

# **Chapter 8**

## **Soil Colloids**

# **Topics**

- **Type of soil colloids**
- **Silicate clays**
- **Cation exchange and sorption**

# **Soil Colloids and Their Types**

**The fine fractions of soils (clays and humus) less than about 2  $\mu\text{m}$**

## **Types:**

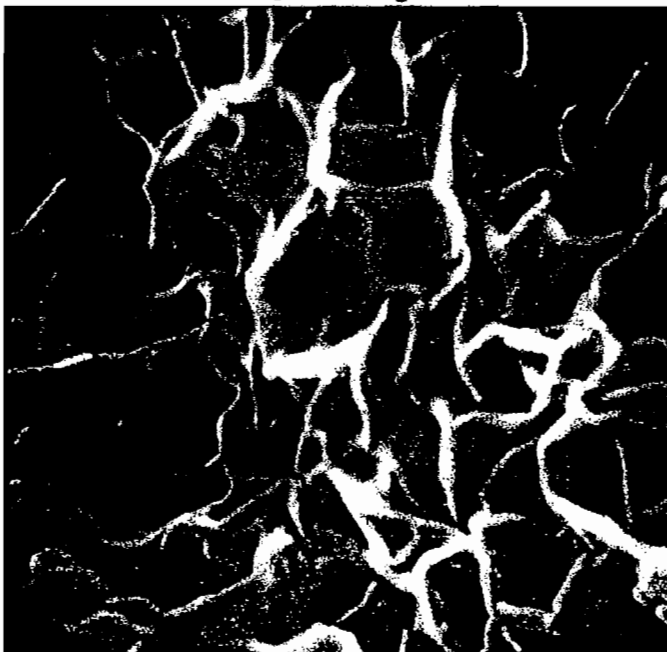
- **Silicate clays - crystallized clay minerals**
- **Iron and aluminum oxide clays**
- **Organic soil colloids - humus**



