

Clay Mineralogy of Lateritic Soils Derived from Granite Basement-A Case Study of Minna Lateritic Soils

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ABSTRACT

Lateritic soils samples taken from four different locations around Minna were subjected to clay mineralogical analysis using X-ray diffraction method. The results show three of the soil samples containing mostly kaolinite as their main clay mineral, while the fourth sample shows the presence of a mineral of the chlorite group. The study shows that kaolinite is the predominant clay mineral present within lateritic soil profiles found around Minna.

KEYWORDS : Lateritic soil; Clay mineral; X-ray diffraction.

INTRODUCTION

The most common residual soil profile is the lateritic weathering profile. These profiles have been defined as soil profiles in which lateritic horizons exist or are capable of developing under favorable conditions (Gidigas and Kuma, 1987). Laterites are the most common tropically pedogenic surface deposits in Australasia, Africa and South America (Gidigas, 1976). Their geotechnical characteristics and field performance are influenced considerably by their pedogenesis, degree of weathering, morphological characteristics, chemical and mineral compositions as well as prevailing environmental conditions (Azam, 2003; Osinubi, 2004).

Mustapha and Alhassan (2012) categorized lateritic weathering profile, derived from granite basement into three major horizons below the humus stained top soil: the first horizon is the sesquioxide rich lateritic horizon (sometimes gravelly and/or hardened in-situ as crust); the second horizon is the mottled zone with evidence of enrichment of sesquioxide sand; the third horizon which overlies the parent rock is referred to as the pallid or leached zone and contains rocks suffering from chemical and mineralogical changes, but retaining their physical appearance.

Engineering pedology begins with knowledge of rocks and weathering conditions prevailing around the area. From these, logical deductions about the nature of the end products especially the clay mineral types present within the soil can be made (Osinubi, 2004). The clay minerals present

exert considerable influence on geotechnical properties such as plasticity, shear strength, compressibility etc. Geotechnical characteristics and field performances of lateritic soils can be interpreted in the light of the following parameters: clay mineralogy and clay-size content, genesis and pedogenic factors and the degree of weathering.

Experience with the tropical laterites has shown that climate, topography and vegetation, determine if the weathering system and drainage conditions favour the development of kaolinites (kaolinite, halloysite), micas (illite) and smectites (Montmorillonite) minerals. Obviously, the mineral status of laterite soils appears to be a function of weathering conditions. The mineralogy of laterite soils and the relationship of the mineralogy of their clay contents, to that of the prevailing weather conditions have shed some light, on the conditions which enable the development of particular types of minerals. This information is useful to engineers in helping them to make inferences as to when and where to expect the occurrence of similar minerals. Clay mineralogical compositions and clay fractions are therefore very important and may be used as a means of soil classification (Osinubi, 2004).

The crystalline mineralogical components of clay fraction of soils are most readily identified by the powder method of x-ray diffraction analysis (Harris and White, 2007; Shrivastava, 2009; Deng et al, 2009). This is generally combined with various auxiliary pre-treatments of the sample. Differential thermal analysis is also commonly employed and for certain uses such as identifying non-crystalline constituents.

Unfortunately, clay mineral analysis of soils is not usually employed in the routine examination of soils for engineering projects. This is partly because the techniques and the equipment used are beyond the resources of the ordinary soil testing laboratory. Although, in the study of the lateritic soil to be used for engineering constructions, the consideration (study) of clay minerals present have proved to be very useful in understanding the soils' behaviours and therefore determining their applications.

LOCATION, CLIMATE AND GEOLOGY OF THE STUDY AREA

The materials studied were collected from four locations around Minna, the capital city of Niger State, Nigeria. The city lies between longitudes 6° E and 7° E and latitudes 9° N and 10° N. According to Wright (1989), the residual soil in this area is under laid by a granite basement and is surrounded to the North and South by older basement rocks of the Precambrian to upper Cambrian age and illo-group formation to the North-west. The area is drained by several rivers which are tributaries of river Niger.

Rainfall in this area varies considerably from station to station. The maximum rainfall per year varies from 1000 mm to 1500 mm for different locations.

METHODOLOGY

The lateritic soil samples used for this work were collected from four sources of borrow materials around Minna, Niger State, Nigeria, at locations as follows: sample 1 was taken at Gurusu village (9° 40' 17" N, 6° 46' 27" E), along Minna-Kuta road; sample 2 was taken at Pago village (9° 30' 59" N, 6° 35' 42" E), along Minna-Paiko road; sample 3 was taken at Nyikangbe village (9° 35' 08" N, 6° 30' 10" E), along Minna-Bida road; sample 4 was taken at Kampala village (9° 40' 52" N, 6° 26' 44" E), along Minna-Zungeru road. The samples were subjected to clay mineral analysis using X-Ray Diffraction (XRD) Analysis.

