Unit 3

Soil Classification, Structure and Clay Minerals

Clay Mineralogy and Soil Structure:

- Introduction, Types-Single grained honey-combed, flocculent and dispersed structures, Types of soil-Water, base-exchange capacity, Common clay minerals in soil and their structures- Kaolinite, Illite and Montmorillonite.

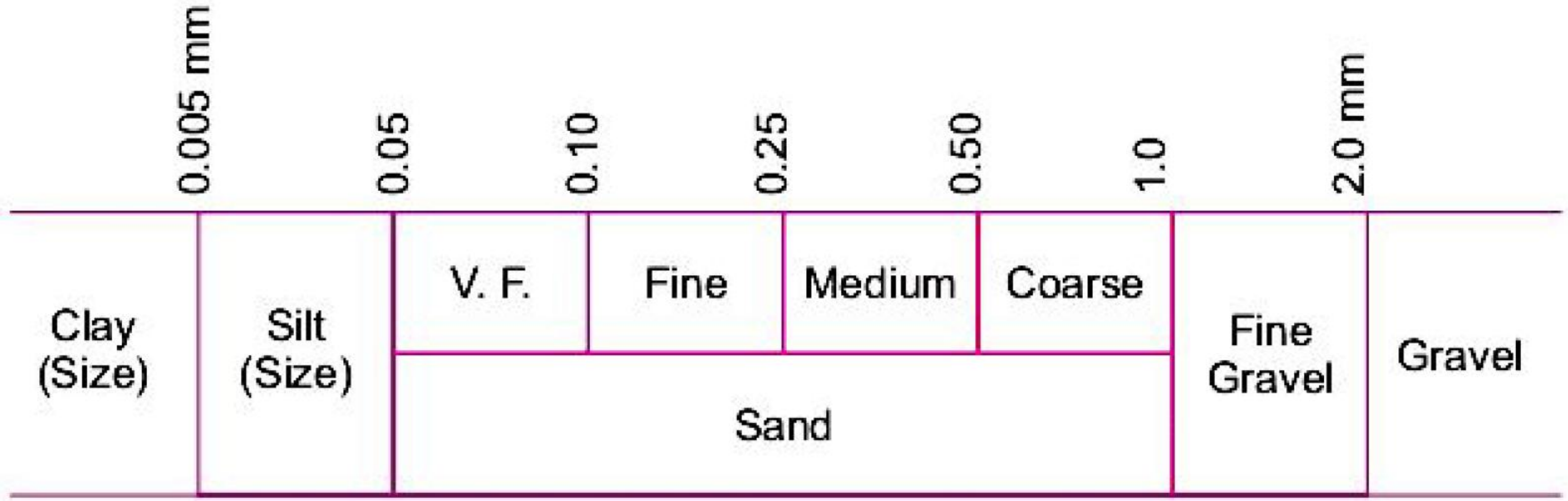
Effective Stress:

- Effective stress concept-Total pressure and Pore pressure, effect of water table, Numerical problems- with and without capillary water.

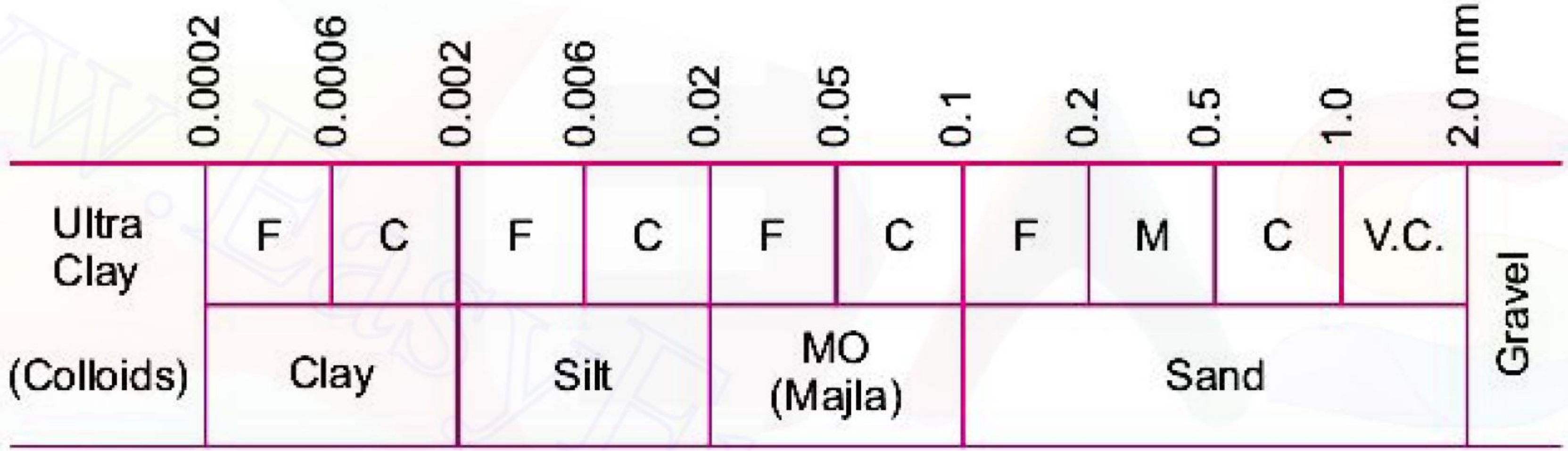
from engineering point of view, the classification may be done with the objective of finding the suitability of the soil for construction of dams, highways or foundations, etc. For general engineering purposes, soils may be classified by the following systems:

1. Particle size classification
2. Textural classification
3. Highway Research Board (HRB) classification
4. Unified soil classification and IS classification system

Particle Size Classification

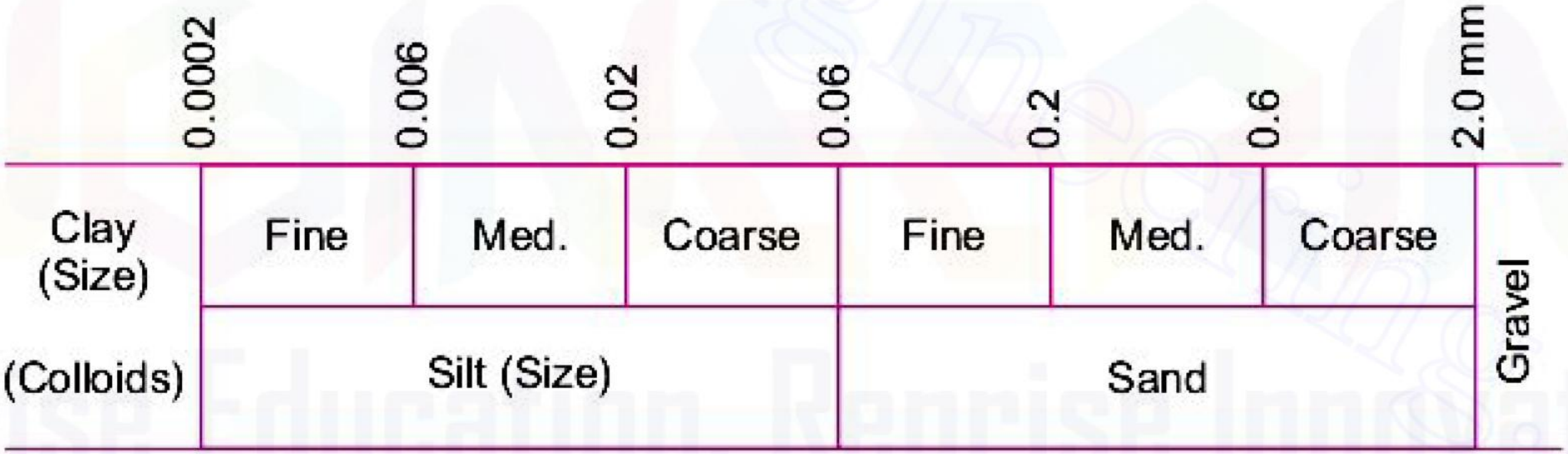


(a) U. S. Bureau of soils and PRA classification

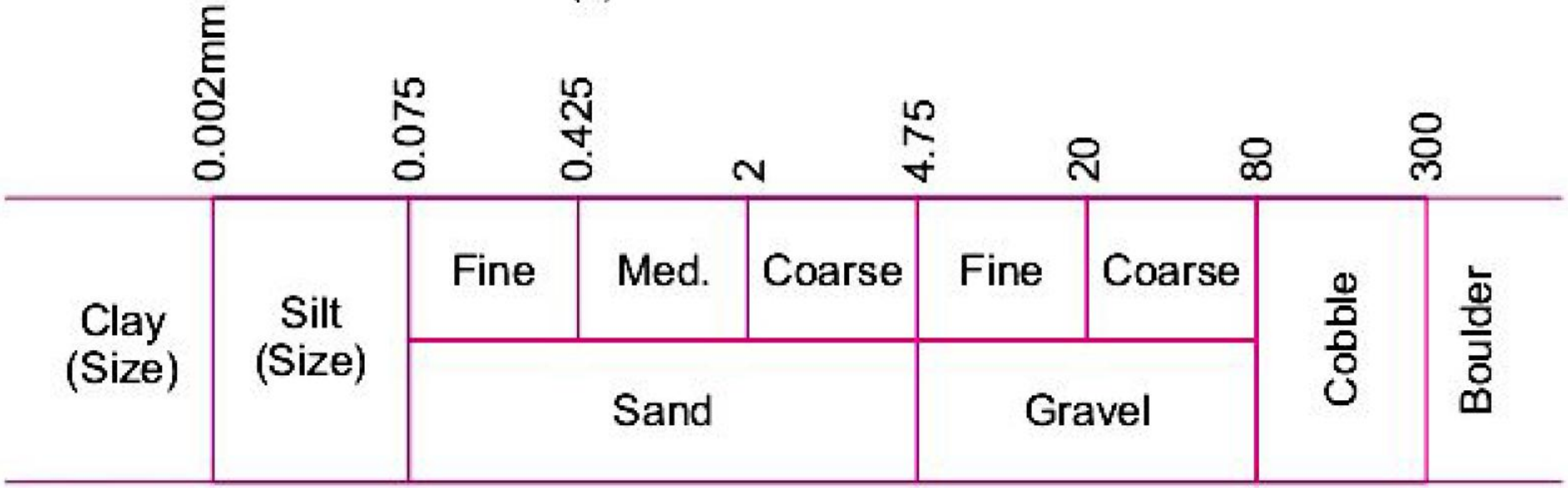


(b) International Classification

Particle Size Classification

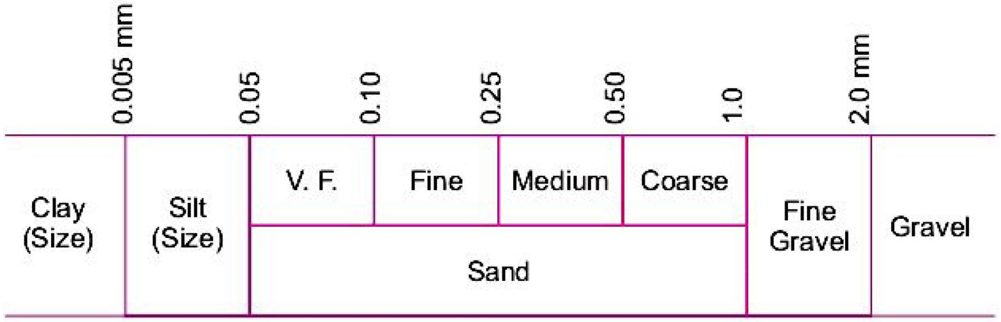


(c) M.I.T. Classification

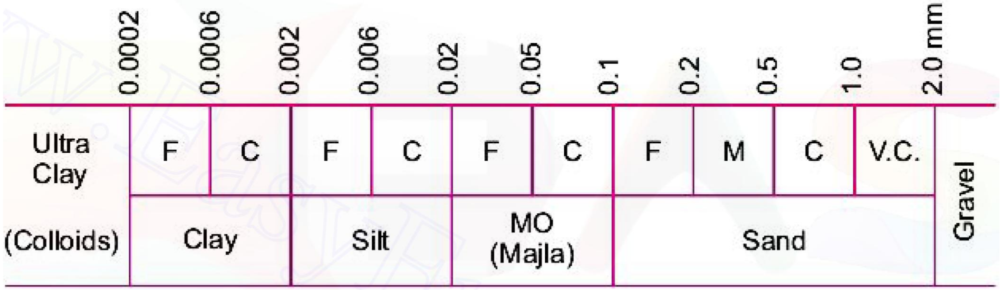


(d) I.S. Classification (IS : 1498–1970)

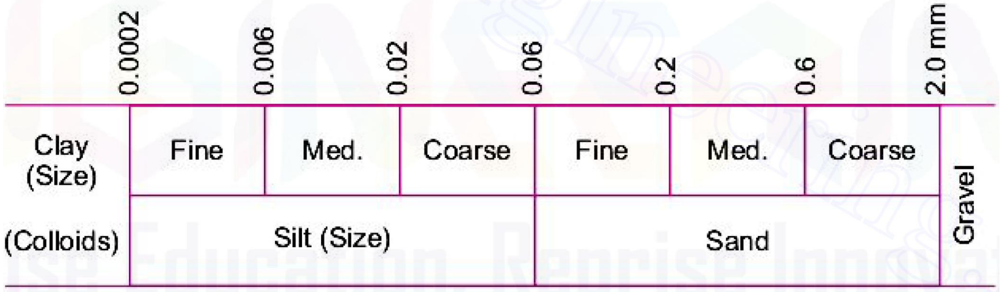
Particle Size Classification



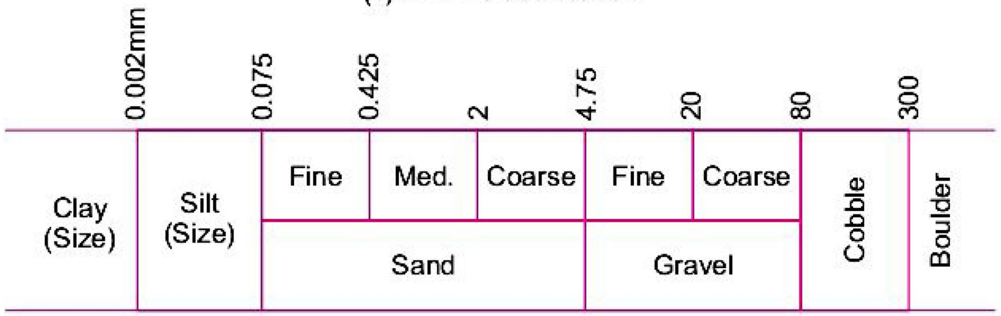
(a) U. S. Bureau of soils and PRA classification



(b) International Classification



(c) M.I.T. Classification



(d) I.S. Classification (IS : 1498–1970)

Textural soil classification

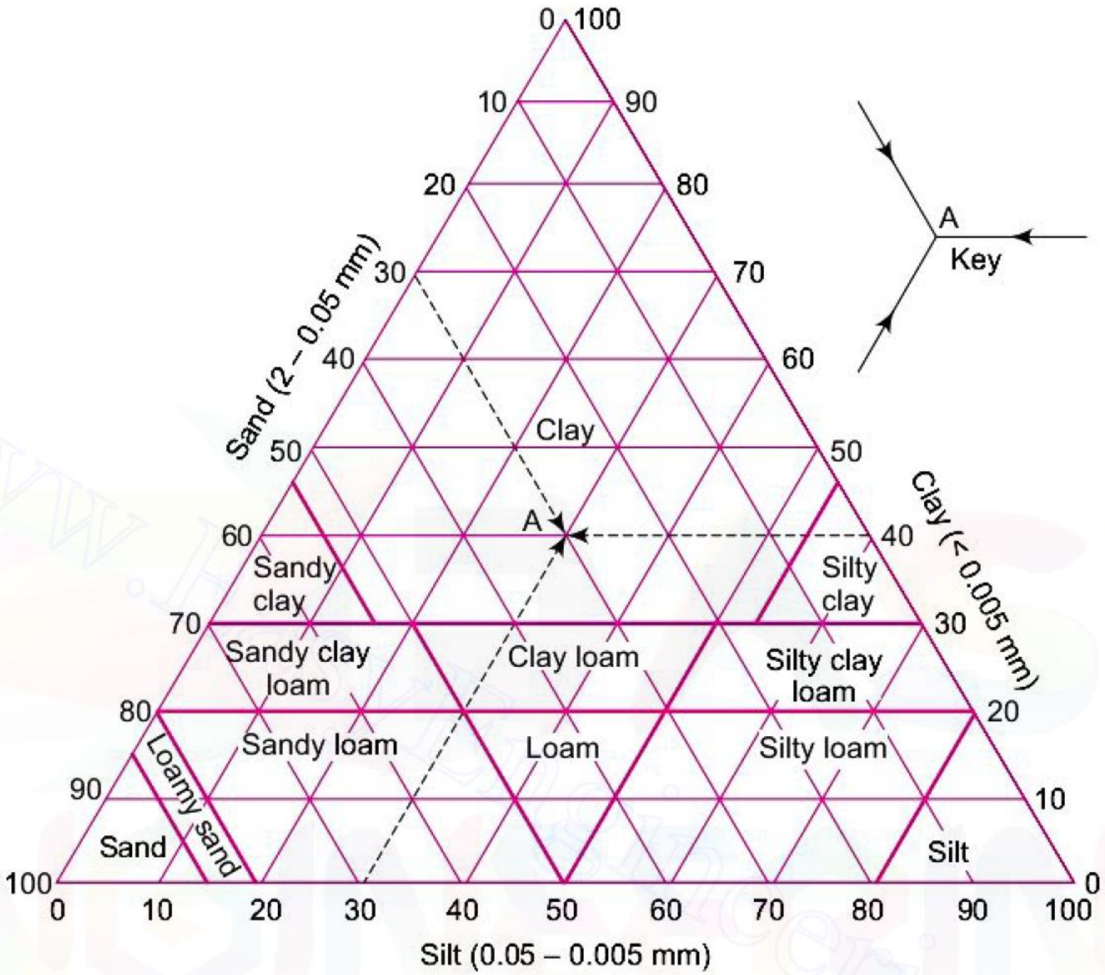
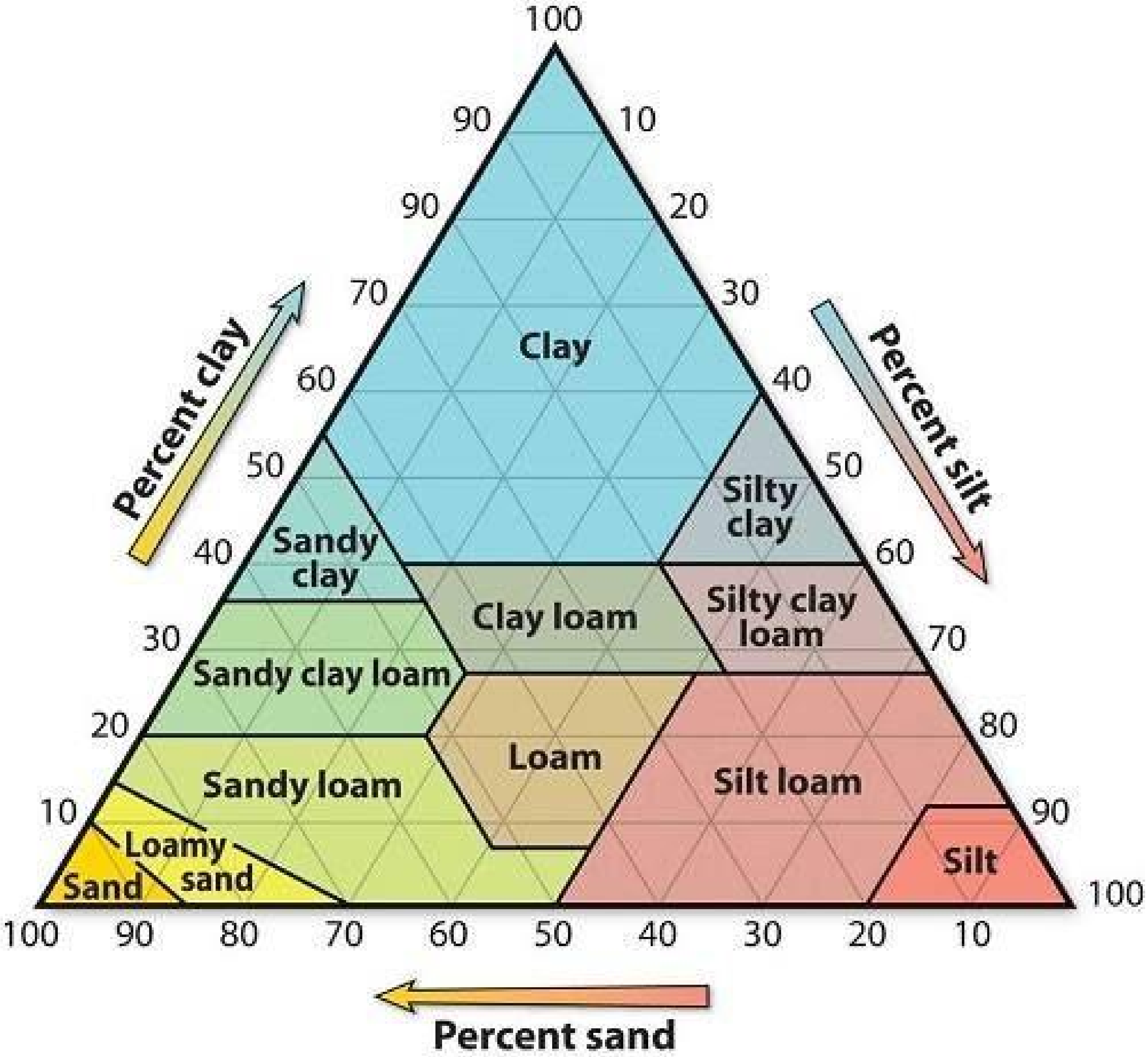


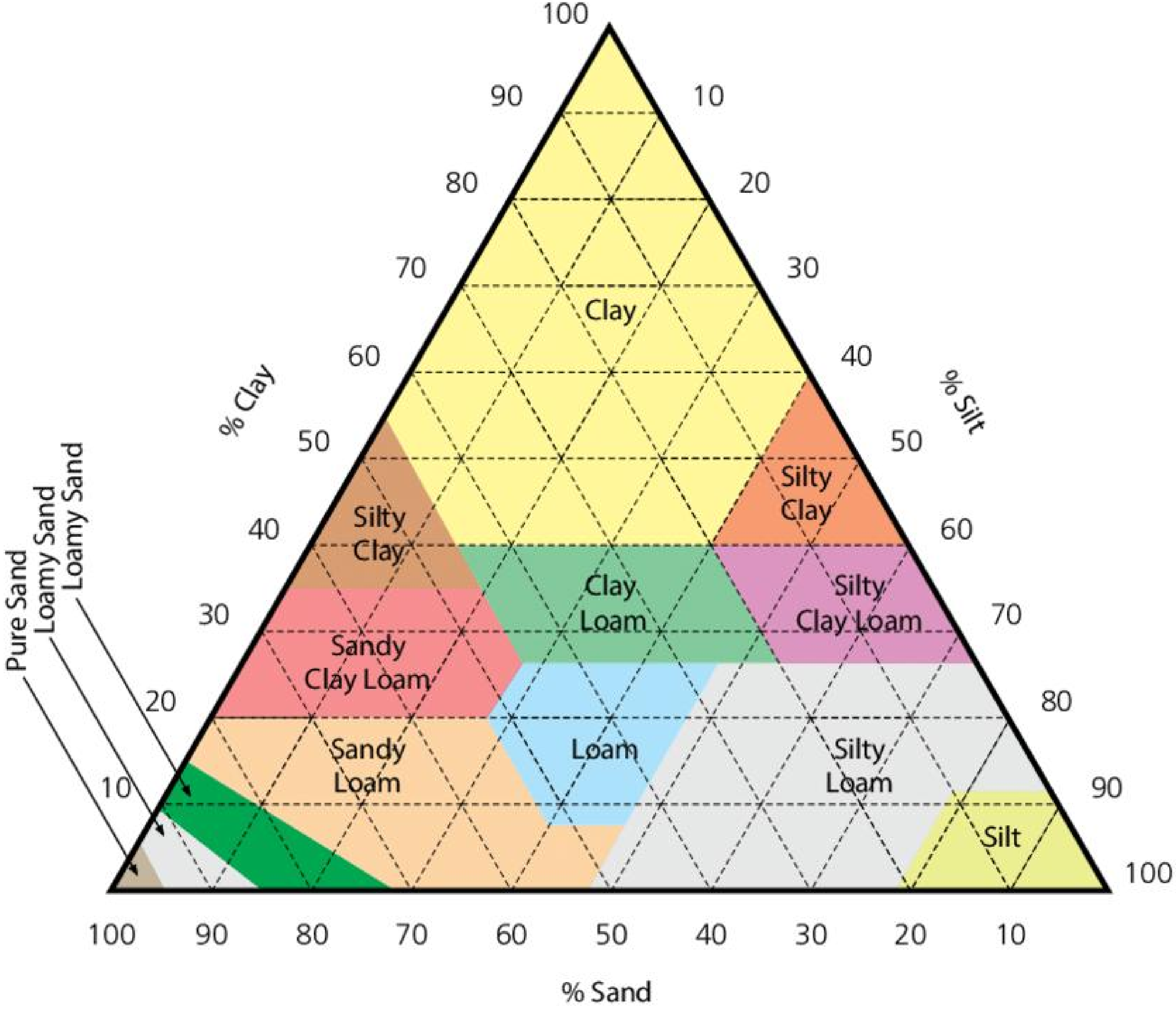
Fig. 4.2 Textural Classification Chart (Adapted from U.S. Public Roads Administration)

To use the chart, for the given percentages of the three constituents forming a soil, lines are drawn parallel to the three sides of the equilateral triangle, as shown by arrows in the 'key' of Fig. 4.2. For example, if a soil is composed of 30% sand, 30% silt sizes and 40% clay sizes, the three lines so drawn intersect at the point *A* situated in the sector designated as 'clay'. Such a soil will be termed as 'clay'.

