Mineralogical Characteristics of Natural Kaolins from Abeokuta, South-West Nigeria.

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ABSTRACT

Twelve (12) samples from five (5) different clay deposits in Abeokuta were studied using X-ray diffraction and chemical analysis. Mineralogical characteristics of these samples revealed kaolinite as the principal mineral but other minerals are present in small quantities: illite, quartz, muscovite, microcline, and zeolite. These clays could be used in the ceramics industry to make tiles, earthenware, refractory lining of furnaces and also in agronomy as supports for chemical fertilizer.

(Keywords: X-ray diffractometer, kaolin, metakaolinite, mineral, characteristics)

INTRODUCTION

The exploitation of the white clay by the Chinese in the industry of ceramics goes back to the first millennium (Grim, 1968). Various layers of this ore were thereafter discovered. We distinguish four types of minerals: kaolinite (most abundant), the dickite (1888), nacrite (1807), and halloysite (1826) which belongs to the kaolin group. These minerals of the group kaolin have mainly three origins (Caillere et al., 1982) by heritage where the inherited minerals are obtained by deterioration and transport, also by degradation major transformations (Hurst and Kunkle, 1985). These are phyllosilicates, characterized by a $Al_2Si_2O_5(OH)_4$. Kaolinite is interesting as a mineral precursor due to its unique asymmetry layered structure with $(SiO)_6$ macroning on one side and aluminum on the other side. This asymmetry creates large cohesive energy (Bailey, 1988a).

Sourcing of appropriate raw materials from the abundant natural endowments in Nigeria for industrial use has not generated significant success because technical information on the integrity of these natural endowments is seldom available. Extensive investigation has been carried out on the liquid mineral endowment of the country, however, not much has been done on the solid mineral endowment of which clay is prominent and consequent upon this, adoption of solid mineral on industrial scale is scanty. The main policy thrust of the economic reform program of the Nigerian government is mobilizing national capability in converting the country's endowments into utility products and services for the common man [4].

A great emphasis is placed on exploiting the abundant solid minerals endowments in the country with a view to diversifying the economic base of the country, improving Gross Domestic Product (GDP) and industrial activity. One of these endowments with tremendous potential for economic utilization is clay. Clay deposit is spread across the six geo- political zones of the country [5]. Clay is a fine textured earth that is plastic when wet but hard and compact when dry or a term used to refer to the finest grain particles in the sedimentary rocks and hydrothermal deposits [6]. There are two general types of clay: expandable and non-expandable [7]. Expandable clay swells up when or if enough water is added to it.

Non-expandable clay called bentonite is used to make drilling mud in the petroleum industry, also in the ceramics industry to make bricks, tiles pottery and porcelains. The important properties of clay are plasticity, color, clay strength, drying and firing shrinkages. The percentage of the mineral oxides (Fe_2O_3, MgO, CaO, and Na_2O) in the clay ultimately determine the areas of application of the clay such as in application of the clay such as in bricks, refractory, floor, tiles, paper, etcetera while the quantity of the alkali metal oxides (Na_2O, K_2O, and CaO) indicate their suitability for making ceramic product [8].

Nigeria has appreciable distribution of industries engaged in metal and process industries hence the need for adequate and appropriate raw materials to support their growth. Clay products such as ceramics wares, burnt bricks, roofing, and floor tiles are cheaper and durable building materials than cement especially under tropical conditions [8].

MATERIALS AND METHODS

Representative samples of the twelve (12) different selected clays from Abeokuta in Ogun-State were taken by hand (as received) from five (5) different geological formations at their respective depths in the pits of Asero, Fajol, Onibode, Ile-Ise Awo, and Ajebo.

Characterization of the Five Different Clay Deposits in Abeokuta.

The physical, chemical, mineralogical properties of the natural kaolins from Abeokuta clay was examined in the Materials Laboratory of Imperial College, London.

