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HUMID TROPIC SOIL MINERALOGY

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Soil

Recent studies have been fruitful in elucidating the mineralogy of highly weathered and leached soils of the humid tropics, improving the management of tropical soils, and calculating the amount of water needed for scheduling irrigation.

Humid tropic soil mineralogy. Knowledge has continued to expand on the nature of the mineralogical composition of highly weathered and leached soils of the humid tropics. The occurrence of minerals not previously associated with these soils has been noted, and the influence of the mineralogical composition has been recognized in the application of new theories to explain their ion-exchange properties. These soils, now called Oxisols and Ultisols in United States soil taxonomy, constitute approximately one-third of the world's potentially arable land. Accordingly, they represent a vast resource for expansion of food production in developing countries, and studies on their mineralogical nature will be of aid in development of agronomic techniques suitable to their efficient utilization.

Nature and composition. A fundamental characteristic of these soils is the nature and composition of the mineral portion. This composition is a reflection of the extreme weathering conditions that these soils have been exposed to over long periods of time. A generalized description of the soil mineral mass would be that it is dominated by sesquioxides (iron and aluminum oxides in varying stages of hydration), the 1:1 layer silicate clay

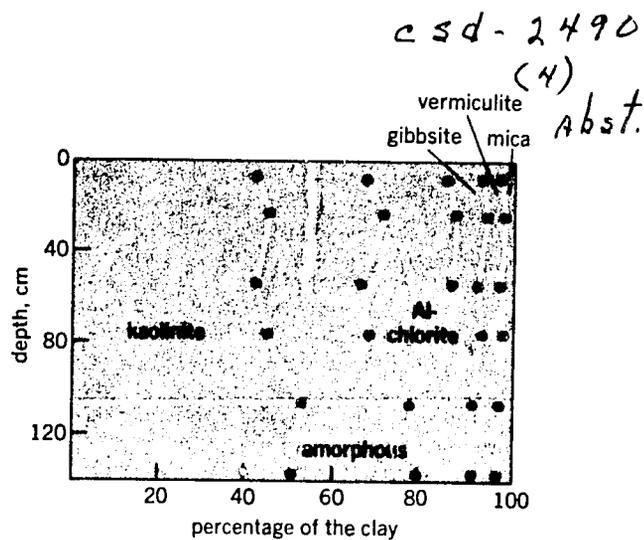


Fig. 1. Mineral composition, exclusive of sesquioxides, of the clay-sized (<0.002 mm) fractions of a clayey Oxisol soil (Catalina tropeptic haploorthox) profile from Puer to Rico.

minerals—kaolinite and halloysite, quartz, and other primary minerals highly resistant to weathering. Primary silicate minerals less resistant to weathering, such as olivine, feldspars, pyroxenes, and amphiboles, are absent or present in only small amounts, as are the 2:1 layer silicate clay minerals—mica, vermiculite, and montmorillonite. Also absent or present in small amounts are those allophanes (noncrystalline or short-range-order hydrous aluminosilicates) of high ion-exchange capacity.

Recently reported results on the mineralogical composition of Ultisols and Oxisols from Africa, Latin America, and Puerto Rico have shown the presence of appreciable quantities of amorphous (noncrystalline or short-range-order) aluminosilicates associated with their clay size (<0.002 mm) fraction. An example of the relative amount of this material encountered in the profile of a clayey Oxisol from Puerto Rico is given in Fig. 1, which shows the proportion of the mineral components of the clay size fraction as a function of depth. For example, the composition of the clay fraction at a depth of 8 cm was 44% kaolinite, 22% amorphous, 20% Al-chlorite, 8% gibbsite, 4% vermiculite, and 2% mica. The mineral content is plotted on an accumulative basis; that is, for the 8-cm depth, kaolinite plus amorphous is 66% (44 + 22); kaolinite plus amorphous plus Al-chlorite is 86% (44 + 22 + 20); and so on until 100% is reached. The percentage of mica would be given by the distance between the fifth line and the 100% line.

The amorphous material is not easily described because of its lack of well defined structure or composition. It is less active in regard to ion-exchange properties and is also less hydrous than the amorphous aluminosilicates called allophanes. The differences between the two types of amorphous aluminosilicates are more understandable when it is noted that allophanes are commonly found in relatively young soils derived from volcanic ash deposits under weathering conditions that are much milder than those associated with the formation of Oxisols and Ultisols. It is not unlikely that this material is a weathering residue of kaolin-

ite or halloysite and probably exists as a thin coating on clay mineral surfaces. The significance of this material to the physical and chemical properties of Ultisols and Oxisols is not yet fully understood. It has, however, been found to be partially responsible for the retention of nitrate and phosphate ions by these soils. Another mineral that appears to have a fairly high frequency of occurrence in recent reports on Ultisols and Oxisols is Al-chlorite. This mineral has been described by a number of different terms, including pedogenic chlorite, vermiculite-chlorite intergrade, and 2:1-2:2 intergrade. The Al-chlorite mineral is a result of the replacement of interlayer hydrated cations of the expansible-layer silicate clay minerals—vermiculite and montmorillonite—with positively charged hydroxy polymers of aluminum. This interlayer polymerization of aluminum ions causes the physical and chemical properties of the expansible-clay minerals to be greatly reduced and resemble those of kaolinite. It has been suggested that the source of vermiculite and montmorillonite for the formation of Al-chlorite, in addition to that of inheritance from the soil parent material, may be the deposition of continental aerosolic dusts over long time periods.

Effect on ion exchange. A clearer understanding of how the mineralogical composition influences the ion-exchange properties of Ultisols and Oxisols has recently evolved. For any soil, the existence of electrical charges on the surfaces of soil particles is responsible for ion-exchange properties. These charges enable soils to act as reservoirs of chemical elements for plant growth. Surface-charge characteristics of soil colloids or clays are of two types—constant potential and constant charge. The type is directly related to the mineralogical composition of the soil colloids. The constant-charge type applies to those clay minerals such as montmorillonite and vermiculite that have a permanent net negative charge as a result of isomorphous substitution within the structure of the mineral. The constant-potential model applies to soil clays or colloids that have charges arising at exterior lattice sources, such as oxides of iron and aluminum, 1:1 layer silicate clay minerals lacking a permanent charge, and clay minerals like Al-chlorite that have the permanent negative charge blocked or neutralized by hydroxy polymers of aluminum. The last-mentioned minerals correspond to those that occur in the highly weathered and leached soils of the humid tropics, and the constant-potential model is the most suitable one to describe the surface-charge characteristics of these soils. In a constant-potential system, charges arise by a proton transfer mechanism across the solid-liquid interface, and the potential determining ions are OH^- and H^+ . This means essentially that the relative amount of positive and negative charge sites will be a function of the pH and the concentration of the electrolyte solution surrounding the soil particles. Generally, under acid conditions, the positive charges will predominate and the soil may even have a net positive charge. At alkaline pH values the negative charges are more prevalent. The pH value at which the number of positive charges is equal to the number of negative charges is called the zero point of charge (ZPC).

It has been suggested that anions may interact with the positive charge on the oxide surface in two ways. First, they can be adsorbed nonspecifically, that is, in the diffuse layer opposite the positive charge on the oxide surface. Second, some anions such as SO_4^{2-} or PO_4^{3-} can be specifically adsorbed; that is, they can displace an OH group of the oxide surface and enter into coordination with the oxide metal ion. This supposedly causes the ZPC to lower or in effect increase the negative charge. This would explain why some Oxisols and Ultisols that have received high applications of phosphate fertilizers show an increase in base-exchange capacity.

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