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MINERALOGICAL CHARACTERIZATION OF SOILS FORMED ON THE BASEMENT COMPLEX PARENT MATERIAL IN NORTHERN GUINEA SAVANNA AGROECOLOGY OF NIGERIA

A.I. Imam*, A.B. Shobayo and Y. Maryam

Department of Soil Science, Faculty of Agriculture/ Institute for Agricultural Research, Ahmadu Bello University, Samaru, PMB 1044 Zaria, Kaduna State.

*Corresponding author email: imamabdulwaheed@gmail.com Phone No.: +2347038613601

ABSTRACT

The soils formed on the basement complex parent material was studied with the aim of characterizing the minerals contained in them to provide the mineralogical information of the soils as they have direct influence on fertility status of our soils. Because soils are dynamic, hence they undergo transformational processes that lead to both destruction and synthesis of original and new minerals respectively. Soils of the study area was formed over the Basement Complex and located in Funtua Local Government Area of Katsina State. Clay mineralogical analysis was done using X-ray diffraction which produced the diffractograms that presented the clay minerals identified in the soils. Clay sized minerals found in the soils were Hematite, Antigorite, Albite Chrysotile and Zeolite suggesting that clay sized minerals present in the study area might have been affected by pedogenic processes and landscape. Other clay sized minerals present as depicted by the diffractograms generated for the soils of the study area were Xonotlite, Phlogopite, Lizardite, Tobermorite, Nacrite, Osumilite, Illite, and Monticellite, however, they were present in small amount, which might be as a result of the age of weathering processes that took place and also due to the nature of chemical composition of basement complex parent material that forms the clay sized minerals in the study area. The order of dominance in increasing sequence were: Hematite > Antigorite > Albite > Chrysotile > Illite > Xonotlite > Osumilite > Monticellite for Funtua (F1) soils. While the order of increasing dominance in the Funtua F2 soils were: Hematite>Chrysotile>Zeolite>Phlagopile >Xonotlite > Lizardite >Tobermorite > Nacrite > Albite.

Keyword: Mineralogical Characterization, Basement Complex, Parent Material and Agroecological Zone.

INTRODUCTION

It is commonly recognized that clay minerals (mineralogical studies) play an important role in determining the physical and chemical properties of soils. They are also of unique value for understanding weathering and soil forming processes. Clay mineral analyses have, therefore, been an integral part of a soil characterization program that has been underway in some countries including Nigeria during the past decade (Ojanuga 1978).

In this time a considerable amount of data on clay mineral distribution in the soils of Nigeria has been documented. Many differences in the clay mineral composition among soil series and also among profiles within a series (Leon J.J. 1963) have been found. What may be asked, are the factors that determine the clay mineral composition of a soil? Clay is ordinarily considered to be that portion of a soil that results from the processes of weathering acting on preexisting minerals or amorphous material. Barshad (1966) concluded that the chemical environment determines the kind and frequency distribution of clay minerals in a soil exclusive of those inherited from the parent material.

According to Mitchell (1956) and Mac Kenzie (1965) clay minerals in a soil may originate by means of three different mechanisms: (1) inheritance from parent material, (2) alteration and degradation of primary minerals, and (3) synthesis. These mechanisms operating under different environmental conditions together with the process of the translocation of material result in soil clay mineral composition becoming a function of soil depth. Weathering with its attendant alteration and synthesis is most intense at the soil surface and decreases in intensity with depth increase, which is the horizon depth function (Jackson *et al.*, 1948) and leads, in many cases, to the development of a profile of weathering in which clay mineral distribution changes with depth. Clay minerals may be significant indicators of earth processes.

Theories had been put forward to explain the genesis of soils formed from rocks of the basement complex in the humid tropical zone of Nigeria. Smyth and Montgomery (1962) observed that weathered rock materials from which the soils develop have a complicated history reflecting the influence of previous climatic variation, cycles of erosion and periods of intense soil forming activities. The soils of the basement complex formation vary a lot in soil characteristics; therefore, intense understanding of the slope processes and spatial distribution is of great importance for sustainable management of the soil.

Nigeria is located in the tropical zone (between latitude 4^o and 14^oN, and longitude 2^oE). The larger part of Nigeria's land mass is dominated by savanna vegetation, broadly classified into sahel, sudan and guinea savanna (Ogundele, 2006). The savanna ecological zone of Nigeria, especially areas north of latitude 12° N was characterized as semi-arid. The area receives between 200mm to 800mm of rainfall annually (IIED, 1989). The guinea savanna is itself diverse, necessitating a classification into southern guinea savanna and northern guinea savanna. These classifications reflect environmental characteristics such as length of growing period, which for instance is 151-180 days for the northern guinea savanna, 181-210 days for the southern Guinea savanna and 211-270 days for the derived savanna/coastal savanna (Jagtap, 1995).