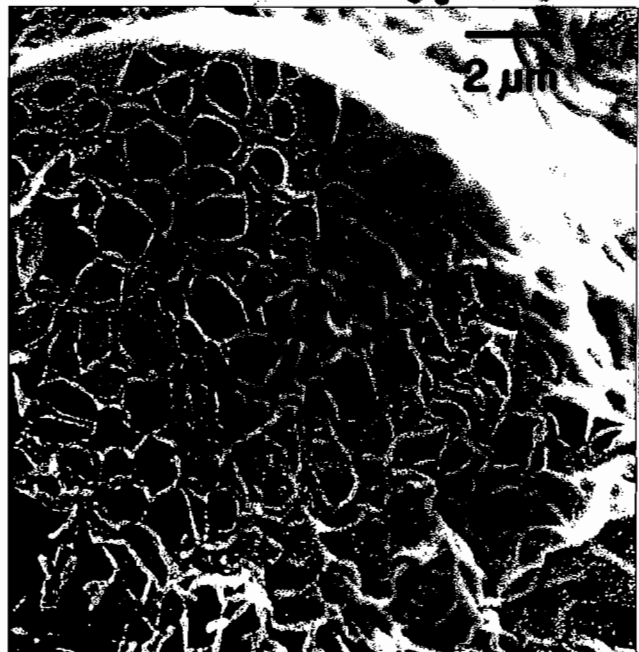
**Kaolinite**



**Mica**

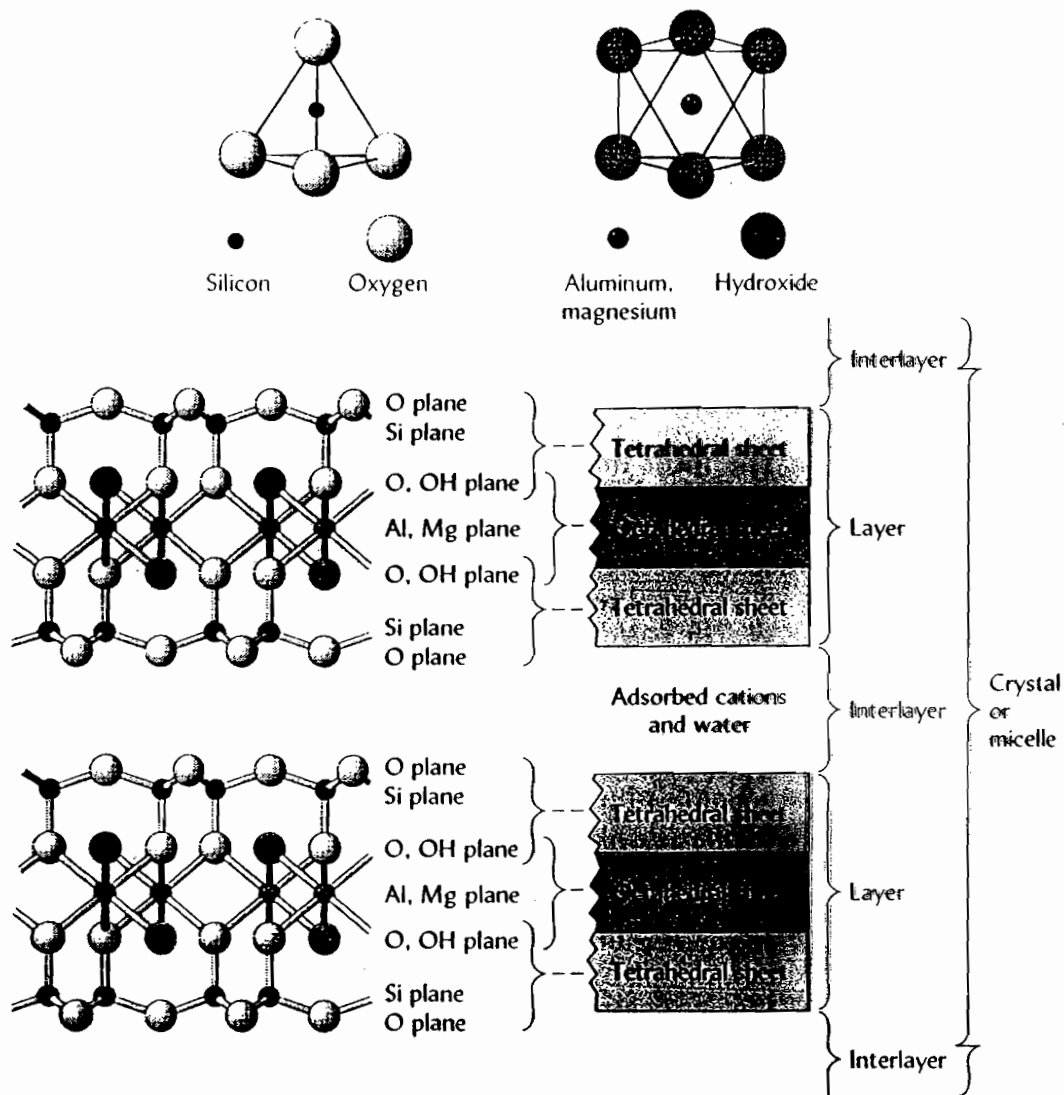


**Montmorillonite**



**Fulvic Acid**

**FIGURE 8.2** Crystals of three silicate clay minerals and a photomicrograph of humic acid found in soils. (a) Kaolinite from Illinois magnified about 1900 times (note hexagonal crystal at upper right). (b) A fine-grained mica from Wisconsin magnified about 17,600 times. (c) Montmorillonite (a smectite group mineral) from Wyoming magnified about 21,000 times. (d) Fulvic acid (a humic acid) from Georgia magnified about 23,000 times. [(a)–(c) Courtesy Dr. Bruce F. Bohor, Illinois State Geological Survey; (d) from Dr. Kim H. Tan, University of Georgia; used with permission of Soil Science Society of America]

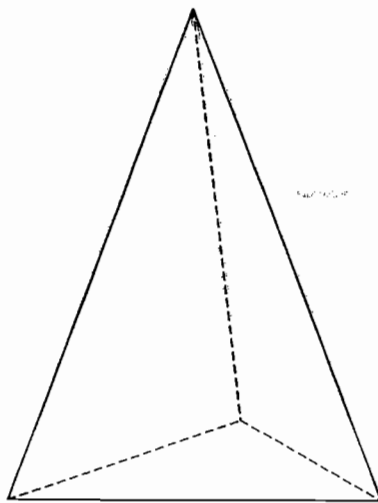


**FIGURE 8.4** The basic molecular and structural components of silicate clays. (a) A single *tetrahedron*, a four-sided building block comprised of a silicon ion surrounded by four oxygen atoms; and a single eight-sided *octahedron*, in which an aluminum (or magnesium) ion is surrounded by six hydroxy groups or oxygen atoms. (b) In clay crystals thousands of these tetrahedral and octahedral building blocks are connected to give planes of silicon and aluminum (or magnesium) ions. These planes alternate with planes of oxygen atoms and hydroxy groups. Note that apical oxygen atoms are common to adjoining tetrahedral and octahedral sheets. The silicon plane and associated oxygen-hydroxy planes make up a *tetrahedral sheet*. Similarly, the aluminum-magnesium plane and associated oxygen-hydroxy planes comprise the *octahedral sheet*. Different combinations of tetrahedral and octahedral sheets are termed *layers*. In some silicate clays these layers are separated by *interlayers* in which water and adsorbed cations are found. Many layers are found in each *crystal* or *micelle* (microcell).

