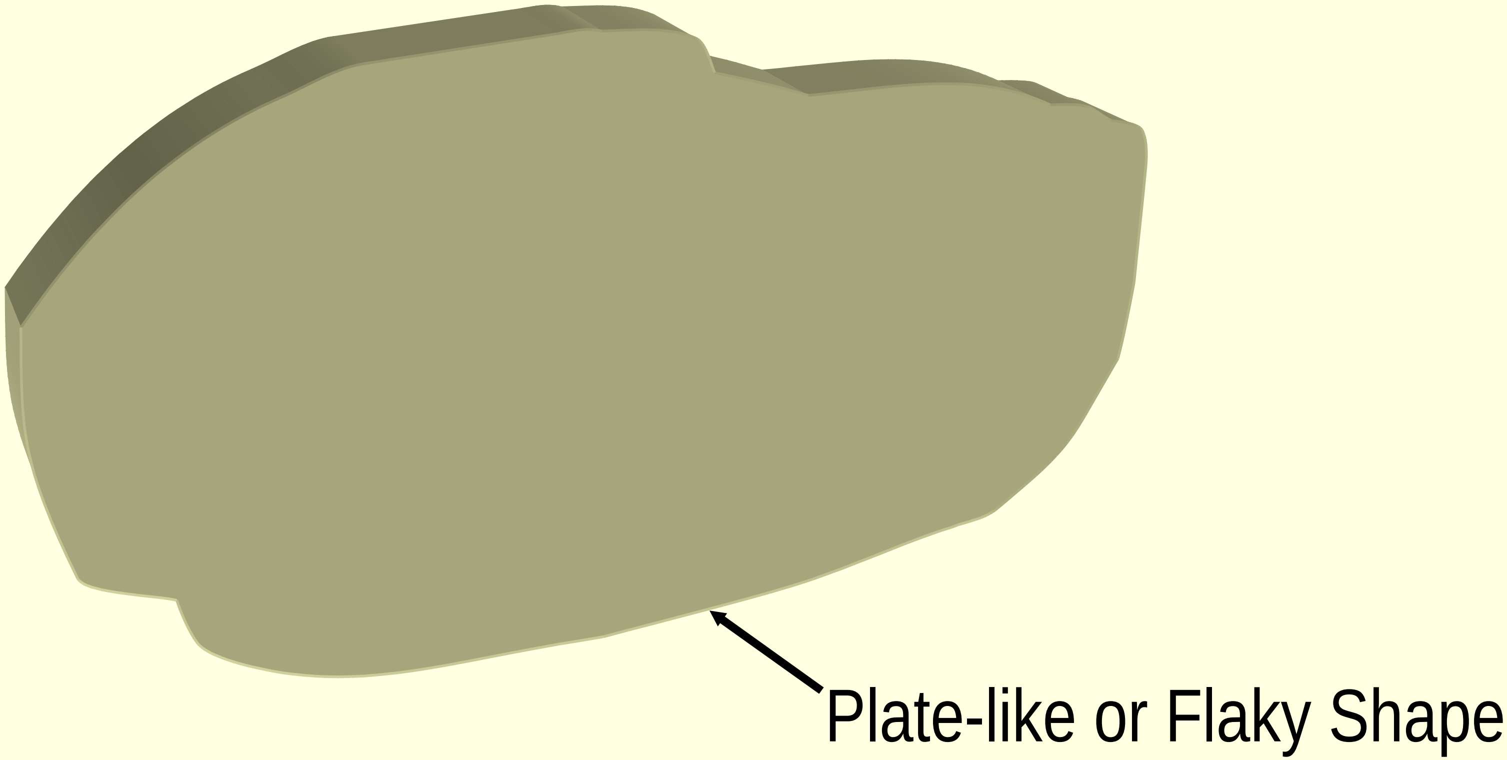
Vermiculite

- montmorillonite family; 2 interlayers of water

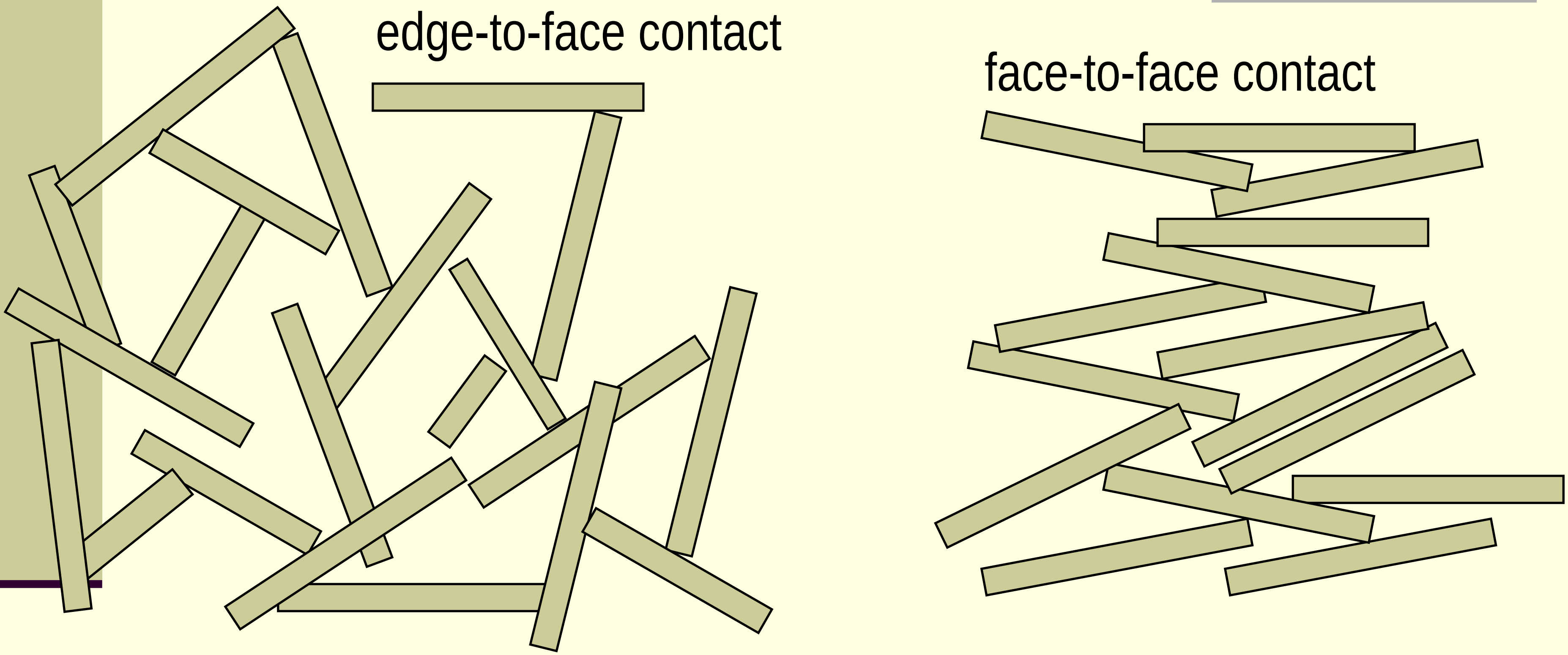
Attapulgite

- chain structure (no sheets); needle-like appearance

A Clay Particle



Clay Fabric



Flocculated

Dispersed

Clay Fabric

- Electrochemical environment (i.e., pH, acidity, temperature, cations present in the water) during the time of sedimentation influence clay fabric significantly.
- Clay particles tend to align perpendicular to the load applied on them.

