Introduction

Clay mineralogy is the science dealing with the structure of clay minerals on microscopic, molecular, and atomic scale. It also includes the study of the mineralogical composition and electrical properties of the clay particles. The behavior of fine-grained soils, on the other hand, depends to a large extent on the nature and characteristics of the minerals present. The most significant properties of clay depend upon the type of mineral.

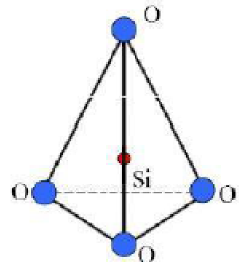
The ingredients necessary to give soil deposit cohesion are clay minerals. There are three types of clay minerals as:

- Kaolinite Clay
- Montmorillonite Clay
- Illite Clay

All these clay minerals have two basic atomic sheets as

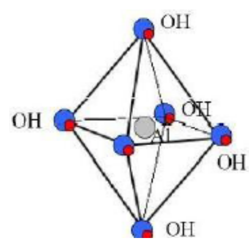
- Tetrahedral Sheet
- Octahedron Sheet

Tetrahedral Sheet



In silica tetrahedral sheet, silica (Si) occupies the center positions and oxygen ions (O) are strongly bonded to the core atoms. Silica tetrahedral sheet is symbolized with a trapezoid, of which the shorter face holds electrically unsatisfied oxygen atoms and the longer face holds electrically satisfied oxygen atoms.

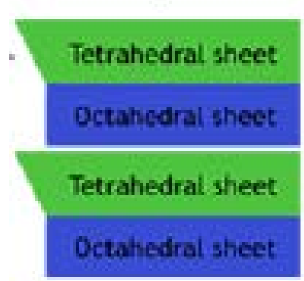
Octahedron Sheet



In aluminum octahedron sheet, aluminum (Al) ion positioned at the center and hydroxyl ion (OH-) bonded to the core atoms. Aluminum octahedron sheet is symbolized with a rectangle with top and bottom faces having the same characteristics of exposed hydroxyl ions. Figure 3.1 gives the atomic structure of the above two basic sheets.

Types of Clay Minerals

Kaolinite Clay

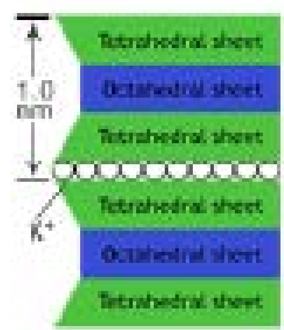


The basic unit of this type of clay is formed by atomic bond of the unsatisfied face of silica sheet and either face of aluminum sheet. The bond between two sheets is strong and is primary bond. However, the stack of two sheets is not a form of clay yet. Many layers of basic kaolinite unit make a kaolinite clay. The thickness of one unit is about 7.2 angstrom. The specific surface is about 15 m^2/gm. Example: China Clay

Montmorillonite Clay

The unused OH- face of aluminum sheet of the silica and aluminum sheet unit in the Kaolinite clay structure may attract the unsatisfied face of another silica sheet to make a three-layer stack. This makes the basic unit of Montmorillonite clay structure with the thickness of about 10 angstroms. The link is due to natural attraction for the cations in the intervening space and due to Vander Waal forces. The negatively charged surfaces of the silica sheet attract water in the space between two structural units. This results in an expansion of the mineral. The soil containing a large amount of the mineral montmorillonite exhibits high shrinkage and swelling characteristics. The specific surface is about 800 m^2/gm.

Illite Clay



Basic structure of this clay is the same as the one of montmorillonite. However, potassium ion (K+) are filled in between facing O2- and O2- surfaces of silica sheets as seen in figure. The characteristics of this clay are classified as in between those of kaolinite and montmorillonite. The specific surface is about 80 m^2/gm.

Clay Particle Interaction

Two types of forces exist between soil particles, namely gravitational forces and surface forces. Gravitational forces are proportional to mass and are important for coarse-grained soils. Surface forces dominates over gravitational forces in the case of clay particles which behaves as colloids. When the particles are very close, the surface forces can be attractive or repulsive. Vander Waal forces, hydrogen bond, cation linkage, dipole-cation-dipole linkage, water dipole linkage and ionic bond are the possible mechanisms for attractive forces between particles. The repulsive force between particles is mainly due to similar charges on particle surface. The repulsive forces between two adjacent particles become effective when they approach each other and their double layers just overlap. For a given type of clay in suspension, the net force between the adjacent particles at a given separation is the algebraic sum of the repulsive and attractive forces acting at that distance. The inter-particle force or potential fields decreases with increasing distance from the mineral surface as shown in the figure. If the total potential energy between two particles decreases as they approach each other, the particle will experience attraction and will flocculate. On the other hand, if there is an increase in the total potential energy, there will be repulsion and the particles will disperse. The various factors affecting flocculation or dispersion are electrolyte concentration, temperature, ion value, pH value, dielectric constant and anion adsorption.