The results were compared with results published in literature, to ascertain if these 12 clays are suitable for the manufacturing of floor tiles, ceramics, stoneware and firebricks

Sample Preparation

All the twelve collected clays, in the form of agglomerated lumps of ten (2) kilograms was initially dried at 110°C over night for 24 hours, in an oven MOV-112 of Imperial College London, and were grounded in a porcelain mortar and pestle and the resulting fine powder was termed the ″Un-treated clay.″

Chemical Analysis

Chemical analyses of the materials were determined using inductively coupled plasma. Atomic emission microscopy (ICP- Varian Vista-Pro ICP-AEP), where all sample were dried at 110°C for eight (8) hours prior to analyses. Samples analyzed by fusion with Lithium Barium ($LiBO_2$) into the plasma flame to produce characteristic emission of major and minor elements.

Mineralogical Analysis X-Ray Diffraction (XRD)

Each of these 12 clay samples was dried in an oven, crushed, ground to a fine powder, and was determined in the laboratory section of Materials Department, Imperial College London. The mineralogical data were obtained on powdered samples using XRD instrument Phillips PW1700 series automated powder diffractometer using CuK_α radiation at 40 Kv/40mA from $5° < 2\theta < 85°$ with the step size 0.04 at the counting time of 2 seconds. Both random and oriented powder samples were studied and was compared with International card for diffractometry data (ICDD).

RESULTS AND DISCUSSION

Chemical Analysis

An ideal kaolinite, $Si_2Al_2O_5(OH)_4$, would have the following chemical composition: SiO_2=46.55%, Al_2O_3=39.49%, and H_2O=13.96% by weight. The results of the chemical analysis by inductively couple plasma are reported in Table 1. Qualitatively, they contain mainly the elements Si, Al with small amounts of Fe, Ti, K, P, Mn, Ca, and Mg as often observed in natural clays. It was observed that variations in the chemical compositional differences in the source area could be due to the sedimentary input.

High silica content was noticed in Fajol clay deposit. Ajebo 2 clay shows that Titanium Oxide (TiO_2) is high when compared with others. The high aluminum oxide content of Ajebo 1 clay indicates that clays rich in alumina are associated with high clays in the free state as alumina are associated with high clay mineral content in the combined state as alumino-silicates and very seldom is found in clays in the free state.

Ile-Ise Awo 1 and 2 has the highest iron oxides (Fe_2O_3) content greater than 4%. Alkali oxides such as potassium oxide (K_2O) and sodium Oxides (Na_2O) are present in all the twelve (12) clay samples in Abeokuta, South West Nigeria.

X-Ray Diffraction

Figures 1 - 12 shows XRD patterns of the representative samples.

Table 1: Chemical Composition (wt %) of the Twelve (12) Raw Cays from Abeokuta. (Source: ICP-Varian-Pro ICP-AEP).

