SOIL MECHANICS

WHAT IS SOIL?

The term *Soil* was originated from the Latin word "*SOLUM*" meaning upper layer of earth

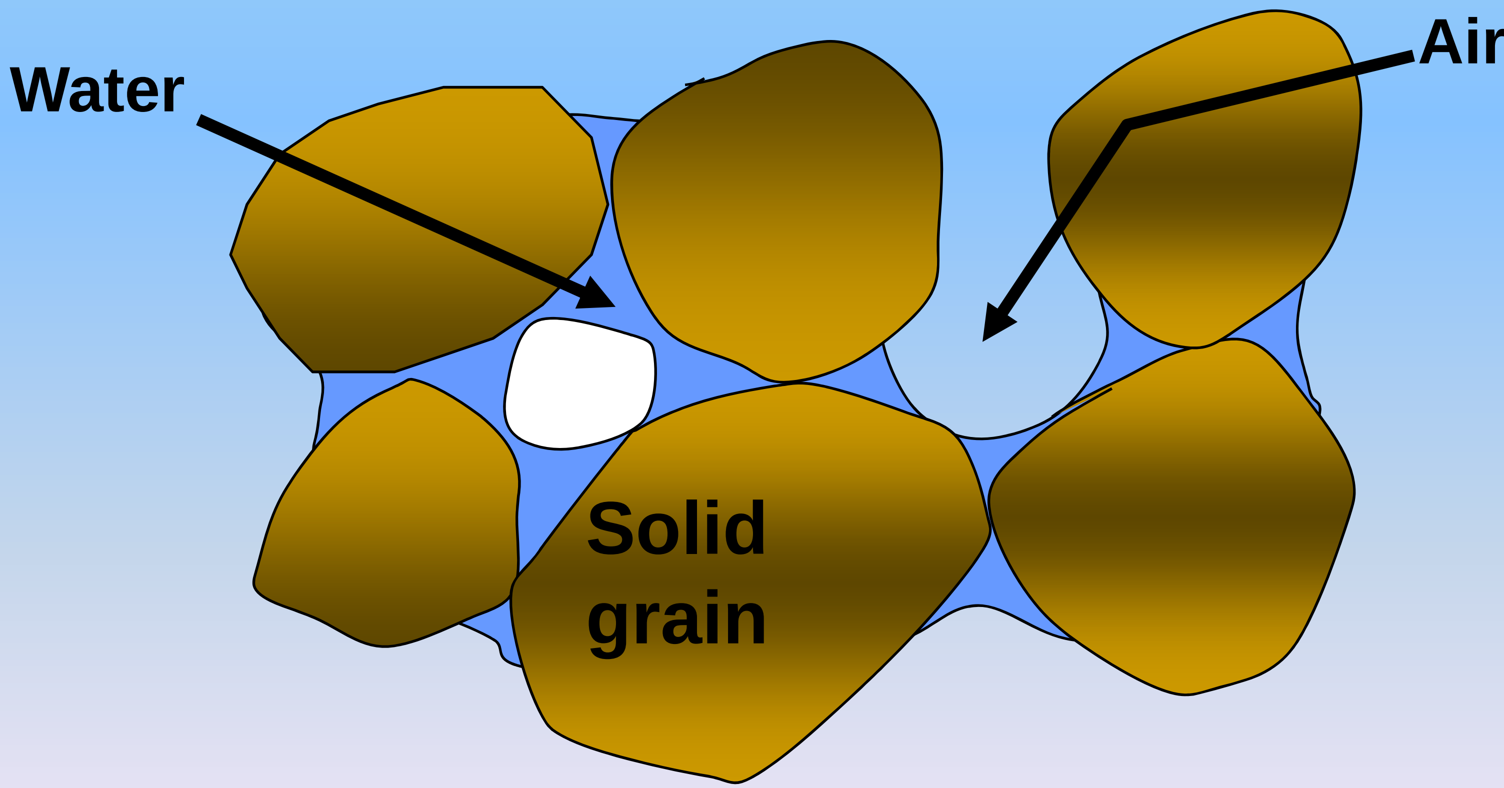
"*Soil* " is an assemblage of discrete solid particles of organic or inorganic composition with the voids filled up with water only or air only or a combination of both water and air

Soils thus can have three phases namely, solids, water and air present in it, and is called partially saturated soil

If there is no air present in a soil then, it is a saturated one.

If there is no water present in a soil then, it is a dry soil.

SOIL: A 3-PHASE MATERIAL



ROCK

A natural aggregation of mineral particles bonded by strong and permanent cohesive forces is called *rock.*

- ***Soil Mechanics*** deals with the strength and deformation behavior of soil due to application of load. It is one of the youngest disciplines of Civil Engineering involving the study of soil, its behavior and application as an engineering material.
- **According to Terzaghi** (1948): "Soil Mechanics is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles produced by the mechanical and chemical disintegration of rocks regardless of whether or not they contain an admixture of organic constituent."
- ***Foundation Engineering*** deals with the design and construction of foundations of structures using the principles of mechanics of soil.

CONTRIBUTORS TO SOIL MECHANICS

- Coulomb (1773): Theory of earth pressure (E P) on retaining wall. Coulomb also introduced the concept of shearing resistance of soil.
- Stokes (1856) : Law of velocity of fall of solid particles through fluids.
- Darcy (1856) : Law of permeability.
- Rankine (1857): The concept of plastic equilibrium of earth mass was included in the theory of earth pressure.
- Culmann (1866): Graphical solution for earth pressure.
- Otto Mohr (1871): Rupture theory of soils and Mohr's circle to determine stresses on inclined planes with respect to principal planes.
- Rehbann (1874): Graphical solution for earth pressure based on Coulomb's theory
- Boussinesq (1885): Theory of stress distribution due to external load.

- Marston (1908): The theory for the load carried by underground conduits.
- Atterberg (1911): Devised simple tests to characterize consistency of cohesive soils.
- Fellenius (1913): “Swedish circle method” to study of stability of slopes.
- Petterson (1916): “Friction circle method” to study of stability of slopes.