Identifying Clay Minerals

Scanning Electron Microscope

- common technique to see clay particles
- qualitative

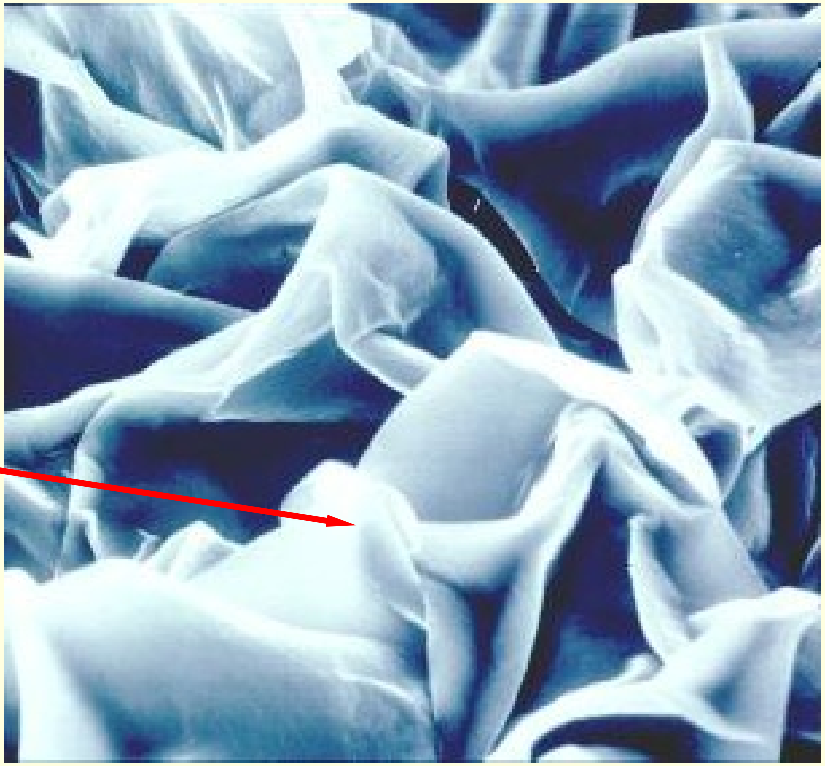


plate-like
structure

Others…

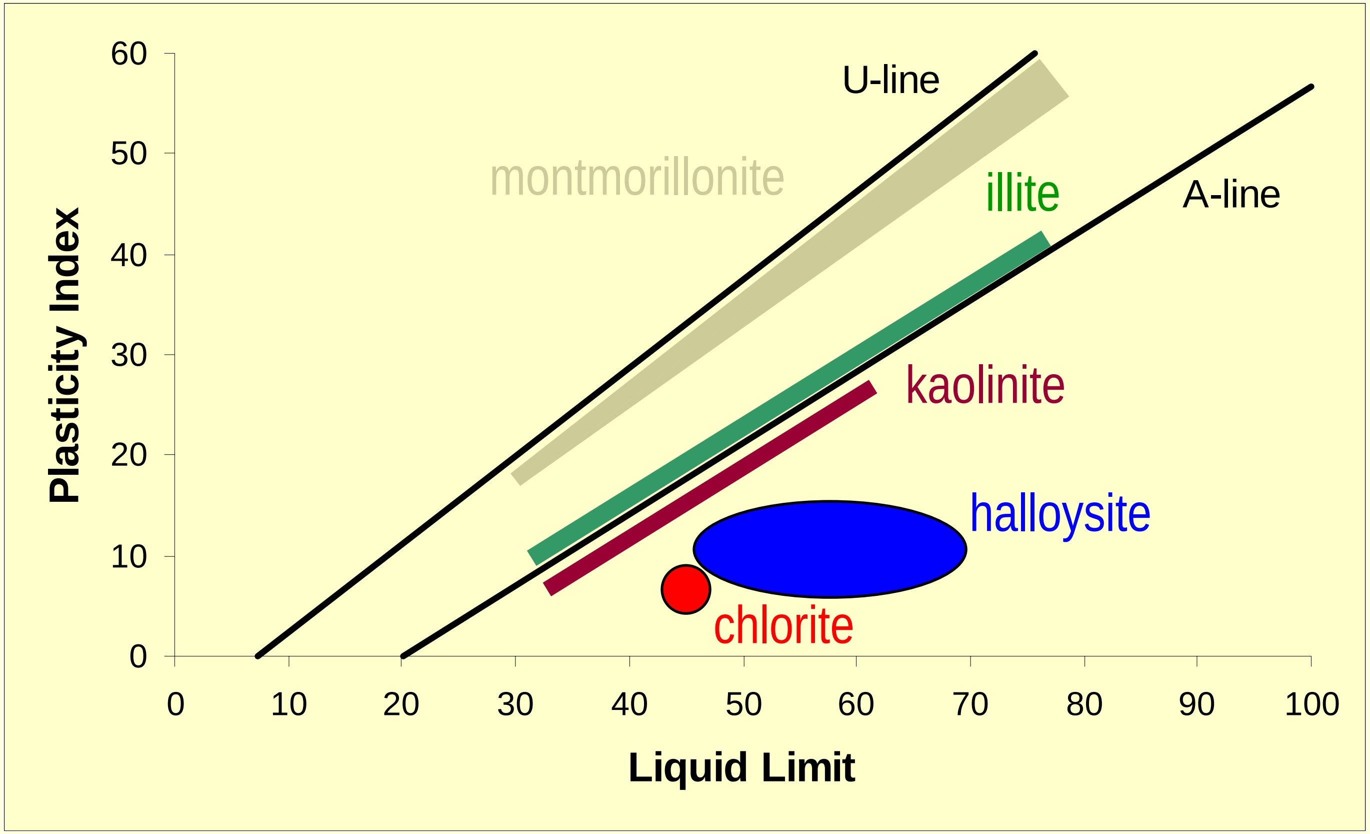
X-Ray Diffraction (XRD)

- to identify the molecular structure and minerals present

Differential Thermal Analysis (DTA)

- to identify the minerals present

Casagrande's PI-LL Chart



Special Terms

Specific Surface

- surface area per unit mass (m^2/g)
- smaller the grain, higher the specific surface