Textural soil classification



Textural soil classification



Highway Research Board (HRB) Classification

$$\text{Group Index } (GI) = 0.2a + 0.005ac + 0.01bd \tag{3.56a}$$

in which,

a = that portion of percentage of soil particles passing No. 200 (ASTM) sieve greater than 35 = $(F - 35)$.

b = that portion of percentage of soil particles passing No. 200 sieve, greater than 15 = $(F - 15)$.

c = that portion of the liquid limit greater than 40 = $(w_l - 40)$.

d = that portion of the plasticity index greater than 10 = $(I_p - 10)$.

F = percent passing No. 200 sieve. If $F < 35$, use $(F - 35) = 0$

Highway Research Board (HRB) Classification

Table 3.16 AASHTO soil classification

General classification	Granular Materials (35 percent or less of total sample passing No. 200)							Silt-clay Materials (More than 35 percent of total sample passing No. 200)			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-*a*	*A*-1-*b*		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve analysis percent passing											
No. 10	50 max										
No. 40	30 max	50 max	51 min								
No. 200	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40											
Liquid limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 max		N.P.	10 max	10 max	11 min	11 max	10 max	10 max	11 min	11 min
Usual types of significant constituent materials	Stone fragments—gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good					Fair to poor					

Highway Research Board (HRB) Classification

Table 2.9A AASHTO classification of soils and soil-aggregate mixtures.

General classification	**Granular materials (35% or less passing No. 200)**			**Silt-clay materials (more than 35% passing No. 200)**			
Group classification	**A–1**	**A–3**[a]	**A–2**	**A–4**	**A–5**	**A–6**	**A–7**
Sieve analysis, % passing							
No. 10 (2.00 mm)	…	…	…	…	…	…	…
No. 40 (425 μm)	50 max	51 min	…	…	…	…	…
No. 200 (75 μm)	25 max	10 max	35 max	35 min	36 min	35 min	35 max
Characteristics of fraction passing No. 40 (425 μm)							[b]
Liquid limit	…	…	[b]	40 max	41 min	40 max	[b]
Plasticity index	6 max	N.P.	[b]	40 max	10 max	11 min	
General rating as subgrade	Excellent to good			Fair to poor			

IS Classification IS 1498: 1970

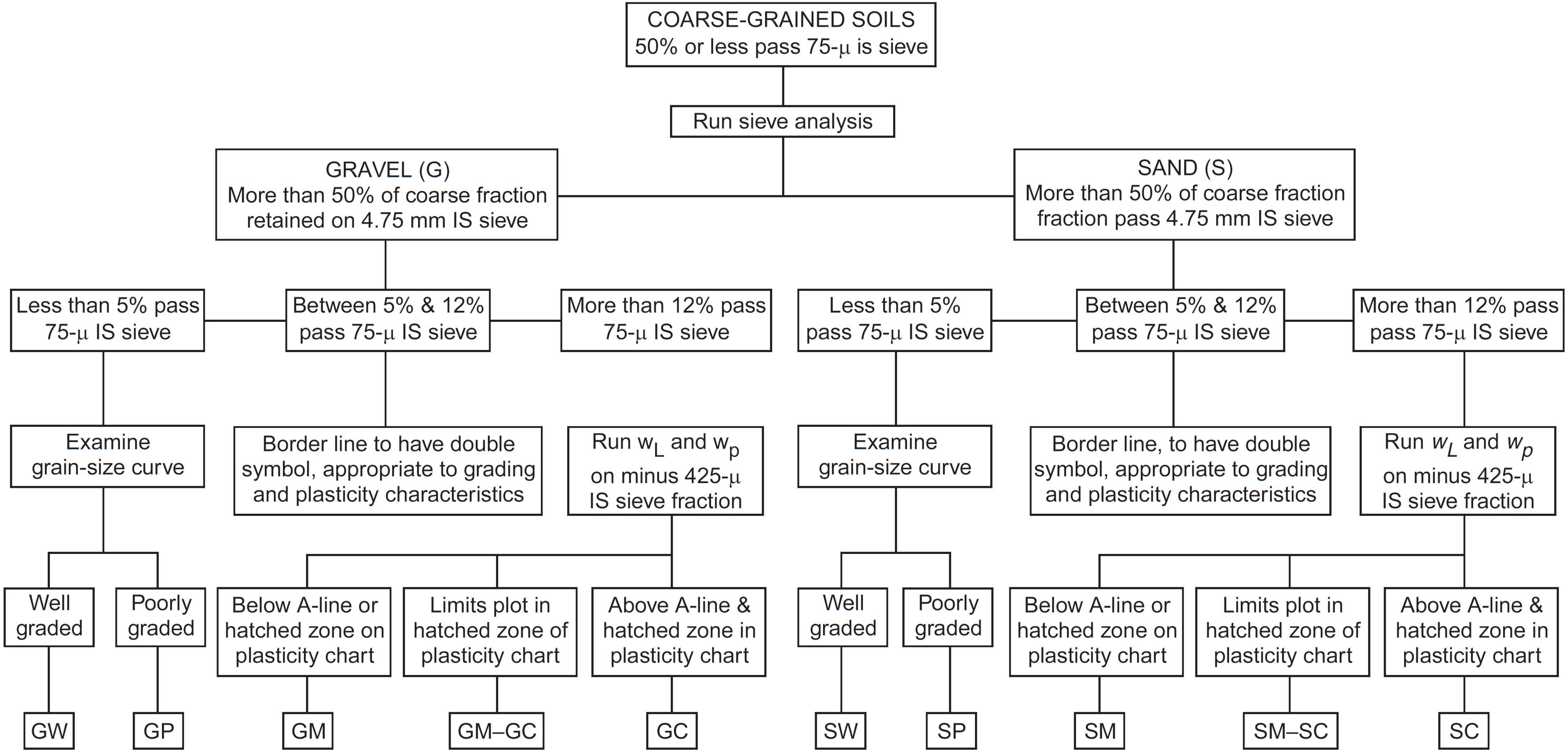
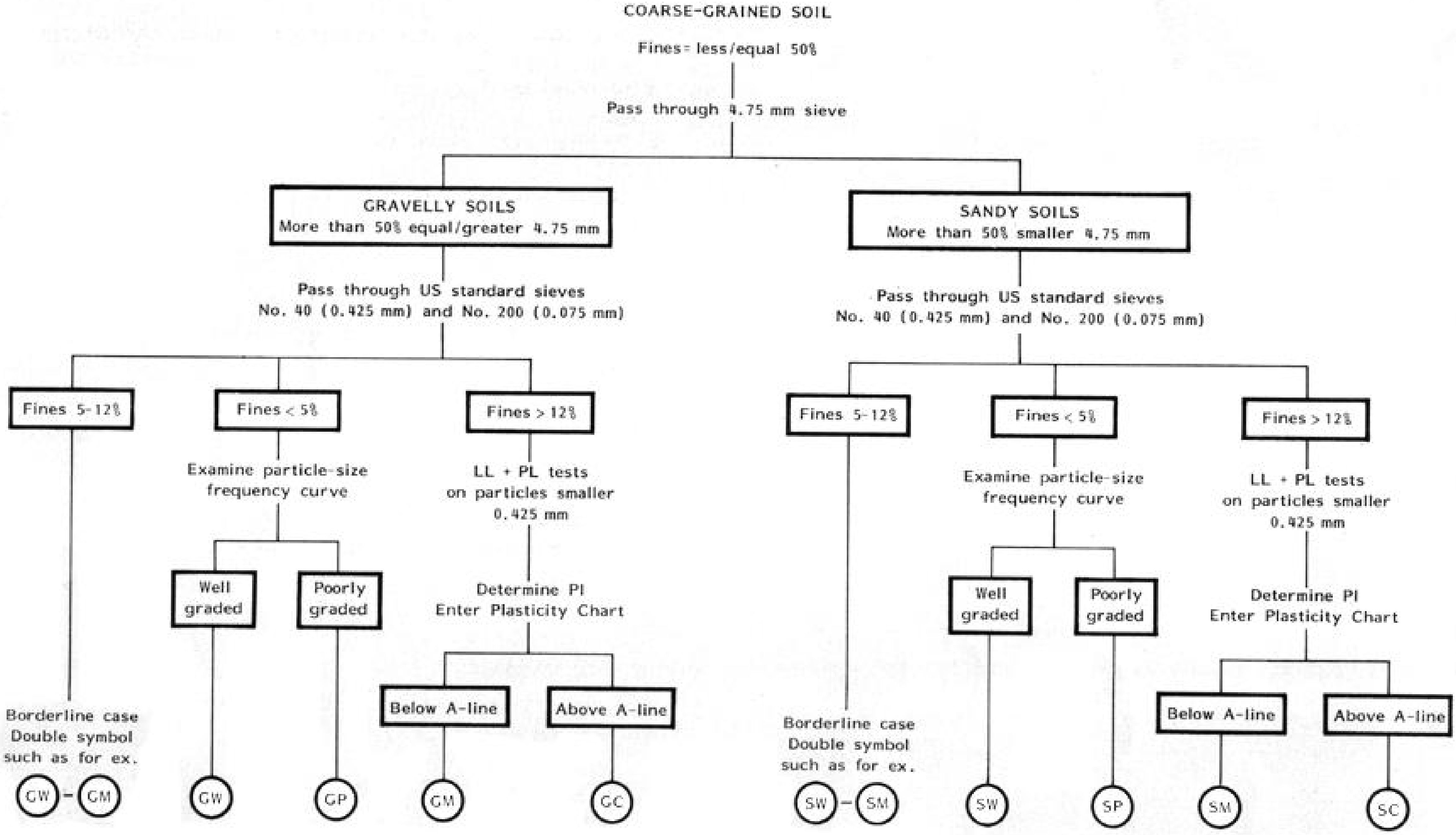


Fig. 4.5 Flow chart for classification of coarse-grained soils


COARSE-GRAINED SOIL
Fines= less/equal 50%
Pass through 4.75 mm sieve
GRAVELLY SOILS
More than 50% equal/greater 4.75 mm
SANDY SOILS
More than 50% smaller 4.75 mm
Pass through US standard sieves
No. 40 (0.425 mm) and No. 200 (0.075 mm)
Pass through US standard sieves
No. 40 (0.425 mm) and No. 200 (0.075 mm)
Fines 5-12%
Fines < 5%
Fines > 12%
Fines 5-12%
Fines < 5%
Fines > 12%
Examine particle-size frequency curve
LL + PL tests on particles smaller 0.425 mm
Examine particle-size frequency curve
LL + PL tests on particles smaller 0.425 mm
Well graded
Poorly graded
Determine PI
Enter Plasticity Chart
Well graded
Poorly graded
Determine PI
Enter Plasticity Chart
Below A-line
Above A-line
Below A-line
Above A-line
Borderline case
Double symbol
such as for ex.
GW - GM
GW
GP
GM
GC
Borderline case
Double symbol
such as for ex.
SW - SM
SW
SP
SM
SC

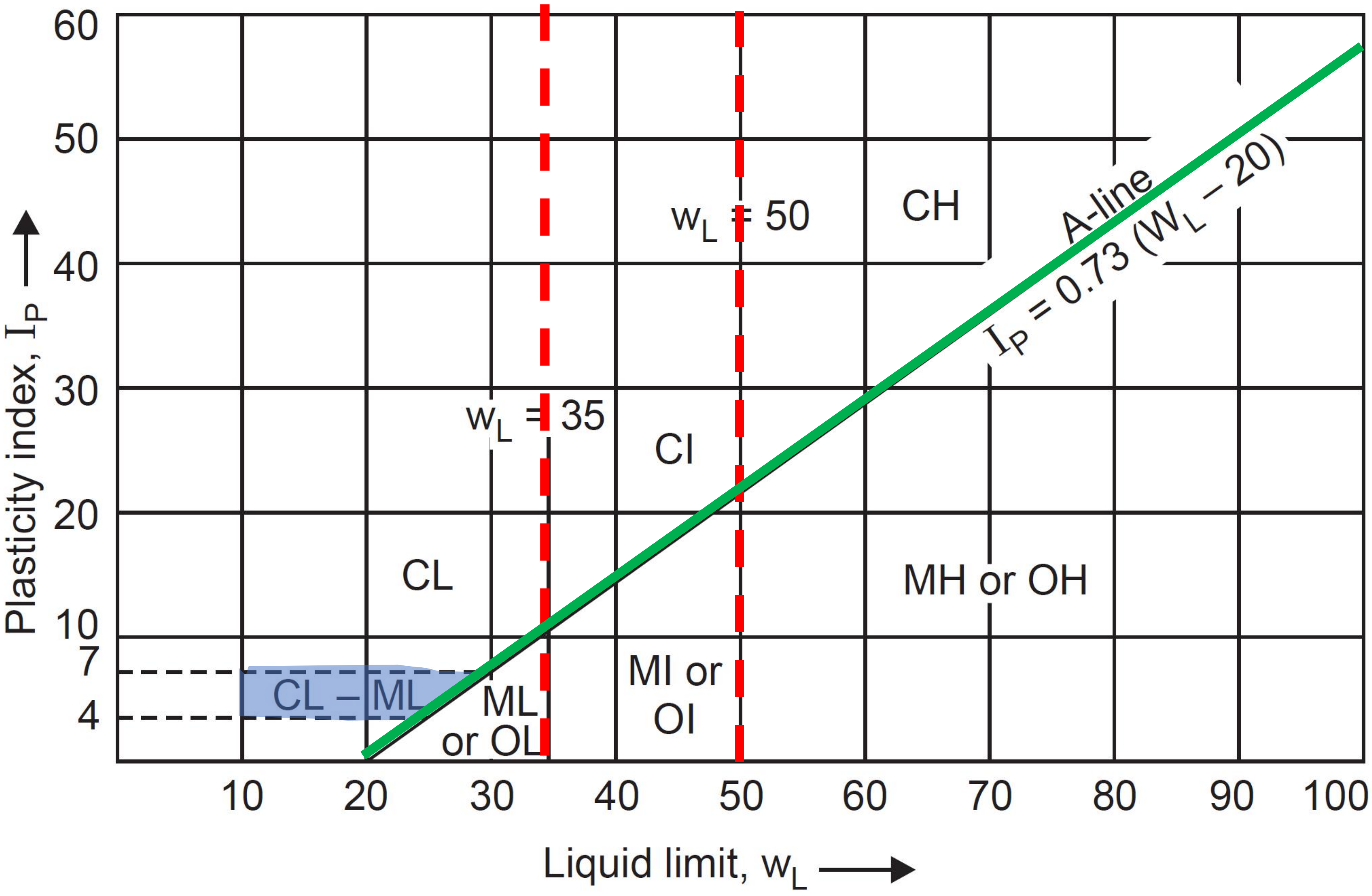


Fig. 4.4 Plasticity chart (I.S. soil classification)

IS Classification

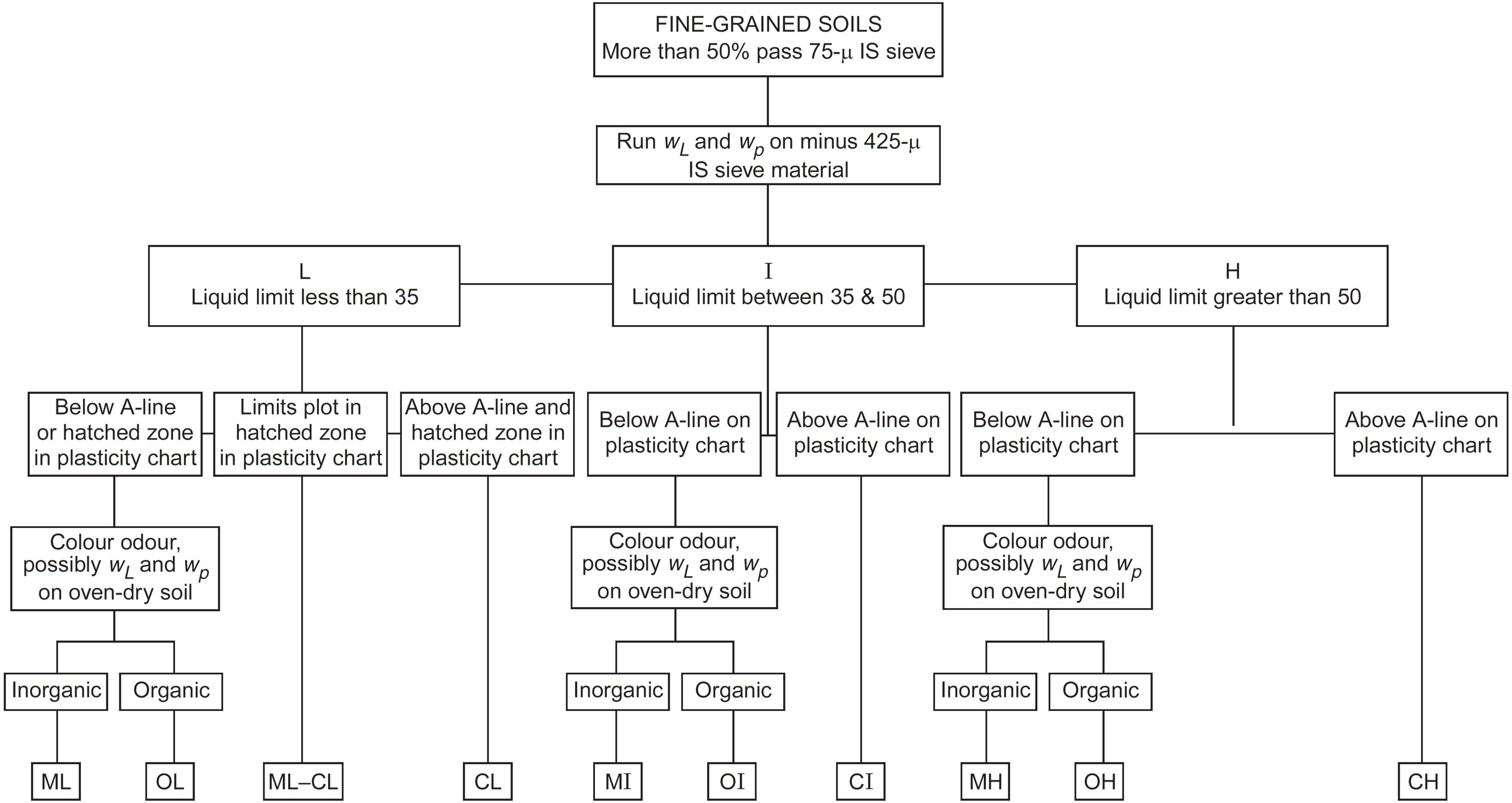
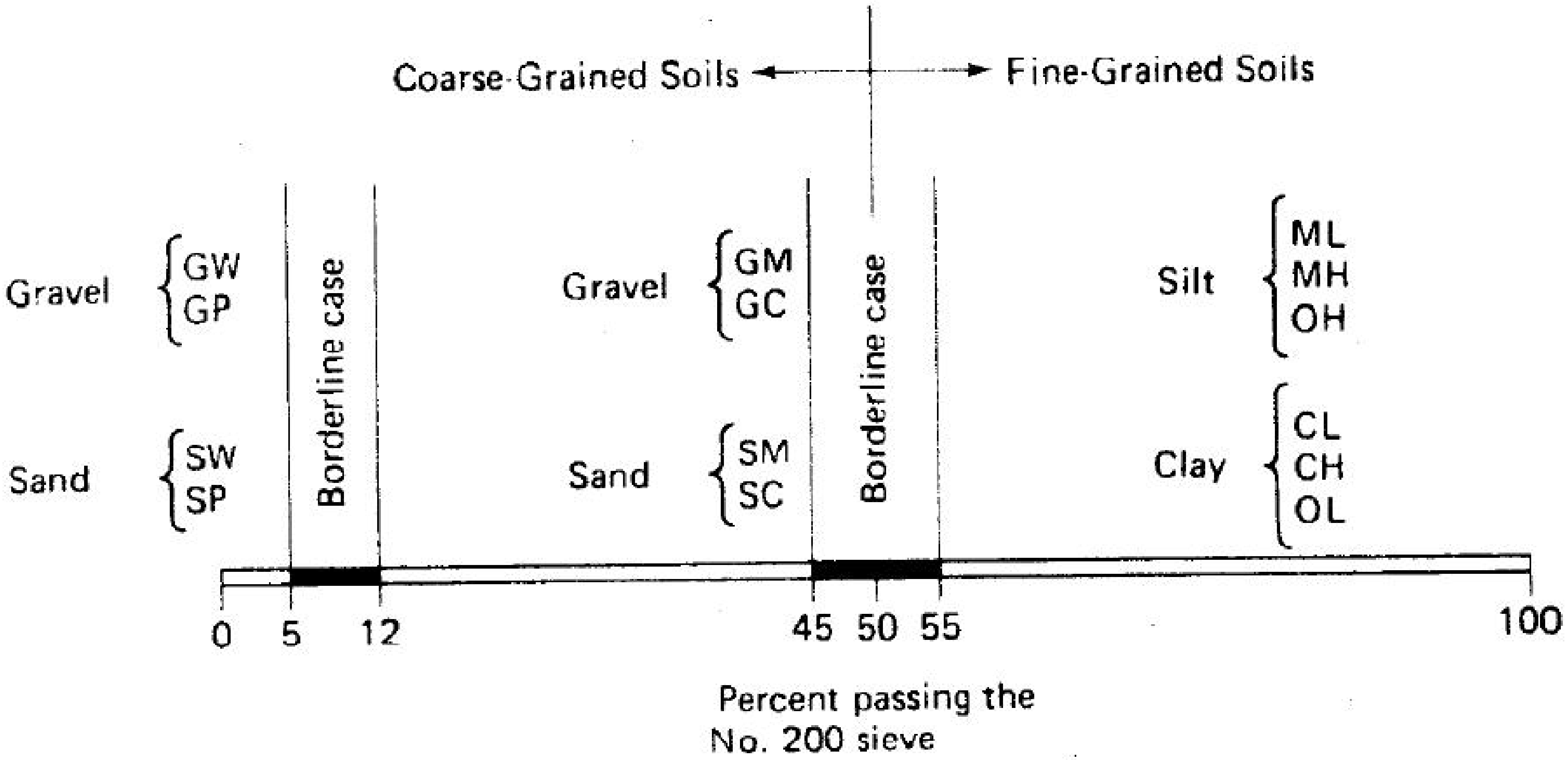


Fig. 4.6 Flow chart for classification of fine-grained soils

Main Soil type	Prefix	Subgroup	Suffix	Classification Group symbols
Gravel	G	Well-graded Poorly-graded Silty Clayey	W P M C	GW GP GM GC
Sand	S	Well-graded Poorly-graded Silty Clayey	W P M C	SW SP SM SC
Silt	M	LL < 35% 35 < LL <= 50% LL >50%	L I H	ML MI MH
Clay	C	LL < 35% 35 < LL <= 50% LL >50%	L I H	CL CI CH
Organic	O	LL < 35% 35 < LL <= 50% LL >50%	L I H	OL OI OH
Peat	Pt			Pt

(Borderline Classifications)



Note: Only two group symbols may be used to describe a soil. Borderline classifications can exist within each of the above groups.