The *modern era* of soil mechanics was contributed by Dr. Karl Terzaghi (1925) (The father of soil mechanics)

APPLICATIONS OF SOIL MECHANICS

Design and construction of:

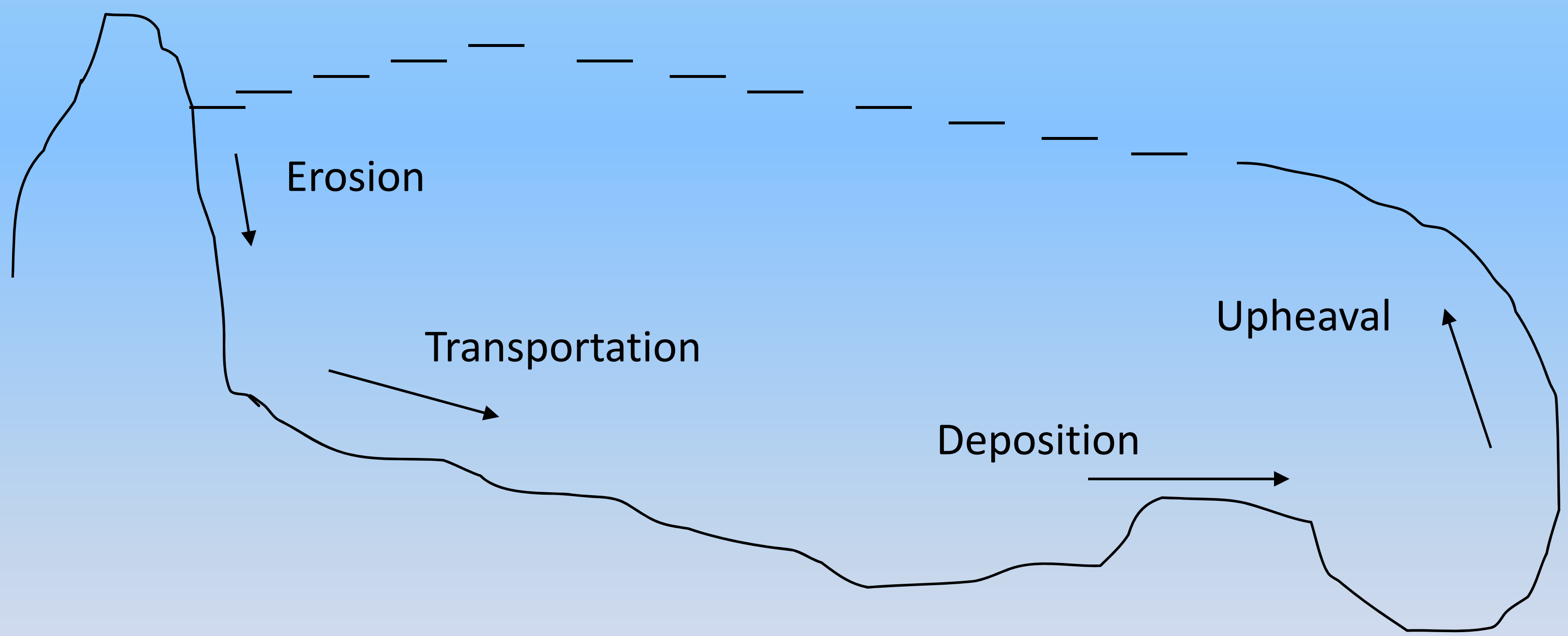
- Foundations (shallow and deep)
- Earth retaining structures
- Stability of slopes
- Earth dam
- Formation of Pavement
- Under ground structures .. tunnels, conduits and shafts

Geotechnical Engineering ..... Is a broader term for Soil Mechanics

Geotechnical Engineering contains:

- Soil Mechanics (Soil Properties and Behavior)
- Soil Dynamics (Dynamic Properties of Soils, Earthquake Engineering, Machine Foundation)
- Foundation Engineering (Deep & Shallow Foundation)
- Pavement Engineering (Flexible & Rigid Pavement)
- Rock Mechanics (Rock Stability and Tunneling)
- Geosynthetics (Soil Improvement)

ORIGIN/ FORMATION OF SOIL



Soil is formed due to weathering of rocks. When a rock surface is exposed to atmosphere for some time it disintegrates into small particles and thus soil is formed

Factors affecting Weathering:

1. Changes in Temperature and Pressure
2. Erosion and transportation by wind, water and glaciers
3. Chemical action such as crystal growth, oxidation, hydration, carbonation and leaching by water.

TYPES OF WEATHERING

i) *Physical or mechanical* weathering/disintegration

ii) *Chemical* weathering/decomposition

In the Earth's surface, rocks extend up to as much as 20 km depth. The major rock types are categorized as igneous, sedimentary, and metamorphic.

Igneous rocks: formed from crystalline bodies of cooled magma.

Sedimentary rocks: formed from layers of cemented sediments.

Metamorphic rocks: formed by the alteration of existing rocks due to heat from igneous intrusions or pressure due to crustal movement.

The nature and structure of a given soil depends on the processes and conditions that formed it:

•**Breakdown** of parent rock: weathering, decomposition, erosion.

•**Transportation** to site of final deposition: gravity, flowing water, ice, wind.

•**Environment** of final deposition: flood plain, river terrace, glacial moraine, lacustrine or marine.

•**Subsequent conditions** of loading and drainage: little or no surcharge, heavy surcharge due to ice or overlying deposits, change from saline to freshwater, leaching, contamination.

PHYSICAL WEATHERING

- Also known as mechanical weathering or disintegration.
- In this rocks gets broken down particles of various sizes without any change in chemical composition.
- The agencies involved are daily and seasonal variation in the temperature, flowing water, glacier and wind.
- E.g. Cohesionless soil (sand and gravel): In sand and gravel gravitational forces are more important than surface forces because of the size and shape.
- Temperature variations are responsible to great extent for physical weathering.
- It manifest in two ways; through the so called frost action in the cold humid climates and through thermal effects in hot dry regions.

FROST ACTION

- Freezing under goes an increase in its volume.
- In areas where climate conditions are such that temperature often falls below the freezing point of water during winter and where humidity is high, freezing of water contained in cavities is a common phenomenon.
- This process effects the rocks which are highly jointed or porous in nature.
- Water trapped in the cracks, cavities of these rocks freezes and expands during low temperature period thereby exerting a pushing pressure on the sides of these openings which leads to widening of these openings or cavities.
- This will lead to partial or total disintegration of the rock into smaller pieces.

THERMAL EFFECTS

- The effect of change of temperature on rock is of considerable importance in arid and semi-arid regions where difference between day-time and night time temperatures is often very high.
- This temperature fluctuations produce physical disintegration which breaks the rock into smaller pieces due to stresses developing by expansion and contraction.

Other processes in physical weathering are :

1. Pressure release : In pressure release, also known as unloading, overlying materials (not necessarily rocks) are removed (by erosion, or other processes), which causes underlying rocks to expand and fracture parallel to the surface. Eg. Granite formation.
2. Hydraulic action: Hydraulic action occurs when water (generally from powerful waves) rushes rapidly into cracks in the rock face, thus trapping a layer of air at the bottom of the crack, compressing it and weakening the rock. When the wave retreats, the trapped air is suddenly released with explosive force.
3. Salt-crystal growth: It causes disintegration of rocks when saline solutions seep into cracks and joints in the rocks and evaporate, leaving salt crystals behind. These salt crystals expand as they are heated up, exerting pressure on the confining rock

CHEMICAL WEATHERING

- In the chemical weathering decomposition of the rocks takes place due to hydration, oxidation, carbonation and leaching reactions
- Soils formed due to chemical weathering will be cohesive in nature
- E.g. Silts and clays
- Clay minerals impart plastic properties to the soil. In clay particles surface forces are predominant than the gravitational forces.
- In this the processes of oxidation and hydrolysis are most important.

