INTRODUCTION TO CLAY MINERALS AND SOILS

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 mid-western 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 adsorb 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 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.

Attapulgite: 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 stable in salt water environments. When drilling for offshore oil, conventional drilling mud falls apart in the presence of salt water. Attapulgite is used as a drilling mud in these instances. Incidentally, attapulgite is the active ingredient in the current formula of Kaopectate.

SOILS

Soil is produced by the weathering of rocks at the earth's surface, usually requiring thousands of years. Many of our present day agricultural soils date back to the last ice age, more than 10,000 years ago. Ideally, a soil has four components, and an idealized percentage for a "good" agricultural soil would be:

- Mineral (45%)
- Organic matter (5%)
- Water (25%)
- Air (25% void space)

Within the mineral fraction, soils are usually divided into three size fractions: sand, silt, and clay. An ideal balance between a soil that is 100% sand ("too loose") vs. 100% clay ("too tight") has a roughly equal sand: silt: clay ratio, and this type of soil is termed a "loam." The term "soil" as used in engineering refers to "any unconsolidated material" and does not necessarily match the geologist's definition. Organic matter comes from products of soil microbes which promote the decay of dead plants and animals. One of these organic materials is known as humus, which mimics/or stimulates the adsorptive properties of clay minerals.

Organic matter is generally dark in color, and a layer of topsoil rich in organic matter is said to be the "O" Horizon.

Tropical Weathering Breaks Down Clay Minerals

In humid tropical climates, clay minerals are unstable and break down under intense chemical weathering to become *hydrated oxides* of aluminum (bauxite) and iron (goethite), which are very poor substitutes for clay minerals in retaining soil nutrients. As a result, jungle soil relies on the presence of **humus**, an organic substance produced by microbes that cause dead plants to decay; humus mimics the ability of clay minerals to retain soil moisture and nutrients. However, humus is much more fragile than clay minerals to chemical weathering, and is protected by the tall rainforest canopy, which softens the torrential rainfall into a gentle sprinkle. When rain forest trees are cut down, the humus is quickly washed away, leaving a barren landscape that bakes to a hard, brick-like consistency under the tropical sun. This "soil" is virtually useless for western style agriculture, and cannot be converted into useful farmland due to the lack of clay minerals. Even adding chemical fertilizers is useless - the soil cannot absorb it, and it runs off the land and pollutes the rivers.

Why There Is High Biological Diversity in Tropical Rain Forests

It is important to note that the apparent abundance of greenery in the tropics is deceiving - *there is no abundance of any single species; instead there is an abundance of different species.* This is known as **biological diversity**. Biological diversity may be likened to *nature's efficiency plan* - it allows a limited resource (soil nutrients) to be shared by a large number of different plants with different diets. The warm, mild climate of tropical rain forests has the highest species diversity in the world. It is from this diversity that most pharmaceutical herbs and drugs are obtained.

How Fertile Soils Facilitate Mono-Crop Agriculture

Since ancient times, farmers have noticed that growing the same crop year after produced successively poorer harvests. This is caused by the removal of nutrients from the soil by that same crop. By alternating a different crop each season, the soil is less depleted of nutrients than by growing the same crop every year. Despite the soundness of crop rotation, for the sake of efficiency, modern US agriculture practices **mono-crop agriculture**, where field upon field of the same crop (corn, wheat, soybeans, etc.) is grown year after year. This is only possible because of the rich agricultural soil of the American mid-west, which contains abundant clay minerals, and has an optimum soil consistency. Still, mono-crop agriculture would not be possible without the intensive use of chemical fertilizers to replenish an already rich soil. A side-effect of mono-crop agriculture is that it encourages the establishment of agricultural pests. Insects which feed on a particular crop will return in greater force with a steady annual supply of food. Consequently, chemical pesticides and pest-resistant seeds are also required to support mono-crop agriculture.