

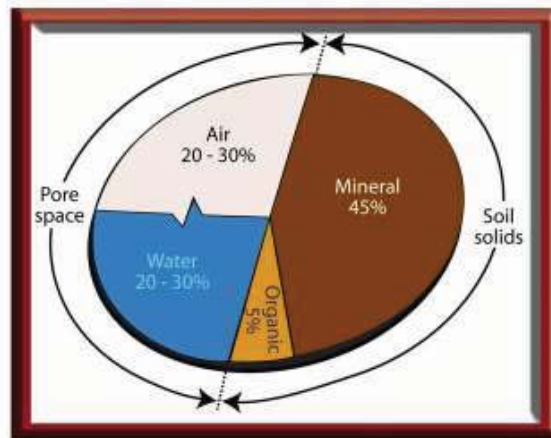
Soil & Soil Colloids

This write-up is made to help better understand a small but important aspect of the mineral and organic portions of soil: CLAY & HUMUS

The Soil is a medium for plant growth. In agriculture, the major roles it plays are:

- Holds air & water
- Holds nutrients
- Medium for plant growth
- Recycles organic wastes
- Habitat for living organisms

This is the classical breakdown of the major soil components:



To better understand C.E.C. (cation exchange capacity), one must understand the various components that make up the mineral and organic fractions of soil. Studying the mineral and organic portions of soil will also lead to a better understanding of the important relationship of Air to Water in the pore space.

Mineral Portion

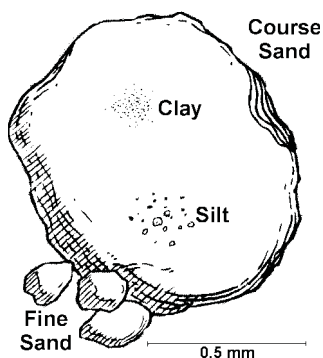
The mineral portion is a mixture of:

1. Gravel
2. Sand
3. Silt
4. Clay

Most soils are a mixture of the above. This mixture is referred to as the soil texture. It is usually stated as Sandy, Sandy loam, silt, Silt loam, Clay loam, etc.

Surface Area of Soil Particles

Particle Type	Diameter (mm)	# of Particles/gram	Surface Area (cm ² /gr)
Very Coarse Sand	2.00 – 1.00	90	11
Coarse Sand	1.00 – 0.50	720	23
Medium Sand	0.50 – 0.25	5,700	45
Fine Sand	0.25 – 0.10	46,000	91
Very Fine Sand	0.10 – 0.05	722,000	227
Silt	0.05 – 0.002	5,780,000	454
Clay	< 0.002	90,300,000,000	8,000,000



Note: Number of particles per gram of soil is an estimate based on the idea that all particles are even spherical shapes. However, this table illustrates the importance of the colloidal fraction of soil. A gram of soil is not much for volume, but consider that this small amount of soil “spread out” would cover about 8,600 square feet!

The surface area of soils affects the soil's ability to hold water. Water is held in the soil structure by forming a thin layer on soil particles, therefore, the higher the surface area of a mixture of sand, silt and clay (soil texture) the higher the water holding capacity.

The same concept applies to nutrient holding capacity. Sand and silt has a very low surface area compared to clay, therefore, a low nutrient holding capacity.

Soil weathering and the release of minerals from this process are also related to the surface area of the particle. An abundance of smaller particles results in more surface area and more release of minerals.

Soil particles also carry negative and positive charges, therefore, the greater the surface area, the greater the ability of the soil to “stick together” and form aggregate structures. A physical example of this is comparing the hardness of dry sand clusters to silt clusters to clay clusters.

Microorganisms tend to colonize and grow on soil particles. Again, the higher the soil surface area, the more “room” and space microorganisms can grow on. Because microbes are such important “chemical manufacturing” plants, a sandy soil contains only a small plant and clay soils would contain larger and more sophisticated chemical production plants.

Helpful table for making visual field method of determining soil texture classes:

Criteria	Sand	Sandy loam	Loam	Silt loam	Clay loam	Clay
Individual grains visible to the eye	Yes	Yes	Some	Few	No	No
Stability of dry clods	Do not form	Do not form	Easily Broken	Moderately easily broken	Hard & Stable	Very hard & Stable
Stability of wet clods	Unstable	Slightly stable	Moderately stable	Stable	Very stable	Very stable
Stability of “ribbon” when wet soil is squeezed	Does not form	Does not form	Does not form	Broken appearance	Thin, will break	Very long & flexible

For the purpose of understanding C.E.C., the mineral portion that needs to be more closely examined is the clay portion.