Fig. 3.3 **Guide for borderline cases of soil classification (after Howard, 1977).**

Typical names of soil groups	Group symbols	Important properties: Permeability when compacted	Shearing strength when compacted and saturated	Compressibility when compacted and saturated	Workability as a construction material
Well-graded gravels, gravel-sand mixtures, little or no fines	GW	Pervious	Excellent	Negligible	Excellent
Poorly graded gravels, gravel–sand mixtures, little or no fines	GP	Very Pervious	Good	Negligible	Good
Silty gravels, poorly graded gravel-sand-silt mixtures	GM	Semipervious to impervious	Good	Negligible	Good
Clayey gravels, poorly graded gravel-sand-clay mixtures	GC	Impervious	Good to fair	Very low	Good
Well-graded sands, gravelly sands, little or no fines	SW	Pervious	Excellent	Negligible	Excellent
Poorly graded sands, gravelly sands, little or no fines	SP	Pervious	Good	Very low	Fair
Silty sands, poorly graded sand-silt mixtures	SM	Semipervious to impervious	Good	Low	Fair
Clayey sands, poorly graded sand-clay mixtures	SC	Impervious	Good to fair	Low	Good
Inorganic silts and very fine sands, rock flour, silty, or clayey fine sands with slight plasticity	ML	Semipervious to impervious	Fair	Medium	Fair
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silky clays, lean clays	CL	Impervious	Fair	Medium	Good to fair
Organic silts and organic silt-clays of low plasticity	OL	Semipervious to impervious	Poor	Medium	Fair
Inorganic silts, micaceous or diatomaceous fine sandy, or silty soils, elastic silts	MH	Semipervious to impervious	Fair to poor	High	Poor
Inorganic clays of high plasticity, fat clays	CH	Impervious	Poor	High	Poor
Organic clays of medium to high plasticity	OH	Impervious	Poor	High	Poor
Peat and other highly organic soils	Pt	–	–	–	–

TABLE 5 CHARACTERISTICS PERTINENT TO ROADS AND AIRFIELDS

(*Clause* 3.8)

Soil Group	Value as Sub-Grade when not Subject to Frost Action	Value as Sub-Base when not Subject to Frost Action	Value as Base when not Subject to Frost Action	Potential Frost Action	Compressibility and Expansion	Drainage Characteristics	Compaction Equipment	Unit Dry Weight g/cm³	CBR Value Percent	Sub-Grade Modulus (*k*) kg/cm³
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
GW	Excellent	Excellent	Good	None to very slight	Almost none	Excellent	Crawlerer-type tractor, rubber-tyred roller, steel-wheeled roller	2·00-2·24	40-80	8·3-13·84
GP	Good to excellent	Good	Fair to good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tyred roller, steel-wheeled roller	1·76-2·24	30-60	8·3-13·84
GM d	Good to excellent	Good	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tyred roller, sheeps-foot roller, close control of moisture	2·00-2·32	40-60	8·3-13·84
GM u	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tyred roller, sheeps-foot roller	1·84-2·16	20-30	5·53-8·3
GC	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tyred roller, sheeps-foot roller	2·08-2·32	20-40	5·53-8·3
SW	Good	Fair to good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tyred roller	1·76-2·08	20-40	5·53-11·07
SP	Fair to good	Fair	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tyred roller	1·68-2·16	10-40	4·15-11·07
SM d	Fair to good	Fair to good	Poor	Slight to high	Very light	Fair to poor	Rubber-tyred roller, sheeps-foot roller, close control of moisture	1·92-2·16	15-40	4·15-11·07
SM u	Fair	Poor to fair	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tyred roller, sheeps-foot roller	1·60-2·08	10-20	2·77-8·3
SC	Poor to fair	Poor	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tyred roller sheeps-foot roller	1·60-2·16	5-20	2·77-8·3
ML, MI	Poor to fair	Not suitable	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tyred roller, sheeps-foot roller, close control of moisture	1·44-2·08	15 or less	2·77-5·53
CL, CI	Poor to fair	Not suitable	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tyred roller, sheeps-foot roller	1·44-2·08	15 or less	1·38-4·15
OL, OI	Poor	Not suitable	Not suitable	Medium to high	Medium to high	Poor	Rubber-tyred roller, sheeps-foot roller	1·44-1·68	5 or less	1·38-2·77
MH	Poor	Not suitable	Not suitable	Medium to very high	High	Fair to poor	Sheeps-foot roller, rubber-tyred roller	1·28-1·68	10 or less	1·38-2·77
CH	Poor to fair	Not suitable	Not suitable	Medium	High	Practically impervious	Sheeps-foot roller, rubber-tyred roller	1·44-1·84	15 or less	1·38-4·15
OH	Poor to very poor	Not suitable	Not suitable	Medium	High	Practically impervious	Sheeps-foot roller, rubber-tyred roller	1·28-1·76	5 or less	0·69-2·77

TABLE 6 CHARACTERISTICS PERTINENT TO EMBANKMENTS AND FOUNDATIONS

(*Clause* 3.8)

Soil Group	Value of Embankment	Permeability cm/s	Compaction Characteristics	Unit Dry Weight g/cm³	Value of Foundation	Requirements for Seepage Control
(1)	(2)	(3)	(4)	(5)	(6)	(7)
GW	Very stable; pervious shells of dikes and dams	$K > 10^{-2}$	Good; tractor, rubber tyred, steel-wheeled roller	2·00-2·16	Good bearing value	Positive cutoff
GP	Reasonably stable, pervious shells of dikes and dams	$K > 10^{-2}$	do	1·84-2·00	do	do
GM	Reasonably stable; not particularly suited to shells, but may be used for impervious cores or blankets	$K = 10^{-3}$ to 10^{-6}	Good; with close control, rubber-tyred, sheeps-foot roller	1·92-2·16	do	Toe trench to none
GC	Fairly stable; may be used for impervious core	$K = 10^{-6}$ to 10^{-8}	Fair; rubber-tyred, sheeps-foot roller	1·84-2·08	do	None
SW	Very stable; pervious sections, slope protection required	$K > 10^{-3}$	Good; tractor	1·76-2·08	do	Upstream blanket and toe drainage or wells
SP	Reasonably stable; may be used in dike section with flat slopes	$K > 10^{-3}$	Good; tractor	1·60-1·92	Good to poor bearing value depending on density	do
SM	Fairly stable; not particularly suited to shells, but may be used for impervious cores or dikes	$K = 10^{-3}$ to 10^{-6}	Good; with close control, rubber-tyred, sheeps-foot roller	1·76-2·00	do	do
SC	Fairly stable; use for impervious core for flood control structures	$K = 10^{-6}$ to 10^{-8}	Fair; sheeps-foot roller, rubber tyred	1·68-2·00	Good to poor bearing value	None
ML, MI	Poor stablility; may be used for embankments with proper control	$K = 10^{-3}$ to 10^{-6}	Good to poor, close control essential; rubber-tyred roller, sheeps-foot roller	1·52-1·92	Very poor, susceptible to liquefaction	Toe trench to none
CL, CI	Stable; impervious cores and blankets	$K = 10^{-6}$ to 10^{-8}	Fair to good; sheeps-foot roller, rubber-tyred	1·52-1·92	Good to poor bearing	None
OL, OI	Not suitable for embankments	$K = 10^{-4}$ to 10^{-6}	Fair to poor; sheeps-foot roller	1·28-1·60	Fair to poor bearing, may have excessive settlements	do
MH	Poor stability; core of hydraulic fill dams not desirable in rolled fill construction	$K = 10^{-4}$ to 10^{-6}	Poor to very poor; sheeps-foot roller	1·12-1·52	Poor bearing	do
CH	Fair stability with flat slopes; thin cores, blankets and dike sections	$K = 10^{-6}$ to 10^{-8}	Fair to poor; sheeps-foot roller	1·20-1·68	Fair to poor bearing	do
OH	Not suitable for embankments	$K = 10^{-6}$ to 10^{-8}	Poor to very poor; sheeps-foot roller	1·04-1·60	Very poor bearing	do
Pt	Not used for construction	—	Compaction not practical	—	Remove from foundation	—

TABLE 7 SUITABILITY FOR CANAL SECTIONS, COMPRESSIBILITY, WORKABILITY AS A CONSTRUCTION MATERIAL AND SHEAR STRENGTH

(*Clause* 3.8)

Soil Group	Relative Suitability for Canal Sections*		Compressibility when Compacted and Saturated	Workability as a Construction Material	Shearing Strength when Compacted and Saturated
	Erosion Resistance	Compacted Earth Lining			
GW	1	—	Negligible	Excellent	Excellent
GP	2	—	Negligible	Good	Good
GM	4	4	Negligible	Good	Good
GC	3	1	Very low	Good	Good to Fair
SW	6	—	Negligible	Excellent	Excellent
SP	7, if gravelly	—	Very low	Fair	Good
SM	8, if gravelly	5 (Erosion critical)	Low	Fair	Good
SC	5	2	Low	Good	Good to Fair
ML, MI	—	6 (Erosion critical)	Medium	Fair	Fair
CL, CI	9	3	Medium	Good to Fair	Fair
OL, OI	—	7 (Erosion critical)	Medium	Fair	Poor
MH	—	—	High	Poor	Fair to Poor
CH	10	8 (Volume change critical)	High	Poor	Poor
OH	—	—	High	Poor	Poor
P_t	—	—	—	—	—

*Number 1 is the best.

Soil Structure

- Defined as the arrangement and state of aggregation of soil particles in a soil mass.
- Mineralogical composition, electrical properties, shape and orientation of solid particles, the nature and properties of soil water and its ionic composition, the interaction forces between soil particles, soil water, and their adsorption complexes.
- Soil particles not only refer to individual soil particles, but the aggregation of smaller fraction.
- Soil structures is an important factor which influences engineering properties such as shear strength, compressibility and permeability.

- **Single grained**: An arrangement composed of individual soil particles. It is a characteristic of coarse grained soil.
- **Honeycomb**: An arrangement of soil particles having loosely arranged bundles of particles, irrespective of arrangement of particles within the bundles. It is a characteristic of fine grained soil.
- **Flocculent**: An arrangement composed of flocs of soil particles instead of individual soil particles. The particles are oriented “egde to edge” or “edge to face” with respect to one another. It is a characteristic of fine grained soil.
- **Dispersed**: An arrangement composed of particles having “face to face” or parallel orientation. It is a characteristic of fine grained soil.
- **Coarse-grained skeleton**: An arrangement of coarse grains forming a skeleton with its interstices partly filled by a relatively loose aggregation of the finest soil grains. It is a characteristic of Composite soil.
- **Cohesive matrix**: An arrangement in which a particle to particle contact of coarse fraction is not possible. The coarse grains remain embedded in a large mass of cohesive fine grains. It is a characteristic of Composite soil.

Single grained structure

- Coarse grained soils (>2micron) settle out of suspension in water as an individual grain independent of other grains. (gravitational forces)
- The weight of the grains causes them to settle, and get particle to particle contact on deposition.

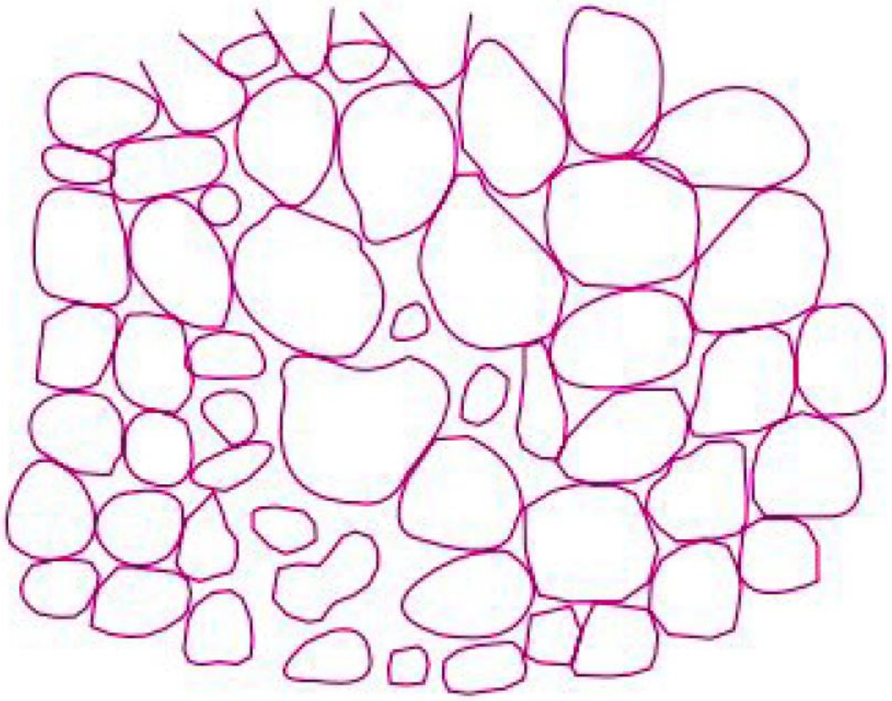
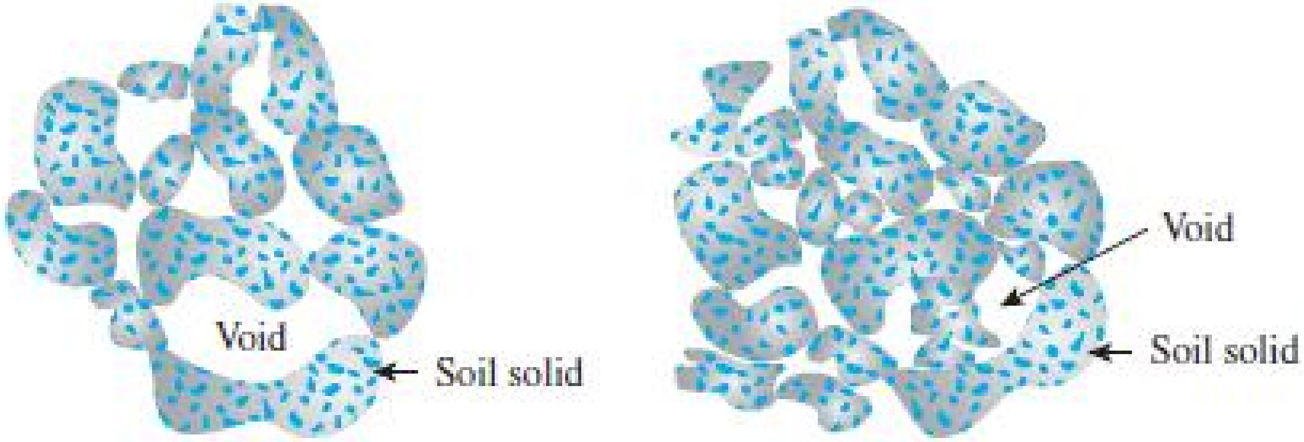
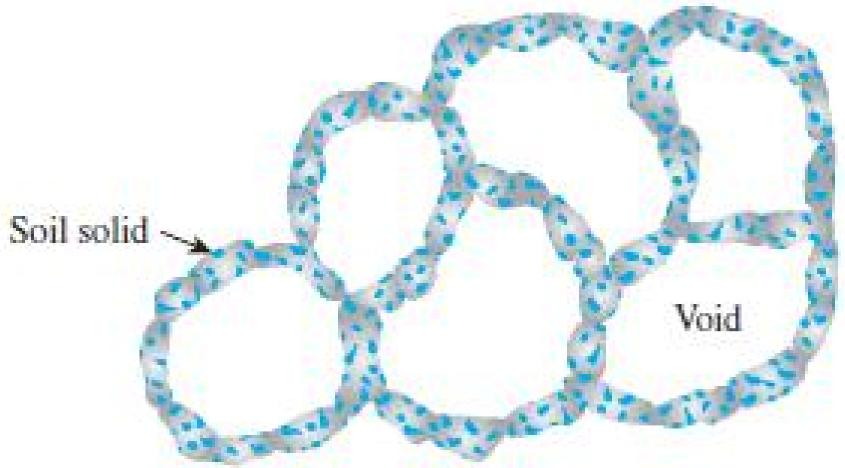


Fig. 5.10 Single grained structure



- ***Honeycomb structure***
- Such structure exists in grains of silts smaller than 0.02mm dia and larger than 0.0002mm.
- Here surface forces also come in to effect when the grains come in contact at the bottom of the suspension preventing from rolling down immediately.
- The grains coming in contact are held until miniature arches are formed, bridging over relatively large void spaces and forming honeycomb structure.