- Hydration: Water combines with the rock minerals and a new chemical compound is formed.
- Carbonation: CO_2 present in the atmosphere combines with water and carbonic acid is formed. The carbonic acid thus formed reacts with the rock minerals and forms a new chemical compound.
- Oxidation: Oxidation occurs when oxygen ions combines with minerals in rocks. It results in decomposition of rocks. This is similar to rusting of steel.
- Hydrolysis: Water gets dissociated into H^+ and OH^- ions. The H^+ replace the metallic ions such as Ca, Na, and K in rock minerals and soils are formed with a new chemical composition.
- Solution: some of the rock minerals form a solution with water when they get dissolved in water. Chemical reaction takes place in the solution and soils are formed.

Further, the soils can be classified as :

1) Residual soil

2) Transported soil

(water, wind, glacier, gravity and combined action)

TRANSPORTED SOILS

- The soils which are transported from the place of origin by various agencies such as wind , water, ice, gravity etc. and get deposited when favorable conditions like a decrease of velocity occur.
- These soils have the following characteristics:

i. High degree of alteration of particle shape, size and texture

ii. High degree of smoothness and fineness of individual grains

- E.g. for transported soil is alluvial, lacustrine, marine deposit, aeolin deposit, dune sand and loess, glacial drift and till

Transported soils are further subdivided into the following types:

1. Alluvial Soils: Soils transported by rivers and streams such as sedimentary clays.

2. Aeoline Soil: Soils transported by wind such as Loess.

3. Glacial Soils: Soils deposited due to the movement of glaciers (drifts and till).

4. Lacustrine Soils: Soils found in lake beds such as silts and clays.

RESIDUAL SOILS

- Soils which are formed by weathering of rocks may remain in position at the place of origin.
- These soils differ very much from transported soils in their engineering behaviour.
- This soil tend to be more abundant in humid and warm zones where conditions are favorable to chemical weathering of rocks and have sufficient vegetation to keep the products of weathering from being easily transported as sediments.
- E.g. Black cotton and lateritic soil

MAJOR SOIL DEPOSITS OF INDIA

- Alluvial deposits
- Black cotton soil
- Lateritic soil
- Desert soil
- Marine clay

- Alluvial Soils: Occurring in Indo-Gangetic Plain north of Vindhyachal Ranges
- Black cotton Soils: Maharashtra, Gujarat, Madhya Pradesh, Karnataka, parts of Andhra Pradesh and Tamil Nadu. On account of high swelling and shrinking potential these are difficult soils to deal with in foundation design
- Laterite Soils: Occurring in Kerala, South Maharastra, Karnataka, Orissa and West Bengal
- Desert Soils: Occurring in Rajasthan. These are wind blown deposits and are uniformly graded
- Marine Soils: Occurring in a narrow belt all along the coast, in Runn of Kutch. It possess low strength and high compressibility

PARTICLE SIZE

I. S. Classification of soil

Clay size	Silt size	Sand size			Gravel size		Cobble size
		Fine	Medium	Coarse	Fine	Coarse	

0.002 0.075 0.425 2 4.75 20 80

Diameter of particles in mm

Not to scale

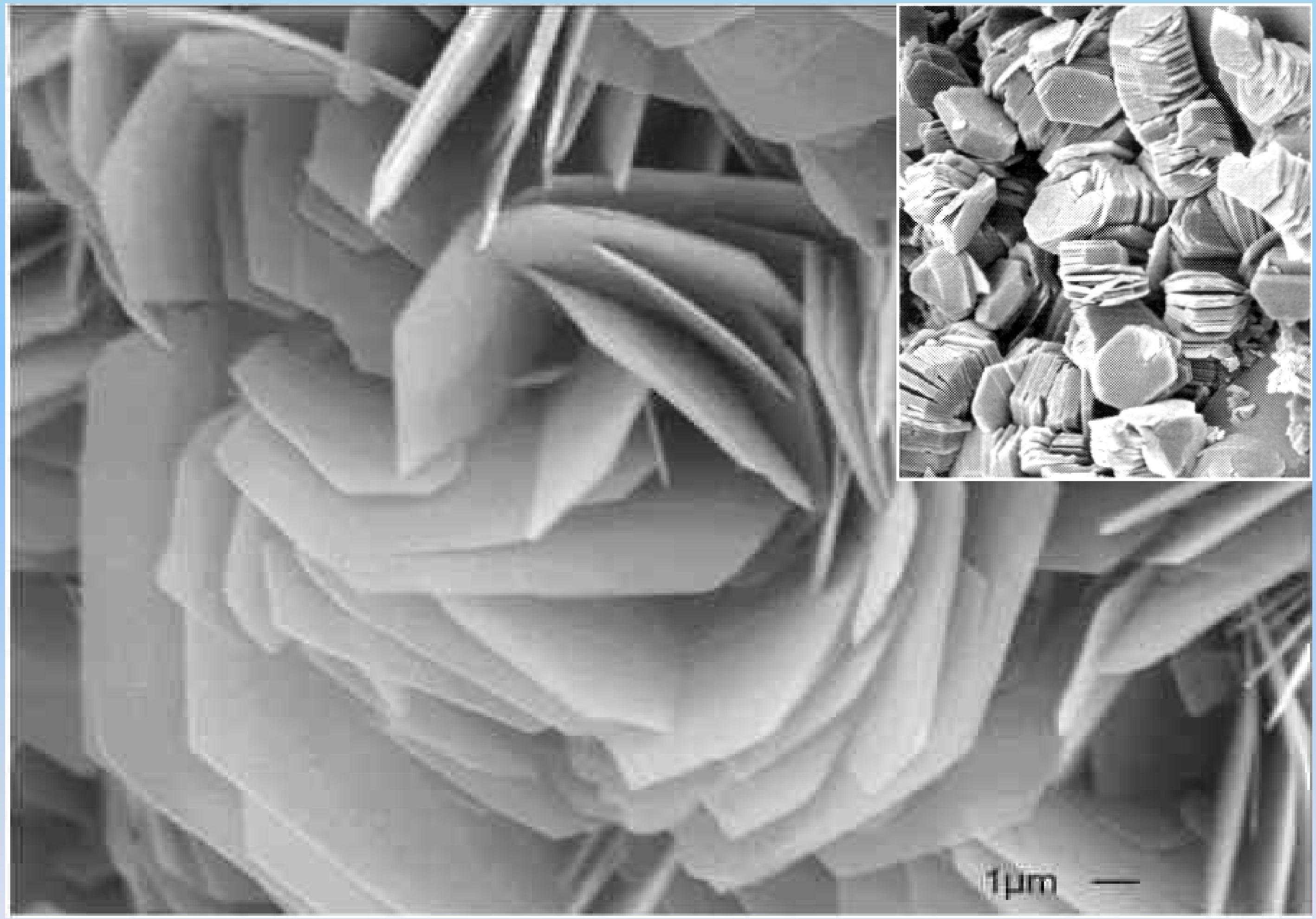
PARTICLE SHAPE

1. Spherical
2. Flaky
3. Needle shaped

- Bulky or spherical grains are described in terms of sphericity. Sphericity is denoted by ‘S’
- In flaky grains or plate shaped grains thickness of the grains is very small as compared to the other two lateral dimensions. It will look like sheet of paper, a leaf or a platelet (Clays)
- Needle shaped grains are those in which one dimension is fully developed and is much larger compared to the other two dimensions. (Kaolinite)