X - Ray Diffraction Analysis

This test was carried out to determine the clay minerals present in the samples. Automated x-ray diffractometer was used. It is made up three main components or parts: i) The diffractometer; ii) The computer system and; iii) Coolers, for cooling the diffractometer. The sample was pulverized and passed through a sieve of size $\leq 150 \mu\text{m}$. In this case, a sieve size of $75 \mu\text{m}$ was used. Three stages are involved in the test:

Bulk Analysis

A small portion of the sieved sample was put into the sample compartment. The scanning angles chosen were between $0^\circ - 70^\circ$. The material was scanned by the X- ray source impinging rays on the sample in the sample holder, while the goniometer (where the sample holder sits) spun and rotated through the set angles.

The receiver in the equipment detected the number of rays that bounced of the sample in the form of "counts". The counts are a measure of the intensity of the presence of the minerals i.e. the more a mineral is present, the higher the counts. A graph of counts on the ordinate and diffraction angles on the abscissa was plotted by the computer and comparisons were made with an already existing database present in the computer. The database is an index prepared by American Society for Testing and Materials (ASTM). The 40 minerals with the highest presence were identified by this comparison and printed out (Figures 1-4).

Clay Fraction Analysis

The clay fraction was extracted by using the centrifuge. The sizes less than $2 \mu\text{m}$ fall under clay fraction. A film was made of the clay extracted and placed on a tiny slide of about 10 mm diameter. This slide was placed on the sample holder and the angle were set to rotate between $0^\circ - 40^\circ$ because the clay peaks appear within this range of angles. The process from scanning to the plotting of the diffractograph was repeated. In this case, the graph plotted was not compared directly with the database but inferences from the usual behaviour of the main clay groups (kaolinites, smectites, micas and chlorites) were used to determine the clay groups present. For example, kaolinite and chlorites have very sharp peak around 12° and 12.5° (2θ).

Confirmatory Tests

i) The next stage was glycolation of the samples. This was done by exposure of the clay fractions to ethylene fumes. After this the samples were again scanned at angles between $0 - 15^\circ$. This was because common clay minerals appear around this range. The results obtained were then checked by inference, from usual behaviour of minerals.

ii) After this, the samples were heated in a furnace for up to 550°C , and then scanned again at angles between $0-15^\circ$. This test is to check for kaolinites. Kaolinites cannot sustain high heat, therefore their lattice structures disintegrate, becoming mullite (non-crystalline structures or minerals with destroyed structures). On scanning after heating, kaolinites' peaks disappeared.

RESULTS AND DISCUSSION

The bulk analysis for sample 1 did not show any of its most prominent minerals as clay. But it showed a very high presence of quartz (SiO_2) and a moderate intensity of Lanthanum silicate (La_2SiO_5) and Olivine (MgFeSiO_2). The clay fraction analysis showed a sharp peak between angle 12° and 13° suggesting the presence of a kaolinite or chlorite. Analysis after glycolation, shows negligible increments in basal spacing and a sharp peak at angle 12° (2θ), confirming this. After heat treatment, disappearance of peak occurred, confirming that a kaolinite is present. The peak count of the sample is 14.83. Kaolinites, generally have relatively low affinity

for water (Loucks et al, 1980; Loucks et al, 1984; Ahmad, 2008; Namdar, 2010). The presence of kaolinite as the clay mineral in this sample could have been responsible for the relatively low plasticity of the soil reported by Alhassan (2006). The XRD diagram for sample 1 is shown in Figure 1.

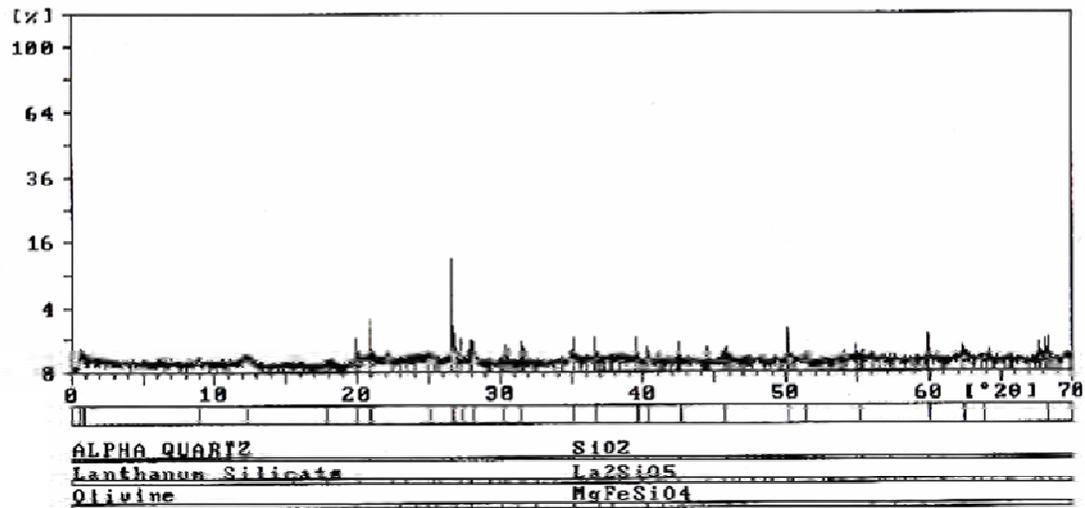


Figure 1: XRD result for soil sample 1.