Various clay deposits	Lab. No	$SiO_2\pm\Delta$	$TiO_2\pm\Delta$	$Al_2O_3\pm\Delta$	$Fe_2O_3\pm\Delta$	$MnO\pm\Delta$	$MgO\pm\Delta$	$CaO\pm\Delta$	$Na_2O\pm\Delta$	$K_2O\pm\Delta$	$P_2O_5\pm\Delta$	L.O.I
FAJOL	L15943	78.3±0.4	0.87±0.3	9.1±0.29	2.94±0.73	0.02±0.3	0.31±0.7	0.26±0.3	0.24±0.3	1.01±0.3	0.03±13	6.92
ASERO 1	L15944	66.8±0.3	0.45±0.2	21.3±0.2	2.34±0.2	< ± <	0.07±0.4	0.08±8.7	0.02±0.6	0.45±0.3	0.61±9.1	8.43
ASERO 2	L15945	59.4±0.3	0.05±0.3	28.1±0.2	0.61±0.42	< ± <	0.17±0.5	< ± <	0.03±0.8	0.92±0.4	< ± <	10.72
AJEBO 1	L15946	46.4±0.5	1.69±0.4	34.0±0.4	2.45±0.5	< ± <	0.04±0.7	0.02±3.0	0.03±0.8	0.08±0.7	0.04±11	17.7
AJEBO 2	L15947	68.6±0.5	1.75±0.5	20.5±0.4	0.16±0.5	< ± <	0.09±0.8	< ± <	0.07±0.8	0.01±0.9	< ± <	8.82
ILE-ISE AWO 1	L15948	67.9±0.3	0.6±0.3	14.7±0.4	5.9±0.6	0.03±0.5	0.8±0.4	0.4±0.43	0.49±0.4	2.46±0.4	0.05±11	6.67
ILE-ISE AWO 2	L15949	69.6±0.3	0.6±0.4	14.3±0.3	5.90±0.4	0.04±0.3	0.7±0.4	0.4±0.3	0.57±0.5	1.44±0.3	0.04±13	6.41
ILE-ISE AWO 3	L15950	66.9±0.3	0.5±0.35	16.0±0.2	5.1±0.8	0.01±0.4	0.5±0.2	0.34±0.4	1.4±0.3	4.12±0.5	0.03±8	5.1
AGBA AKIN 1	L15951	63.7±0.2	0.7±0.4	18.7±0.3	5.6±0.5	0.02±0.2	1.0±0.9	1.1±0.44	1.35±0.3	1.9±0.41	0.04±10	5.89
AGBA AKIN 2	L15952	64.5±0.4	0.6±0.8	16.9±0.4	5.5±0.5	0.02±0.5	0.9±0.8	0.9±0.5	1.45±0.5	2.7±0.9	0.03±18	6.5
AGBA AKIN 3	L15953	66.7±0.2	0.9±0.3	14.6±0.3	4.6±0.3	0.03±0.3	0.6±0.5	0.01±0.3	0.26±0.2	5.2±0.3	0.1±4.0	7.0
AGBA AKIN 4	L15954	65.5±0.2	0.8±0.4	17.0±0.3	4.2±0.3	0.03±0.3	0.7±0.3	0.9±0.4	1.69±0.2	3.8±0.3	0.12±2.8	5.26

These are from from five (5) clay deposits of Abeokuta, compared to sample of kaolinite from Saint-Austell (SAU), in England and International Card for Diffractometry Data (ICDD), used as reference. Ajebo 1 clay sample contained kaolinite as the principal mineral (with characteristic peak ay 7.19A^0) having ~99.9% kaolin, while others have kaolin at lowest peak (Fajol-7.20A^0, Asero 1-7.15A^0, Asero 2-7.18A^0, Ajebo 2-7.17A^0, Ile-Ise Awo 1-7.18A^0, Ile-Ise Awo 3-724A^0, Agba-Akin1-7.12A^0, Agba-Akin 2-7.38A^0, Agba-Akin 3-7.20A^0, Agba-Akin 4-7.26A^0), with the only exception of Ile Ise-Awo 2 without kaolin mineral

DISCUSSION

The clay minerals concerns are: kaolin while some other clay deposits studied contain muscovite, quartz, illite, microcline, and zeolite minerals. It was generally observed the variations in the chemical composition of the selected clay deposits in Abeokuta can be attributed to compositional differences in the source areas and variations in the sedimentary or residual supply input. This is in line with the works of Ingles and Ramos-Guerrero (1995) on sedimentological control on the clay mineral distribution in the marine and non-marine Palaeogene deposits of Mallorca (Western Mediterranean) and Yoothong et al. (1997) on clay mineralogy of Thai soils.

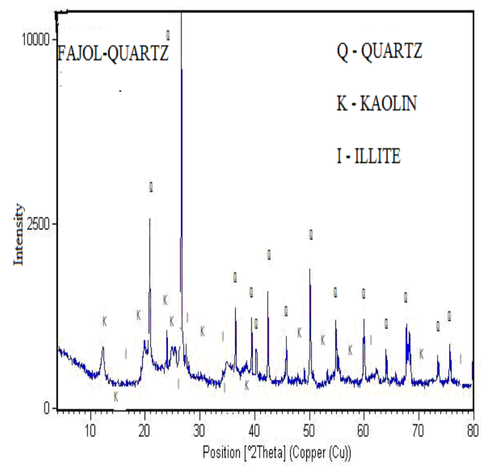

Figure 1: XRD Trace of Fajol Clay.