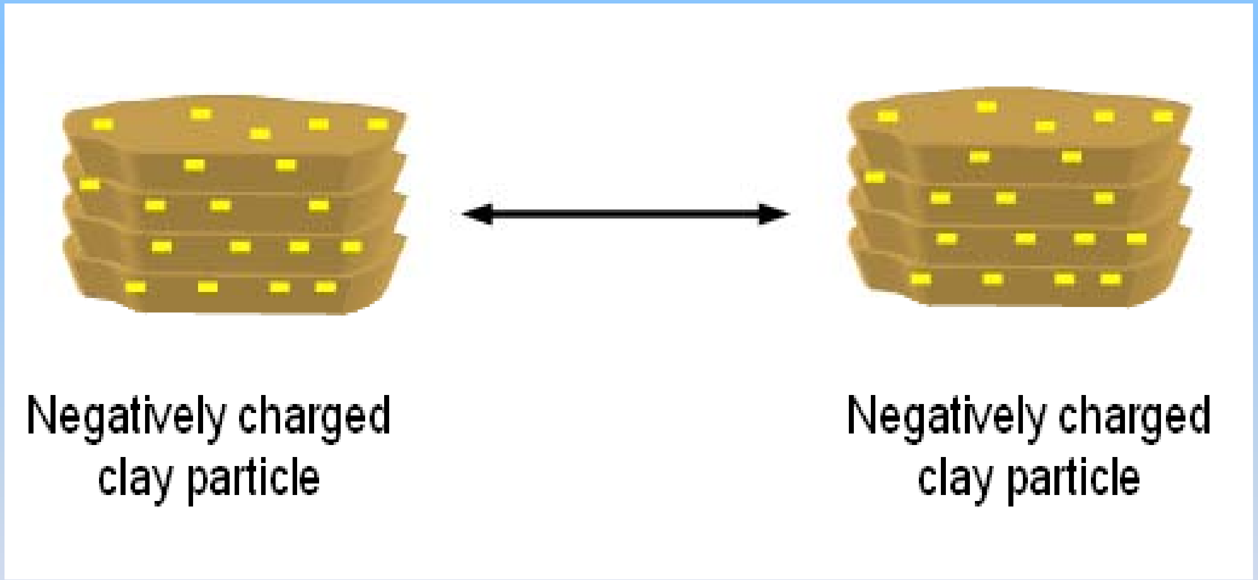
BULKY MATERIAL (ANGULAR & SUBANGULAR)

FLAKY PARTICLE (CLAY)



Very small in size, flaky, large surface area

CLAY PARTICLES SHEET LIKE SHAPE



INTER-PARTICLE FORCES IN A SOIL MASS

1. Gravitational forces are proportional to the mass and is important to coarse grained soil.

2. Surface forces are important for fine-grained soil as the specific surface area is large in the colloids. Surface forces are divided into two:
    1) Attractive forces
    2) Repulsive forces

ATTRACTIVE FORCES

- Van der waals London forces: it is the universal attractive force and may be the effective one in some soil. It gets much stronger as the particle approach.
- Hydrogen bond:is the one of the strongest Inter-particle bond
- Cation linkage: it acts as a bridge between two adjacent particles carrying negative charge.
- Dipole cation linkage
- Water dipole linkage
- Ionic bond

TYPES OF REPULSIVE FORCES

- Particle charge
- Cation-cation repulsion

The particles will repel with each other due to like charges

SOIL STRUCTURE

Structure of a soil may be defined as the arrangement of soil grains. In the study of structure of soils we study the following:

1. Mineralogical Composition
2. Electrical Properties
3. Orientation and shape of soil grains
4. Nature and properties of soil water
5. Interaction of soil water and soil grains

Structural composition of soil influences many engineering properties such as permeability, compressibility and shear strength.

The geometrical arrangement of soil particles with respect to one another:

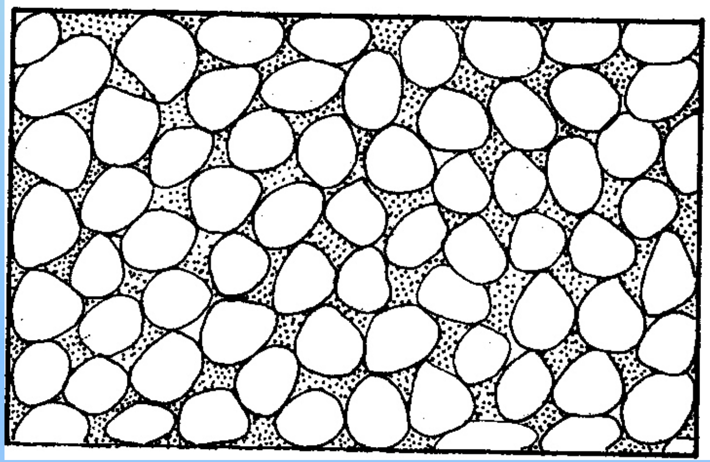
- Single grained structure (Coarse grained-Gravels and sands)
- Honey-comb structure (Fine sands or silts 2-20 mm)
- Flocculated structure (Clay)
- Dispersed structure (Clay)