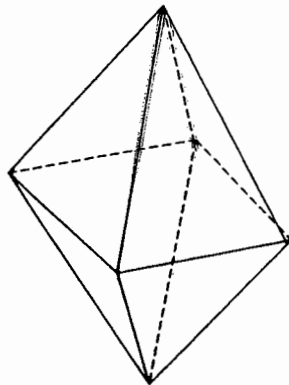
## Silicate Clays

### Structure:

- **tetrahedron** - a unit composed of one silicon atom surrounded by four oxygen atoms
- **tetrahedral sheet** - an array of tetrahedra that share oxygens with one another

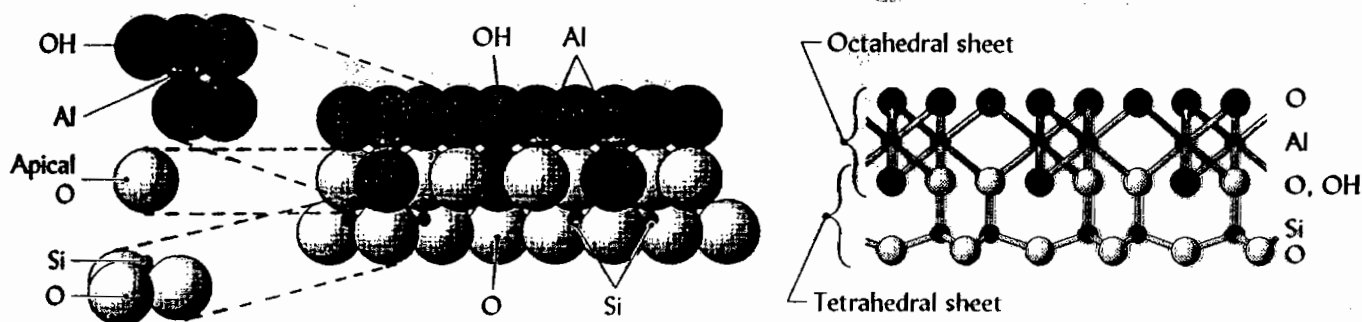


- **Octahedron** - a unit composed of an aluminum atom surrounded by six oxygen atoms
- Numerous octahedra linked together comprise the **octahedral sheet**.



### **Isomorphous Substitution:**

the replacement of one atom by another of similar size in a crystal lattice without disrupting or changing the crystal structure of the mineral. For example,  $\text{Al}^{3+} \rightarrow \text{Si}^{4+}$ ,  $\text{Mg}^{2+} \rightarrow \text{Al}^{3+}$