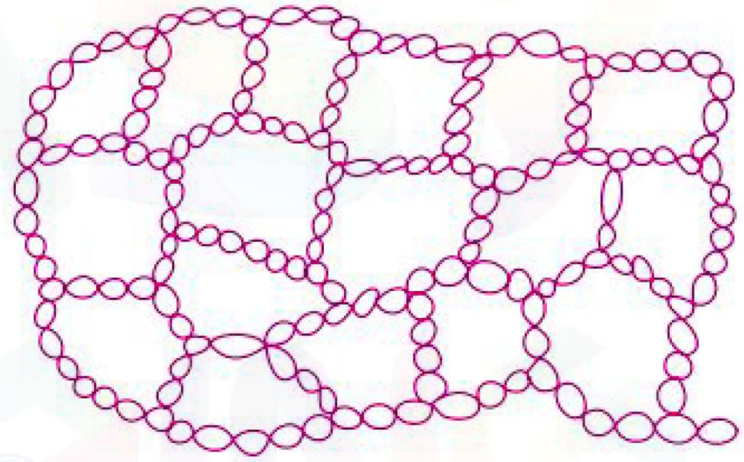
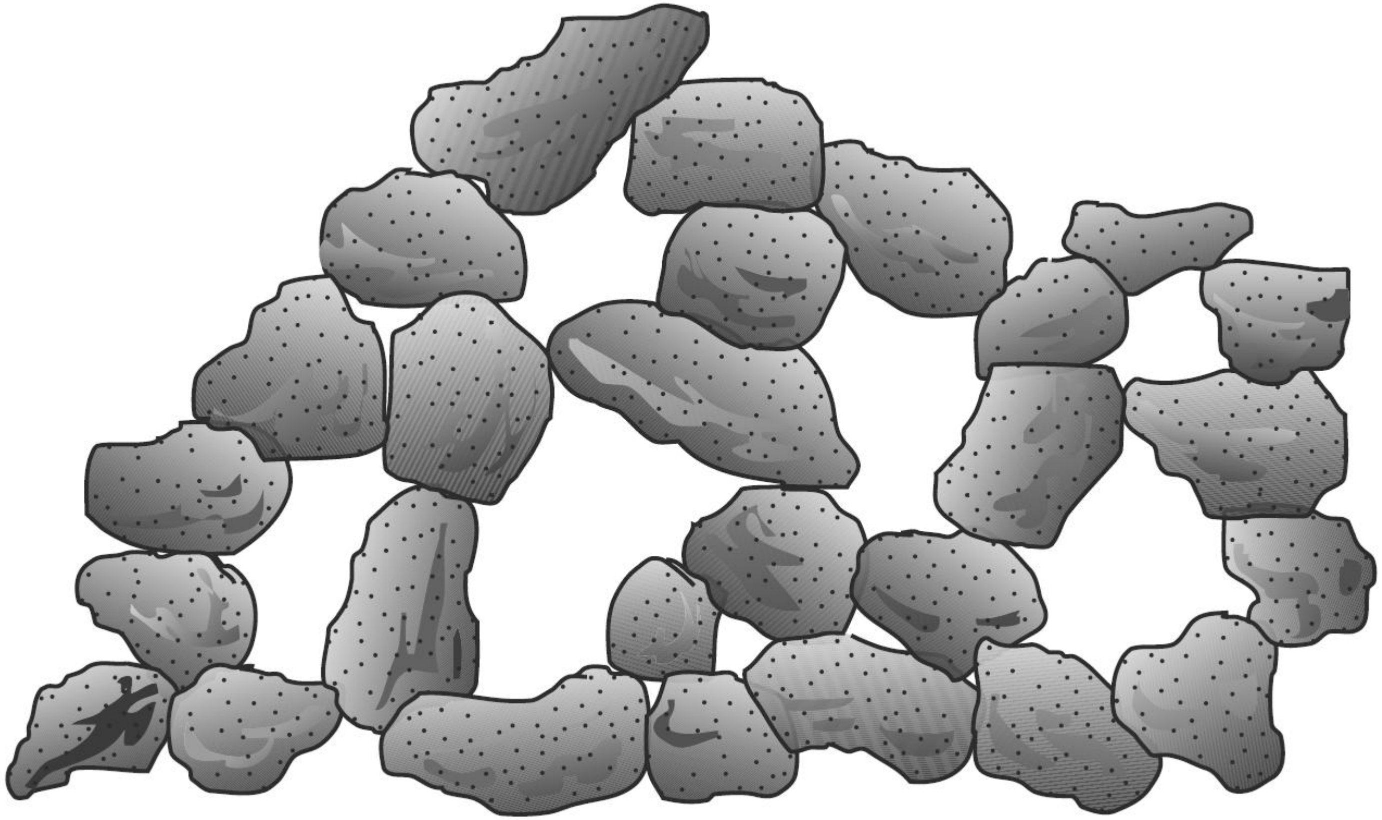


Fig. 5.11 Honeycomb structure

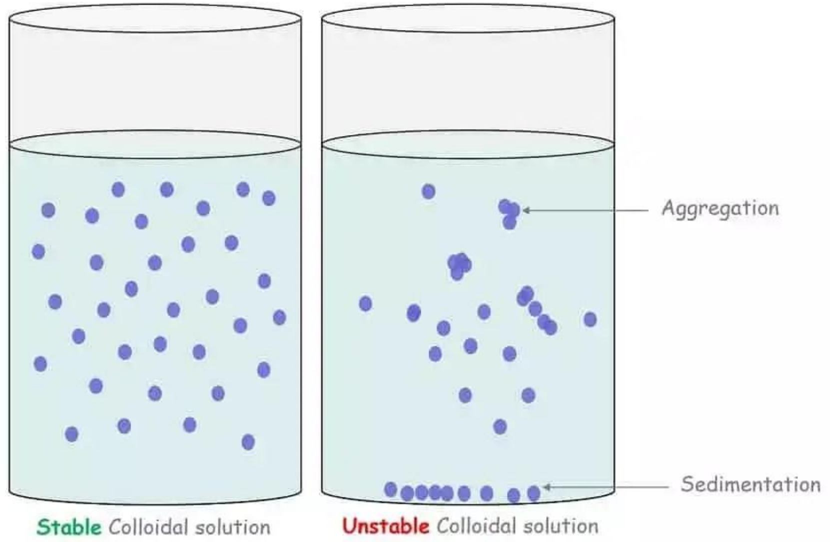
- **Classification by Structure**

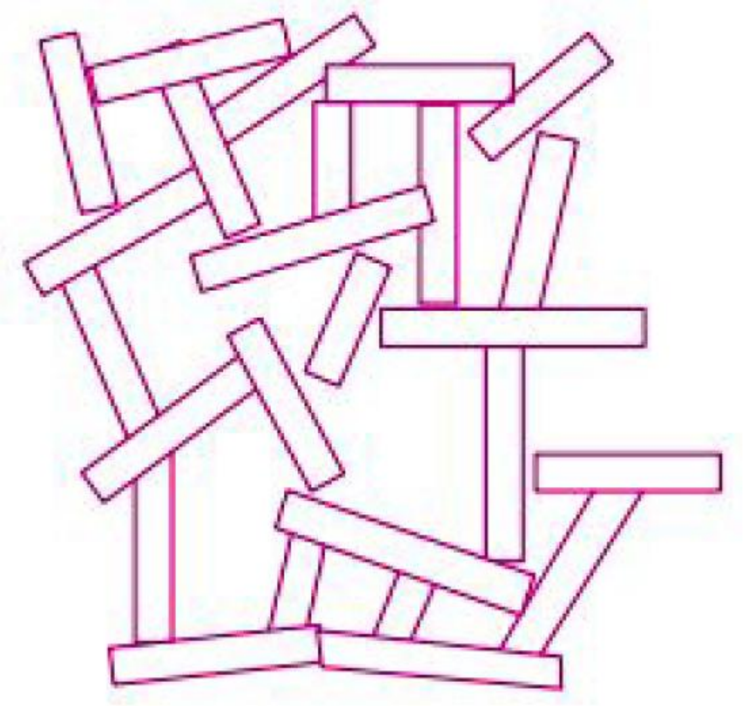


Honeycomb structure in a granular soil.

<u>Flocculent structure and Dispersed structure</u>

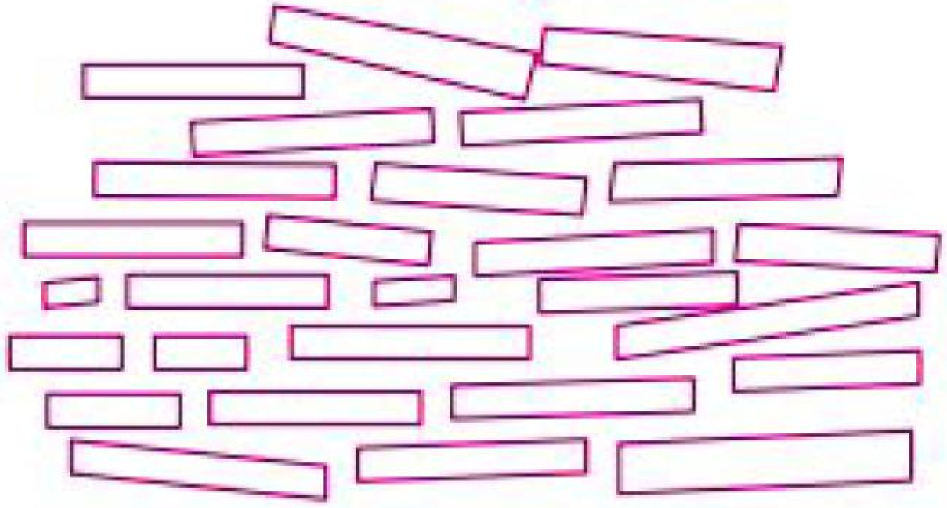
- Occurs in clays consisting of very fine particles or colloids.
- Flocculated structure of clay platelets is formed when there are egde to edge contacts between platelets. Such a structure is formed if the net electrical forces between adjacent soil particles at the time of deposition are attraction forces.



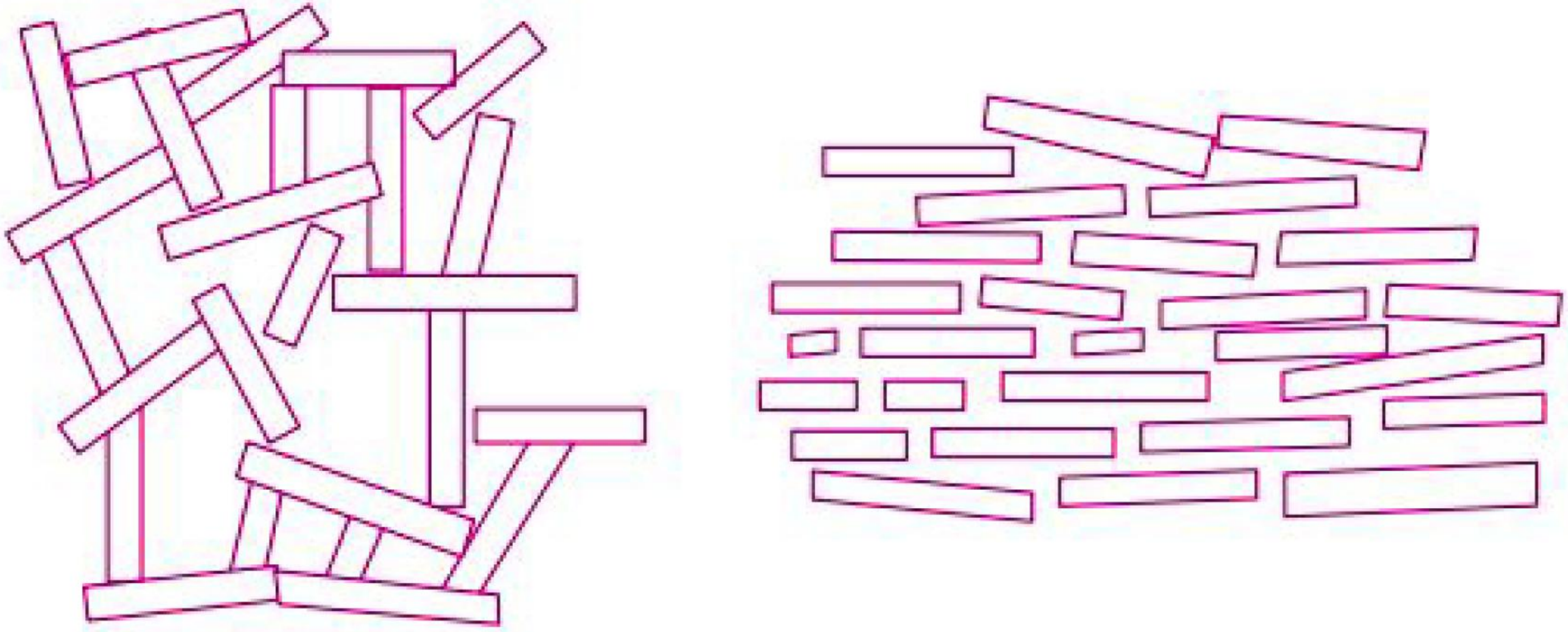


(a) Flocculated structure

- Dispersed structure is formed when the platelets have face to face contact in more or less parallel array. Such a structure is formed if the net electrical forces between adjacent soil particles at the time of deposition are repulsive forces.



(b) Dispersed structure



(a) Flocculated structure (b) Dispersed structure

Fig. 5.12 Goldschmidt-Lambe concept of cardhouse structure

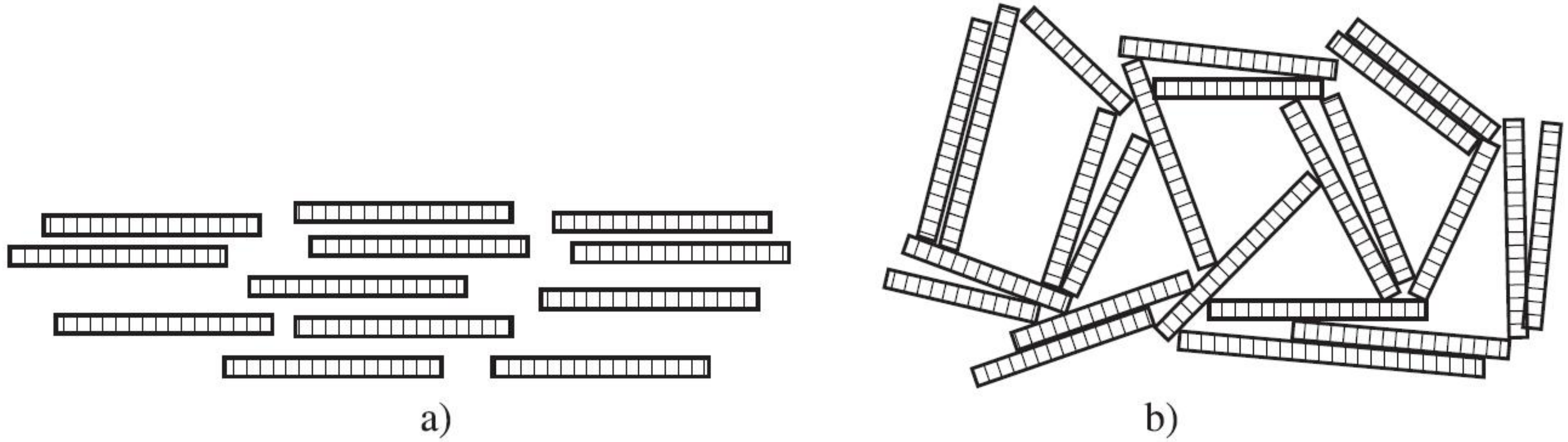
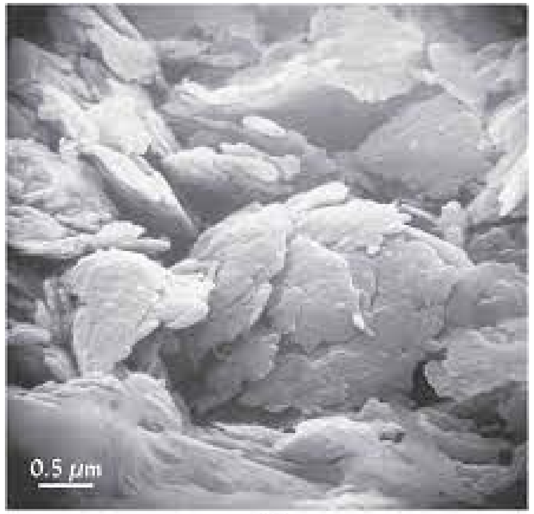
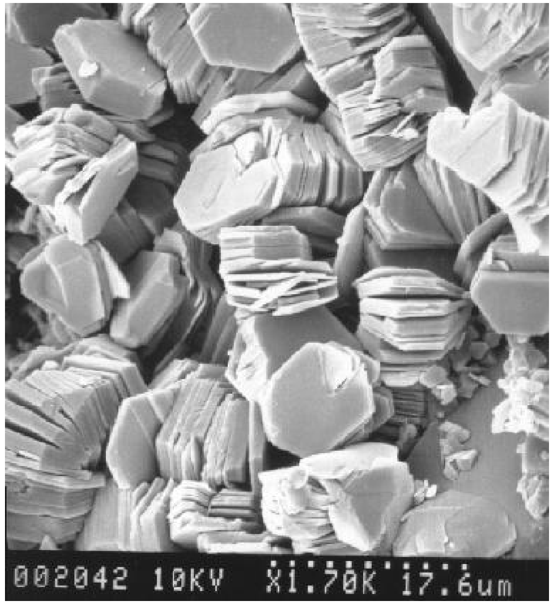
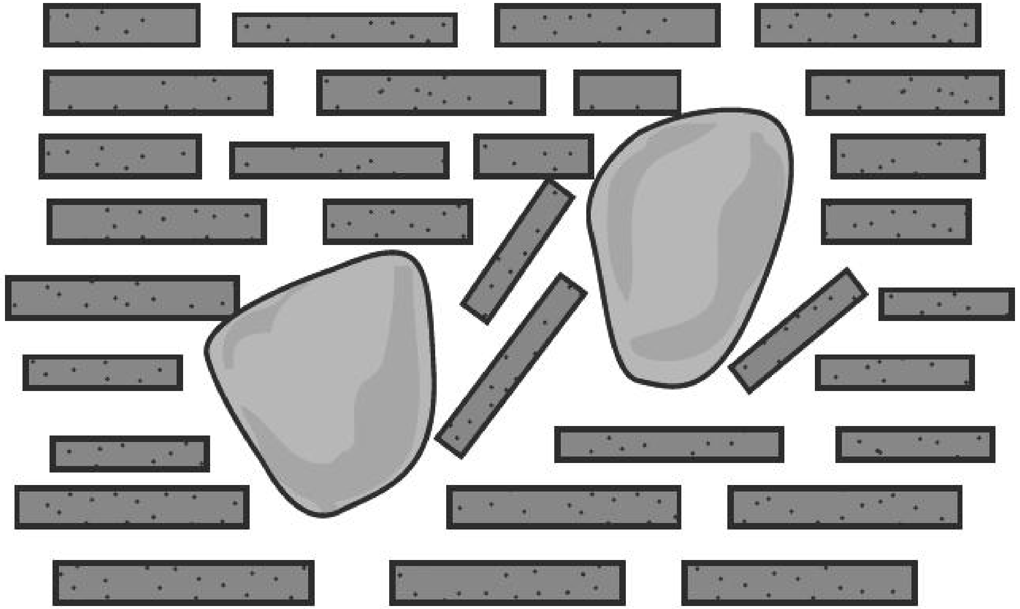


Figure 1.1. *a) Dispersed clay structure; b) flocculated clay structure ("cardhouse")*

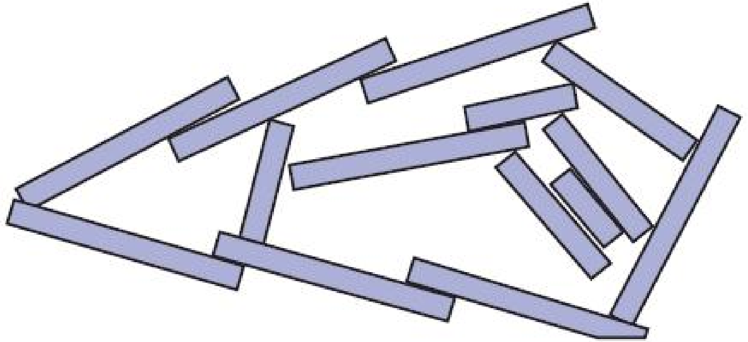




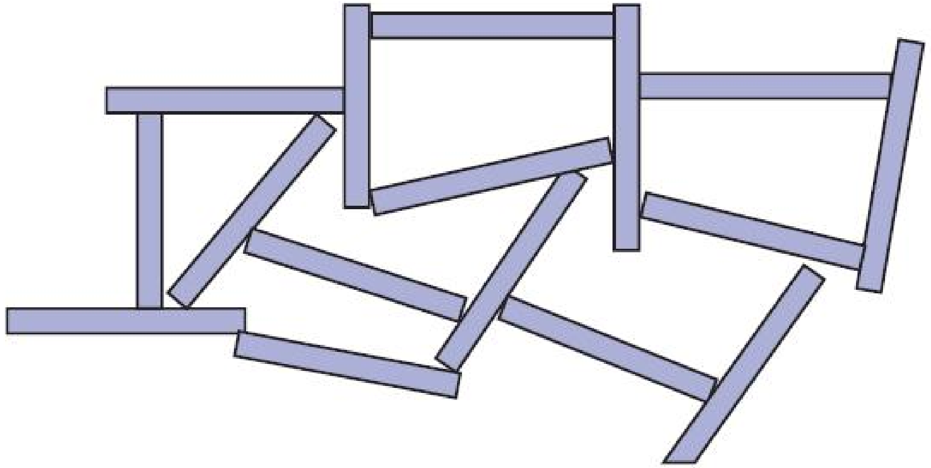


Schematic diagram of particle orientation.

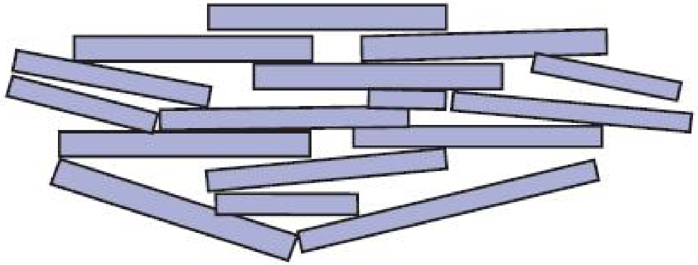
- Soil fabric



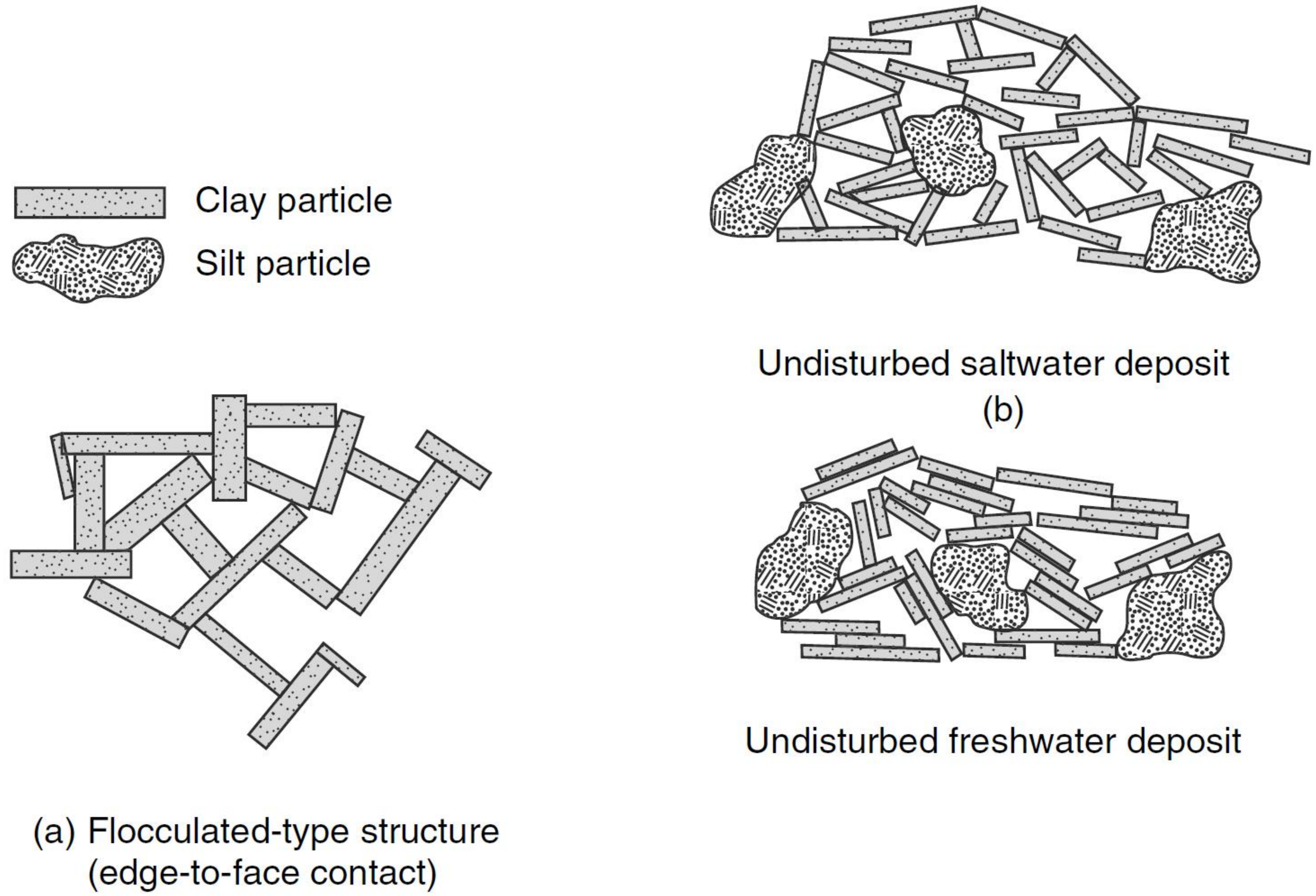
(*a*) Flocculated structure—saltwater environment



(*b*) Flocculated structure—freshwater environment



(*c*) Dispersed structure



Schematic diagram of types of particle orientations [201].