Important Point:

Next to photosynthesis and respiration, no process in nature is as important to plants (and animals) as the soil's ability to exchange ions (nutrients) between soil particles and plants. This important process takes place on the surface of the smaller and finer portion of soil mineral and organic matter... clay and humus. Clay, is the “inorganic” colloid and humus, is the “organic” colloid. It is important to better understand the types of clay and the function of humus in the soils you work with.

What is a Colloid? Clay and organic matter are very small particles (less than 0.001 mm in size) that are considered colloids. A mixture of these small particles in another medium (such as water) is considered a colloidal system. Examples of colloidal systems are blood, milk and humic acid additives.

Soil colloids are important because they have a very large surface area. One pound of clay has 1,000 times the surface area of 1 pound of coarse sand. To put surface area of soils into perspective, consider the following:

One Acre of Clay Soil

**6” deep has a
Surface Area of up to 110,000 Square Miles!
(The area of the State of NEVADA)
(Probably more productive, too!)**

Types of Soil Colloids

There are four types of colloids found in most soils:

1. Layer silicate clays
2. Iron and aluminum oxide clays
3. Amorphous clays
4. Humus

Rather than look at all the technical factors of these types of clay, we will make generalized statements about each type of clay that are important for crop production.

Layer Silicate Clays

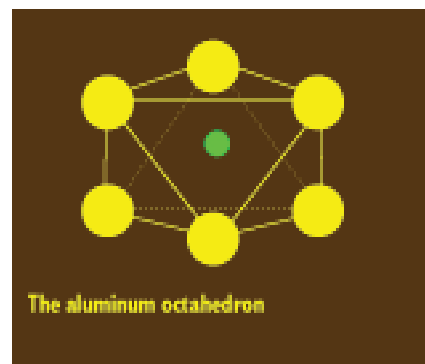
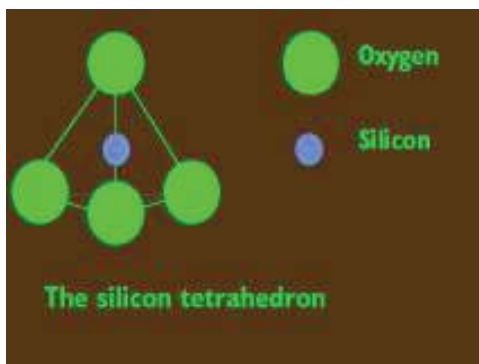
“Layer” – so named because of the layerlike structures, much like pages in a book.

“Silicate” – so named because of the silica compounds that make up the layers.

Silicate clays are the most common types of clay in most areas.

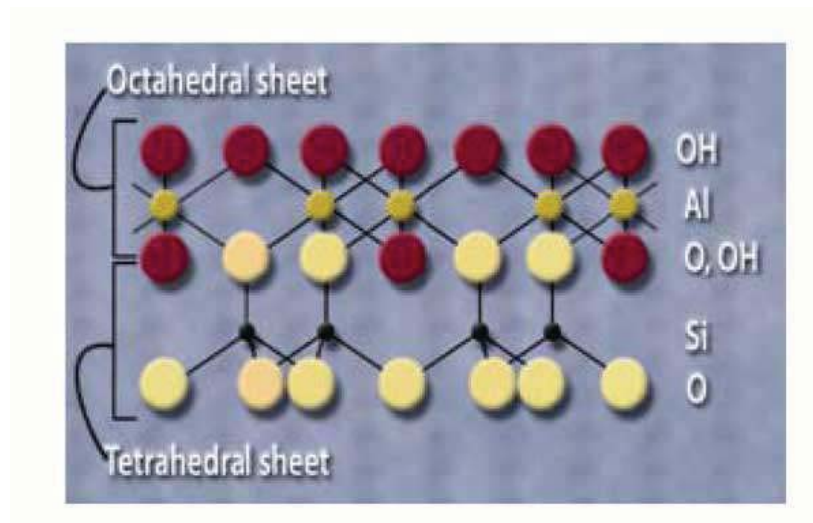
There are various groups of layer silicate clays that can be further broken down by the different layer arrangements. These clays are made up of alternating sheets of silica compounds and aluminum (and/or magnesium – iron) compounds. A little bit of this arrangement must be understood to fully appreciate the reaction of clays with minerals in the soil.