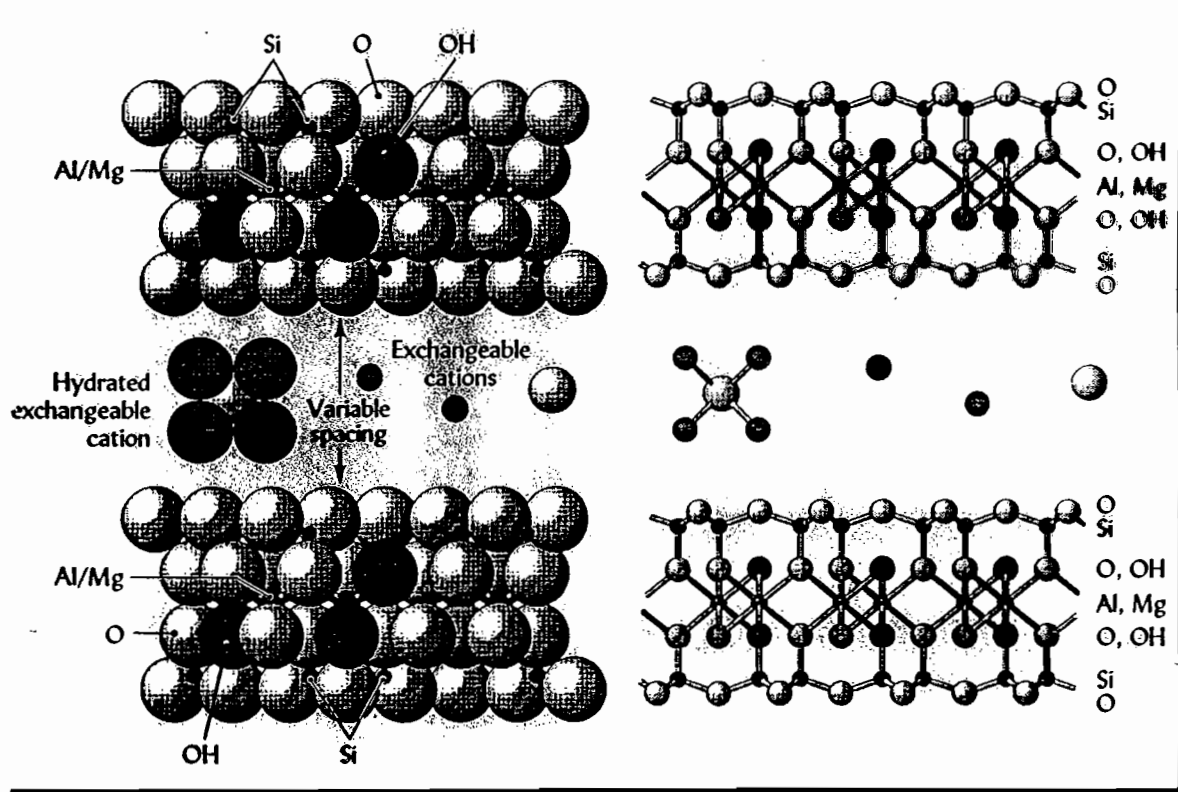


**FIGURE 8.5** Models of ions that constitute a layer of the 1:1-type clay kaolinite. The primary elements of the octahedral (upper left) and tetrahedral (lower left) sheets are depicted as they might appear separately. In the crystal structure, however, these sheets are held together by common oxygen ions that are known as *apical oxygen* ions. Note that each layer consists of alternating octahedral (alumina) and tetrahedral (silica) sheets—hence, the designation 1:1. Aluminum ions surrounded by six hydroxy groups and/or oxygen atoms (counting the apical oxygen) make up the octahedral sheet (upper left). Smaller silicon ions associated with four oxygen atoms (counting the apical oxygen) constitute the tetrahedral sheet (lower left). The octahedral and tetrahedral sheets are bound together (center) by mutually shared (apical) oxygen atoms. The result is a layer with hydroxys on one surface and oxygens on the other. A schematic drawing of the ionic arrangement (right) shows a cross-sectional view of a crystal layer. Note the common apical oxygen ions that hold the sheets together. The kaolinite mineral is comprised of a series of these flat layers tightly held together with no interlayer spaces. [Note: To permit us to view the front silicon atoms in the silicon plane (center drawing), we have not shown the bottom oxygen atoms that are normally present].



## 2:1 Type Minerals - Kaolinite

- Minerals that are made up of **one** tetrahedral (silica) sheet and **one** octahedral (alumina) sheet
- Adjacent layers are bonded by hydrogen bonding, which make the structure fixed
- No expansion ordinarily occurs between layers when the clay is wetted
- Small specific area: 10-30 m<sup>2</sup>/g



**FIGURE 8.6** Model of two crystal layers and an interlayer characteristic of montmorillonite, a smectite expanding-lattice 2:1-type clay mineral. Each layer is made up of an octahedral (alumina) sheet sandwiched between two tetrahedral (silica) sheets with shared apical oxygen ions that hold the sheets together. There is little attraction between oxygen atoms in the bottom tetrahedral sheet of one unit and those in the top tetrahedral sheet of another. This permits a variable space between layers, which is occupied by water and exchangeable cations. The internal surface area thus exposed far exceeds the surface around the outside of the crystal. Note that magnesium has replaced aluminum in some sites of the octahedral sheet. Likewise, some silicon atoms in the tetrahedral sheet may be replaced by aluminum (not shown). These substitutions give rise to a negative charge, which accounts for the high cation exchange capacity of this clay mineral. A schematic drawing of the ionic arrangement is shown at the right.