The major soils found in this agroecological zones have coarse-textured surface soil. The soils of the savanna region are physically fragile because the topsoil contains a large proportion of sand, causing weak aggregation given the low level of organic matter in the layer. The physical constraints are further compounded in gravelly soils or soils with shallow depth overlying plinthic or hardpan layers (Adeoye and Mohammed-Saleem, 1990; Salako *et al*.,2002).

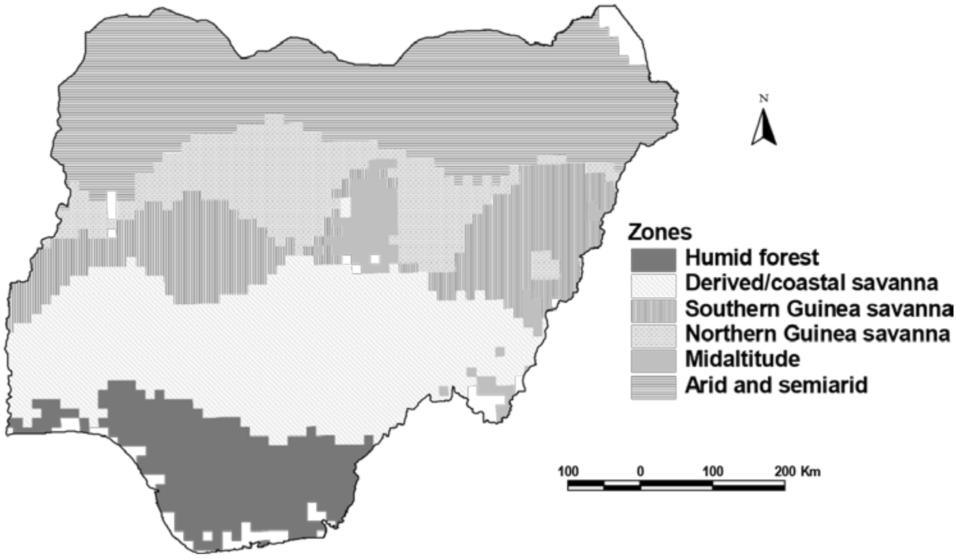

Fig. 1.1: Agroecological zones of Nigeria (Source: Salako, 2003)

A study sites have been selected for this study, located on the basement complex situated at Funtua in Funtua local government area of Katsina State, which is underlain by crystalline rocks of the basement complex with numerous quartzitic and granitic hills which rise from about 60 - 200 m above the surrounding plains. The hills are probably the result of the intrusion of the older granites into the basement complex which have undergone long periods of denudation (Ogezi, 2002). The climate of study area is typically characterised by a long dry season and a shorter but very conspicuous wet season with total annual rainfall figures ranging from 800 – 1000 mm. Nature of parent material is said to profoundly influence the development and characteristics of soils (Brady and Well, 2005). In small regions with uniform climate, the nature of the parent material is probably more important than any other single factor in determining the characteristics and productivity of a soil (Lombin, 1983). Minerals are everywhere, they form our soils, they are solid, naturally occurring chemical elements or compounds that are homogenous, meaning they have a definite chemical composition and a very regular arrangement of atoms. Soil forming minerals play a significant role in dictating the suitability and behavior of the soil for various land uses.

Therefore, the objective of this study was:

To carryout soil mineralogical characterization of clay sized minerals formed on the basement complex parent material of the study area.

METHODOLOGY

Location of Study Area

The study area lies between latitude and longitude 11°25'N 7° 16'E and 11° 34'N 7° 22'E respectively, located in Funtua, Funtua Local Government Area of Katsina State, Nigeria. The study area has a single rainy season occurring with a rainfall peak in August and the precipitation drops sharply in October. The three wettest months are July, August and September. From the months of November to March, there is either no rain at all or the total monthly precipitation is less than 25.50mm, the lower limit of effective rainfall. The mean monthly maximum range of temperature was between 35.40 and 28.70 °C; while the minimum range between 16.89 °C and 32.70 °C. During the dry season, there is much radiation at night and the minimum temperatures are lowered with a diurnal range of temperatures greatly increased to about 16.89 °C in January. The vegetation consists of broad-leaved species with tall tussocky grasses of guinea affinities, mixed up with fine-leaved species of thorny trees with continuous short and feathery grass cover (IAR Meteorological center).