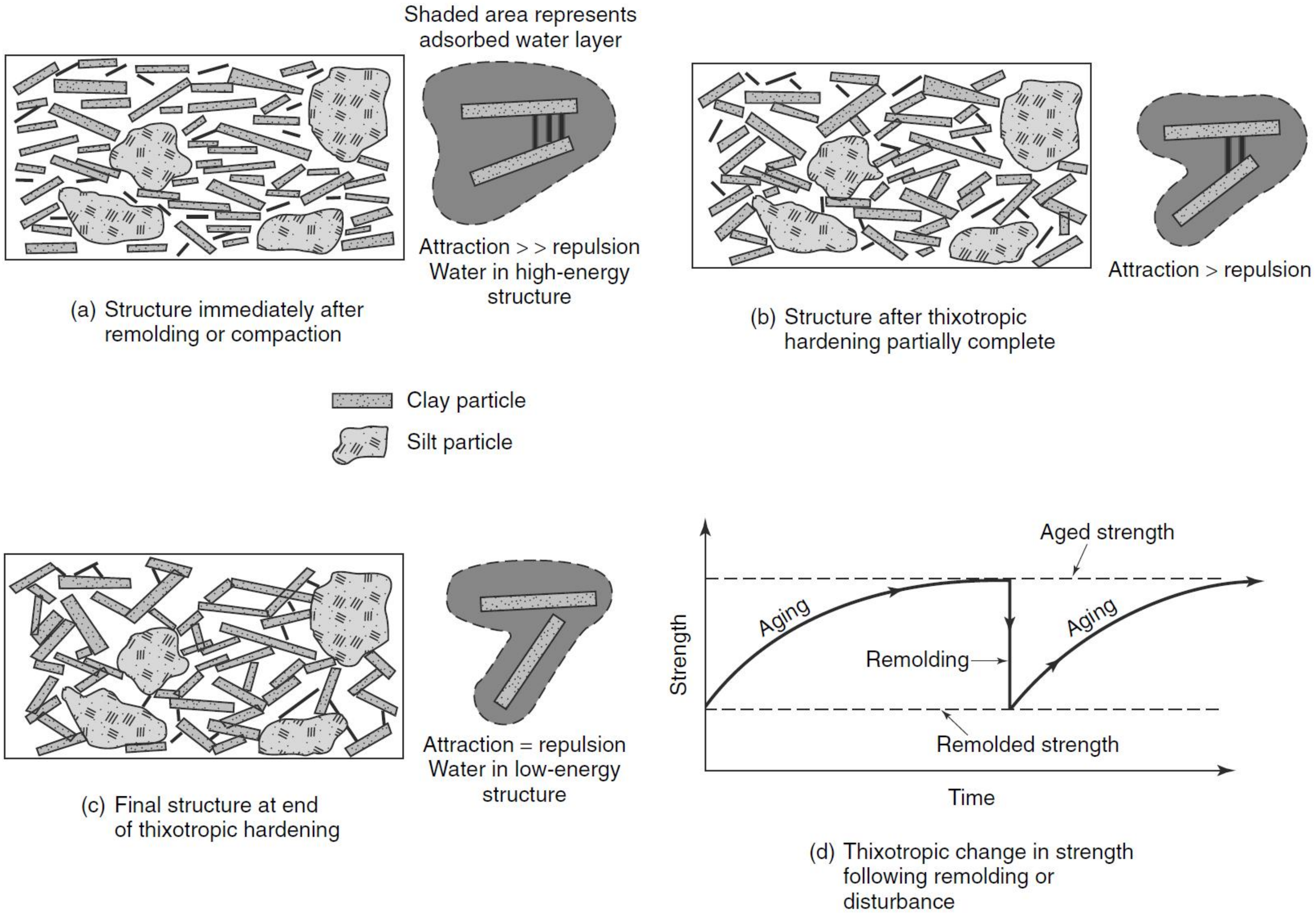


Figure 10 Schematic diagram of thixotropic structure change in a fine-grained soil [242].

Structure of composite soils

- **Coarse grained skeleton**, the void spaces are filled with clay particles. This bulky particles form a continuous relatively incompressible framework.
- **Cohesive matrix**, clay content is more and bulky particles are not in position and hence no particle to particle contact and relatively more compressible

- Coarse grained particles are composed of primary minerals with bulky minerals
- They do not have plasticity or cohesion but are governed by gravitational forces

- Fine grained soils are composed of crystalline minerals and amorphous minerals having effect on soil behaviour.
- These minerals, which have low surface activities and do not contribute plasticity or cohesion are referred as ***non-clay minerals***.
- Crystalline minerals whose surface activity is such that they develop cohesion and plasticity are called as ***clay minerals***.
- About 15 minerals are classed as clay minerals and these belong to four main groups
- Kaolinite, Montmorillonite, Illite and playgorskite

- Chemically, the clay minerals are silicates of aluminium and/or iron and magnesium
- Most of the clay minerals are sheet or layered like structures
- Clays are considered essentially made up of extremely small particles, each one of which is either a book of sheet like units.
- Clays behave like colloids. A colloid is a particle whose specific surface (surface area per unit volume or unit mass) is so high that its behaviour is controlled by surface energy rather than mass energy.
- Smaller the particle, larger is the surface area per unit volume.

Atomic and Molecular Bonds

1. Electrostatic or Primary Valence Bond
2. Hydrogen Bond
3. Secondary Valence Bond

- Atoms bonding to atoms forming molecules (intramolecular bond) are called primary valence bonds. Sufficiently strong bond.
- Atoms in one molecule bonding to atoms in molecule (intermolecular bonds) are called secondary valence bonds. Relatively weaker bond

Electrostatic or Primary Valence Bonds

- Ionic bond
- Covalent bond

bond. Since the transition from one type of bond to another can be gradual, the classification of certain forces is arbitrary. The ionic bond is the simplest and strongest of the bonds that holds atoms together. This bond is made by the exchange of electrons in the union of ions. In the combination of simple elements, an element having an excess of electrons in a ring or shell can exchange the excess electron with an element lacking electrons to complete its outer ring or shell. The exchange of electrons ties the atoms together with an exceptionally strong electrostatic bond. An example of such a bond is illustrated by the union of Al and O. Aluminium has an excess of 3 electrons in its outer ring and oxygen lacks 2 electrons in its outer ring. The linking of the ions of these two elements can be indicated as shown in Fig. 5.1 in which each of the joining lines can be considered as a unit electrostatic force bonding the aluminium and oxygen ions into a molecule of aluminium oxide. In the covalent bond, elements are bonded by sharing of a common electron by two atoms. However, since the primary valence bonds in cohesive soils are seldom broken, they are of minor concern to the engineer.

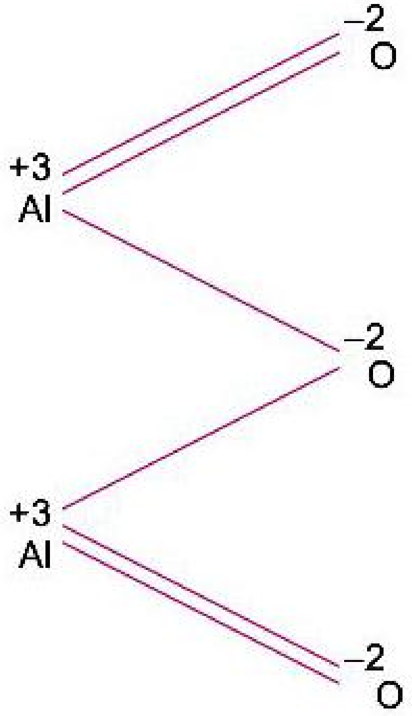
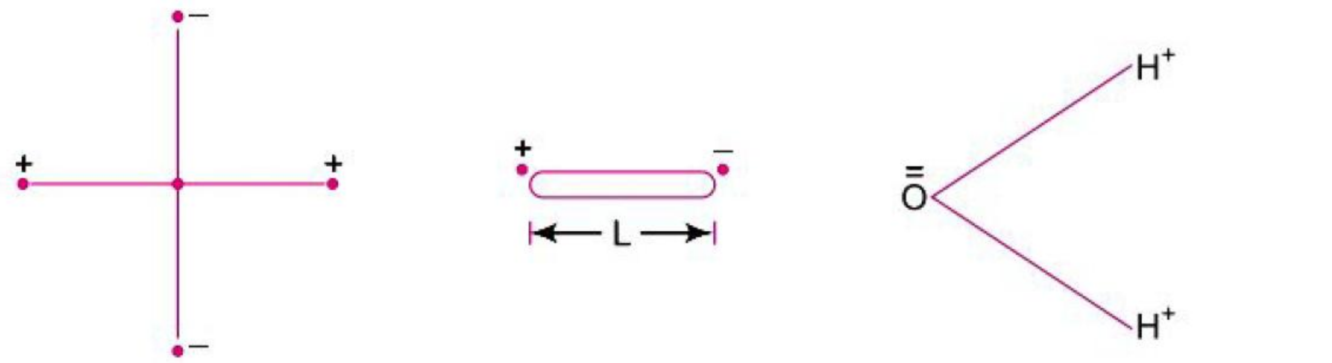


Fig. 5.1 Ionic bond (aluminium oxide)

Secondary valence forces

- Vander Waal forces
- Hydrogen Bonds

Waal forces and the *hydrogen bonds*. Secondary valence forces acting between molecules are attributed to the presence of electric moments in the individual molecules. If, in an electrical system the centre of action of positive charge coincides with the centre of action of negative charges, the system has no dipole moment, and is termed *non-polar* [Fig. 5.2 (*a*)]. Although a molecule is electrically neutral, the centre of gravity of the positive and negative charges may not coincide. An electric moment is thus developed, and the system is referred to as being *polar*. System of Fig. 5.2 (*b*) has a *dipole mement* of $e \times L$. The atoms in the water molecule are held together by a heterpolar bond and the resulting molecule is not electrically symmetrical; the hydrogen-oxygen bonds are at an angle of 105° [Fig. 5.2 (*c*)]. The water molecule is therefore a dipole.



(a) Non-polar system (b) Polar system (dipole) (c) Water molecule (dipole)

Fig. 5.2 Polar and non-polar system (the solid lines represent primary valence bonds)

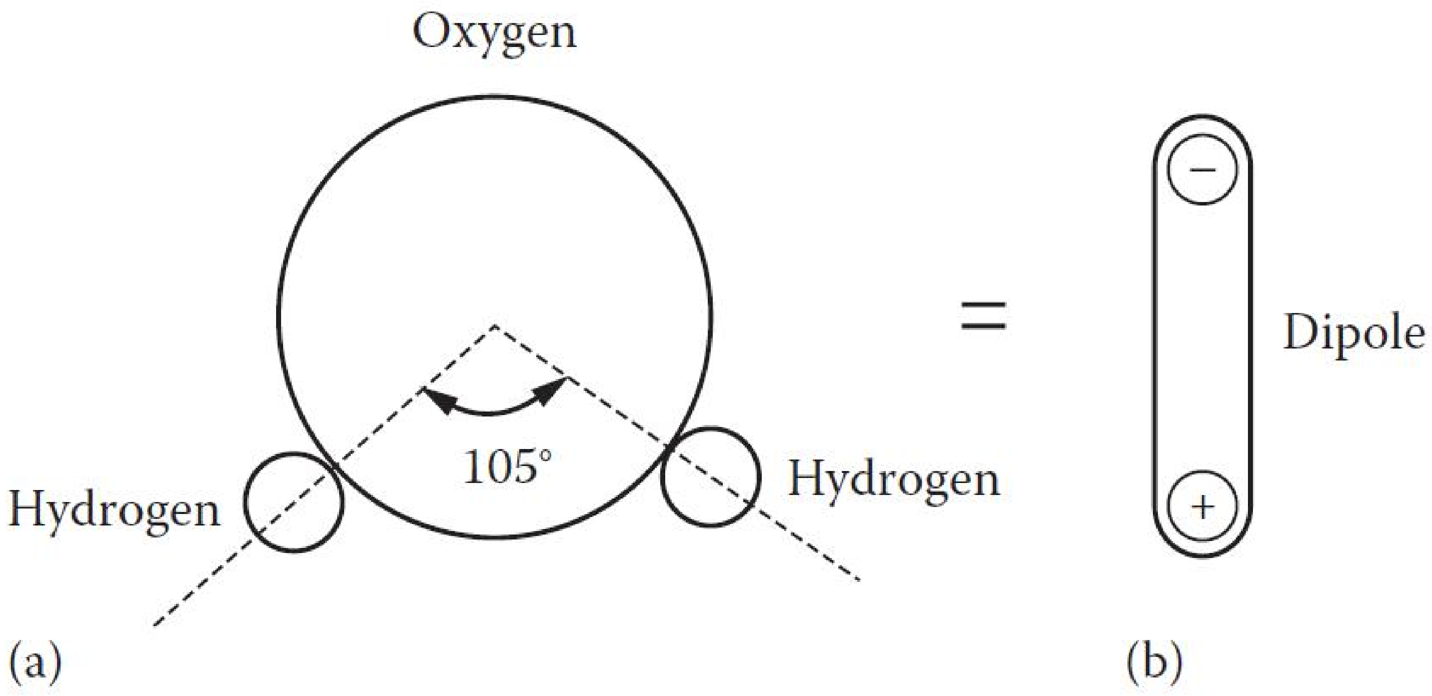


Figure 1.6 Dipolar nature of water: (a) unsymmetrical arrangement of hydrogen atoms; (b) dipole.

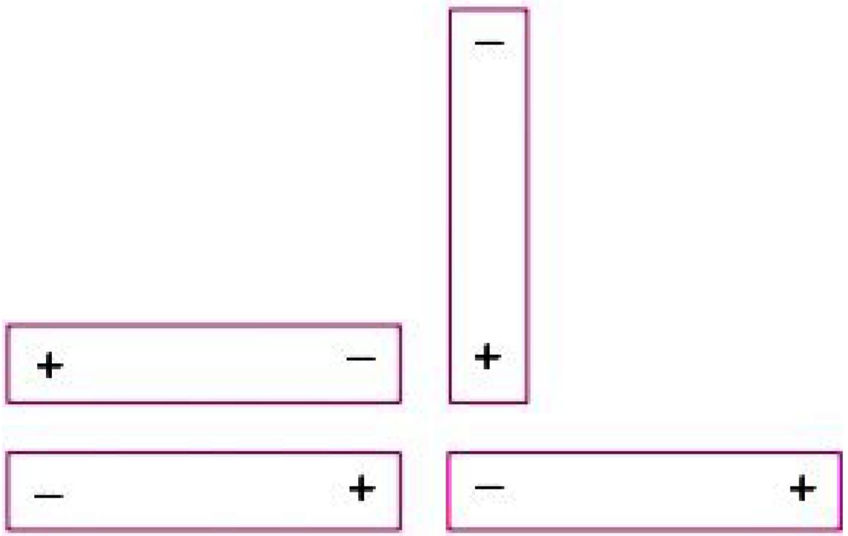


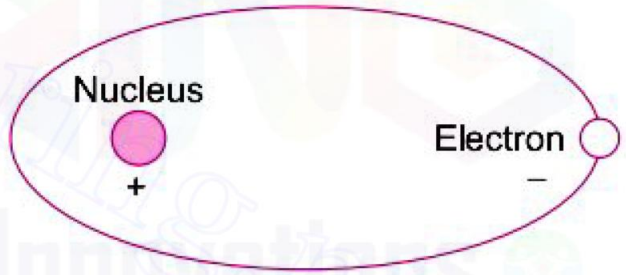
Fig. 5.3 Oriented dipole

van der Waals (1873) postulated the existence of a common attractive force acting between all atoms and molecules of matter. Later, Keeson proposed that this force is caused by two oriented dipoles and calculated the average attractive force between such oriented dipoles. Many types of orientations are possible with unsymmetrical water molecules (Fig. 5.3).

- Secondary valence forces caused by orientation effect is commonly known as Vander Waal's forces
- 3 Effects contributing to secondary valence forces
- Thermal agitation tends to upset the alignment of dipoles, ***orientation effect*** is highly dependent upon temperature.
- ***Induced Effect :*** Non-polar molecules become polar when placed in an electric field, since it causes a slight displacement of electrons and nuclei. Since the moment is induced hence the name.
- ***Dispersion Effect*** (Dispersive energy) holds the molecules together . This energy occurs between atoms and molecules that are dipolar.

Since all electron vibrate constantly, there is a relative displacement between electrons and nuclei.

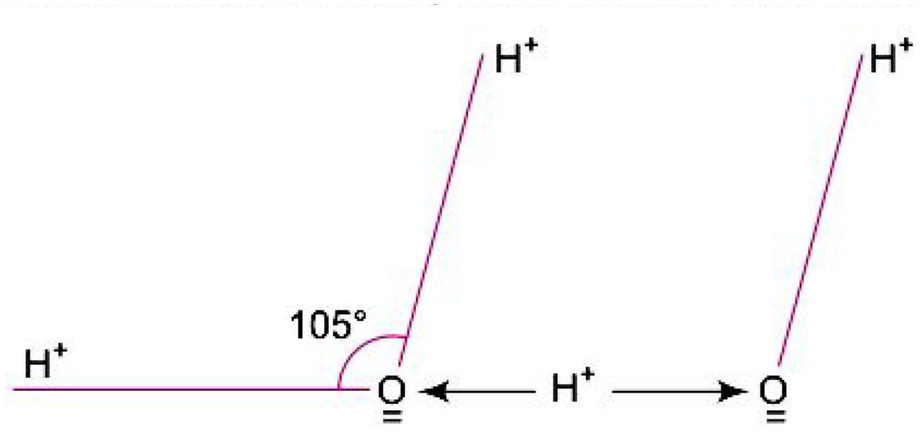
As electrons revolve around the nucleus, electrons at its furthest distance produces a statistical dipole, this induces magnetic moments and produce attraction known as London Vander Waal forces



- Orientation 77%
- Dispersion 19%
- Induction 04%

Hydrogen bond

- This occurs when an atom of hydrogen is rather strongly attracted by two other atoms. The hydrogen cannot decide to which atom to bond, and oscillates between them.
- E.g. bond between water molecules



Type of bond	*Strength in kcal per g-mole*	*Interatomic or Intermolecular distance in Å*
1. Primary valence	20–200	1–2
2. Hydrogen	5–10	2–3
3. Secondary valence	0.5–5	> 5

Diffuse double layer

- A soil colloid suspended in water carries a negative charge
- Since net electrical charge of the entire soil water suspension must be zero, the charge on each of the colloid must be neutralised by ions from the water which swarm around each colloid. These ions are called as ***exchangeable ions***.
- Thus their positions are compromised between particle charge which pulls them in and attraction by other bodies which keeps them away. The counter ions thus constitute the ***diffuse double layer*** of the colloid

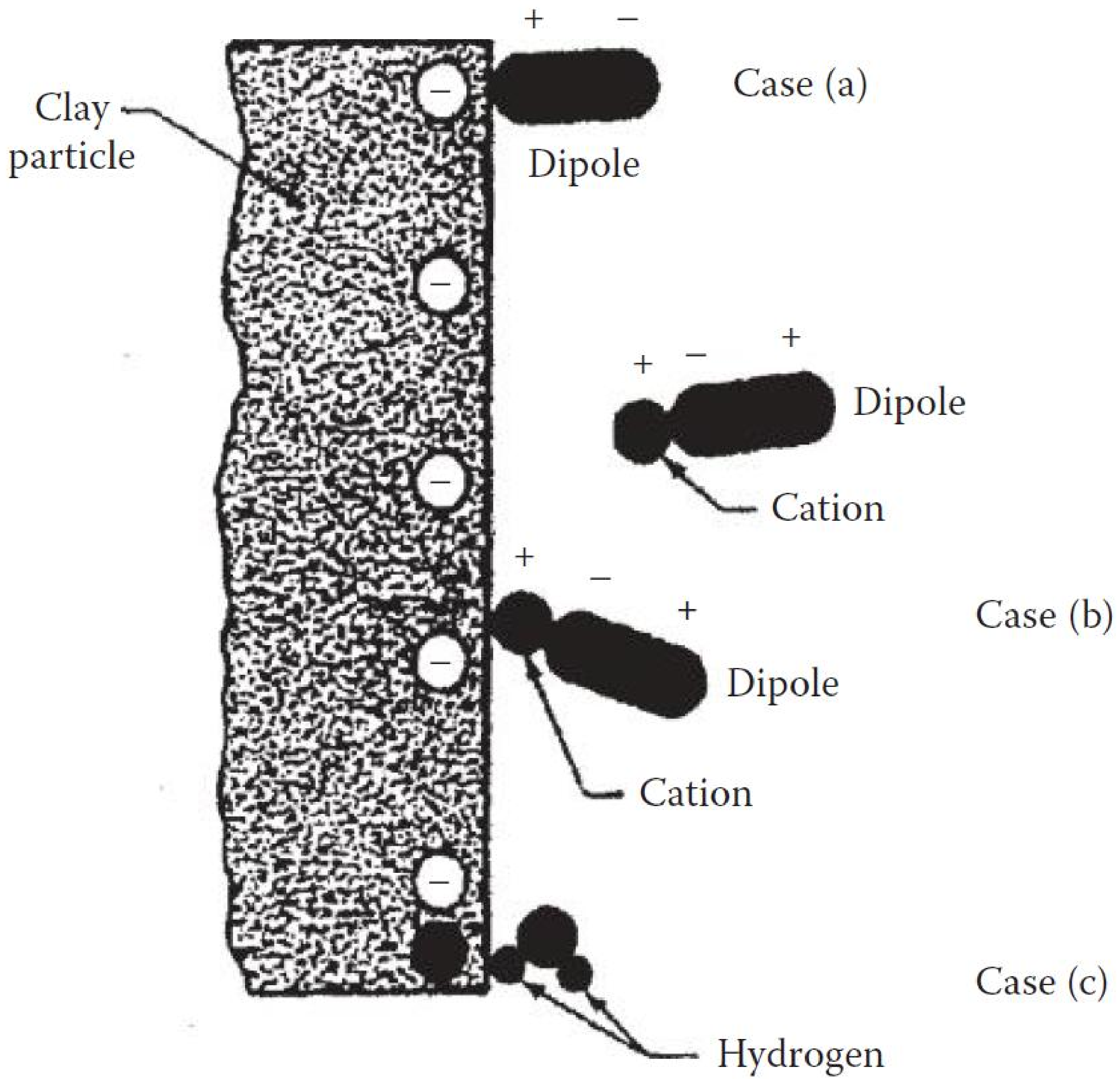
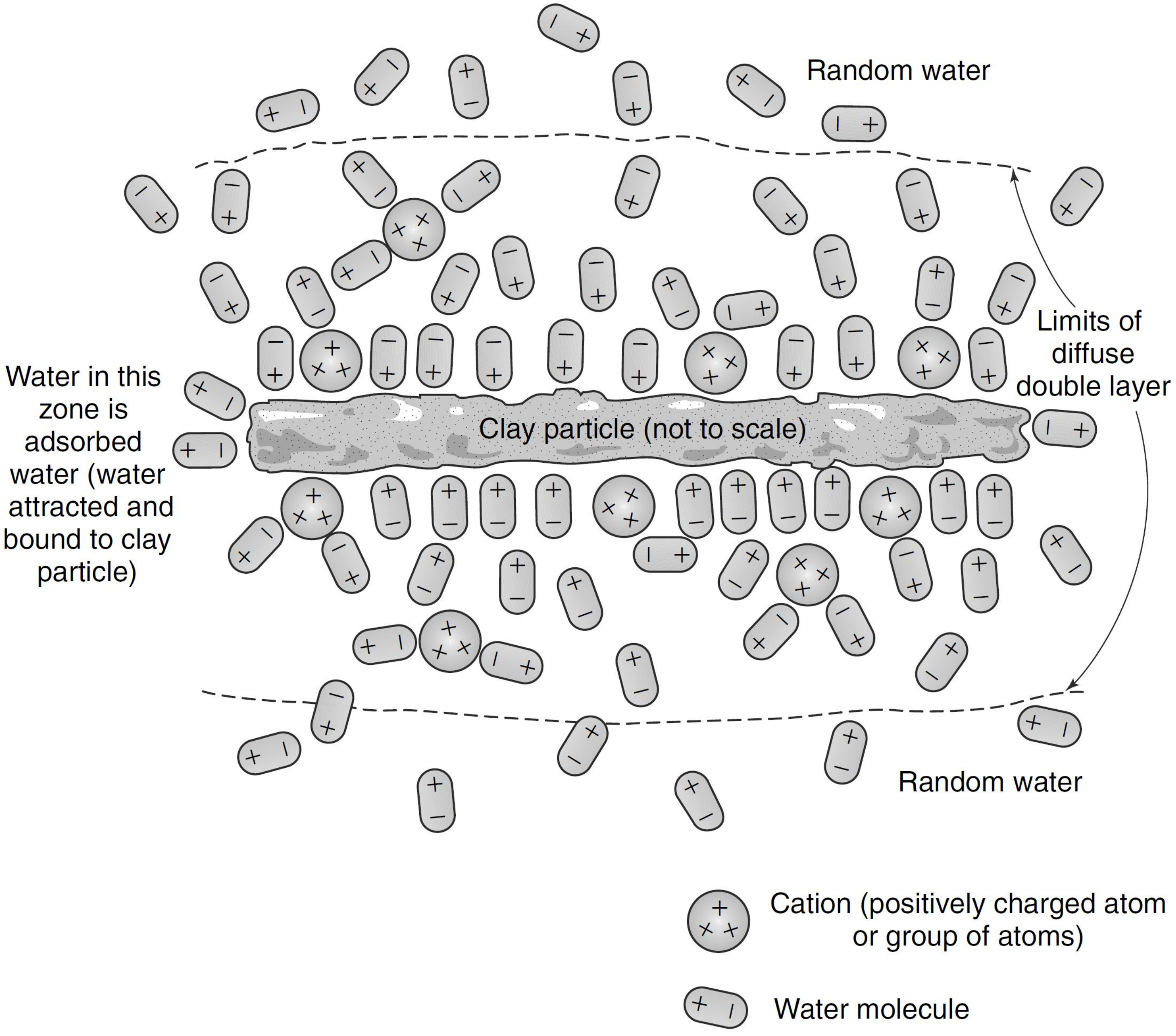