Two basic sheets, in varying arrangements, make up the following important classifications of layer silicate clays:

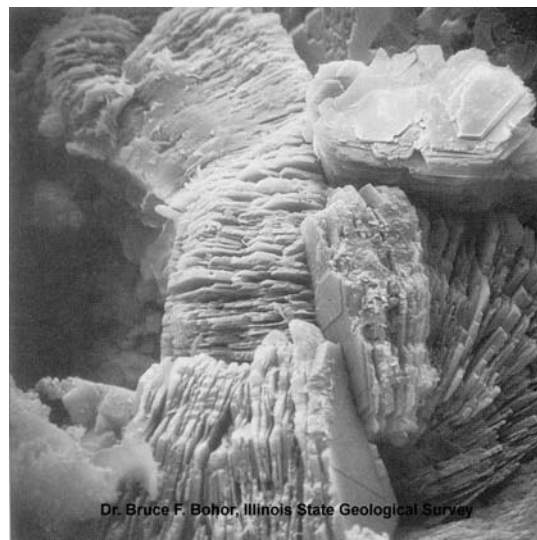


The arrangement of the layers is what makes up three important types of clay. They are 1:1 clays, 2:1 clays and 2:1:1 clays. There is, of course, a mixture and blend of these types, but these are important groups.

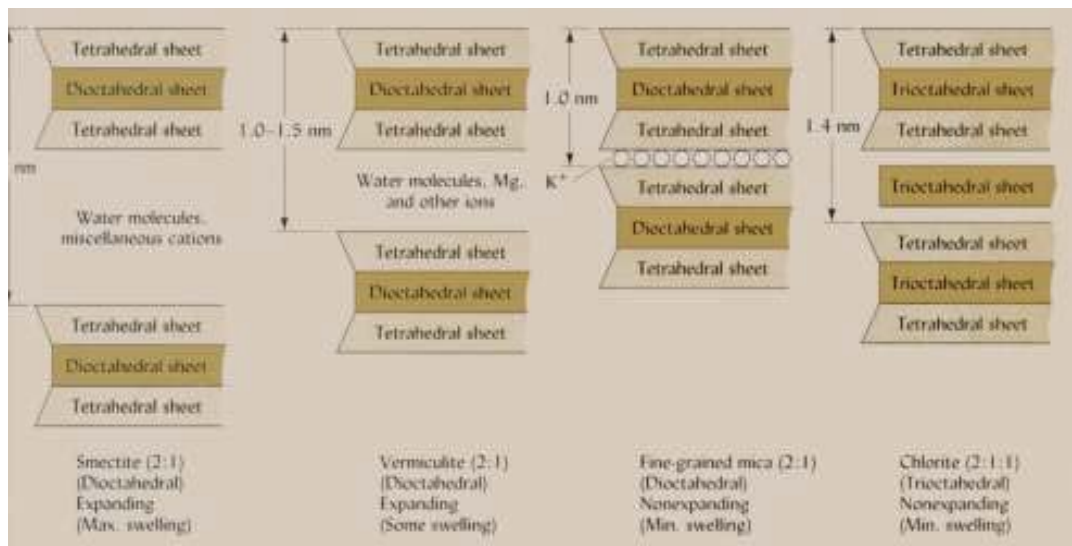
The first, a 1:1 clay is a made up of a silica layer bound to one aluminum based layer as follows:



This clay is unique from other types, because the silica based layer (tetrahedral sheet) and the aluminum-based layer (octahedral sheet) are tightly bond and do not open or “swell.” This means that in comparison to other types of clay, this type does not have surface area and capacity to absorb cations. Kaolinite is the most commonly found is soils:



There are several major types of 2:1 clays, three of which are illustrated in the layer structure below.



As you can see, varying types of layers and arrangements makes up layered clays. Some 2:1 clay such as montmorillonite expands a great deal because of the amount of water it allows into the layers. On the other hand, mica hardly swells at all. Following is a useful table of various types of clay and their perspective characteristics.

Property	Smectite	Vermiculite	Fine mica	Chlorite	Kaolinite	Humus
Size (μm)	0.01-1.0	0.1-5.0	0.2-2.0	0.1-2.0	0.5-5.0	0.1-1.0
Shape	Flakes	Plates; flakes	Flakes	Variable	Hexagonal crystals	Variable
External surface (m^2/g)	70-120	50-100	70-100	70-100	10-30	500-800
Internal surface (m^2/g)	550-650	500-600	--	--	--	500-800
Net Negative Charge (cmol_c/kg) ^c	80-120	100-180	15-40	15-40	2-5	100-550

From: "The Nature and Properties of Soil", 11th edition, Brady & Weil, pg. 250

Iron & Aluminum Oxide Clays

These clays are dominant in highly weathered soils of the tropics and semitropics. However, make up a part of the "red" and "yellow" soils common in the southeastern United States.

Fe & Al oxide clays are not as sticky and plastic as layer silicate clays. In high pH soils, these clays carry only a small negative charge and are surrounded mostly by cations such as Ca, Mg, Na & K. However, in low pH (acid) soils, these clays carry a larger negative charge and are therefore surrounded by more anions. This brings up an important reason to further learn about clay types. A.E.C. (anion exchange capacity) is rarely discussed in agricultural circles, because of the difficulty of testing and quantifying, not its importance.