The study area forms part of the extensive plains known as the high plains of Hausaland. It is composed of undulating plains which generally rise gently from 360m to 600m around Funtua. The geological formation is underlain by crystalline rocks of the basement complex which has two main geological formations namely, the migmatite and granite gneiss; the third with limited occurrence is undifferentiated schist. The climate of the study area is typical of that of the guinea savanna of Nigeria Shobayo (2017).

The geological map of Nigeria was used to identify the parent material that produced the soils examined for this study. Two pedons were dug at the crestal positions at spacing of 100 m interval, soil samples were taken from the genetic horizons which were later subjected to laboratory analysis. The soils were air-dried in the laboratory, crushed with porcelain pestle, mortar and sieved to remove materials greater than 2 mm (gravel). The following analyses of less than 2 mm soil particles were carried out; Particle size distribution was determined by the method described by Day (1965), Pretreatment for mineralogical analysis (exchangeable cations, organic matter and sesquioxides was obtained from the samples following the method described by Kunze and Dixon (1986). After following procedure, a clear suspension of clay was formed above, while the unwanted settled at the bottom of the test tube. A dropper was used to take some quantity of the suspended clay, saturated with magnesium ions and was applied on a clean labeled glass slides. This was allowed to dry overnight in an oven at 105 °C, and ready for XRD analysis.

The X-Ray diffraction (XRD) analysis was done at the National Steel and Raw Materials Exploration Agency, Malali, Kaduna, Kaduna State, Nigeria. The XRD procedures were employed in keeping the equipment in a good condition to run the analysis,

The clay sample was analysis using XRD analysis set up which pronounced peaks or diffractograms displayed by expressing the minerals' composition at the various angle of the degree theta.

RESULTS AND DISCUSSIONS

Physical Properties of Soils of the Study Area.

The physical properties determined for the soils were depth and particle size distribution. The physical properties are discussed below. Table 1.1 presents the physical properties of the soils.

Pedon F1 occupied flat to nearly level (0 – 2%) slope position in the landscape (crest). This is not beyond the critical slope limit of 3% for the use of machinery and has no limitation to crop production. The soils were very deep (150 - 200 cm), well drained, clay loam to loam to sandy clay loam. Extent of root development is highly controlled by the effective soil depth, which is the depth beyond which roots will not readily penetrate the soil (Shobayo, 2017).The soils were very deep, hence will provide ample root zone and support greater capacities to store plant nutrients and water.Soils on pedon F2 were imperfectly to poorly drained deep (82 – 147 cm) situated on nearly level (0 – 2%) to gently sloping (2 – 4 %) ground on lower slope to floodplain of the study area.This suggests that, water logging condition is expected on this site (especially during peak period of rainfall in this area). It is therefore important that surface drainage channels are constructed on such fields to convey excess water out of the fields as soon as possible.

Pedon F1 had sand as the dominant particle size with values ranging from 300 to 510 gkg^{-1}in the soils which increased irregularly with depth. Next to sand in proportion is the silt content, it ranged from 250 to 500 gkg^{-1}. Clay content ranged between 100 and 360 gkg^{-1} in the soils and had irregular distribution trend. In pedon F2, sand was high in surface horizon, ranging from 620 to 640 gkg^{-1} and decreased in the subsoil with highest value of 420 gkg^{-1} recorded. Silt particle dominated in the subsoil. The pedon was dominated by loam and silty loam. Clay content ranged from 120 to 180 gkg^{-1} and distributed irregularly within the pedons.

Table 1.1: Particle size distribution of soils of the study area

Horizon	Depth (cm)	Gravel	Sand	Silt	Clay	Textural class USDA
		←	gkg^{-1}		→	
Soil F1 (Pedon P1) Location: Lat.:11°25'23.3" Long.: 7°19'49.5" Alt.: 680m asl						
Ap	0-9	-	480	280	240	SCL
BA	9- 50	-	420	340	240	L
B	50 -84	-	440	340	220	L
Bt	84-200	-	510	250	240	SCL
Soil F1 (Pedon P2) Location: Lat.:11°25'8.3" Long.: 7° 9'54.4" Alt.: 693m asl						
Ap	0-29	-	300	500	200	L
B	29 -65	-	460	440	100	L
Bt	65-110	-	340	380	280	CL
BCtv	110- 165	874	320	320	360	CL
Soil F2 (Pedon P1) Location: Lat.:11°26'14.6" Long.: 7°20'14.7" Alt.: 680m asl						
Ap	0-17	-	620	260	120	SL
Bg1	17 – 40	-	420	400	180	L
Bg2	40 – 82	-	400	460	140	L
Soil F2 (Pedon P2) Location: Lat.: 11°26'13.9" Long.: 7°19'34.2" Alt.: 673m asl						
Ap	0-29	-	640	220	140	SiL
B	29-66	-	300	520	180	SiL
Bg1	66- 98	-	260	560	180	SiL
Bg2	98-147	-	280	560	160	SiL