Figure 1.7 Dipolar water molecules in diffuse double layer.



Concept: Adsorbed water and cations in diffuse double layer surrounding clay particle.

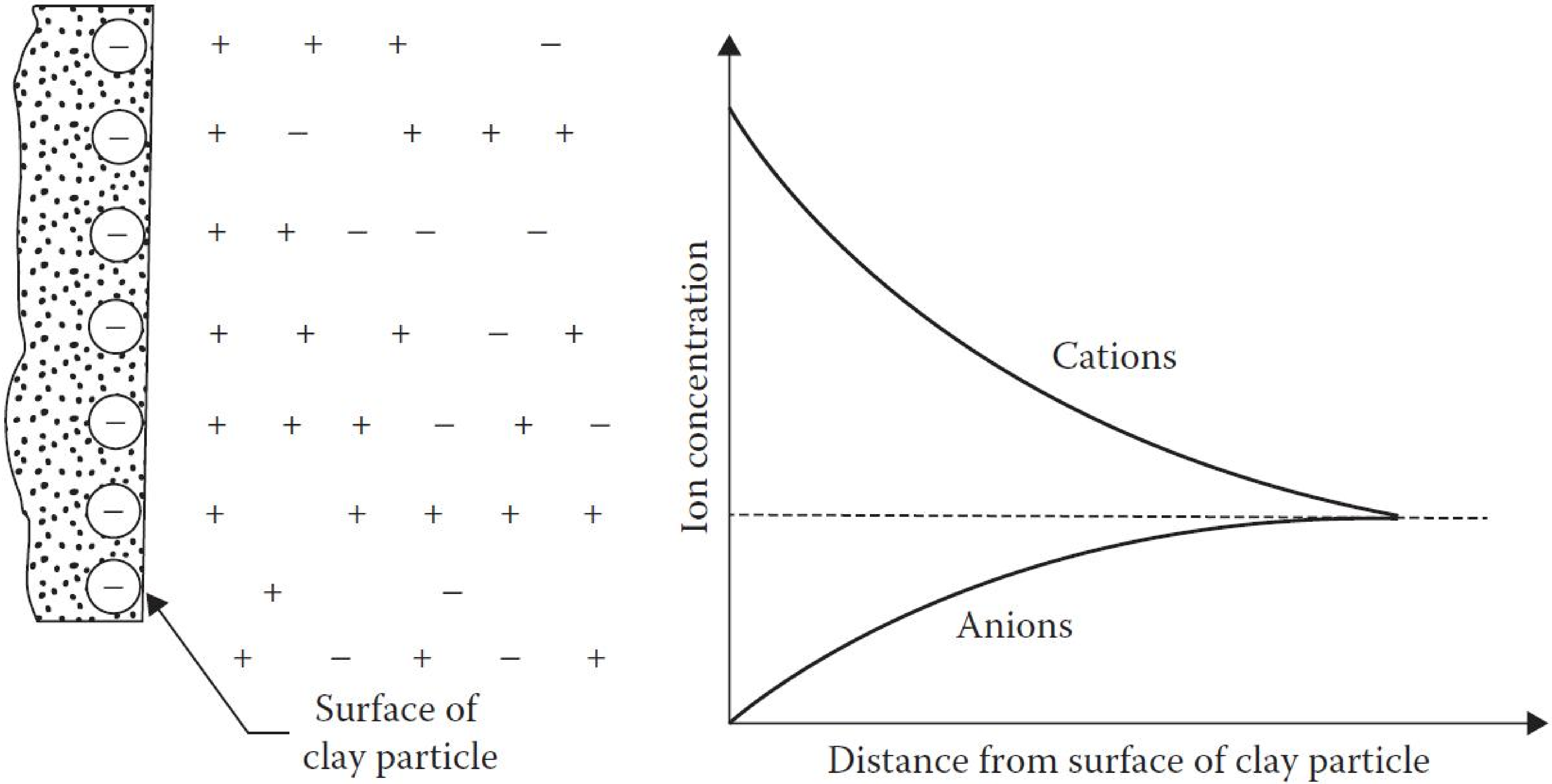
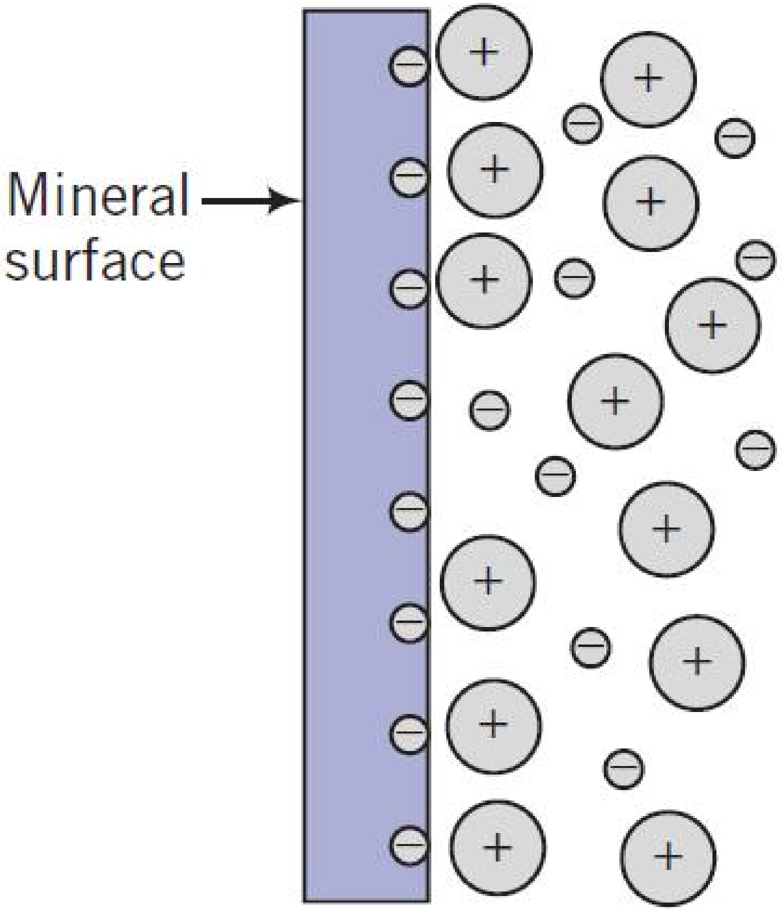
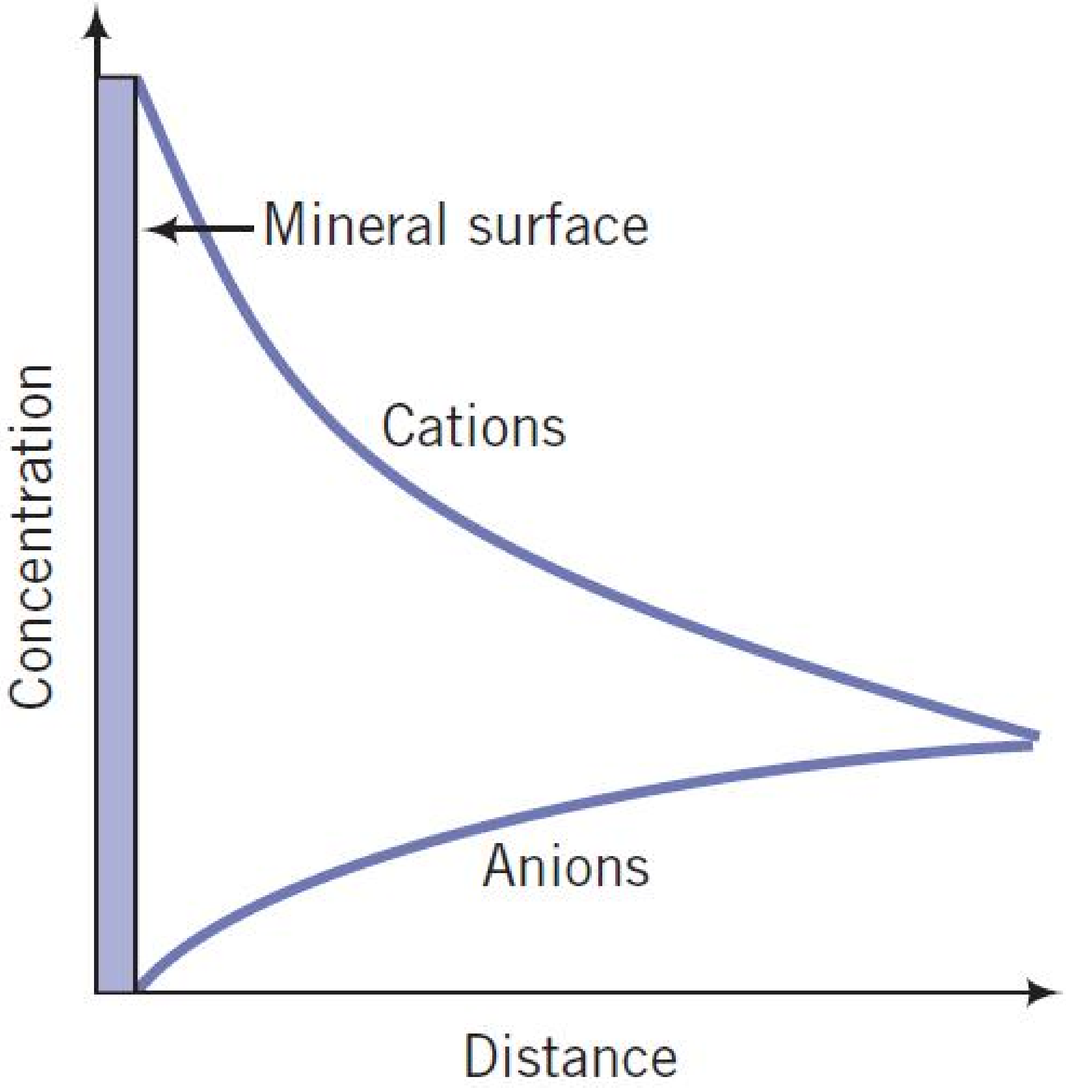


Figure 1.5 Diffuse double layer.



Diffuse double layer



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

This series indicates that, for example, Al^{3+} ions can replace Ca^{2+} ions, and Ca^{2+} ions can replace Na^+ ions. The process is called *cation exchange*. For example,

$$Na_{clay} + CaCl_2 \rightarrow Ca_{clay} + NaCl$$

Cation exchange capacity (CEC) of a clay is defined as the amount of exchangeable ions, expressed in milliequivalents, per 100 g of dry clay.

- Inter particle forces in a soil mass
- Gravitational forces: proportional to mass and are important for coarse grained soils
- Surface forces: proportional to specific surface of the colloids and are important for fine grained soils.
- ***Attractive forces***

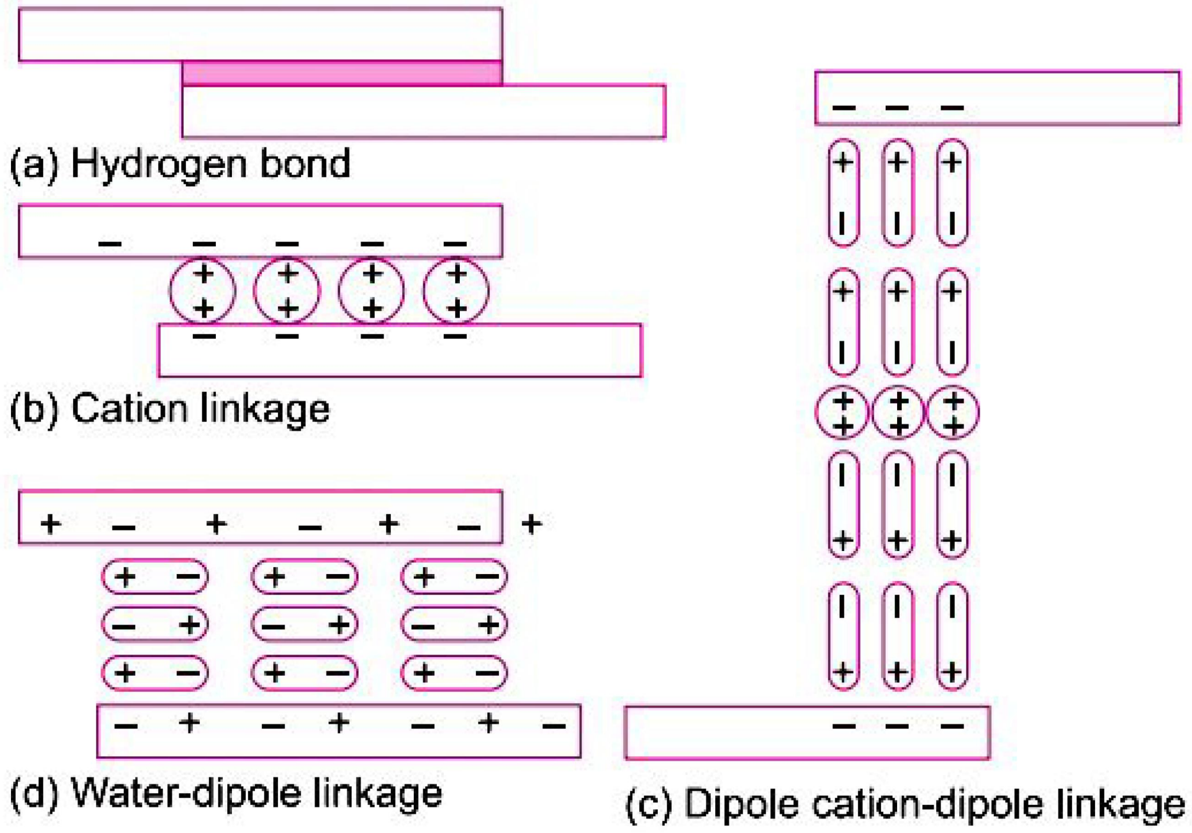


Fig. 5.8 Interparticle attractive forces (Lambe, 1953)

- ***<u>Repulsive forces</u>***

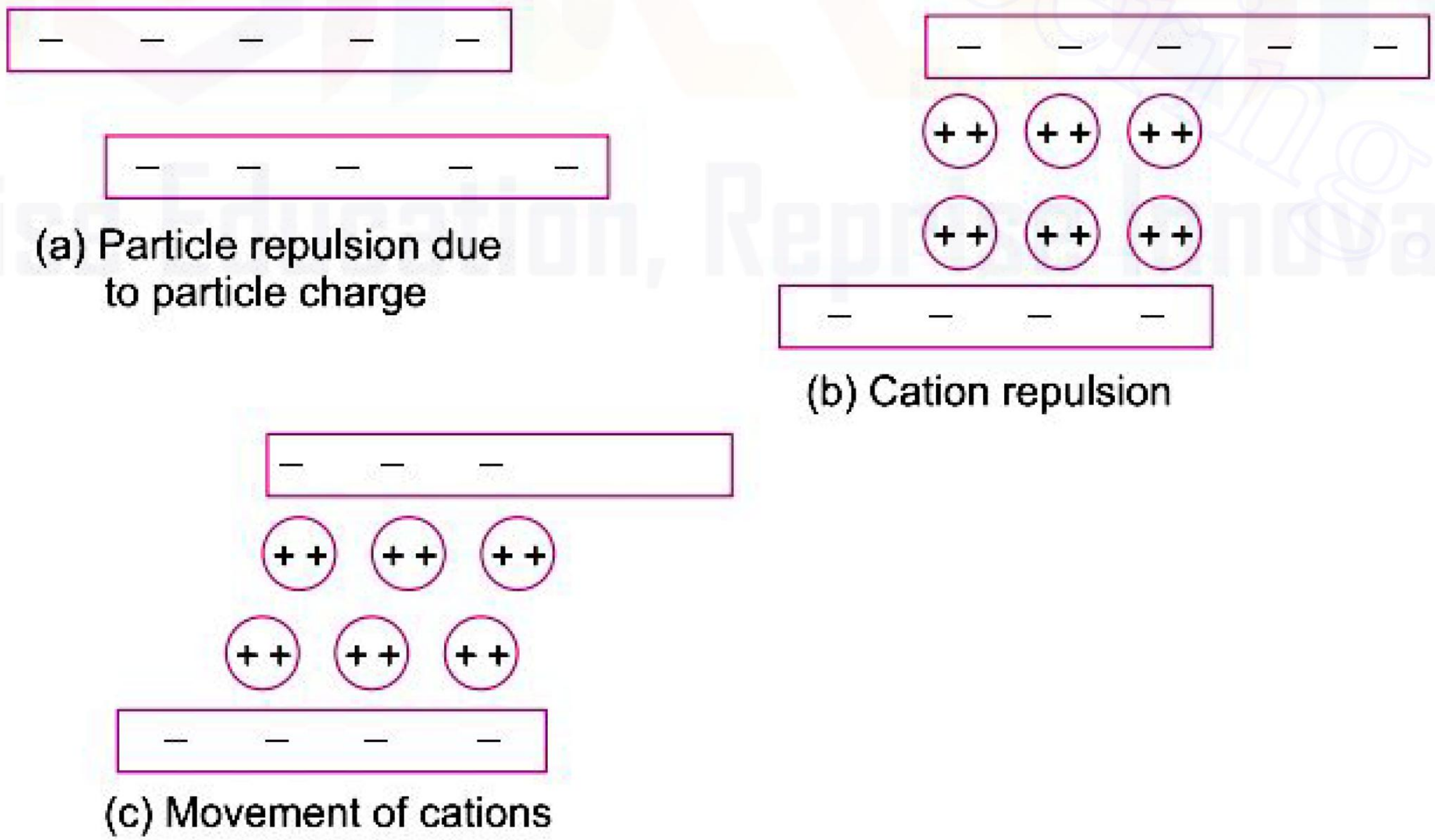


Fig. 5.9 Interparticle repulsive forces (Lambe, 1953)

Clay minerals

Silica tetrahedral unit where four oxygen or hydroxyls having configuration of a tetrahedron enclose a silicon atom.