e.g., soil grain with specific gravity of 2.7

10 mm cube

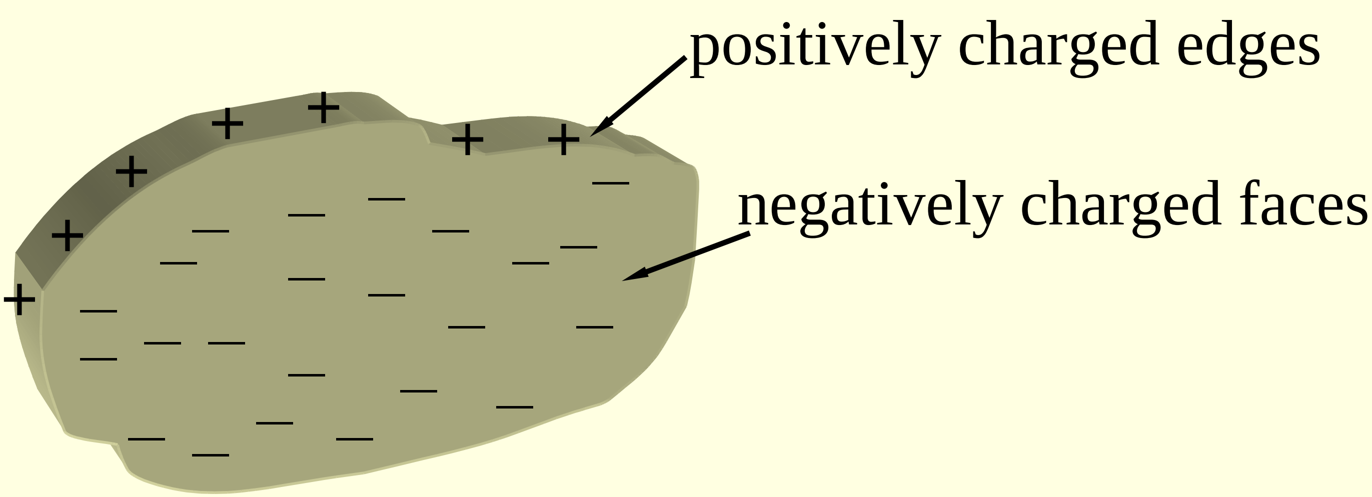
1 mm cube

spec. surface = 222.2 mm^2/g

spec. surface = 2222.2 mm^2/g

Isomorphous Substitution

- substitution of Si^{4+} and Al^{3+} by other lower valence (e.g., Mg^{2+}) cations
- results in charge imbalance (net negative)



Clay Particle with Net negative Charge

Cation Exchange Capacity (c.e.c)