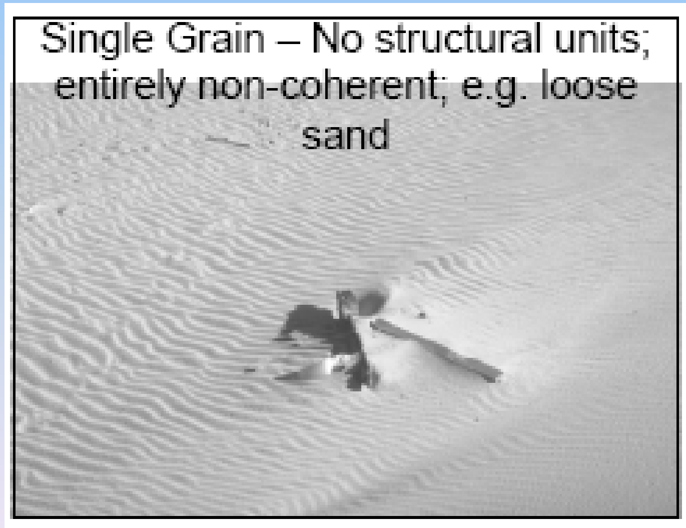
COMPOSITE STRUCTURE

- Coarse grained skeleton
- Clay matrix structure

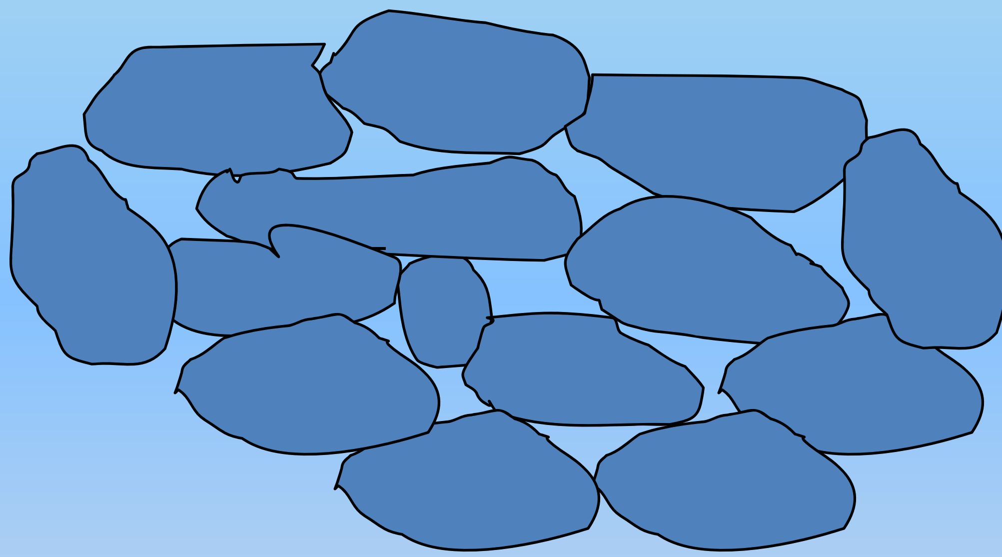
SINGLE GRAINED STRUCTURE

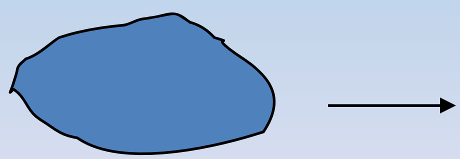
Single-grained structure is the property of coarse-grained soils with a particle size >0.02 mm. Gravitational forces dominates the surface forces and grain to grain contact results. The deposition may occur in a loose state with large voids or in a dense state with less of voids.





SINGLE GRAINED STRUCTURE (COARSE GRAINED)

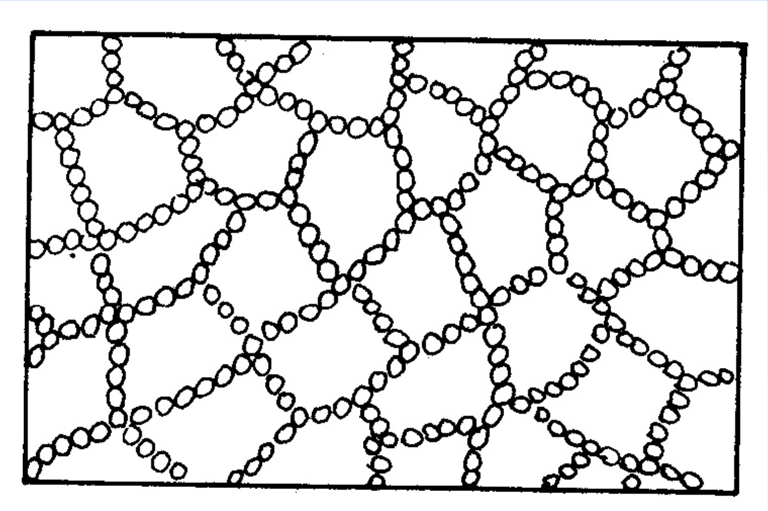




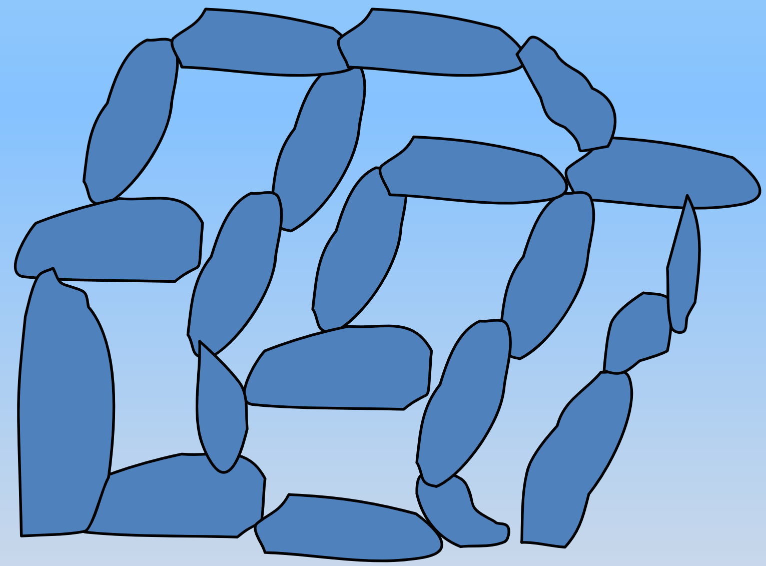
Sand or gravel grain

HONEY COMB STRUCTURE

This type of structure can occur in case of fine grained soils such as silt and rock flour. In this structure, gravitational forces and inter-particle surface forces play an important role in settling down. Miniature arches are formed which bridge over large void spaces. This results in the formation of a honey comb structure. The structure has a large void space and may carry high loads without a significant volume change. The structure can be broken down by external disturbances.