## **2:11 Type Minerals**

**Minerals that are made up of two tetrahedral sheet and one octahedral sheet**

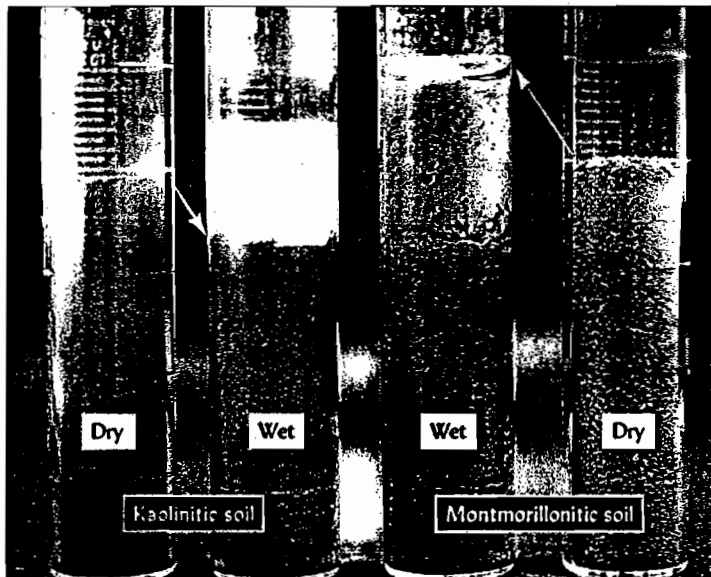
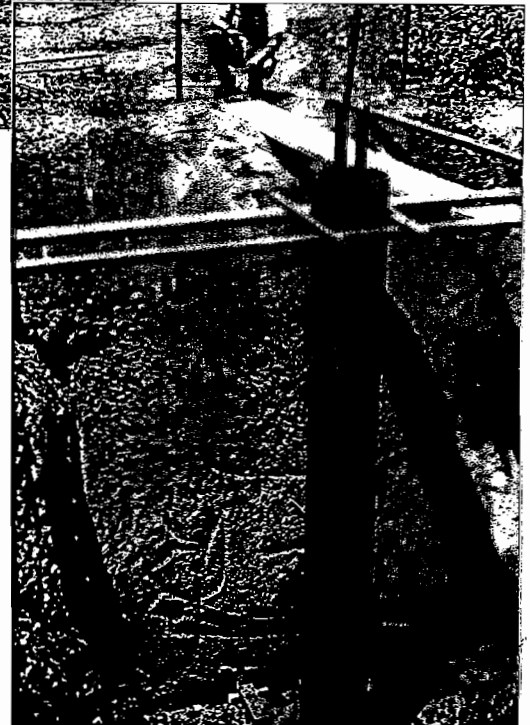
- **Expanding Minerals:**

- smectite group (e.g. montmorillonite)
- swell when wet
- large specific surface area: **650-800 m<sup>2</sup>/g**

- **Nonexpanding Minerals:**

- micas and chlorites
- **K<sup>+</sup> is strongly attracted to the adjacent layers**
- medium specific area: **70-100 m<sup>2</sup>/g**

Vertisol

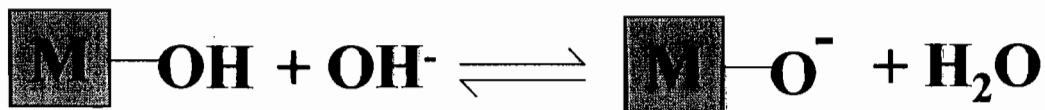
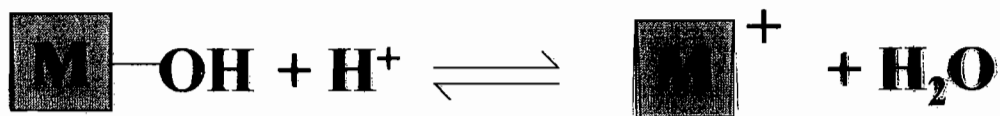


**FIGURE 8.20** The different swelling tendencies of two types of clay are illustrated in the lower left. All four cylinders initially contained dry, sieved clay soil, the two on the left from the B horizon of a soil high in kaolinite, the two on the right from one of a soil high in montmorillonite. An equal amount of water was added to the two center cylinders. The kaolinitic soil settled a bit and was not able to absorb all the water. The montmorillonitic soil swelled about 25% in volume and absorbed nearly all the added water. The scenes to the right and above show a practical application of knowledge about these clay properties. (Upper) Soils containing large quantities of smectite undergo pronounced volume changes as the clay swells and shrinks with wetting and drying. Such soils (e.g., the California Vertisol shown here) make very poor building sites. The normal-appearing homes (upper) are actually built on deep, reinforced-concrete pilings (lower right) that rest on nonexpansive substrata. Construction of the 15 to 25 such pilings needed for each home more than doubles the cost of construction. (Photo courtesy of R. Weil)