Mineralogy of Soils

The mineralogy of clay fractions of the soils (Pedons 1 and 2) developed on the Basement Complex parent material is discussed below and their diffractograms are shown in Figures 1.2 and 1.3.

The X-ray diffractogram of clay sized fraction revealed three major (or strongest) peaks in pedon Fl as shown in Fig. 1.2 at the following 2Theta Bragg's angles viz: The first strongest peak subtends at 2Theta Bragg's angle 24.0453 with corresponding intensity ratio of 100 (Table 1.2). The second strongest peak subtends at 2Theta Bragg's angle 31.3347 with corresponding intensity ratio of 53 and the third strongest peak subtends at 2Theta Bragg's angle 49.2495 with corresponding intensity ratio 43. Analysis of the diffractogram shows column 3, 4 and 5 have the first, second and the third strongest peaks.

Close observation on the individual strongest peak on the diffractogram have some residual peaks (minor peaks). These residual peaks are found at the 2Theta Bragg's angle corresponding to angles, 27.7200, 35.4029, 52.2412 and 59.3566. The major minerals contained in F1 as confirmed by the various peaks against corresponding 2Theta Braggs angle were: hematite (3.698 Å), chrysotile (2.852 Å), illite (1.847 Å), xonotlite (1.556 Å), chamosite (1.7496Å), greenalite (1.5557Å), antigorite (1.749 Å) and osumilite (2.533 Å). The minor minerals found were: albite (1.842 Å) and monticellite (3.216 Å). The dominance of hematite in this soil was responsible for its red colour and suggest the soil is in advanced stage of weathering. Chrysotile which is a polymorph of serpentine (kaolinite) dominates next to hematite which defines further the soil's age.

The presence of illite indicated that it was inherited from the parent material and might be product of transformation of mica. Next to illite was xonotlite an inosilicate which was thought to be inherited from the parent material. antigorite, chamosite and greenalite also are polymorph of serpentine subgroup (kaolinite) was found among the minerals dominating the soil, hence, kaolinite is one of the most widespread clay minerals in this soil. Serpentine minerals are relatively unstable in near-surface conditions and weather easily into other layer silicates, such as smectite and vermiculite (Hseu *et al*., 2007). Osumilite is a silicate mineral produced by high grade metamorphism which points to the importance of this mineral being inherited from the Basement Complex.

Trace amount of albite and monticellite were found in this soil, the former being a member of alkali feldspar and the later, an olivine. These two minerals are excellent source of Na, Ca and Mg in which their relative ease of weathering might have contributed to CEC of the soil.

Table 1.2: Significant peak data list generated by diffractometer for F1

Peak No	º2θ	d (Å)	Intensity ratio	FWHM (deg)	Intensity (counts)	Integrated intensity (counts)
1	24.0453	3.69806	100	0.14180	253	2123
2	24.3450	3.65321	3	0.08000	8	54
3	27.6000	3.22932	4	0.10660	9	53
4	27.7200	3.21561	4	0.10000	11	70
5	31.3347	2.85242	53	0.15640	133	1184
6	35.4029	2.53341	13	0.17920	33	334
7	49.2495	1.84869	43	0.13910	109	894
8	49.4400	1.84201	5	0.08000	13	129
9	52.2412	1.74964	13	0.12900	34	277
10	59.3566	1.55575	13	0.13330	34	284