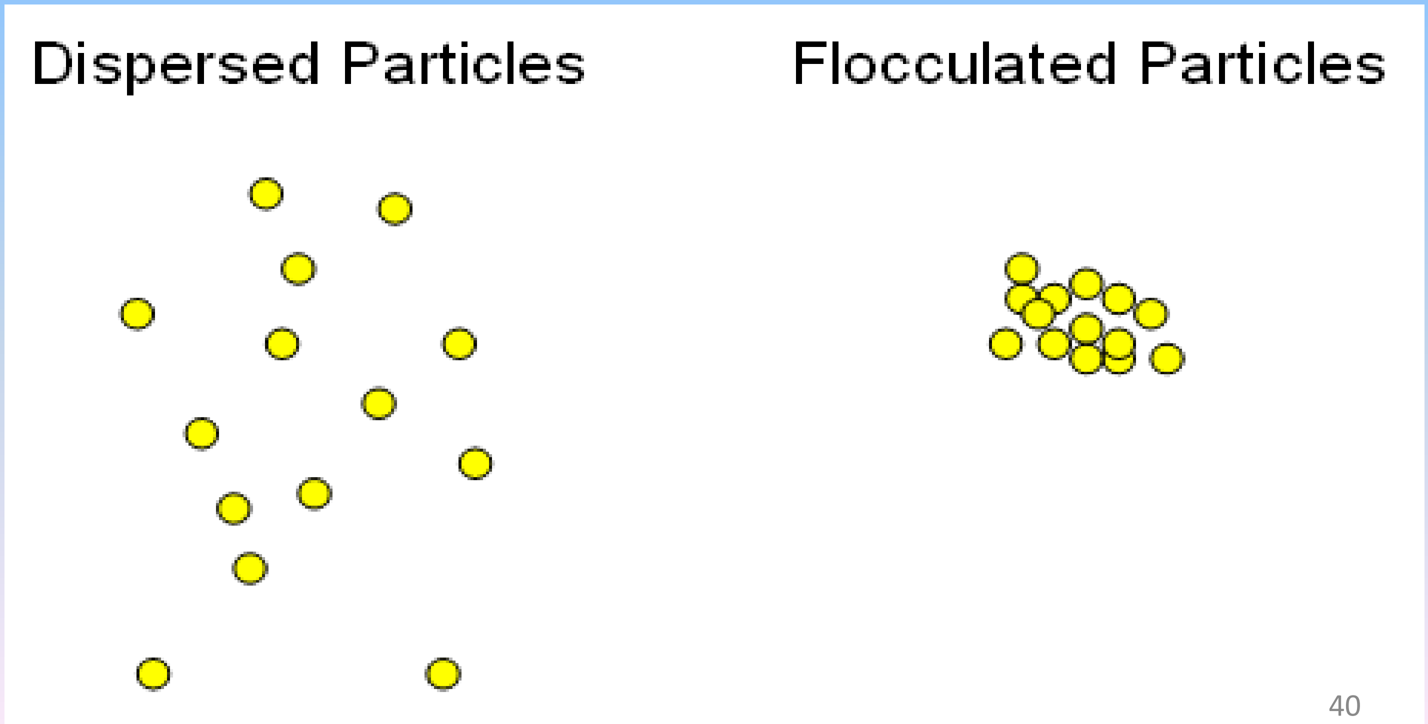


Honey-comb structure (Fine sands or silts 2-20 μ)

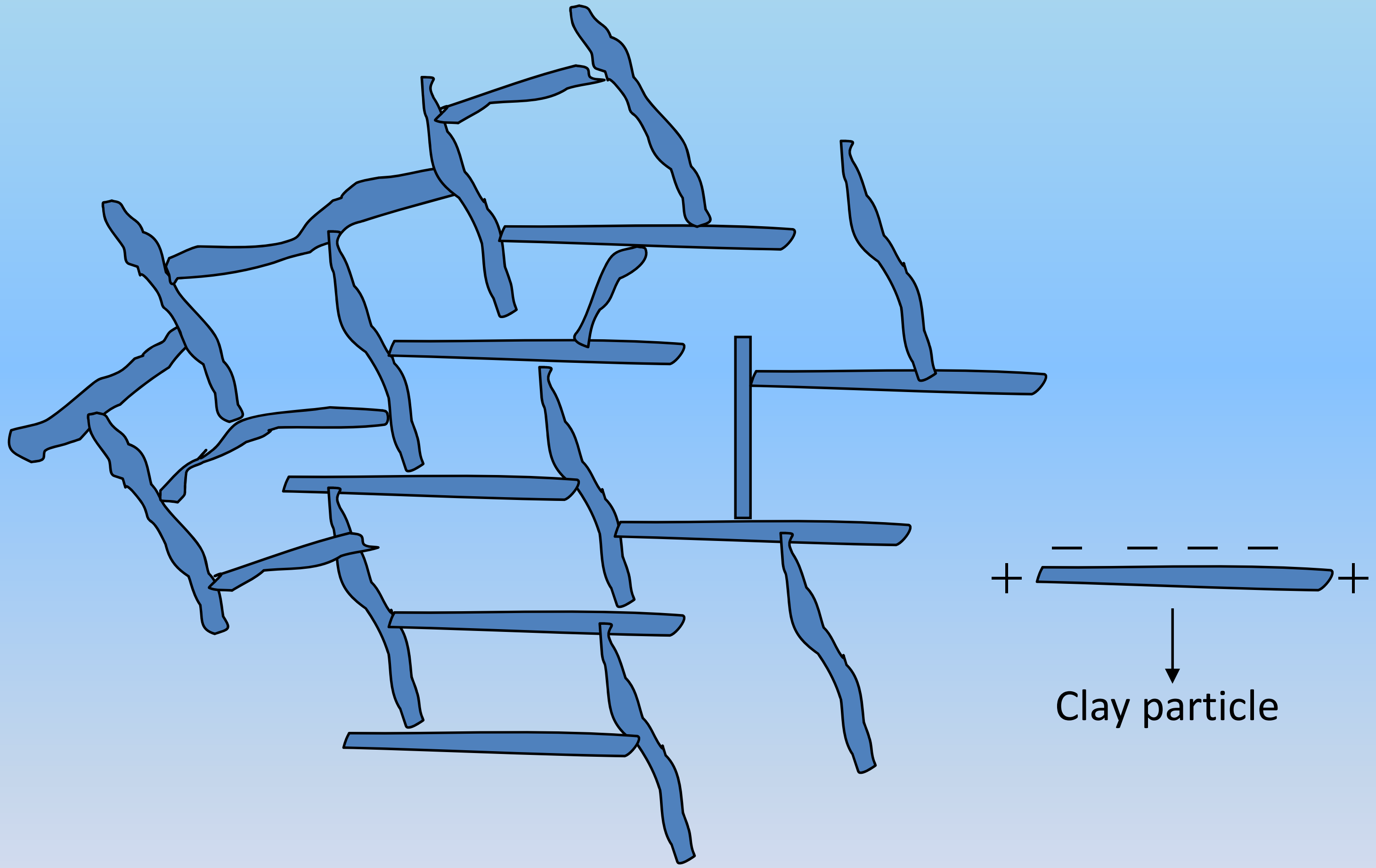


FLOCCULENT AND DISPERSED STRUCTURE

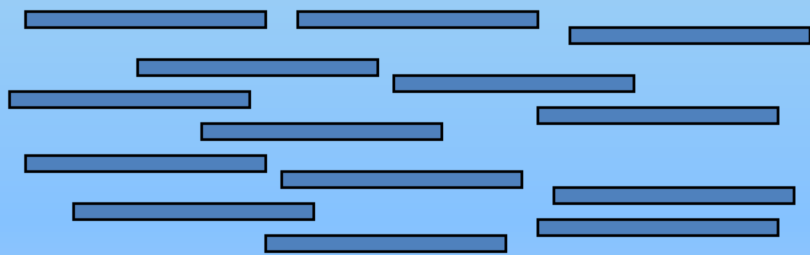
Soil clay particles can be unattached to one another (*dispersed*) or clumped together (*flocculated*) in aggregates. Soil aggregates are cemented clusters of sand, silt, and clay particles.