known as exchangeable cations

- capacity to attract cations from the water (i.e., measure of the net negative charge of the clay particle)

- measured in meq/100g (net negative charge per 100 g of clay)

milliequivalents

- The replacement power is greater for higher valence and larger cations.

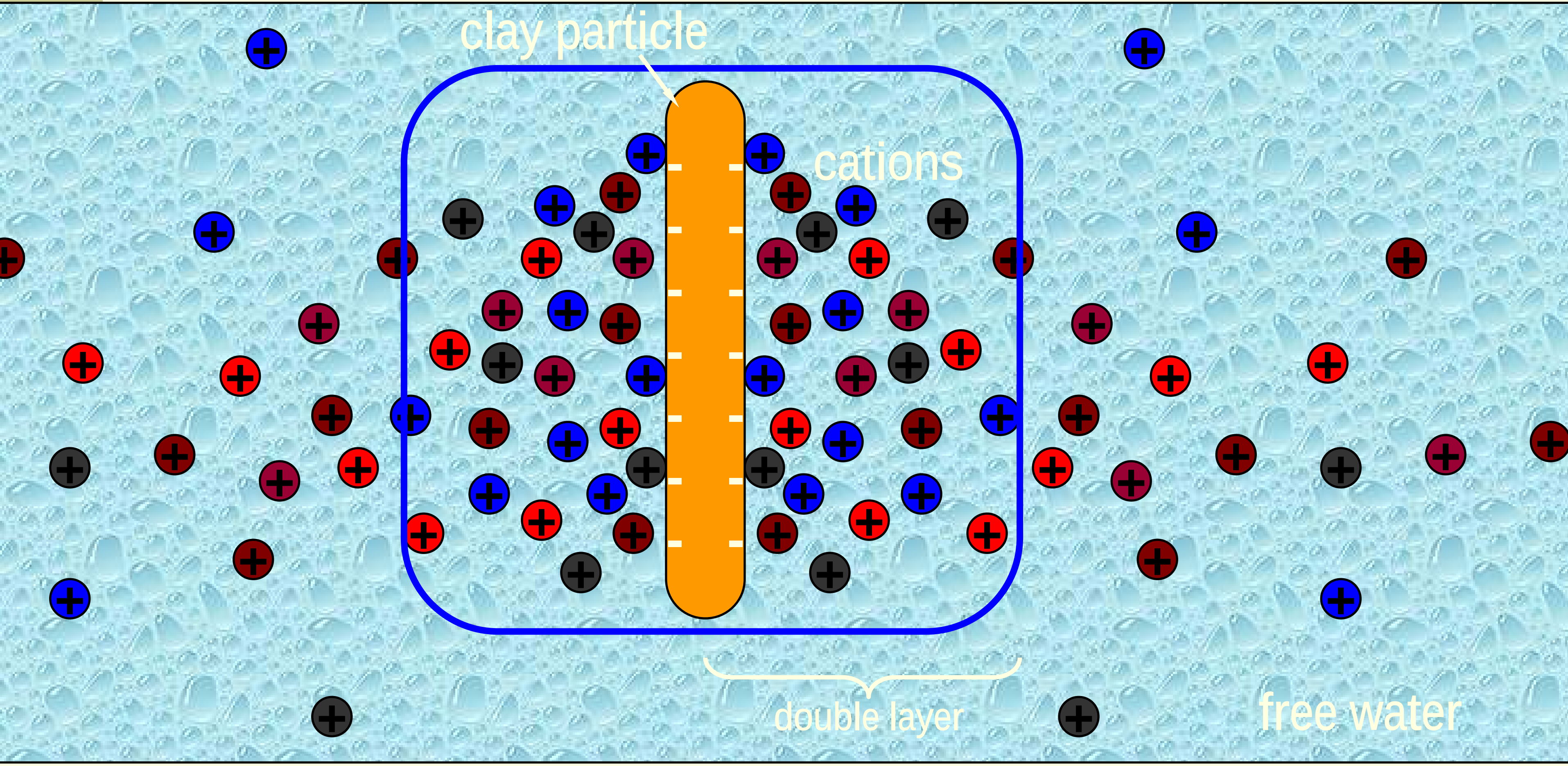
$$Al^{3+} > Ca^{2+} > Mg^{2+} >> NH_4^+ > K^+ > H^+ > Na^+ > Li^+$$

