

# SOIL CLAY MINERALS AND THEIR RELEVANCE TO ENVIRONMENTAL CHANGE

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## INTRODUCTION

The clay fraction of soil is that fraction which contains the smallest particles and is defined as the fraction containing particles with an equivalent spherical diameter of less than 2 microns. This size fraction can contain a wide range of minerals, including primary minerals in very young soils such as those formed on parent material derived from glacial deposits. The clay minerals, particularly expansible phases such as smectite and vermiculite, are very sensitive to the environment in which they occur. Because of the nature of the interlayer region, hydroxy-interlayered vermiculite and smectite are highly variable and changes in environmental conditions can be reflected in the degree of interlayer filling and in the relative stability of the interlayer components. Hence hydroxy-interlayered clay phases in soils can be affected by changes in their environment caused by changes in land use and land management. Using data from several publications, this paper will demonstrate how clay minerals in soils react to changing environments and reflect environmental change.

## ACID DEPOSITION

Many areas where there has been concern over acidification of surface waters from acid deposition from the atmosphere (so-called "acid rain") are those with podzolic soils in granitic terrain where the transformation of micas to vermiculite is one of the main mineral weathering processes (Wilson, 1986). Usually this process is manifested by the presence of interstratified mica-vermiculite with the interlayer space in the vermiculite often partially filled with polymeric hydroxyaluminium. In a peaty podzol developed on quartz-mica-schist in Scotland, regularly interstratified mica-vermiculite was shown by Bain et al., 1990 to develop at the expense of mica and is the dominant mineral in the Eh horizon. This phase was concentrated by chemical treatments to remove organic matter and free iron oxides and both the mica and vermiculite components were shown to

be dioctahedral in character. The amount of interstratified mica-vermiculite increased towards the surface in the soils studied with the result that there is more interlayer space available for adsorption on hydroxyaluminium in the upper horizons. The degree of interlayering as indicated by the degree of collapse of the vermiculite structure on heating was shown to be pH-dependent. Therefore the amount of hydroxyaluminium being leached down from the surface and which is adsorbed by the vermiculite appears to depend on the pH. Conversely, if the pH of a horizon should decrease, because of, say, acid precipitation, Al from the interlayer will be mobilized and may find its way into stream waters with potentially toxic consequences to fish. Hydroxyaluminium interlayered vermiculite may play a major role in the amounts of mobile Al<sup>3+</sup> in catchments and variations in the clay mineral suites may play a key role in the chemical response and weathering processes occurring in catchments. Thus hydroxyaluminium interlayered swelling phases such as vermiculite and smectite could serve as good indicators of gradual changes in natural soil environments.

## EFFECT OF LAND USE CHANGE

Three Scottish soil profiles in close proximity to each other and developed on similar schistose parent material but under different land use were studied by Bain and Griffen (2002). The profile under 50 year-old Sitka spruce trees was the most acidic, the second profile under rough grassland was less acidic and the third profile in an arable field which had been fertilized was the least acidic. The clay fractions of all three profiles are similar. However, computer simulations of the X-ray diffraction patterns of the clay phases using a modified version of NEWMOD revealed two possible weathering trends: (1) an increasing proportion of vermiculite in interstratified mica-vermiculite in the upper horizons of the arable and forested soils due to weathering of mica by loss of interlayer potassium; (2) formation of high-charge

corrensite by weathering of chlorite in all three profiles but least pronounced in the arable soil. The differences in clay mineralogy amongst the profiles are minor, but these two different weathering trends may be due to the effects of different land use.

### **EFFECT OF DIFFERENT AGRICULTURAL PRACTICES**

Velde and Peck (2002) investigated the clay mineralogy of soil samples taken at various intervals between 1913 and 1996 from the Morrow Plot Experiment (University of Illinois, Urbana Campus). Analyses of the soil samples indicated that there is a significant influence of the cropping method on the clay minerals in the soils. X-ray diffraction curve decomposition methods were used to identify and follow the evolution of the different clay minerals: mica, illite and two randomly mixed-layered illite-smectite phases. The most striking difference found was for continuous corn and corn-oats-hay rotations. Little change in clay mineralogy was seen in the rotation plot while a significant loss of illitic material from different phases was noted for the continuous-corn cultivation plots. Use of NPK fertilizer since 1955 appeared to restore the clay mineralogy in continuous-corn cropping compared to that of the 1913 samples. From these data, Velde and Peck considered that the illite-smectite minerals play the role of a K buffer, becoming K-poor when the soil cannot furnish enough K from mineral reserves of detrital phases and K-rich when the soil is able to release enough K to enter into the illite-smectite minerals, where it is available during a growing season, for plant growth. This work shows that crops can affect the clay mineralogy of the soils on which they are grown over periods of time relevant to modern agriculture and that there can be a significant influence of cropping method on soil clays over 80 years.