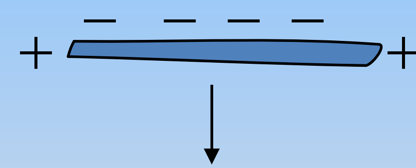


Flocculated structure (Clay)



Dispersed structure (Clay)





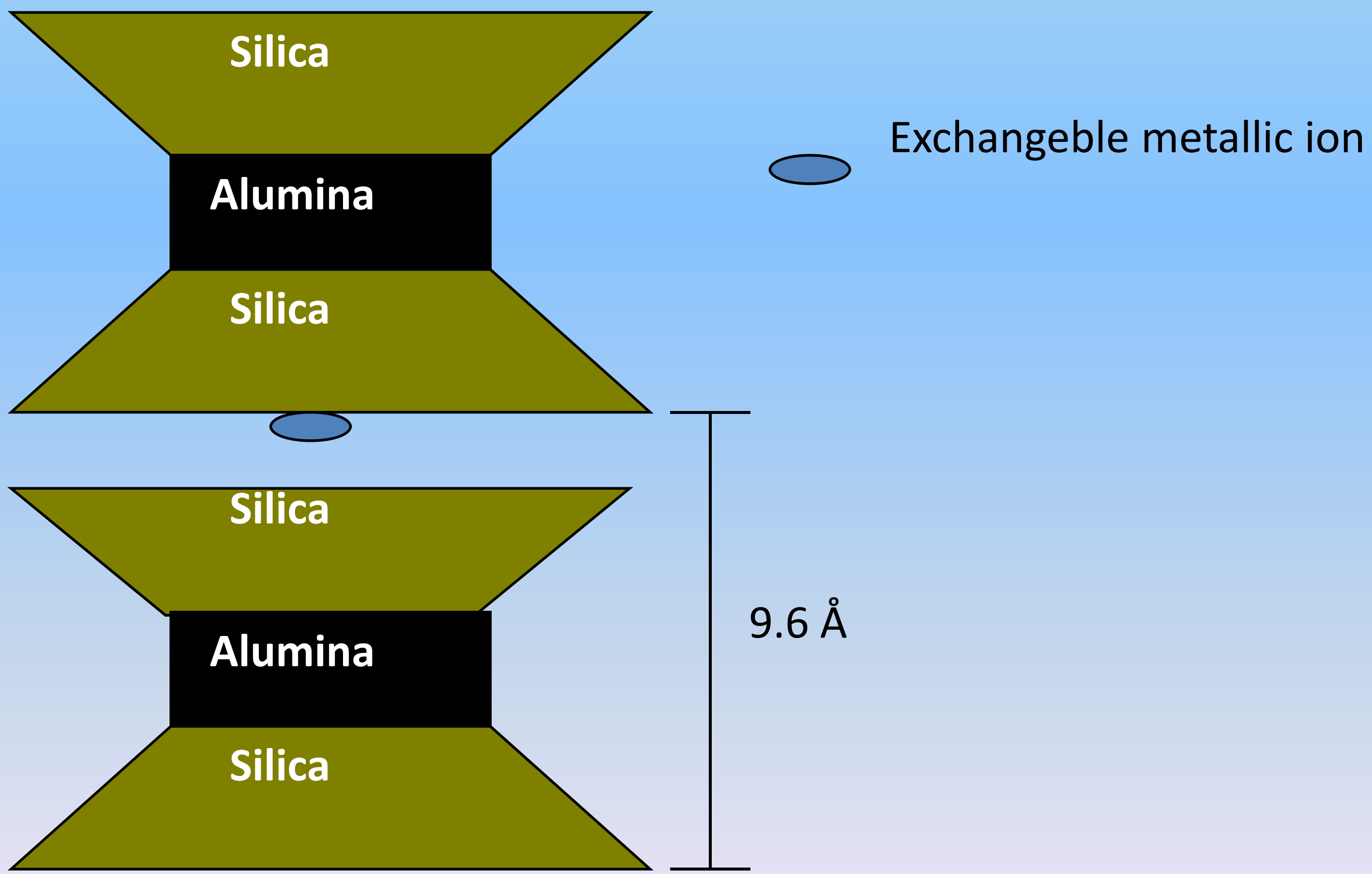
Clay particle

PRINCIPAL CLAY MINERALS

Clay minerals are tiny crystalline substances of one or more members of small groups of minerals . The principal clay minerals are as follows:

1. Montmorillonite
2. Illite
3. Kaolinite

MONTMORILLONITE



MONTMORILLONITE

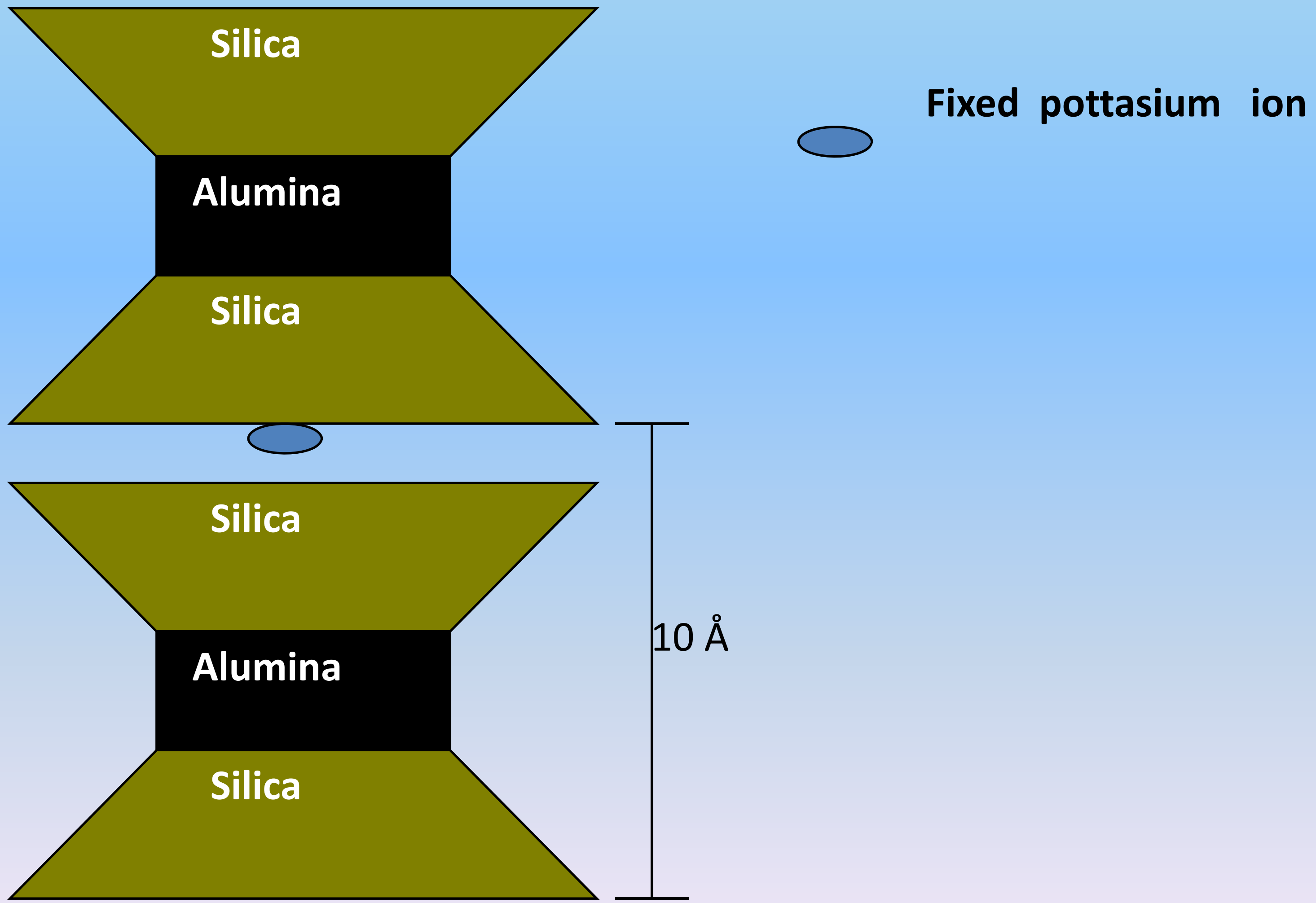
- The structural unit consists of two silica sheets and one alumina sheet a 2:1 mineral.
- The octahedral sheet is sandwiched between two silica sheets with the tips of the tetrahedra combining with the hydroxyls of the octahedral sheet to form a single layer.
- The thickness of the layer is about 9.6 Å. Other directions are indefinite.
- The inter layer bonding between the tops of Silica sheets is mainly due to Van der waals forces and is thus very weak.
- A large amount of water and other exchangeable ions can easily enter between layers and get separated.
- It has largest specific surface area compared to other clay minerals .