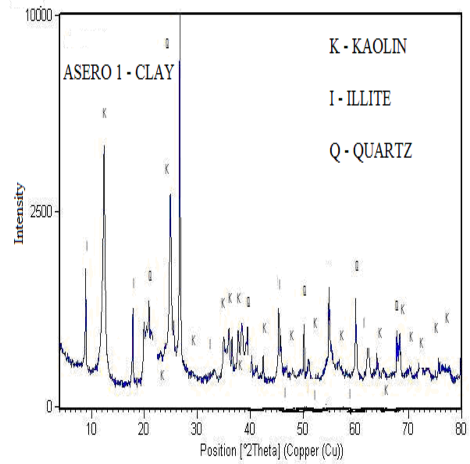

Figure 2: XRD Trace of Asero 1 Clay.

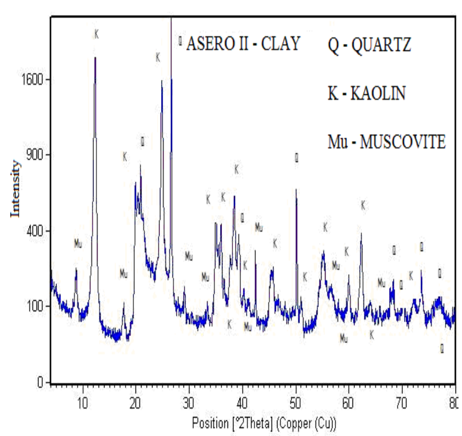

Figure 3: XRD Trace of Asero 2 Clay.

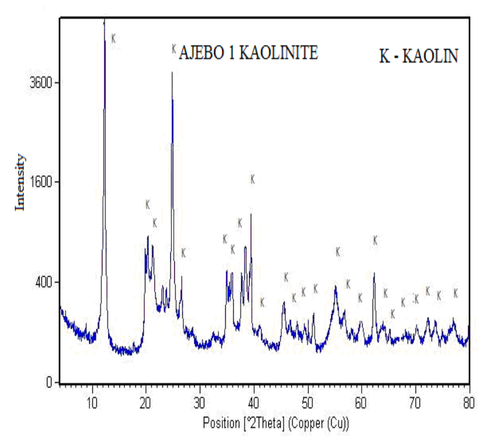

Figure 4: XRD Trace of Ajebo 1 Clay.

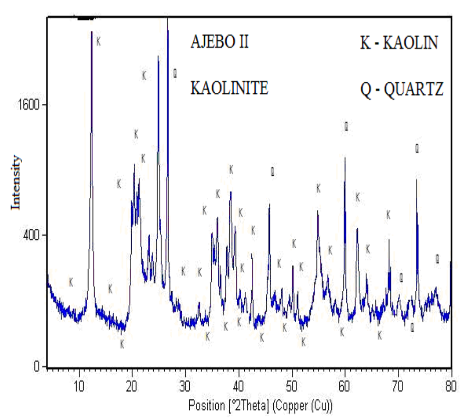

Figure 5: XRD Trace of Ajebo 2 Clay.

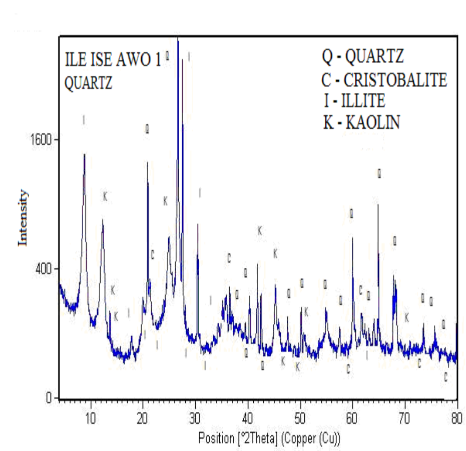

Figure 6: XRD Trace of Ile-Ise Awo 1 Clay.