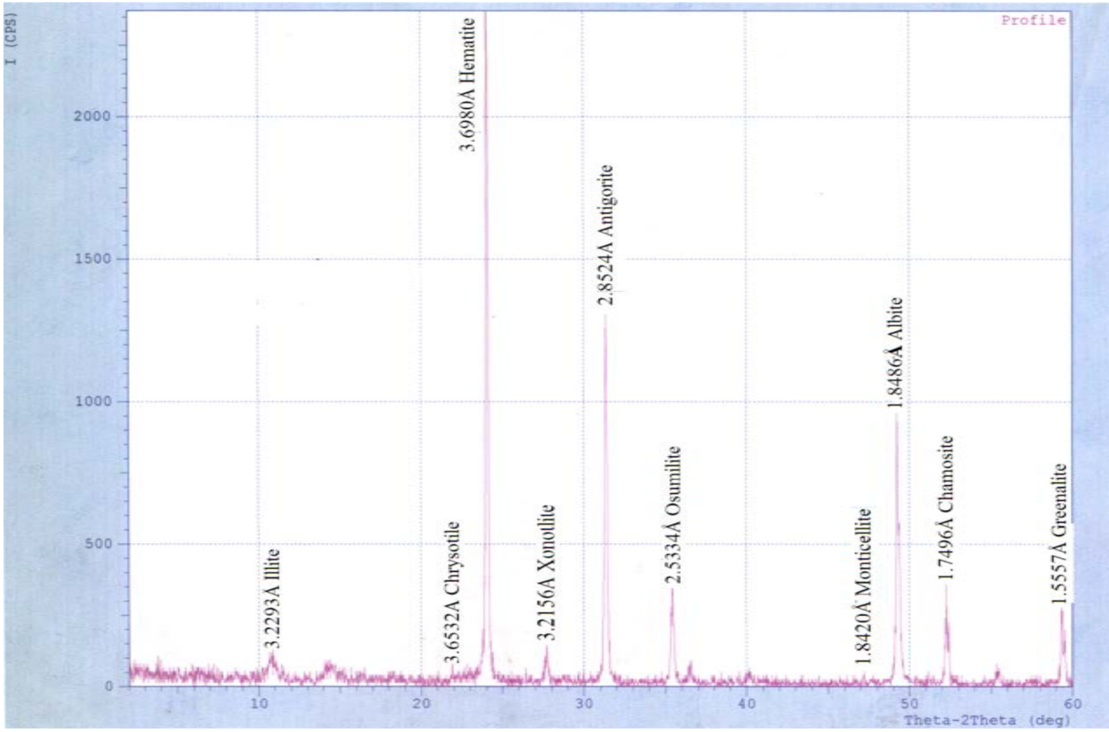

Fig. 1.2: X-ray diffractograms of clay sized particle of soil F1

The three major or strongest peaks for pedon F2 as shown on the difrractogram were as follows: Column 3 has the first strongest peak corresponding to the2Theta Bragg's angle at 23.9802. Column 2 has the second strongest peak corresponding to the2Theta Bragg's angle 18.2341. Column 5 has the third strongest peaks corresponding to the2Theta Bragg's angle at 47.5141. The intensity ratios exhibited were 100, 20 and 18 respectively for the major peaks (Table 1.3). Some minor peaks found correspond to the2Theta Bragg's angles at 36.8087, 39.8002, 43.1325, 47.5141, 52.2325 and 57.3151. The major minerals as confirmed by the various peaks were: hematite (3.7079Å), chrysotile (4.8614Å), zeolite (1.9121Å), lizardite (2.6422Å) and tobermorite (2.4398Å), while the minor minerals found were; xonotlite (3.64928Å), nacrite (2.2631Å), albite (2.0956Å), actinolite (1.6062Å), amesite (1.7499Å) and phlogopite (3.75115 Å)

The dominance of these major minerals is an indication that the soil had weathered considerably however they may not have been formed insitu but brought about by erotional and depositional processes. Presence of tobermorite might have contributed to the enrichment of calcium in the soil. nacrite, amesite and actinolite on the other hand are species of the kaolinite which may have been inherited from the acid sediments from which the soil may have been formed. Trace amount of albite in the soil suggested that the soil had been strongly weathered because it was present in the clay fraction of soils which were subject to moderate weathering (Huang *et al.*, 2002).

