

Soil colloids – Properties, nature, types and significance

SOIL COLLOIDS

The colloidal state refers to a two-phase system in which one material in a very finely divided state is dispersed through second phase. The examples are: Solid in liquid (Dispersion of clay in water) and Liquid in gas (Fog or clouds in atmosphere). The clay fraction of the soil contains particles less than 0.002 mm in size. Particles less than 0.001 mm size possess colloidal properties and are known as soil colloids.

General Properties of Soil Colloids

1. Size

The inorganic and organic colloids are extremely small size - smaller than 2 micrometers in diameter. These particles cannot be seen using an ordinary light microscope but can be seen only with an electron microscope.

2. Surface area

Because of their small size, all soil colloids have a larger external surface area per unit mass. The external surface area of 1 g of colloidal clay is 1000 times that of 1 g of coarse sand. Certain silicate clays have extensive internal surfaces occurring between plate like crystal units that make up each particle and often greatly exceed the external surface area. The total surface area of soil colloids ranges from 10 m²/g for clays with only external surfaces to more than 800 m²/g for clays with extensive internal surfaces. The colloid surface area in the upper 15 cm of a hectare of a clay soil could be as high as 700,000 km² g⁻¹.

3. Surface charges

Both external and internal surfaces of soil colloids carry negative and/or positive charges. Most of the organic and inorganic soil colloids carry a negative charge. When an electric current is passed through a suspension of soil colloidal particles they migrate to anode, the positive electrode indicating that they carry a negative

charge. The magnitude of the charge is known as *zeta potential*. The presence and intensity of the particle charge influence the attraction and repulsion of the particles towards each other, thereby influencing both physical and chemical properties. The sources of negative charge on clays come from

- i) ionizable hydrogen ions
- ii) isomorphous substitution.

i) Ionizable hydrogen ions: These are hydrogen from hydroxyl (OH) ions on clay surfaces. The -Al-OH or -Si-OH portion of the clay ionizes the H and leaves an unneutralized negative charge on the oxygen (-AlO⁻ or -SiO⁻). The extent of ionized hydrogen depends on solution pH and hence these negative charges are *pH dependent charges*. More ionization occurs in alkaline (basic) solutions.

ii) Isomorphous substitution: This is due to the substitution of a cation of higher valence with another cation of lower valence but similar size in the clay crystal structure. In clay crystals some ions fit exactly into mineral lattice sites because of their convenient size and charge. Dominantly, clays have Si⁴⁺ in tetrahedral sites and Al³⁺ in octahedral sites. Other ions present in large amounts during clay crystallization can replace some of the Al³⁺ and Si⁴⁺ cations. Common substitutions are the Si⁴⁺ replaced by Al³⁺, and replacement of Al³⁺ by Fe³⁺, Fe²⁺, Mg²⁺ or Zn²⁺. As the total negative charge from the anions (oxygen) remains unchanged, the lower positive charge of the substituted cations result in excess negative charges on clay crystals.

4. Adsorption of cations: As soil colloids possess negative charge they attract and attach the ions of positive charge on the colloidal surfaces. They attract cations like H⁺, Al³⁺, Ca²⁺ and Mg²⁺. This gives rise to an ionic double layer.

The Isomorphous substitution in the colloidal particle makes the external and internal layers of clay minerals negatively charged and these surfaces act as huge anions, which form the inner layer of the double layer. The outer layer is

made up of a swarm of loosely held (adsorbed) cations attracted to the negatively charged surfaces.

5. Adsorption of water: A large number of water molecules are associated with soil colloidal particles. Some water molecules are attracted to the adsorbed cations and the cation is said to be in hydrated state. Others water molecules are held in the internal surfaces of the colloidal clay particles. These water molecules play a critical role in determining both the physical and chemical properties of soil.

6. Cohesion: (Attractive force between similar molecules or materials). Cohesion indicates the tendency of clay particles to stick together. This tendency is due to the attraction of clay particles for water molecules held between them. When colloidal substances are wetted, water first adheres to individual clay particles and then brings about cohesion between two or more adjacent colloidal particles.

7. Adhesion: (Attractive force between different molecules or materials). Adhesion refers to the attraction of colloidal materials to the surface of any other body or substance with which it comes in contact.

8. Swelling and shrinkage: Some soil clay colloids belonging to smectite group like Montmorillonite swell when wet and shrink when dry. After a prolonged dry spell, soils high in smectite clay (e.g. Black soil -Vertisols) often show crises-cross wide and deep cracks. These cracks first allow rain to penetrate rapidly. Later, because of swelling, the cracks will close and become impervious. But soils dominated by kaolinite, chlorite, or fine grained micas do not swell or shrink. Vermiculite is intermediate in its swelling and shrinking characteristics.

9. Dispersion and flocculation: As long as the colloidal particles remain negatively charged, they repel each other and the suspension remains stable. If on any account they lose their charge, or if the magnitude of the charge is reduced, the particles coalesce, form flock or loose aggregates, and settle down. This phenomenon of coalescence and formation of flocks is known as flocculation. The

reverse process of the breaking up of flocks into individual particles is known as de-flocculation or dispersion.

10. Brownian movement: When a suspension of colloidal particles is examined under a microscope the particles seem to oscillate. The oscillation is due to the collision of colloidal particles or molecules with those of the liquid in which they are suspended. Soil colloidal particles with those of water in which they are suspended are always in a constant state of motion. The smaller the particle, the more rapid is its movement.