Diffuse Double Layer

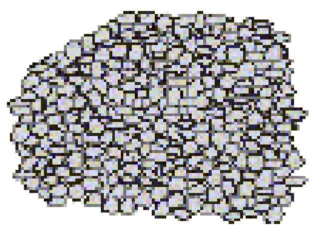
Clay particle carry net residual negative charges on their faces. When suspended in water cations from nearest water molecules are attracted towards the surface of a clay particle. Thus, each particle will be surrounded by cations plus some anions and these are called counter ions or exchangeable ions since they can be replaced. The swarm of counter anions and the surface charges of the particle together constitute the diffuse double layer. The layer extending from the clay particle surface to the limit of attraction is known as diffuse double layer. The electric potential decreases with an increase in distance from the surface of particle, till at some distance free water exists. The water held in diffuse-double layer is known as adsorbed water or oriented water. Outside the diffuse double layer, the water is normal, non-oriented. The total thickness of the diffuse-double layer is about 400 A^o. The adsorbed water affects the behavior of clay particles when subjected to external stresses, since it comes between the particle surfaces. To drive off the adsorbed water, the clay particle must be heated to more than 200^{o}C, which would indicate that the bond between the water molecules and the surface is considerably greater than that between normal water molecules.

Soil Structure

Soil structure is defined as the geometrical arrangement of soil particles in a soil mass. The soils in nature have different structures depending upon the particle size and the mode of formation. If the individual particles are packed very close to each other, the void ratio is low and the soil is dense and strong. More voids in the soil makes the soil weak and loose.

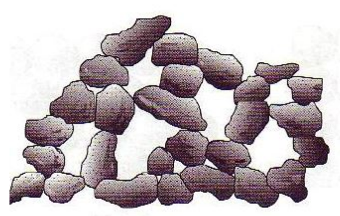
The formation of soil structure is governed by several factors as the force of gravity for coarse-grained soils and the surface bonding forces for fine grained soils.

Single grained structure



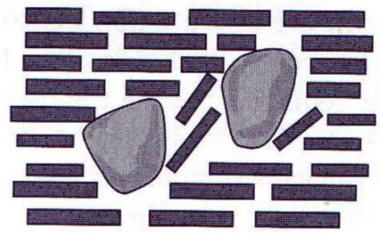
Cohesion less soils, such as gravel and sand, are composed of bulky grains in which the gravitational forces are more predominant than surface forces. When deposition of these soil occurs, the particles settle under gravitational forces and take an equilibrium position as shown in Figure. Each particle is in contact with those surrounding it. The arrangement is somewhat similar to the stacking of oranges on a grocer's counter. Depending upon the relative position of soil particles, the soil may be a loose structure or dense structure.

Honey comb structure



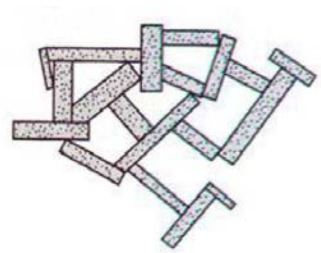
It is possible for fine sands or silts to be deposited such that the particles when setting develop a particle-to-particle contact that bridges over large voids in the soil mass (Refer to Figure). The honeycomb structure usually develops when the particle size is between 0.002 mm and 0.02 mm.

Dispersed clay



The final structures of clay are established from the balance of interactive forces and external forces applied to the clay assemblage. If the final inter particle forces are repulsive, the particles want to separate from each other when the boundary confinements are removed. This is a situation of dispersed clay. The soils in dispersed structure generally have a low shear strength, high compressibility, and low permeability.

Flocculated Structure



If the inter particle force are attractive, then particles want to come together, making flocculated clay. If the edge charges are positive, most likely, the edges are attracted to the flat surface of other clay particles. This makes a card house structure of flocculated clay, most commonly in salt water environment. In freshwater environments, more face-to-face flocculated structures are formed due to negative charges at the edges.

Coarse-grained Skeleton

A coarse-grained skeleton is a composite structure which is formed when the soil contains particles of different types. When the amount of bulky, cohesionless particles is large compared with that of fine-grained clayey particles, the bulky grains are in particle to particle contact. These particles form a skeleton. As long as soil structure is not disturbed, a coarse-grained skeleton can take heavy loads without much deformation.

Clay-matrix Structure

Clay-matrix structure is also a composite structure formed by soils of different types. However, in this case, the amount of clay particles is very large as compared with bulky coarse-grained particles. The clay forms a matrix in which bulky grains appear floating without touching one another.

Refer text book provided for more.