Table 1.3: Significant peak data list generated by diffractometer for F2

Peak No	º2θ	d (Å)	Intensity ratio	FWHM (deg)	Intensity (counts)	Integrated intensity (counts)
1	18.2341	4.86141	20	0.18450	149	1604
2	23.7000	3.75115	3	0.11340	23	245
3	23.9802	3.70795	100	0.16970	764	6894
4	24.3716	3.64928	6	0.12330	43	352
5	33.8995	2.64224	10	0.18760	78	823
6	36.8087	2.43981	7	0.15400	57	516
7	39.8002	2.26305	6	0.17050	49	483
8	43.1325	2.09562	6	0.14500	46	406
9	47.5141	1.91208	18	0.16040	139	1222
10	52.2325	1.74991	5	0.18500	36	468
11	57.3151	1.60622	11	0.15300	83	735

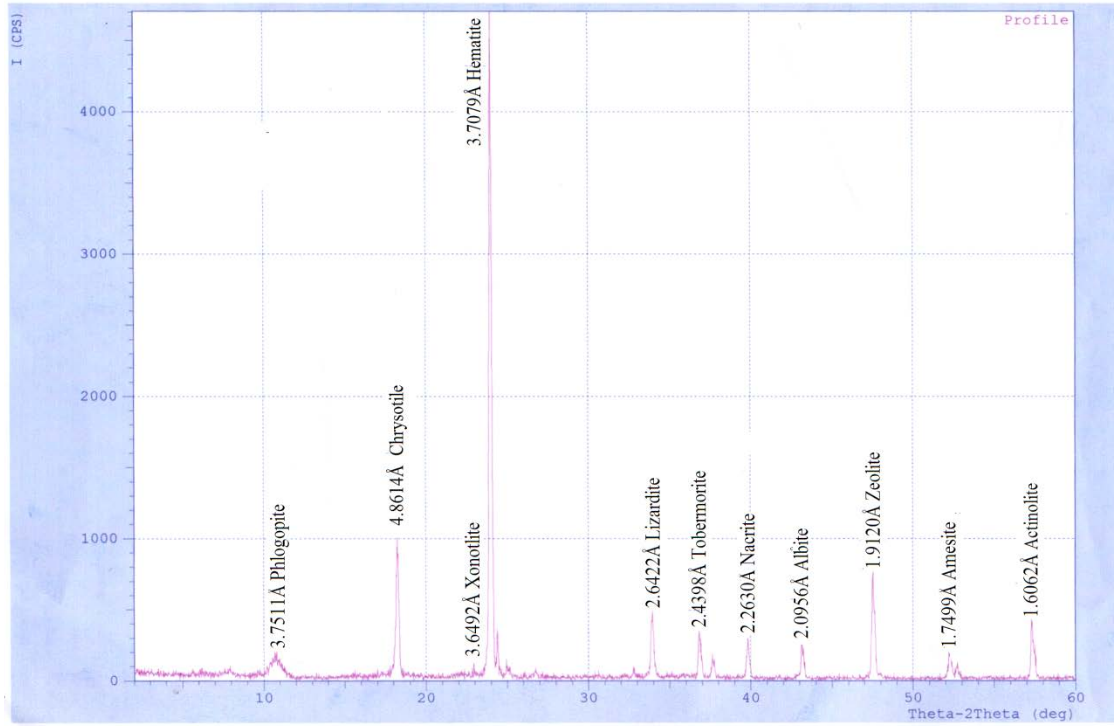

Fig. 1.3: X-ray diffractograms of clay sized particle of soil F2

SUMMARY AND CONCLUSION

The soils formed on the basement complex parent material was studied with the aim of characterizing the minerals contained in them to provide the mineralogical information, soils as it has direct influence on fertility status of our soils. Because soils are dynamic hence they undergo transformational processes that lead to both destruction and synthesis of original and new minerals respectively.

This research study confirmed and showed the presence of the dominant clay sized minerals in the soils which might have been originated or inherited from the parent material; altered and degraded from primary minerals and their synthesis. The mechanisms operating within the northern guinea savanna under the perceived environmental conditions together with the processes of the weathering of the parent material have resulted in the soil clay sized minerals identified.

The presence of clay sized minerals (other than just the clay minerals) in large amount in the soils (e.g hematite, osumilite and xonotlite) might be as a result of the intensive weathering activities that influenced the basement complex parent material which has been co-influenced by the nature of the landscape and consequently influenced the development and characteristics of soils of the study area. Thus, the order of increasing dominance of the clay sized minerals found in soil F1 were; hematite > antigorite > albite > chamosite > greenalite > chrysotile > illite > xonotlite > osumilite > monticellite, while soils of F2 exhibited; hematite > chrysotile > zeolite > lizardite > tobermorite > xonotlite > nacrite > albite > actinolite > phlogopite >amesite in that order.

The type of clay sized minerals as was confirmed by this study will help in predicting the chemical and physical property of soils that can be found, as well as stating the fertility status of the soils and the possible management practice to be adopted by various land users, which in such away will improve the use efficiency of soils in the study area.

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