11. Non permeability: Colloids, as opposed to crystalloids, are unable to pass through a semi-permeable membrane. Even though the colloidal particles are extremely small, they are bigger than molecules of crystalloid dissolved in water. The membrane allows the passage of water and of the dissolved substance through its pores, but retains the colloidal particles.

TYPES OF SOIL COLLOIDS

There are four major types of colloids present in soil

1. Layer silicate clays
2. Iron and aluminum oxide clays (sesquioxide clays)
3. Allophane and associated amorphous clays
4. Humus

Layer silicate clays, iron and aluminum oxide clays, allophane and associated amorphous clays are inorganic colloids while humus is an organic colloid.

1. Layer silicate clays

These important silicate clays are also known as phyllosilicates (Phyllon - leaf) because of their leaf-like or plate like structure. These are made up of two kinds of horizontal sheets. One dominated by silicon and other by aluminum and/or magnesium.

Silica tetrahedron: The basic building block for the silica-dominated sheet is a unit composed of one silicon atom surrounded by four oxygen atoms. It is called the silica tetrahedron because of its four-sided configuration. An interlocking array or a series of these silica tetrahedra tied together horizontally by shared oxygen anions gives a tetrahedral sheet.

Alumina octahedron: Aluminium and/or magnesium ions are the key cations surrounded by six oxygen atoms or hydroxyl group giving an eight sided building block termed octahedron. Numerous octahedra linked together horizontally comprise the octahedral sheet.

An aluminum-dominated sheet is known as a di-octahedral sheet, whereas one dominated by magnesium is called a tri-octahedral sheet. The distinction is due to the fact that two aluminum ions in a di-octahedral sheet satisfy the same negative charge from surrounding oxygen and hydroxyls as three magnesium ions in a tri-octahedral sheet.

The tetrahedral and octahedral sheets are the fundamental structural units of silicate clays. These sheets are bound together within the crystals by shared oxygen atoms into different layers. The specific nature and combination of sheets in these layers vary from one type of clay to another and control the physical and chemical properties of each clay.

2. Iron and aluminum oxide clays (sesquioxide clays): Under conditions of extensive leaching by rainfall and long time intensive weathering of minerals in humid warm climates, most of the silica and alumina in primary minerals are dissolved and slowly leached away. The remnant materials, which have lower solubility are called sesquioxides. Sesquioxides (metal oxides) are mixtures of aluminum hydroxide, $\text{Al}(\text{OH})_3$, and iron oxide, Fe_2O_3 , or iron hydroxide, $\text{Fe}(\text{OH})_3$. The Latin word *sesqui* means one and one-half times, meaning one and one-half times more oxygen than Al and Fe. These clays can grade from amorphous to

crystalline. Examples of iron and aluminum oxides common in soils are gibbsite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$) and goethite ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$). Less is known about these clays than about the layer silicates. These clays do not swell, not sticky and have high phosphorus adsorption capacity.

3. Allophane and other amorphous minerals: These silicate clays are mixtures of silica and alumina. They are amorphous in nature. Even mixture of other weathered oxides (iron oxide) may be a part of the mixture. Typically, these clays occur where large amount of weathered products existed. These clays are common in soils forming from volcanic ash (e.g., Allophane). These clays have high anion exchange capacity or even high cation exchange capacity. Almost all of their charge is from accessible hydroxyl ions (OH^-), which can attract a positive ion or lose the H^+ attached. These clays have a variable charge that depends on H^+ in solution (the soil acidity).

4. Humus (Organic Colloid)

Humus is amorphous, dark brown to black, nearly insoluble in water, but mostly soluble in dilute alkali (NaOH or KOH) solutions. It is a temporary intermediate product left after considerable decomposition of plant and animal remains. They are temporary intermediate because the organic substances remain continue to decompose slowly. The humus is often referred to as an organic colloid and consists of various chains and loops of linked carbon atoms. The humus colloids are not crystalline. They are composed basically of carbon, hydrogen, and oxygen rather than of silicon, aluminum, iron, oxygen, and hydroxyl groups.

The organic colloidal particles vary in size, but they may be at least as small as the silicate clay particles. The negative charges of humus are associated with partially dissociated enolic ($-\text{OH}$), carboxyl ($-\text{COOH}$), and phenolic groups; these groups in turn are associated with central units of varying size and complexity.

Difference between organic and inorganic colloids

Humus	Clay
Made up of C,H,O	Made up of Si,Ai,O
Complex amorphous organic colloid	Inorganic and crystalline
More dynamic,formed and destroyed more rapidly	Clays are stable relatively
Complex structure not well known	Clays have definite and well known structure

Significance of soil colloids

Th organic and inorganic contaminats are often transported via colloidal particles.

Majority of surface area and electrostatic charge in a soil resides in the less than 1 μm size fraction, with particles with radii between 20 and 1000 nm constituting the major part of soil surface area. Since major part of the surface area is in the colloidal fraction of the soil, almost all surface controlled processes including adsorption reactions, nucleation and precipitation involve colloids. In addition to these chemical processes, colloids are mobile in soils, and thus affect not only the chemical transport of otherwise immobile chemicals, but also exert a strong influence on soil hydraulic properties.
