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## Clay minerals

**Clay minerals** are layer silicates that are formed usually as products of chemical weathering of other silicate minerals at the earth's surface. They are found most often in shales, the most common type of sedimentary rock. In cool, dry, or temperate climates, clay minerals are fairly stable and are an important component of soil. Clay minerals act as "chemical sponges" which hold water and dissolved plant nutrients weathered from other minerals. This results from the presence of unbalanced electrical charges on the surface of clay grains, such that some surfaces are positively charged (and thus attract negatively charged ions), while other surfaces are negatively charged (attract positively charged ions). Clay minerals also have the ability to attract water molecules. Because this attraction is a surface phenomenon, it is called **adsorption** (which is different from *absorption* because the ions and water are not attracted deep inside the clay grains). Clay minerals resemble the micas in chemical composition, except they are very fine grained, usually microscopic. Like the micas, clay minerals are shaped like flakes with irregular edges and one smooth side. There are many types of known clay minerals. Some of the more common types and their economic uses are described here:

**Kaolinite:** This clay mineral is the weathering product of feldspars. It has a white, powdery appearance. Kaolinite is named after a locality in China called Kaolin, which invented porcelain (known as china) using the local clay mineral. The ceramics industry uses it extensively. Because kaolinite is electrically balanced, its ability of adsorb ions is less than that of other clay minerals. Still, kaolinite was used as the main ingredient for the original formulation of the diarrhea remedy, Kaopectate.

**Illite:** Resembles muscovite in mineral composition, only finer-grained. It is the weathering product of feldspars and felsic silicates. It is named after the state of Illinois, and is the dominant clay mineral in midwestern soils.

**Chlorite:** This clay mineral is the weathering product of mafic silicates and is stable in cool, dry, or temperate climates. It occurs along with illite in midwestern soils. It is also found in some metamorphic rocks, such as chlorite schist.

**Vermiculite:** This clay mineral has the ability to adsorb water, but not repeatedly. It is used as a soil additive for retaining moisture in potted plants, and as a protective material for shipping packages.

**Smectite:** This clay mineral is the weathering product of mafic silicates, and is stable in arid, semi-arid, or temperate climates. It was formerly known as *montmorillonite*. Smectite has the ability to absorb large amounts of water, forming a water-tight barrier. It is used extensively in the oil drilling industry, civil and environmental engineering (where it is known as **bentonite**), and the chemical industry. There are two main varieties of smectite, described in the following:

**Sodium Smectite:** This is the *high-swelling* form of smectite, which can adsorb up to 18 layers of water molecules between layers of clay. Sodium smectite is the preferred clay mineral for

drilling muds, for creating a protective clay liner for hazardous waste landfills to guard against future groundwater contamination, and for preventing seepage of groundwater into residential basements. Sodium smectite will retain its water-tight properties so long as the slurry is protected from evaporation of water, which would cause extensive mud cracks. As a *drilling mud*, sodium smectite mixed with water to form a slurry which performs the following functions when drilling an oil or water well: 1) lubricates the drill bit to prevent premature wear, 2) prevents the walls of the drill hole from collapsing inwards, 3) suspends the rock cuttings inside the dense mud so that the mud may be pumped out of the drill hole, and 4) when the dense mineral *barite* is added to drilling mud, it prevents *blowouts* caused by internal pressure encountered during deep drilling. Sodium smectite is also used as commercial **clay absorbent** to soak up spills of liquids. High-grade deposits of sodium smectite are found in South Dakota.

**Calcium smectite:** The *low-swelling* form of smectite adsorbs less water than does sodium smectite, and costs less. Calcium smectite is used locally for drilling muds. Much of the domestic supplies of calcium smectite are mined from the state of Georgia.

**Attapulgitite:** This mineral actually resembles the amphiboles more than it does clay minerals, but has a special property that smectite lacks - as a drilling fluid, it is stable in salt water environments. When drilling for offshore oil, conventional drilling mud falls apart in the presence of salt water. Attapulgitite is used as a drilling mud in these instances. Incidentally, attapulgitite is the active ingredient in the current formula of Kaopectate.

## Soil structure

Soil structure refers to how particles of soil are grouped together into aggregates (also called peds). They are cemented or bound together by physical, chemical, and biological processes.

Physical-chemical processes that build soil structure include:

- Polyvalent cations like  $\text{Ca}^{2+}$ , magnesium  $\text{Mg}^{2+}$ , and aluminum  $\text{Al}^{3+}$  bind together clay particles
- Soil particles are pushed closer together by freezing and thawing, wetting and drying, and by roots pushing through the soil as they grow in length and width.

Biological processes that build soil structure include:

- Soil particles are cemented together by humus, by organic glues created by fungi and bacteria decomposing organic matter, and by polymers and sugars excreted from roots.
- Fungal hyphae and fine roots stabilize aggregates (University of Minnesota Extension 2002.)
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Organic matter and plant roots are therefore key to soil structure.

Factors that can deteriorate or destroy soil structure include, for example:

- Compaction
- Cultivation
- Removal of vegetation
- Excessive moving and handling of soil
- Screening
- Excessive sodium

A high proportion of sodium to calcium and magnesium causes clay particles to repel each other when wet, so aggregates are dispersed and the process of soil structure formation is reversed. Soils with too much sodium become almost impermeable to water because the dispersed clay and small organic particles clog up remaining soil pores (Donahue et al 1983). Excessively high sodium levels can result from irrigation and salting roads.

Soil structure is classified by type (shape), class (size) of peds, and grade (strength of cohesion) of aggregates. Shape, size and strength of aggregates determine pore structure, and how easily air, water, and roots move through soil (Donahue et al 1983). Granular structure is the most common in surface soil layers, especially those with adequate organic matter. Granular structures offer the most pore space of any structure. Columnar structure is often found in soils with excessive sodium, due to the dispersing effects of sodium, which destroys soil structure, rendering the soil effectively sealed to air and water movement.

Platy structure has the least amount of pore space and is common in compacted soils. Some soils have no true structure, like single grain soils (like a loose sand with little to no attraction between the grains of sand), and massive soils.

Preserving soil structure may increase the range of soil textures acceptable for bioretention. Bioretention soils are often sand based, primarily to ensure adequate infiltration rates. Clay and silt content is often limited to a maximum of only 3 to 5 percent, which is very, very low, limiting soils to sands according to the soil textural triangle. While a clay soil that has been screened and has no structure will have a very low infiltration rate, with proper structure, many soils with more clay can also have adequate infiltration rates. Increasing clay content above the very low maximum of 3 to 5 percent could provide important benefits, including increased soil water holding capacity and increased cation exchange capacity, which increase potential pollutant removal. When increasing clay content, however, keep in mind that the higher the clay content, the more crucial it becomes to protect soil from compaction and from excess

salt, as clay soils are more prone to compaction and loss of structure, and unacceptable decrease of infiltration rates due to dispersion from sodium ions.

**Reference:**

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