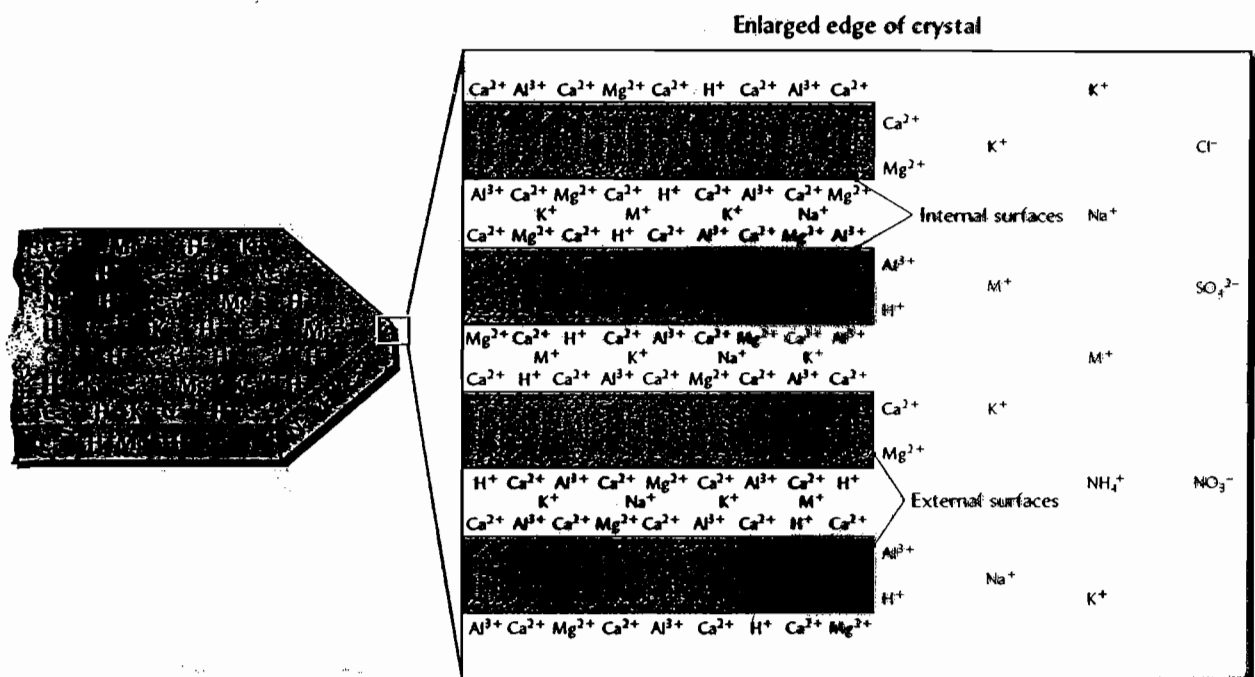
# The Charges on Soil Colloids

## Sources of charges

- hydroxyls and other such functional groups - **variable** or **pH dependent charges**



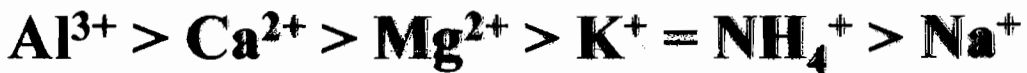
- the charge imbalance brought about by the isomorphous substitution - **permanent** or **constant charges**



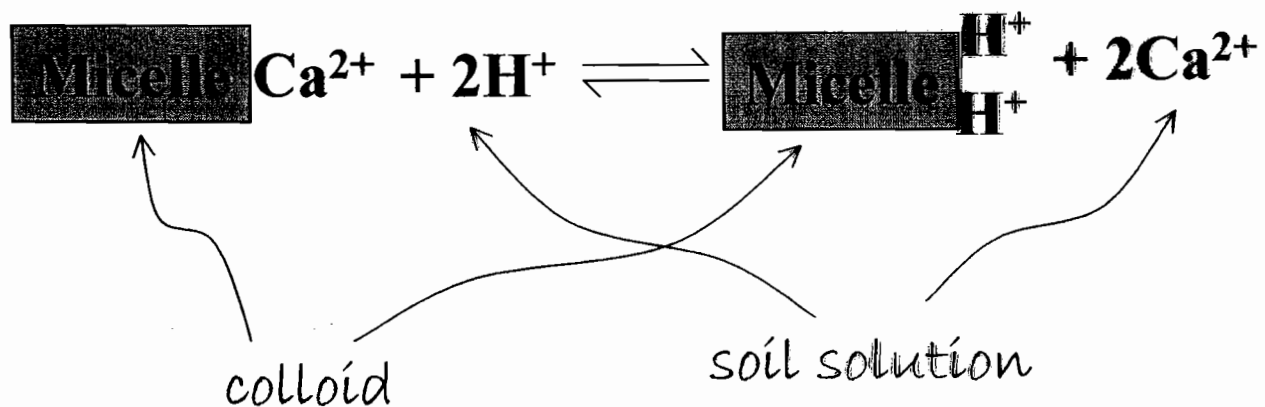
**FIGURE 8.1** Diagrammatic representation of a silicate clay crystal with its sheetlike structure, negative surface charges, and associated adsorbed cations. The enlarged schematic view of the edge of the crystal illustrates the negatively charged internal as well as external surfaces to which cations and water molecules are attracted. Note that the orderly structured particle provides an inner negatively charged ionic layer that attracts a swarm of positively charged cations. Together they constitute what is known as an ionic double layer. Some clays exhibit positive charges (not shown) that can attract negative ions, such as  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$ .