The tetrahedra are combined in a sheet structure so the oxygens of bases of all the tetrahedra are in common plane, and each oxygen belongs to two tetrahedra

The silica sheet represents the oxygen basal layer and hydroxyl apex layer

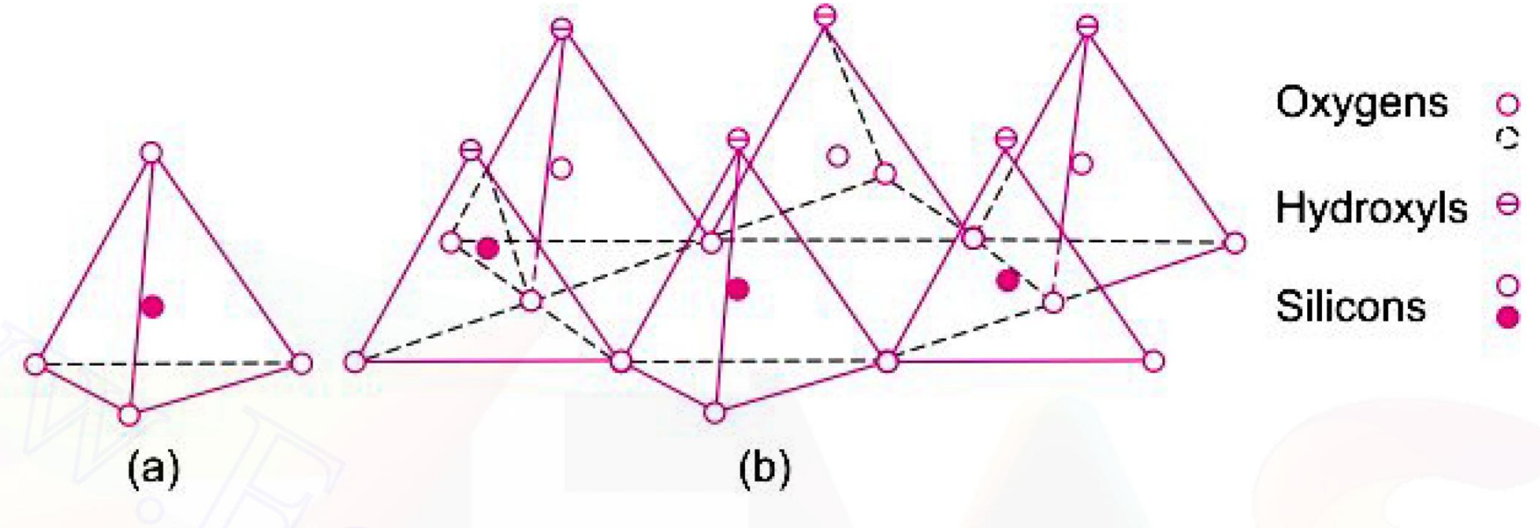
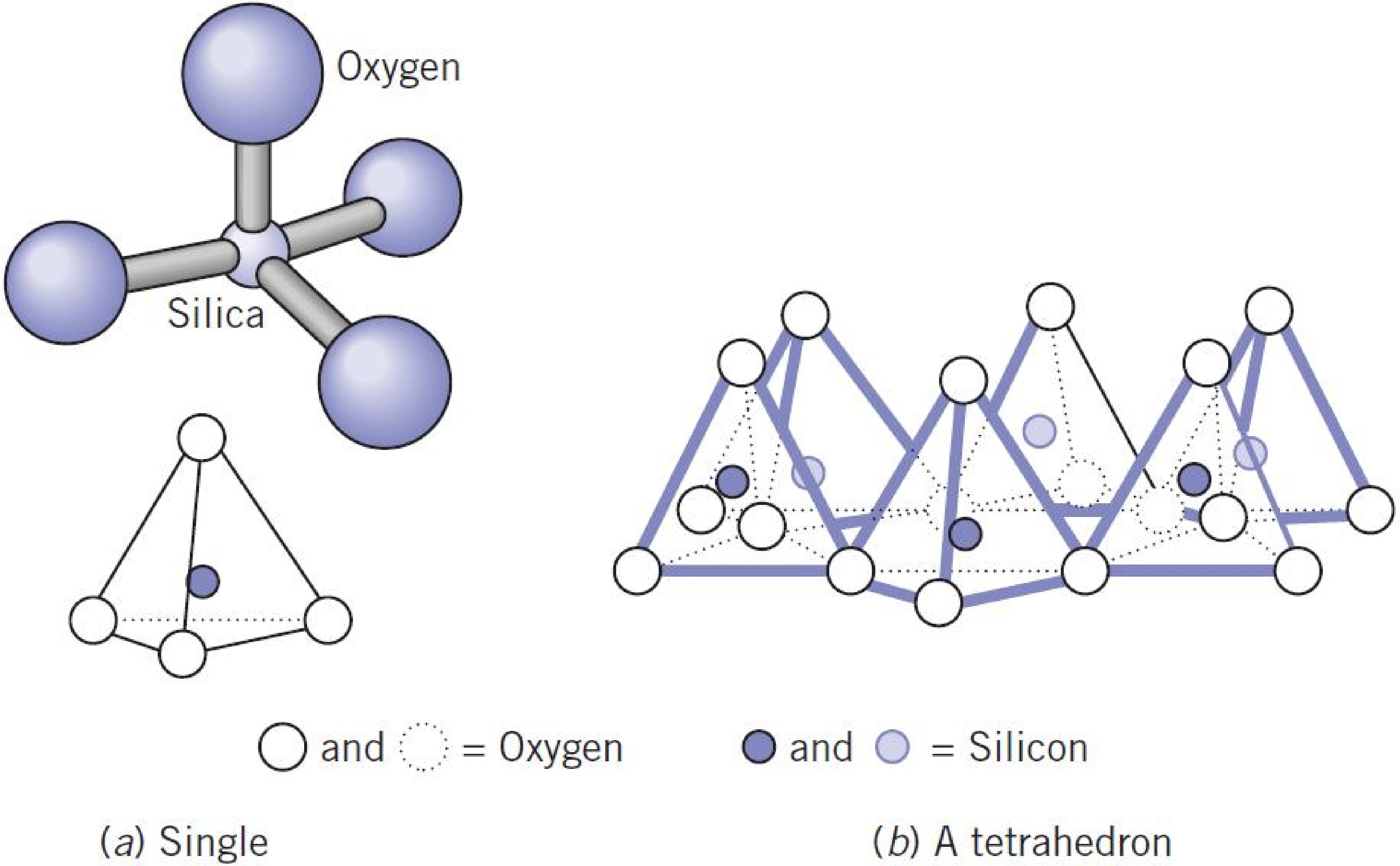


Fig. 5.14 Basic structural units in the silica sheet (Grim, 1959)



(a) Silica tetrahedrons, (b) silica sheets,

- ***<u>Gibbsite octahedral unit</u>*** in which an aluminium, iron or magnesium atom is enclosed in six hydroxyl having configuration of an octahedron.
- The octahedral units are put together into a sheet structure, which may be viewed as two layers of densely packed hydroxyl with cation between sheets in octahedral co-ordination and is known as gibbsite

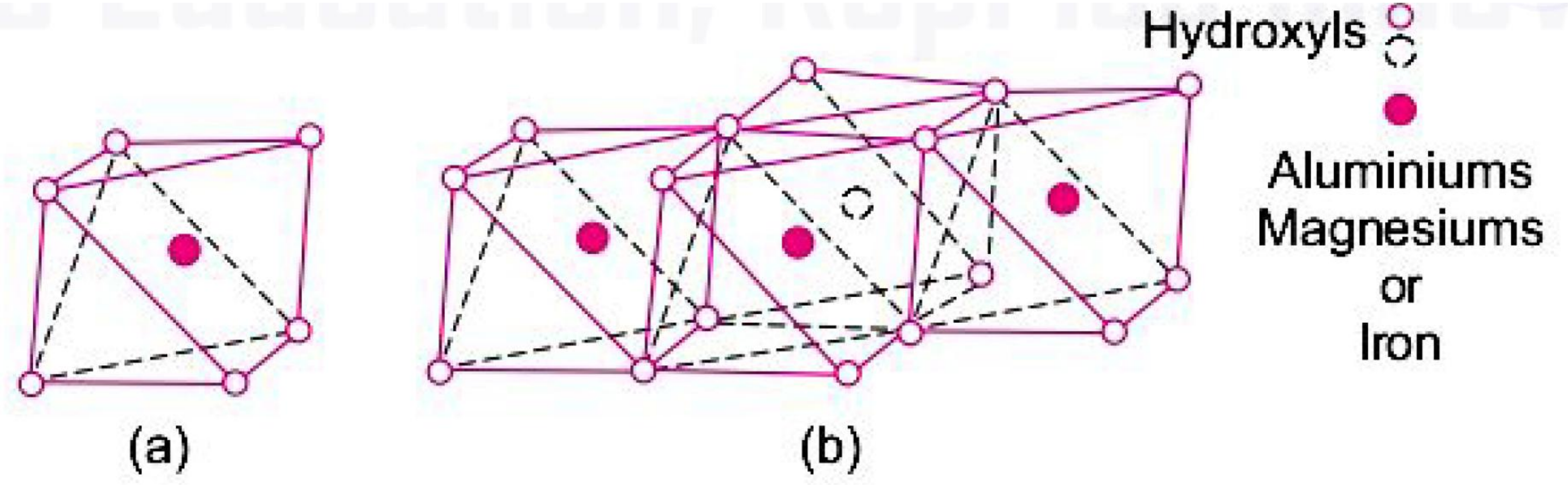
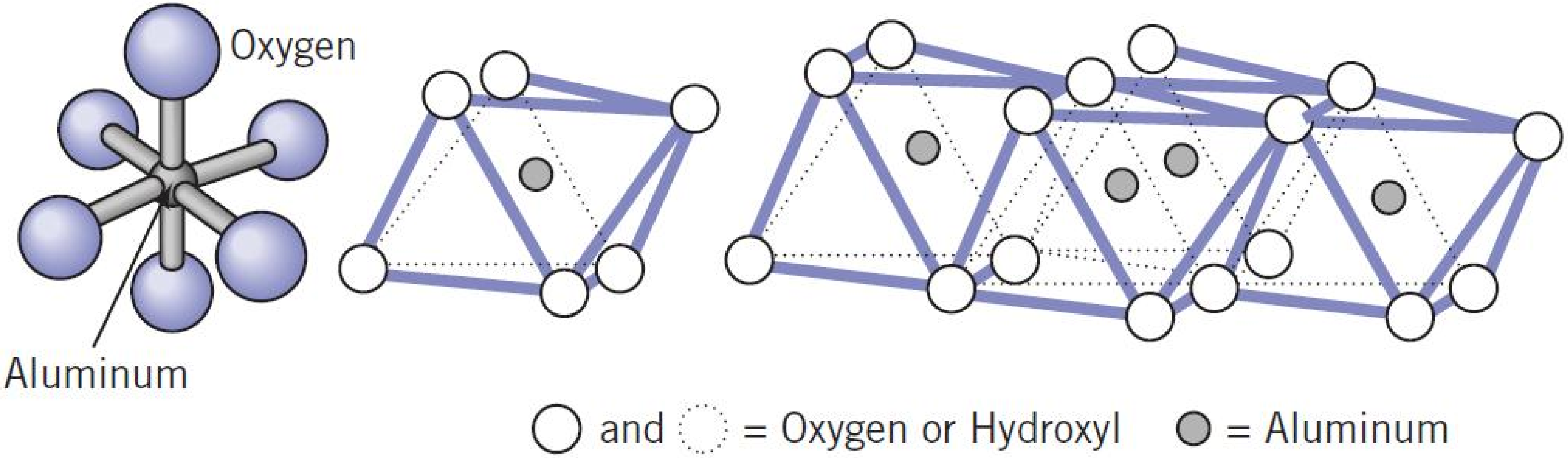


Fig. 5.15 Basic structural units in the octahedral sheet (Grim, 1959)



(*c*) Single octahedrons

(*d*) Octahedral sheet

(c) single aluminum octahedrons,

(d) aluminum sheets.

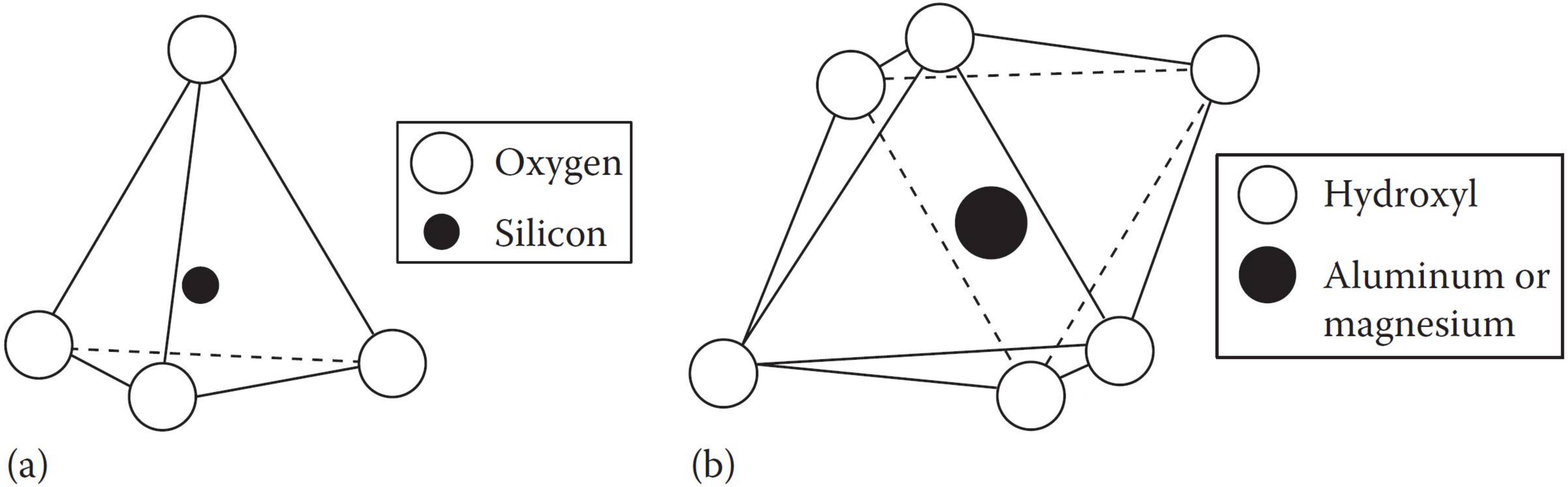


Figure 1.1 (a) Silicon–oxygen tetrahedron unit and (b) aluminum or magnesium octahedral unit.

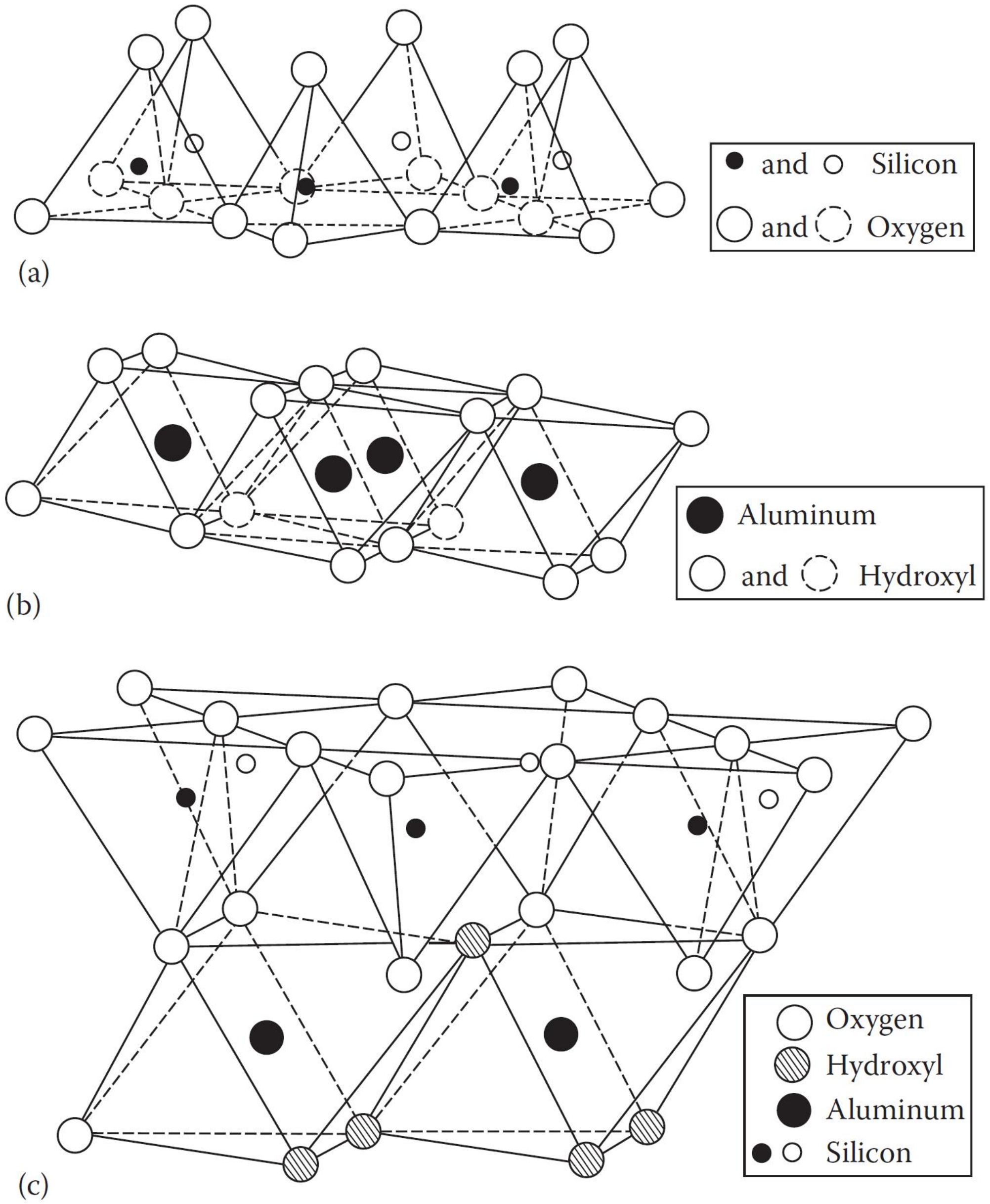
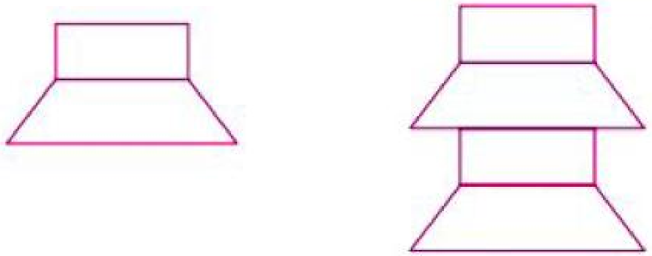


Figure 1.2 (a) Silica sheet, (b) gibbsite sheet, and (c) silica–gibbsite sheet. (After Grim, R.E., *J. Soil Mech. Found. Div., ASCE*, 85(2), 1–17, 1959.)

Kaolinite

- Made up of gibbsite sheets joined to silica sheets through the unbalanced oxygen atoms at the apexes of the silicas.
- It is 7A thick (one angstrom 1A=10-7mm =10-10m)
- A kaolinite mineral or crystal is stacking of such 7A thick sheets forming a book. Successive layers are held together with hydrogen bonds.
- It is 1000A to 20,000A wide by 100A to 1000A thick. Held by hydrogen (strong) bond and little/no swelling on wetting
- Platelets carry negative electromagnetic charge which attracts thick layer of adsorbed water thereby producing plasticity. E.g. China Clay



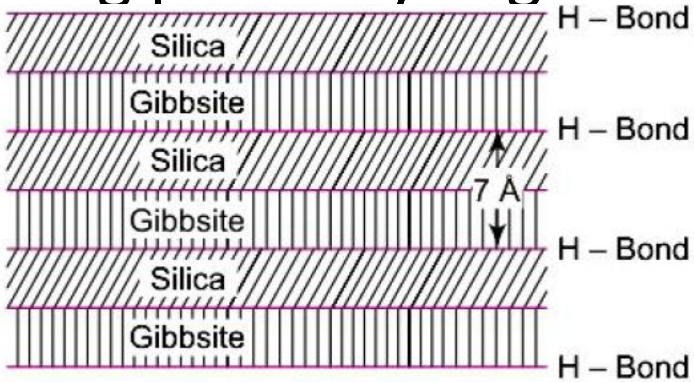
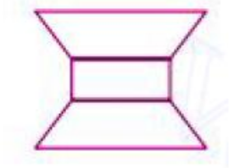
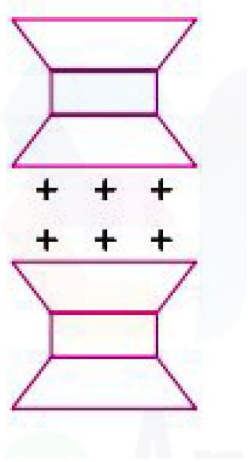


Fig. 5.16 (b) Structure of kaolinite

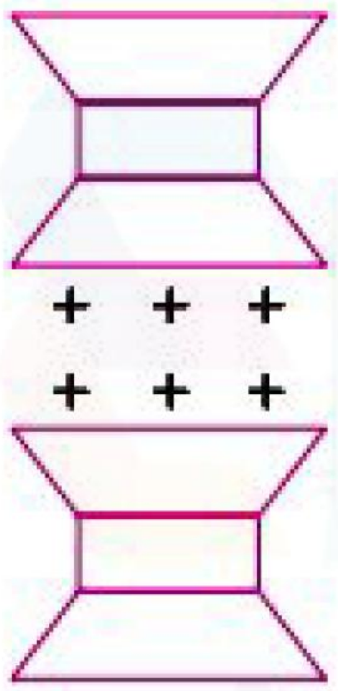
Montmorillonite

- Common in expansive clay soils.
- Basic structure of each unit is made up of gibbsite sheet sandwiched between two silica sheets. Thickness of each unit is 10A and dimensions in other two directions are indefinite.
- Gibbsite layer may include atoms of aluminium, iron, magnesium or their combination.
- Silicon atoms of tetrahedra may interchange with aluminium atoms. This structural change are called as amorphous changes





- There is a weak bond between successive sheets and water may enter between the sheets causing the mineral to swell. This spacing is influenced by the amount of water
- Soils containing montmorillonite minerals exhibit high shrinkage and swelling characteristics, depending on the nature of exchangeable cations present.



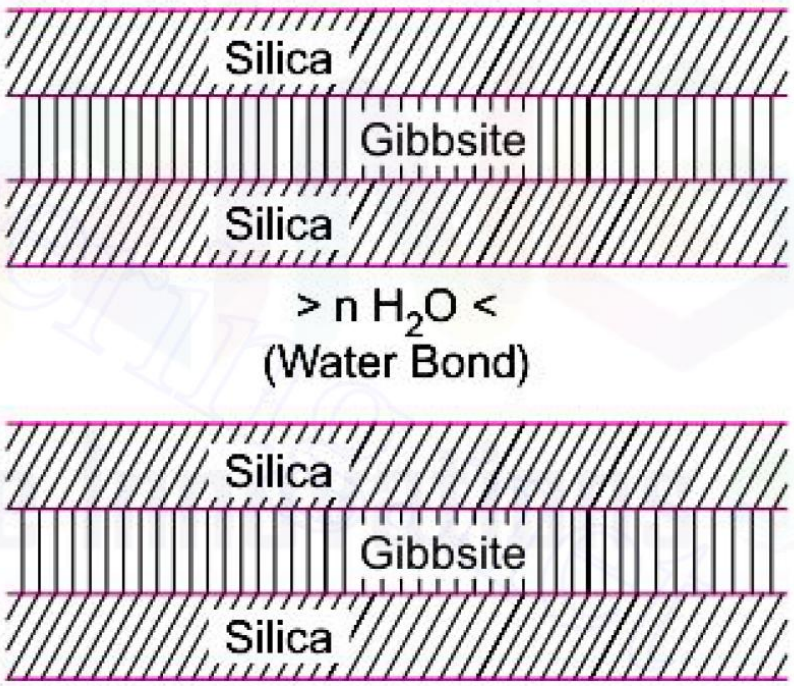
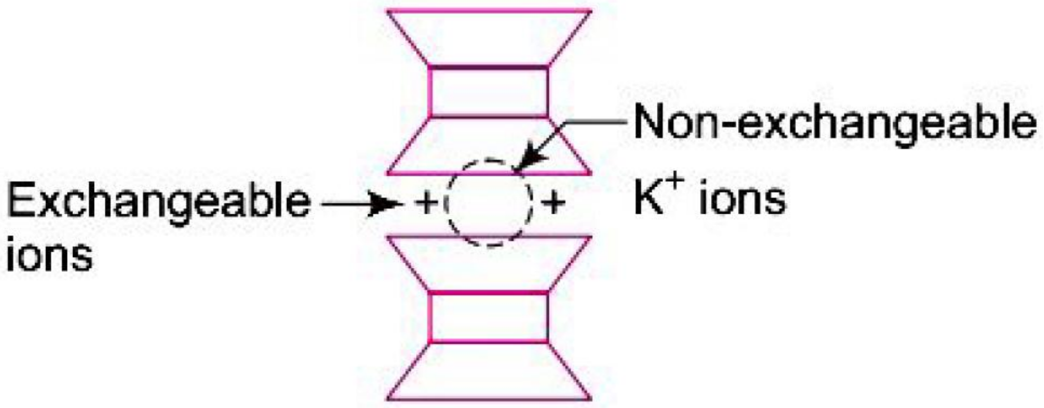


Fig. 5.17 (b) Structure of montmorillonite

Illite

- Structure is similar to that of montmorillonite except that there is always replacement of silicon by aluminium in tetrahedral layers and potassium are between the layers serving to balance the charge resulting from the replacement and to tie the sheet units together.
- Cation bond of illite is weaker than hydrogen bond of kaolinite, but stronger than the water bond of montmorillonite.
- Illite clay mineral is about 50A to 500A thick and 1000A to 5000A in lateral directions.
- It is a non swelling mineral because of the movement of water between the sheets.