- In moist state montmorillonite is highly plastic, it swells and shrinks highly with the interference of water.
- Bentonite is a montmorillonite clay derived from volcanic ash
- It is used as drilling mud in drilling oil wells and Clay grout
- Black cotton soils are also coming under montmorillonite group (20% of India)

ILLITE

- Illite mineral is also a 2:1 mineral like montmorillonite.
- Illite does not swell as much as montmorillonite .

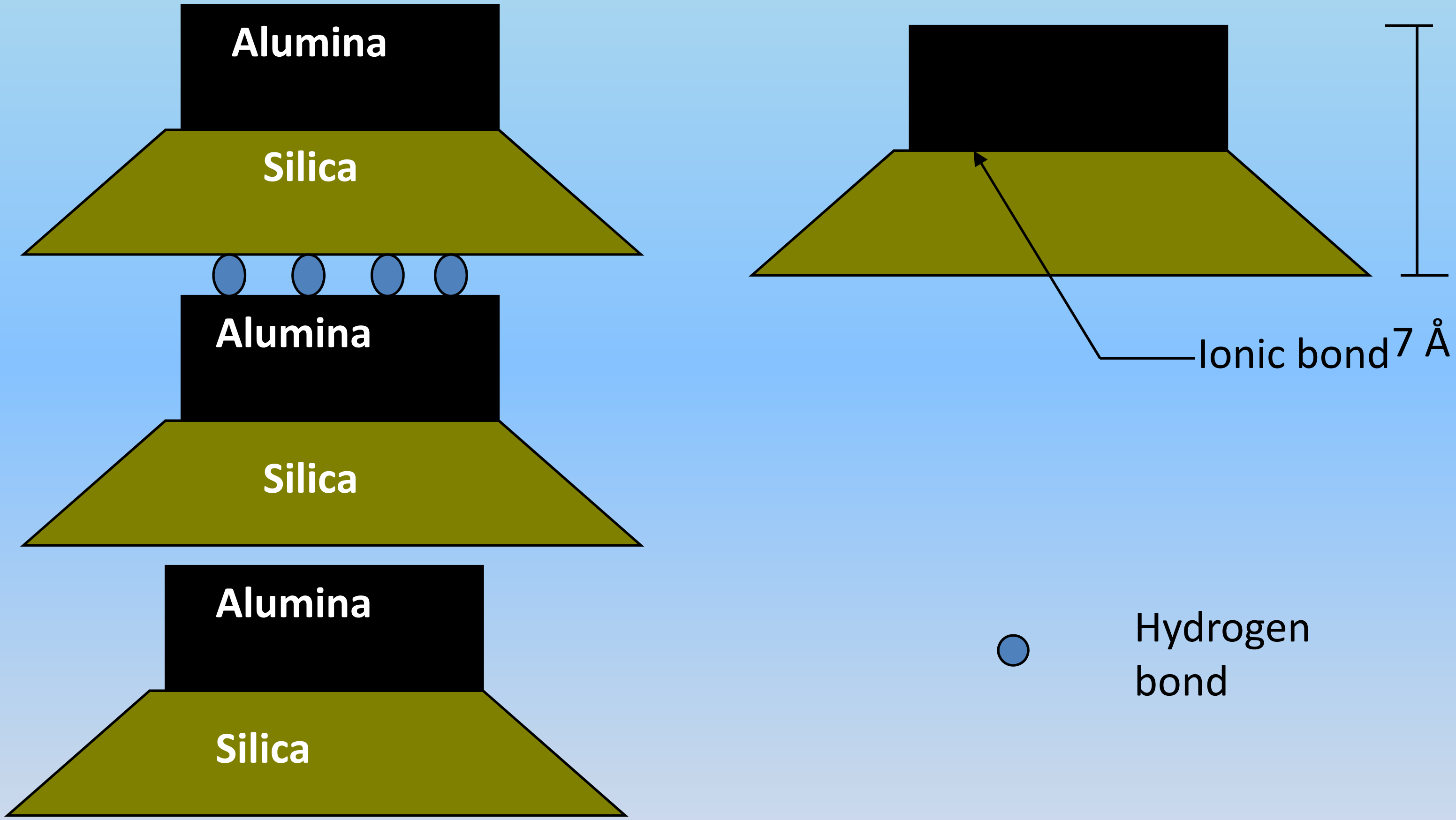
ILLITE



Silica
Alumina
Silica
Silica
Alumina
Silica
10 Å
Fixed pottasium ion

KAOLINITE

- Kaolinite structural unit consists of alternating layers of silica tetrahedra with tips embedded in alumina (Gibbsite) octahedral units
- The structural units are held together by hydrogen bonding
- Thickness of the layer is 7 Å and the dimensions of other directions are indefinite. (1 Å = 10^{-10} m)
- Kaolinite crystal is a staking of 70 -100 or more of these basic 7 Å thick layers.
- Total thickness may be 500 Å to 1000 Å
- Kaolinite is the least active clay mineral



Schematic diagram of kaolinite structure

To conclude, “soil mechanics” is a ever green, alive, active and interesting subject in the civil engineering discipline.