### **EFFECT OF LAND USE PRACTICES**

The clay minerals in flood-irrigated Chinese paddies cultivated for 3, 10, 15, 30 and 80 y in clayey (45 wt.%), red soils derived from red Quaternary sediments were determined by Li et al. (2003). Three clay minerals were found to be initially present in these soils: illite-mica, magnesian chlorite and an interstratified mica-aluminous chlorite mineral; this last phase was identified using computer simulations of X-ray diffraction patterns. The K-bearing phases (discrete mica and illite as well as interstratified mica layers) are to a large extent lost while the Fe content

decreases in the soil as a whole and increases in the chlorite. The mica component in the mixed-layer mineral also decreases. Li et al. (2003) concluded that these changes in clay mineralogy and relative abundance suggest a loss of potassic minerals and an increase in the formation of less siliceous, more ferromagnesian chlorite. Thus, flood irrigation was found to cause a rather rapid irreversible transformation of soil clay minerals and loss of potassic minerals (in 30 years or less) despite the use of NPK fertilizers.

### **EFFECT OF LAND USE PRACTICES**

In another study of a chronosequence of soils, Velde et al. (2003) found that the clay minerals appear to change significantly under the influence of pasture development on poldered sediments in the Baie d'Authie area (Somme, France). X-ray diffraction analyses of cores 40–90 cm deep from recent salt marsh sediments and poldered sediments developing grass pastures since 1737, 1575 and 1158 indicated that the natural mineral suite of kaolinite, mica, illite, and two disordered mixed-layered illite-smectite phases common to the sedimentary input changes gradually but significantly in the materials. In the oldest, best-developed profile, there is a dominance of a disordered, illitic illite-smectite in the humic upper part of the profile and a more abundant, more smectitic illite-smectite mineral below. It appears that grass-derived humic materials tend to stabilize closed (collapsed) or illitic behavior in illite-smectite clays. The natural evolution of the sediment (lower part of the profile) is towards a smectitic clay assemblage. Destruction of organic matter of the smectitic illite-smectite minerals by oxidation indicates that this material can significantly modify the physical behaviour of the clays keeping the structure open to polar molecules.

### **CONCLUSIONS**

A number of studies of soil clays, often using chronosequences of soils, have shown that soil clays are dynamic systems which can react to changes in the environment in which they occur, such as due to acid deposition or changes in land use and land management. These changes can sometimes be manifested by changes to the interlayer region of expansible phases such as smectite and vermiculite, as this is particularly sensitive to the local environment. In other cases, the changes can be subtle and can only be detected by detailed studies of X-ray diffraction patterns using modern procedures.

Some of the changes to the soils clays are reversible, whereas others are irreversible.

## REFERENCES

- Bain, D.C. y Griffen, D.T. (2002). Possible effects of land use on the clay mineralogy of a brown forest soil. *Clay Minerals*, 37, 663-670.
- Bain, D.C., Mellor, A. y Wilson, M.J. (1990). Nature and origin of an aluminous vermiculitic weathering product in acid soils from upland catchments in Scotland. *Clay Minerals*, 25, 467-475.
- Li, Z., Velde, B. y Li, D. (2003). Loss of K-bearing clay minerals in flood-irrigated, rice-growing soils in Jiangxi Province, China. *Clays and Clay Minerals*, 51, 75-82.
- Velde, B. y Peck, T. (2002). Clay mineral changes in the Morrow experimental plots, University of Illinois. *Clays and Clay Minerals*, 50, 364-370.
- Velde, B., Goffé, B. y Hoellard, A. (2003) Evolution of clay minerals in a chronosequence of poldered sediments under the influence of a natural pasture development. *Clays and Clay Minerals*, 51, 205-217.
- Wilson, M.J. (1986). Mineral weathering processes in podzolic soils on granitic materials and their implications for surface water acidification. *Journal of the Geological Society of London*, 143, 691-697.