A Comparison

Mineral	Specific surface (m^2/g)	C.E.C (meq/100g)
Kaolinite	10-20	3-10
Illite	80-100	20-30
Montmorillonite	800	80-120
Chlorite	80	20-30

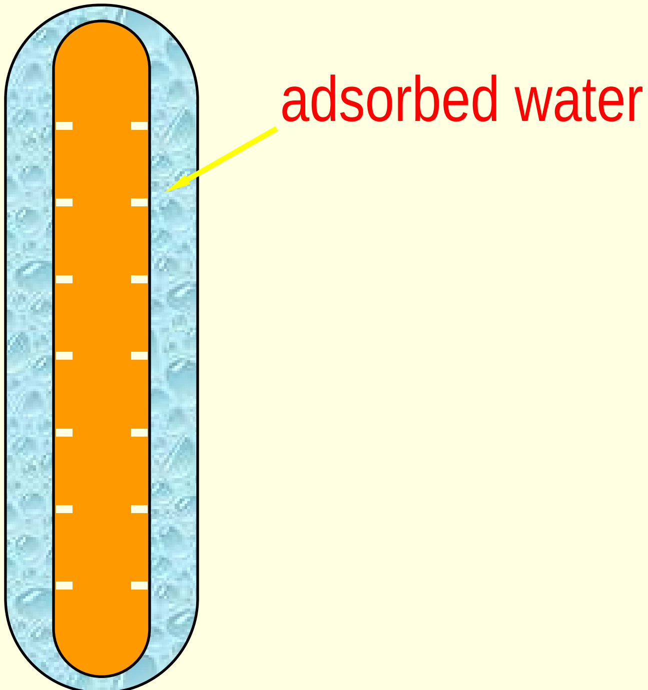
Cation Concentration in Water

- cation concentration drops with distance from clay particle

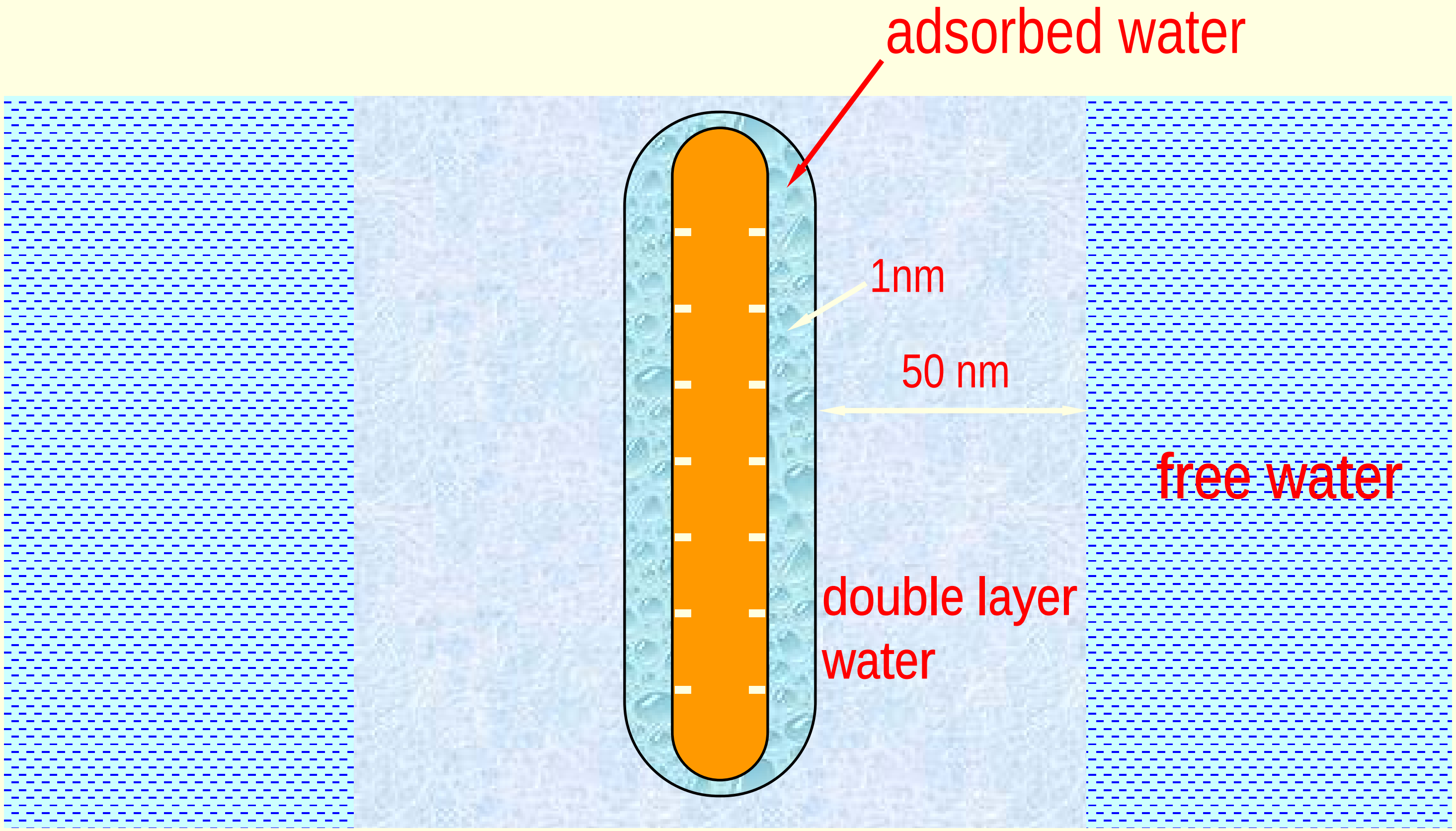


Adsorbed Water

- A thin layer of water tightly held to particle; like a skin
- 1-4 molecules of water (1 nm) thick
- more viscous than free water



Clay Particle in Water



Practical Significance

Summary - Clays

- Clay particles are like plates or needles. They are negatively charged.
- Clays are plastic; Silts, sands and gravels are non-plastic.
- Clays exhibit high dry strength and slow dilatancy.

Summary - Montmorillonite

- Montmorillonites have very high specific surface, cation exchange capacity, and affinity to water. They form reactive clays.

- Montmorillonites have very high liquid limit (100+), plasticity index and activity (1-7).

- Bentonite (a form of Montmorillonite) is frequently used as drilling mud.