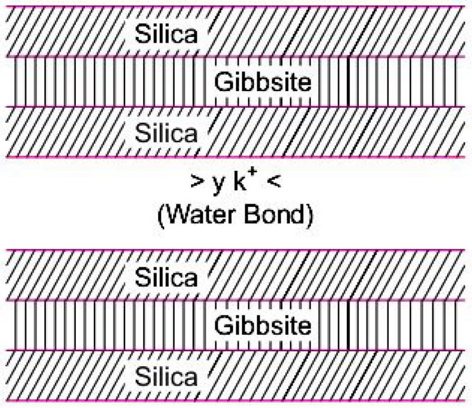
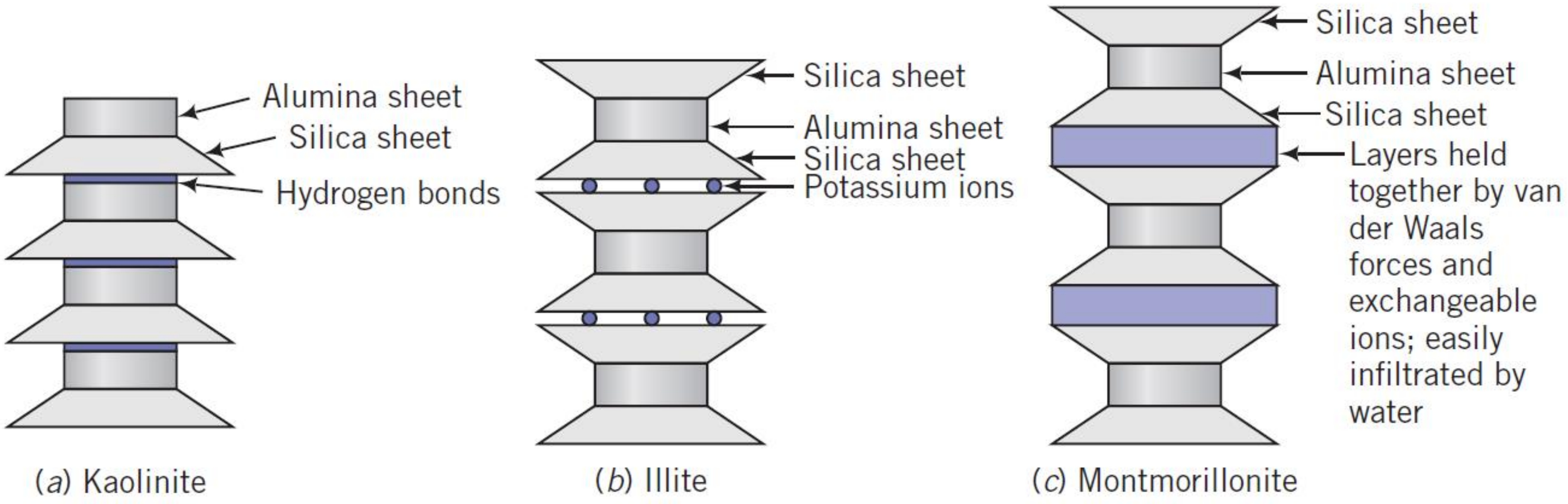
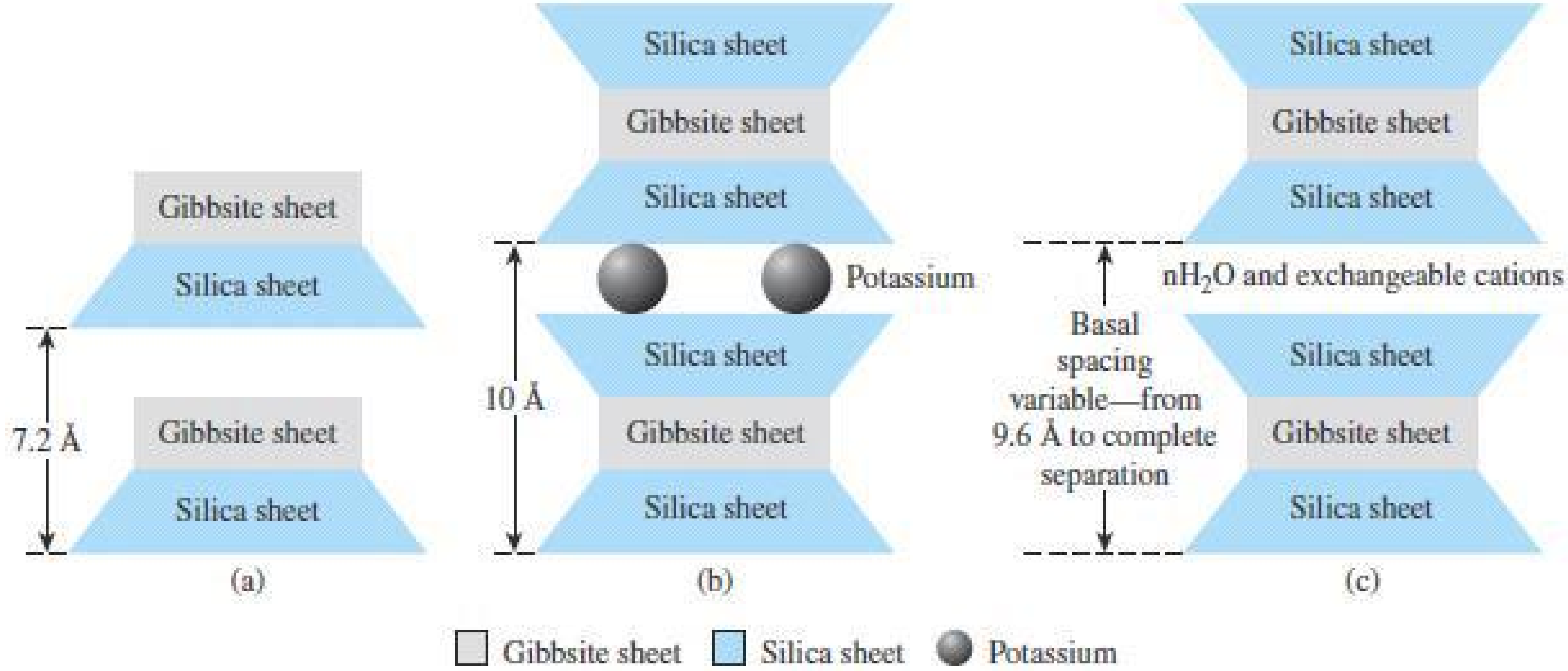


Fig. 5.18 (b) Structure of illite



Alumina sheet
Silica sheet
Hydrogen bonds
(a) Kaolinite
Silica sheet
Alumina sheet
Silica sheet
Potassium ions
(b) Illite
Silica sheet
Alumina sheet
Silica sheet
Layers held together by van der Waals forces and exchangeable ions; easily infiltrated by water
(c) Montmorillonite



Gibbsite sheet
Silica sheet
7.2 Å
(a)
Silica sheet
Gibbsite sheet
Potassium
10 Å
(b)
nH$_2$O and exchangeable cations
Basal spacing variable—from 9.6 Å to complete separation
(c)
Gibbsite sheet
Silica sheet
Potassium

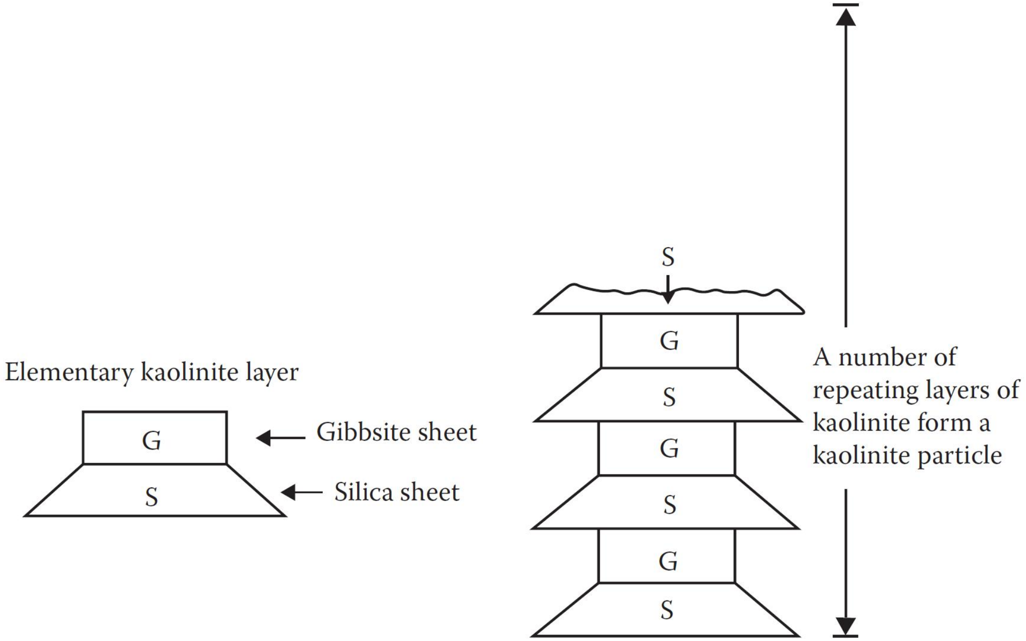


Figure 1.3 Symbolic structure for kaolinite.

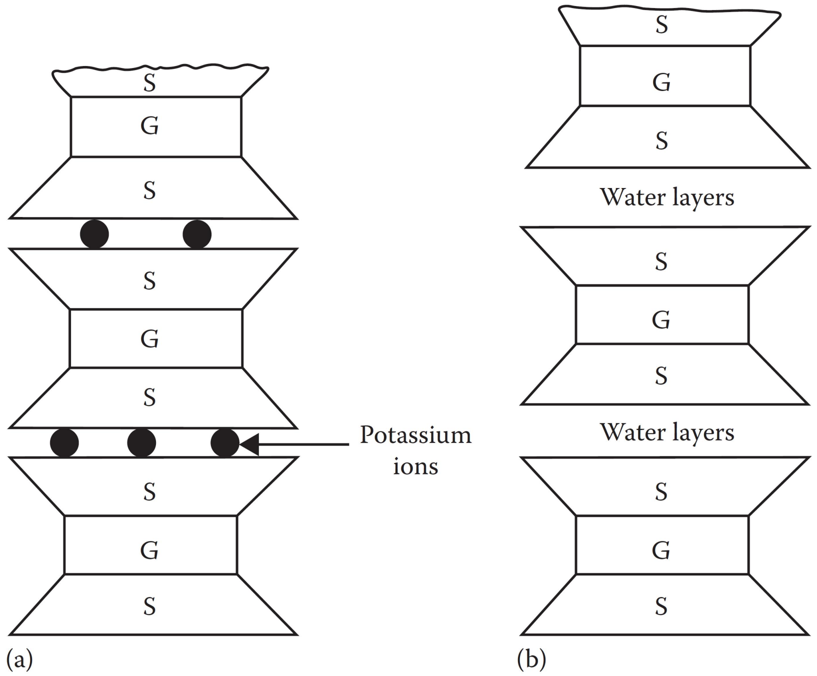


Figure 1.4 Symbolic structure of (a) illite and (b) montmorillonite.

Table 2 Basic Properties of Some Typical Clays

Clay Mineral	Composition	Layer Thickness	Shape of Mineral, General Properties, and Comments
Kaolinite	One silica, one alumina sheet. Very strongly bonded together.	7.5 Å	The most prevalent clay mineral. Very stable, with little tendency for volume change when exposed to water. Kaolinite layers stack together to form relatively thick particles. Particles are plate-shaped. Form from crystalline rocks in humid climates.
Halloysite	One silica, one alumina sheet make up the layer. Has sheet of water molecules between layers. (Similar to kaolinite except for sheet of water.)	10 Å	Sheets of halloysite curl into tubes. Strength and plasticity are significantly affected by drying and removal of the water. After drying, the clay mineral will not reinstate a water layer if again exposed to water. Caution is required in identifying this mineral and in using remolded (and rewetted) samples in laboratory testing to determine properties. Dried halloysite has characteristics of kaolinite. Rewetted samples appear stronger and less plastic than naturally wetted halloysite.
Illite	Alumina sheet sandwiched between two silica sheets. Potassium provides the bond between layers.	10 Å	Irregular flake shape. Generally more plastic than kaolinite. Does not expand when exposed to water unless a deficiency in potassium exists. Illite clays seem most prevalent in marine deposits and soil derived from micaceous rock (schists, etc.).
Montmorillonite (also identified as smecite)	Alumina sheet sandwiched between two silica sheets. Iron or magnesium may replace the alumina in the alumina sheet; aluminum may replace some silicons in the silica sheet (isomorphous substitution). Weak bond between layers.	9.5 Å (variable)	Irregular plate shapes or fibrous. Because of the weak bond between layers and the negative charge resulting because of isomorphous substitution, the clay readily absorbs water between layers. Has a great tendency for large volume change because of this property. Forms mostly from ferromagnesium rock and develops mostly in semi-arid and temperate climates; also from decomposition of volcanic ash.
Chlorite	Alumina sheet sandwiched between two silica sheets, but layers are bonded together with an alumina sheet.	14.1 Å	Irregular plate shapes. Nonexpanding. Formed from well-drained soils and micaceous rocks in humid areas.

Note: $1\ \text{Å} = 1 * 10^{-7}$ mm.

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Halloysite	One silica, one alumina sheet make up the layer. Has sheet of water molecules between layers. (Similar to kaolinite except for sheet of water.)	10 Å	Sheets of halloysite curl into tubes. Strength and plasticity are significantly affected by drying and removal of the water. After drying, the clay mineral will not reinstate a water layer if again exposed to water. Caution is required in identifying this mineral and in using remolded (and rewetted) samples in laboratory testing to determine properties. Dried halloysite has characteristics of kaolinite. Rewetted samples appear stronger and less plastic than naturally wetted halloysite.

Illite	Alumina sheet sandwiched between two silica sheets. Potassium provides the bond between layers.	10 Å	Irregular flake shape. Generally more plastic than kaolinite. Does not expand when exposed to water unless a deficiency in potassium exists. Illite clays seem most prevalent in marine deposits and soil derived from micaceous rock (schists, etc.).
Montmorillonite (also identified as smecite)	Alumina sheet sandwiched between two silica sheets. Iron or magnesium may replace the alumina in the alumina sheet; aluminum may replace some silicons in the silica sheet (isomorphous substitution). Weak bond between layers.	9.5 Å (variable)	Irregular plate shapes or fibrous. Because of the weak bond between layers and the negative charge resulting because of isomorphous substitution, the clay readily absorbs water between layers. Has a great tendency for large volume change because of this property. Forms mostly from ferromagnesium rock and develops mostly in semi-arid and temperate climates; also from decomposition of volcanic ash.
Chlorite	Alumina sheet sandwiched between two silica sheets, but layers are bonded together with an alumina sheet.	14.1 Å	Irregular plate shapes. Nonexpanding. Formed from well-drained soils and micaceous rocks in humid areas.

Note: 1 Å = $1 * 10^{-7}$ mm.

List the three most common clay minerals of engineering significance. With a neat sketch describe one clay mineral which if present in the soil causes swelling in the presence of moisture. . **06**

c) Identify , sketch and explain the type of soil structure formed when **06**

i) Fine sand is dumped in to a fill without compacting or when water is added to fine sand.

ii) When clay is compacted beyond optimum water content.

a) Identify and explain the features of the soil structure formed when : **04**

i) Fine sand and silt is dumped in a fill without compacting

ii) Clay is remoulded

b) Sketch and outline the structure of illite clay mineral. **03**

Explain the structure of illite clay mineral. **04**

a Explain with neat sketches, Kaolinite and Montmorillonite clay minerals. **10**

b) Outline the general characteristics of : **06**

i) Kaolinite clay mineral ii) Honeycomb structure

Discuss three types of Soil structure. **06**

Explain Base exchange capacity and Capillarity in soils. **04**

With the help of neat sketches explain the principle clay minerals Kaolinite, Montmorillonite. **04**

Define soil structure. List the differences between (i) single grained and honey combed structure (ii) flocculent and dispersed structure. **06**

Explain the following clay minerals with a neat sketch of their basic structural units. **06**

i) Kaolinite ii) Montmorillonite

Sketch and discuss any two types of soil structures. **06**

Discuss flocculated and dispersed soil structures with a neat sketch **06**

What are the three most common clay minerals of engineering significance? With a neat sketch **describe** one clay mineral which if present in the soil causes swelling in the presence of moisture. Also give reasons for the soil to swell due to the presence of that mineral and give the common values of specific surface area, cation Exchange capacity of the clay mineral. **08**

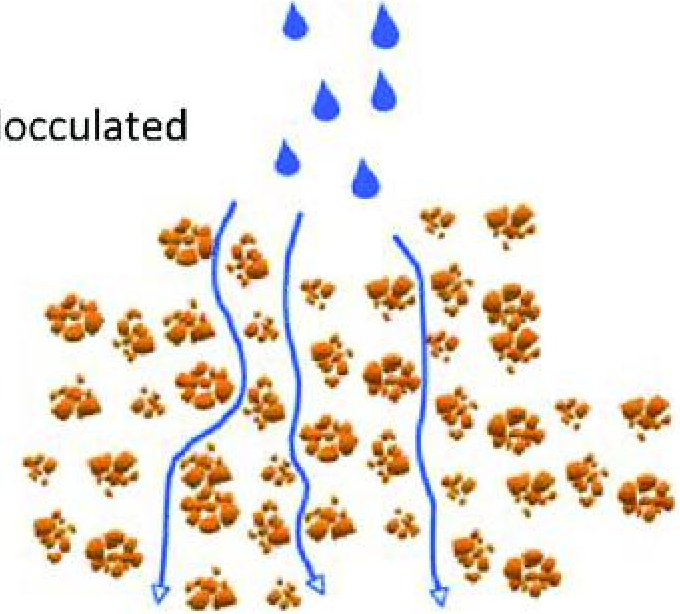
With the help of neat sketches, explain the following principal clay minerals; **06**
(i) Kaolinite, (ii) Montmorillonite.

Discuss the following terms: **06**
i) Flocculent structure 2) Adsorbed water

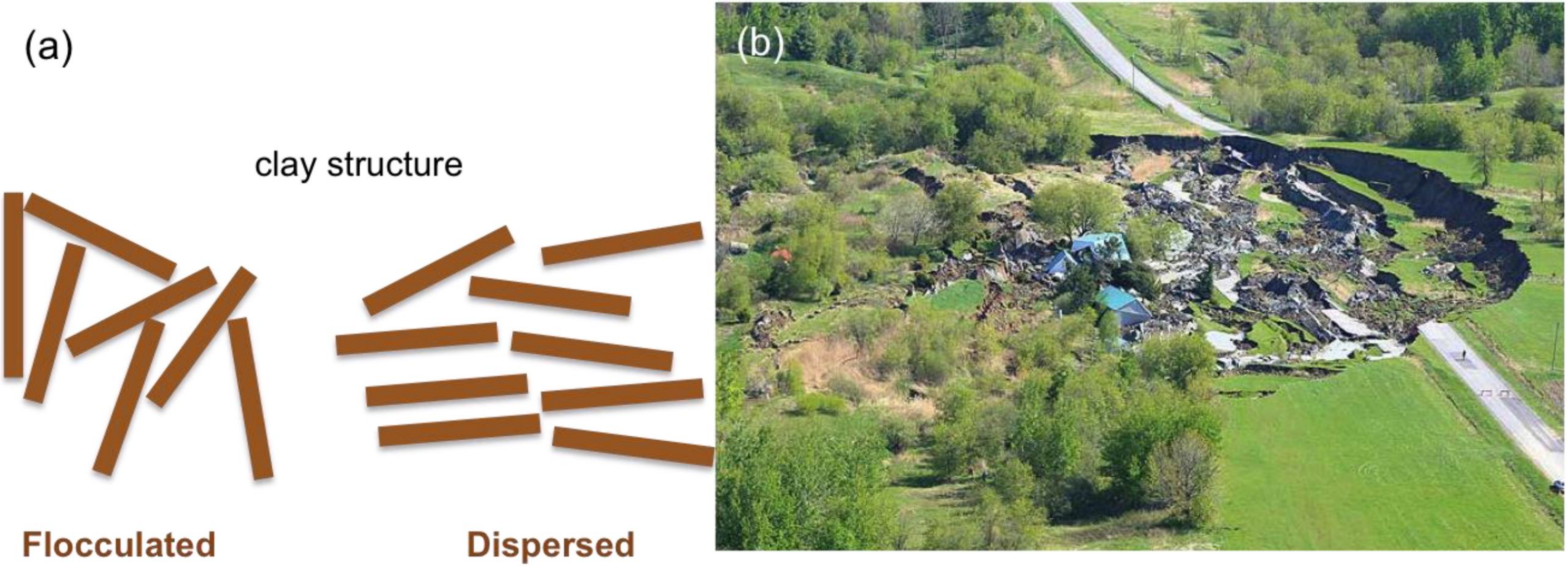
With the help of neat sketches, explain the following principal clay minerals; (6)
(i) Kaolinite, (ii) Montmorillonite.

Define soil structure. List the differences between: (i) single grained and homey combed structure (ii) flocculent and dispersed structure (6)

Flocculated



Dispersed



e 1.32. (a) Flocculated and dispersed clay structure, and (b) Sensitive (quick) clay slide in Leda clay (C