## Adsorbed Cations and Cation Exchange

- A **colloidal complex**: a colloidal particle with adsorbed cations
- Cation prominence - the order of strength of adsorption:



- Cations exchange:



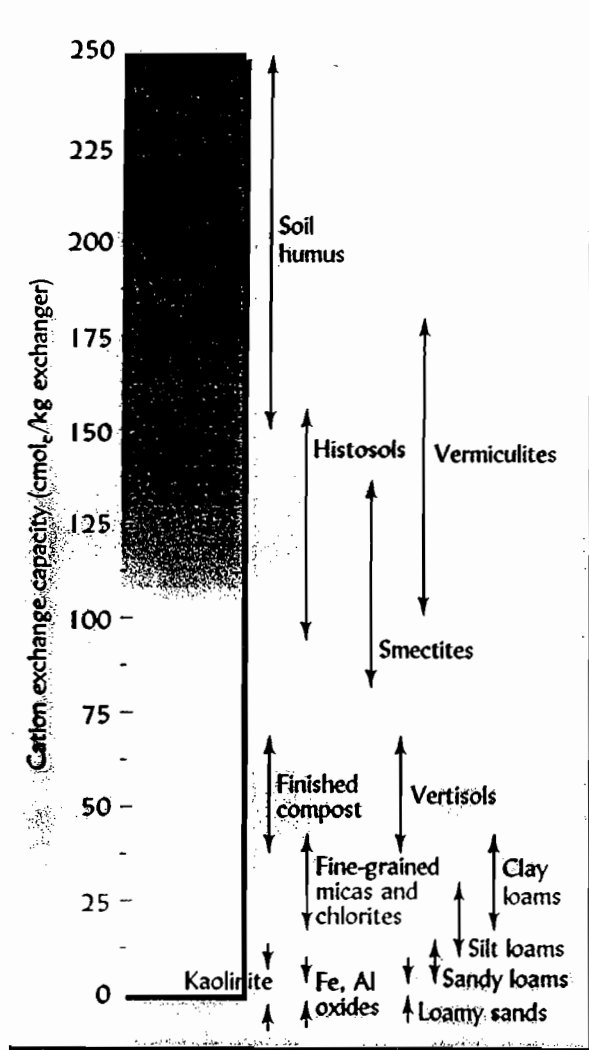
## **Cation Exchange Capacity (CEC):**

**the sum total of the exchangeable cations that a soil can adsorb**

### **• means of expression:**

- centimol of positive charge per kg of soil (cmol<sub>c</sub>/kg)**
- milliequivalent per 100 g of soil (meq/100g)**
- 1 cmol<sub>c</sub>/kg = 1 meq/100g**
- CEC of clay > loam > sand**
- CEC of organic soils > mineral soils**