Sample 2 also showed a very high presence of quartz in the sample's bulk analysis. But this analysis also showed the presence of two clay minerals, a mica called lepidolite ($K(LiAl)_3(Si_2Al)_4O_{10}$) and a kaolinite called halloysite ($Al_2Si_2O_5(OH)_4 \cdot 2H_2O$). The analysis of the clay fraction confirmed this with a sharp peak appearing at angle 12.5° (2θ). After glycolation, a slight increment in basal spacing was observed due to the swelling minerals (halloysite and lepidolite). A slightly diffused peak appeared between angles 12° and 13° (2θ). After heat treatment the peak remained. Since kaolinite's peaks disappear upon heat treatment, this occurrence suggested the presence of a chlorite. The glycolation analysis counts is 34.2 which is lower than the heat treatment analysis counts of 39.0 suggesting that lepidolite (a chlorite group) is more prominent in the sample. The XRD diagram for sample 2 is shown in Figure 2.

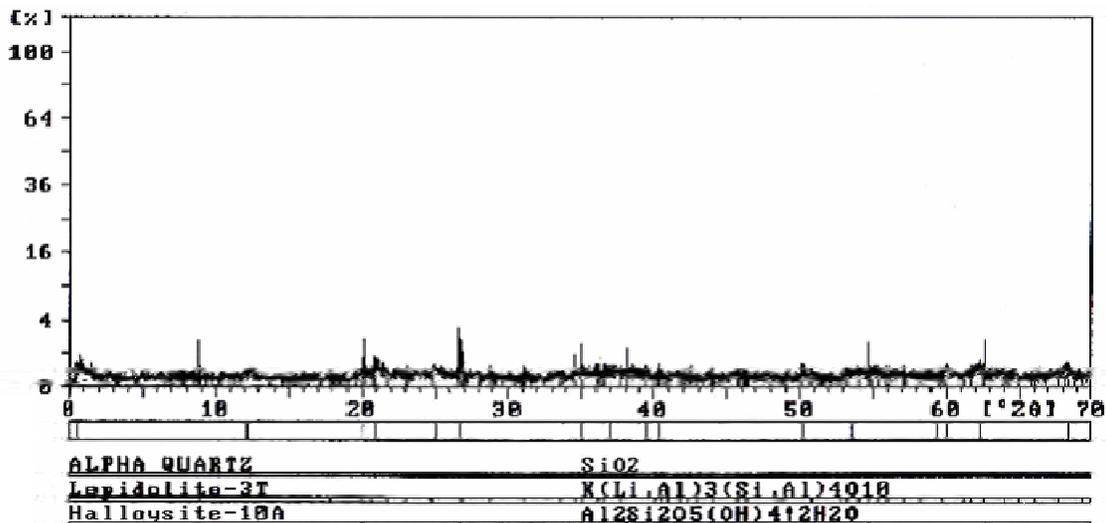


Figure 2: XRD result for soil sample 2.

The bulk analysis of the sample 3, like sample 1, did not show a clay mineral as one of its most prominent minerals. Quartz (silicon oxide (SiO_2)) had the highest presence. Also Boron nitride (BN) is very prominent. The analysis of the clay fraction carried out showed a peak appearing between angles 12° and 13° (2θ) hinting that a kaolinite or chlorite is present in the sample. After heat treatment, the analysis showed an absence of a peak i.e. no peak appeared, confirming a kaolinite's presence. The peak count of the sample is 66. The presence of kaolinite as the clay mineral in this sample could have been responsible for the relatively low plasticity of the soil reported by Alhassan (2006). The XRD diagram for sample 3 is shown in Figure 3.