Amorphous clays

“Amorphous” – means lacking definite form; shapeless; or more fitting for clay, lacking distinct crystalline structure.

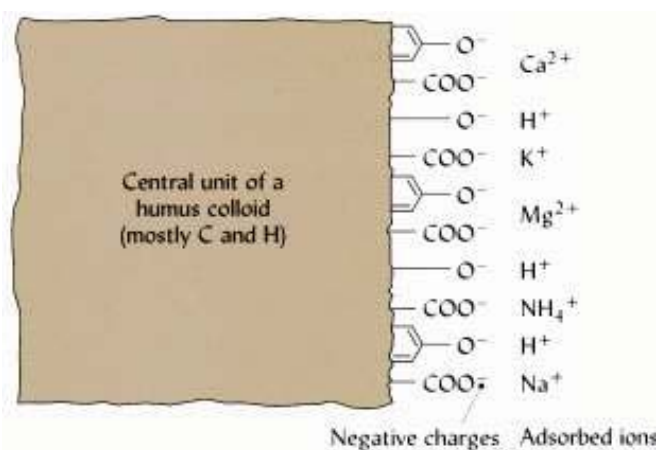
The most common type is found in the volcanic soils of the Northwestern United States in the form of allophane. Allophane has a high capacity to absorb cations and also has enough positive sites to be quite effective at absorbing anions as well. Because of a lack of definite structure, these types of clay are not well understood.

Humus – Organic Soil Colloids

The term “humus” refers to the portion of soil organic matter that is in a “stabilized” form. This means that it is quite resistant to microbial breakdown and decomposes very slowly. The term “stable humus” refers to the combination of humus (the organic part) and clay (the mineral part).

In a strictly chemical sense, the difference between “inorganic” clay and “organic” humus colloids is that clay is made up of minerals such as silica, aluminum, magnesium, iron that are combined with oxygen. On the other hand, humus is made up of mostly carbon, oxygen, hydrogen and some nitrogen and sulfur.

The diagram below is a simple illustration of how humus acts as a cation exchange site:



There are two important points about humus that need to be pointed out:

1. Humus does NOT come in a bucket from a humic acid's manufacturer. Yes, many of these products contain parts of soil humus, especially the lower molecular weight humic and fulvic acids, but they are not the complex products of healthy microbial production.
2. As illustrated in an earlier table, humus does have more C.E.C. than most clay. However, an important point to make is that humic acids are several more times effective in higher pH soils (7.5 and above) than they are in lower pH soils (6.0 and lower).

The Practical “Stuff”

In order to make practical applications of clay and humus technical explanations, following are some generalizations or “rules of thumb”.

- Smectites (a form of 2:1 clay) holds on to calcium more tightly than Kaolinite (a form of 1:1 clay). Therefore, a 70% plus of C.E.C. should be maintained in soils high in Smectite clay, whereas 50% is sufficient in Kaolinite clay soils.
- Smectites fix potassium strongly, even larger silt sized particles. On the other hand Kaolinite fixes (holds on to) K poorly.
- Higher expanding clays such as Montmorillonite and much more supportive of important microbial life than are poor expanding clays such as Illite.
- In acid pH soils, potassium (K) is held less tightly than in basic (high pH) soils.
- Antagonism #1 – High calcium limits potassium release.
- Antagonism #2 – High potassium limits magnesium release.
- Most layered silicate clay predominates in negative charges. However, hydrous oxides of iron and aluminum can be very effective at holding anions at lower pH soils. This is an important consideration for nitrate, sulfate, boron and molybdenum availability and movement.
- Humic acids are more effective in high pH soils than in low pH soils.
- Although it is a general rule that coarse soils (lower in clay) do not have the cation exchange capacity of finer soils, higher in clay; soils with similar humus contents but higher amounts of 1:1 clay can be lower in C.E.C. than soils with even smaller amounts of some 2:1 clay.
- The strength of adsorption of minerals to clay is as follows;
$$\text{Al}^{3+} > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ = \text{NH}_4^+ > \text{Na}^+$$
- Therefore, K is less tightly held in acid soils (higher in Al & H) than in neutral to alkaline soils (higher in Ca & Mg).
- Liming acid soils results in better K stability and less leaching.
- A low percentage of K in a soil test is not necessarily an indication of potential fertilizer K tie up. Certain clay, especially expanding clay, has the ability to hold tightly onto K. However, many soil colloids (humus included) are very ineffective at holding K, some as low as 1-2%. In low C.E.C. soils, sandy soils and poor “K” clay soils, it is always better to feed K slowly and when needed (just like treating N applications).