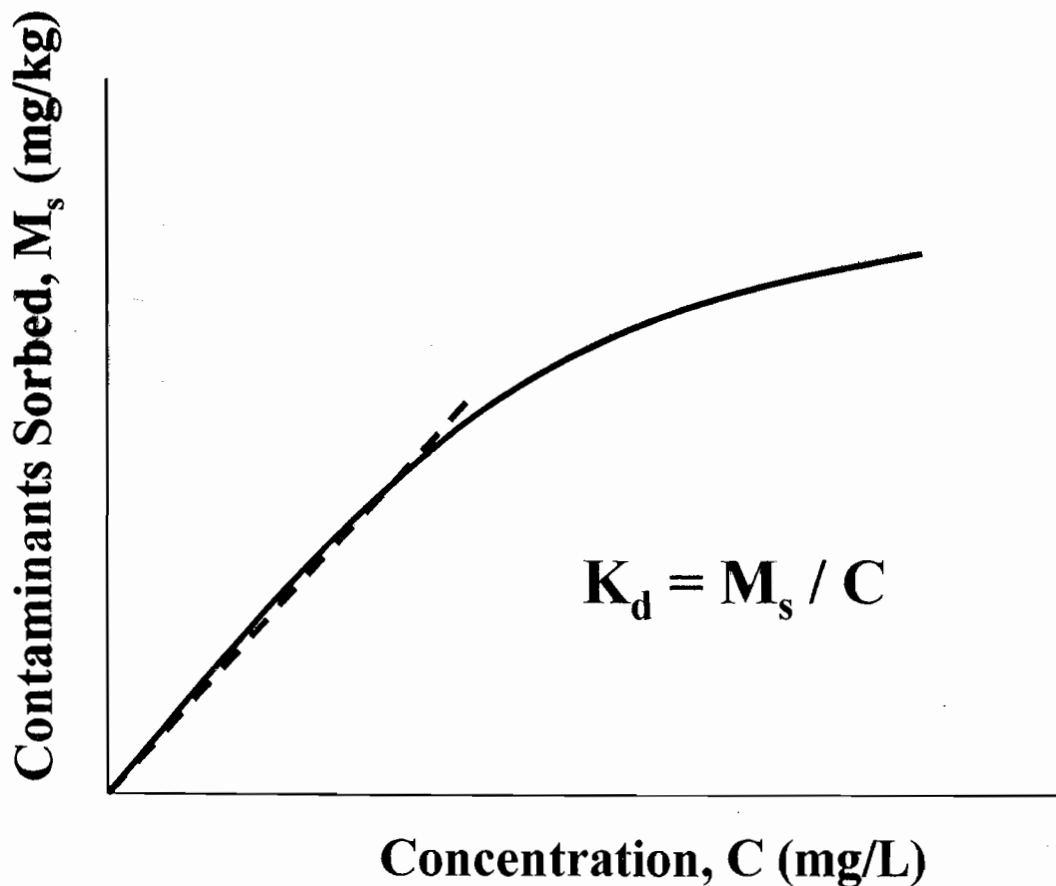


**FIGURE 8.16** Ranges in the cation exchange capacities (at pH 7) that are typical of a variety of soils and soil materials. The high CEC of humus shows why this colloid plays such a prominent role in most soils, and especially those high in kaolinite and Fe, Al oxides, clays that have low CECs.

## Sorption

The tendency of contaminants to leach into the groundwater is determined by

- the solubility of the compound and
- the **soil distribution coefficient**  $K_d$ :  
the ratio of the amount of contaminants sorbed by the soil ( $M_s$ ) to that remaining in solution ( $C$ )



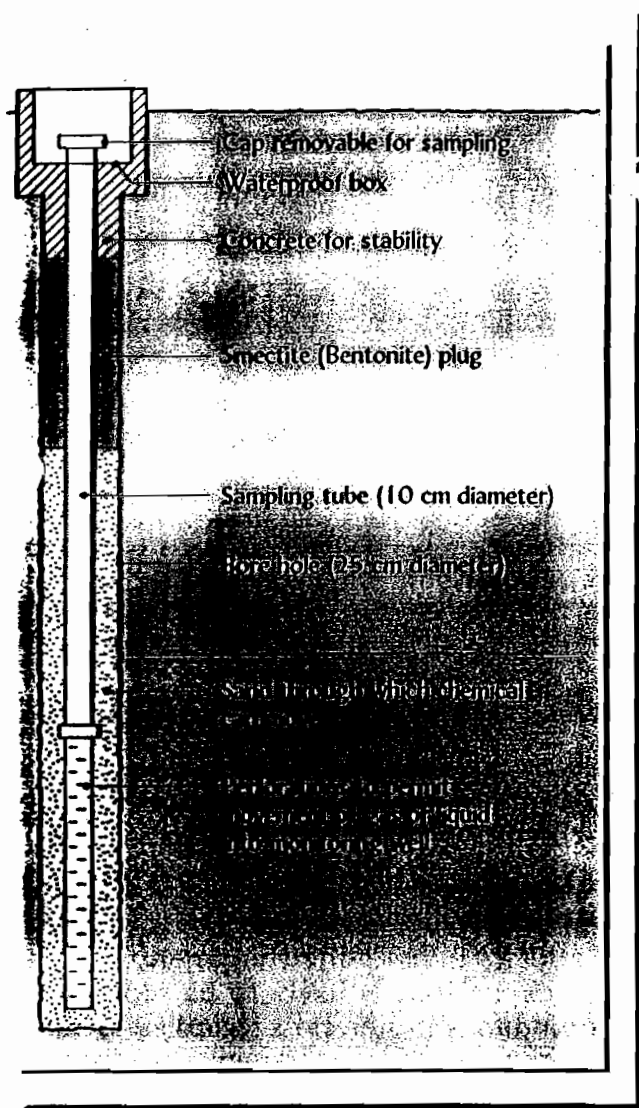


FIGURE 8.21 Illustration of the use of a smectite (bentonite) as a plug or sealant to prevent upward leakage through a borehole that was drilled to permit the installation of a well for monitoring the presence of organic chemicals in soils. Air-dry bentonite is tapped in place and then wetted. When the wetted clay swells, it fits tightly around the sampling tube and the bore hole walls. The wet smectite resists the upward movement of organic materials, forcing them to enter the perforated sampling tube from which they can be removed for analysis. The plug also protects the well from the possibility of chemicals washing down from the soil surface and therefore being mistaken for groundwater contaminants. [Redrawn from Reid and Ulery (1998)]