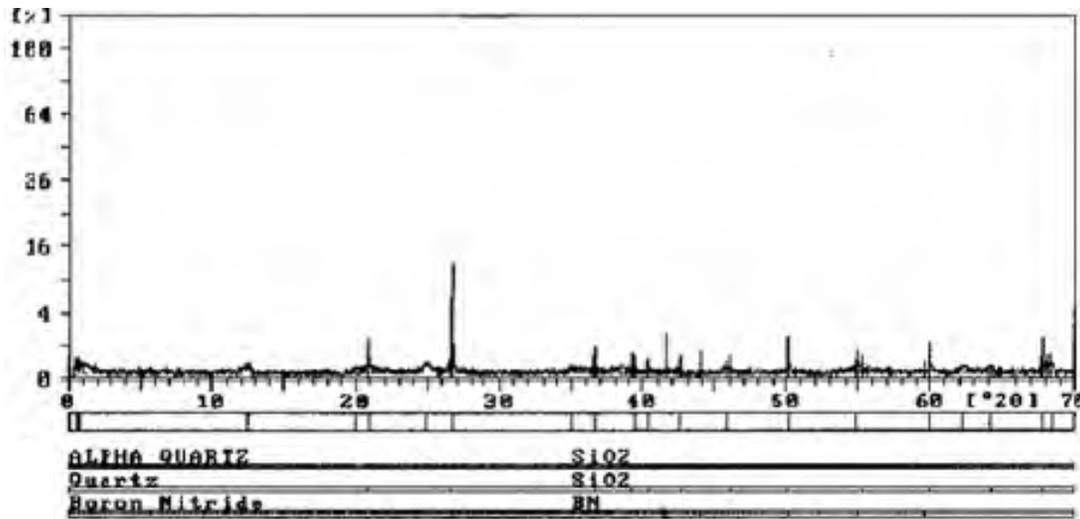


Figure 3: XRD result for soil sample 3.

Sample 4 showed a very high presence of quartz in its bulk analysis. However, the presence of kaolinite ($\text{Al}_2\text{Si}_2\text{O}_2(\text{OH})_4$) as one of its most prominent minerals was detected, unlike other samples which reflected their clay presence only after treatment. Clay fraction analysis showed a sharp peak at angle 12° (2θ), suggesting the presence of a kaolinite or chlorite. Analysis after glycolation showed negligible increments in basal spacing, and sharp peak at angle 12° (2θ). Disappearance of the peak after heat treatment confirmed that kaolinite is present in the soil sample. The peak count of the sample is 54.33. The presence of kaolinite as the clay mineral in this sample could have been responsible for the relatively low plasticity of the soil reported by Alhassan (2006). The XRD diagram for sample 4 is shown in Figure 4.

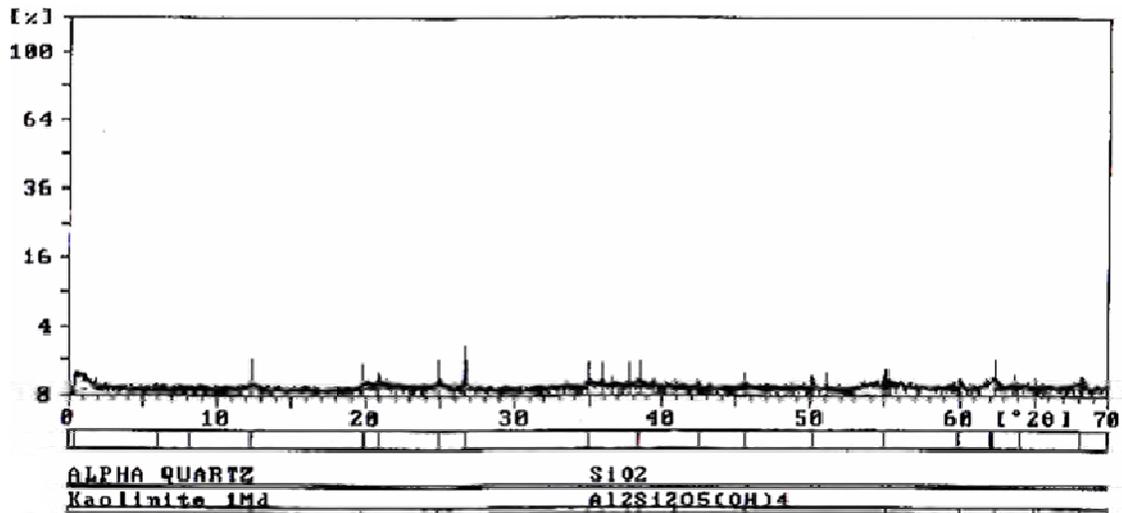


Figure 4: XRD result for soil sample 4.

CONCLUSION

The x-ray diffraction analysis showed that soil samples 1, 3 and 4 contain kaolinite as their main clay minerals, while soil sample 2 contain a mineral of the chlorite group (lipidolite) as its main clay mineral.

The study shows that kaolinite is the predominant clay mineral present within lateritic soil profiles found around Minna.

The presence of kaolinite as the clay mineral within the lateritic soil profiles in this area could have been responsible for the relatively low plasticity reported in previous works with soils from this area.

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