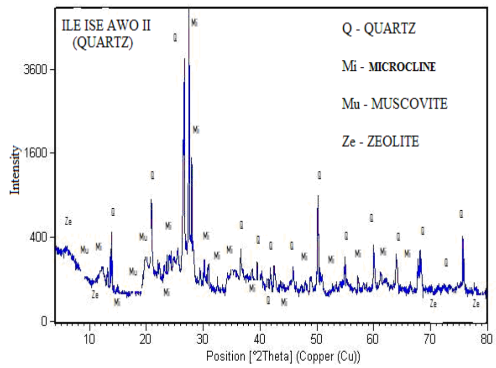

Figure 7: XRD Trace of Ile-Ise Awo 2 Clay.

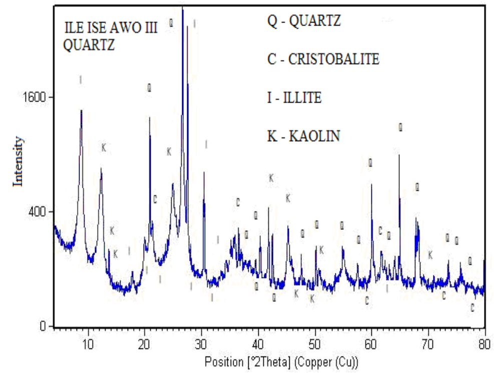

Figure 8: XRD Trace of Ile-Ise Awo 3 Clay.

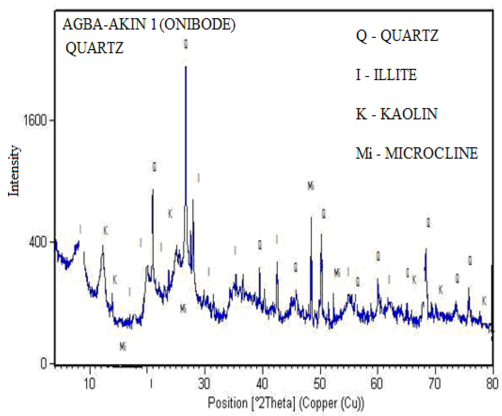

Figure 9: XRD Trace of Agba-Akin Clay 1.

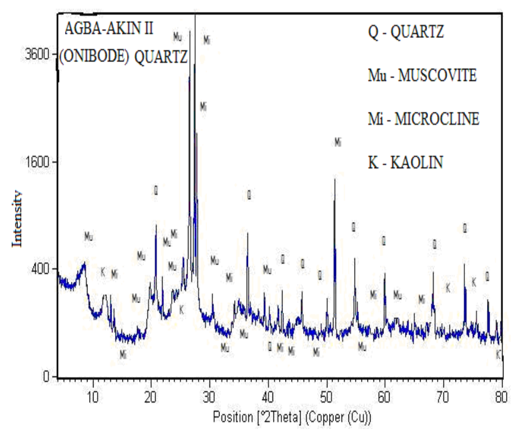

Figure 10: XRD Trace of Agba-Akin 2 Clay.

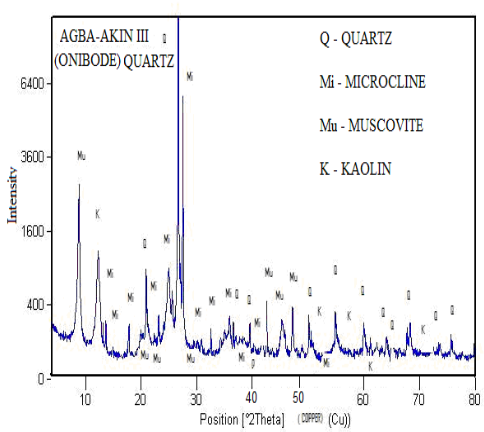

Figure 11: XRD Trace of Agba-Akin 3 Clay.

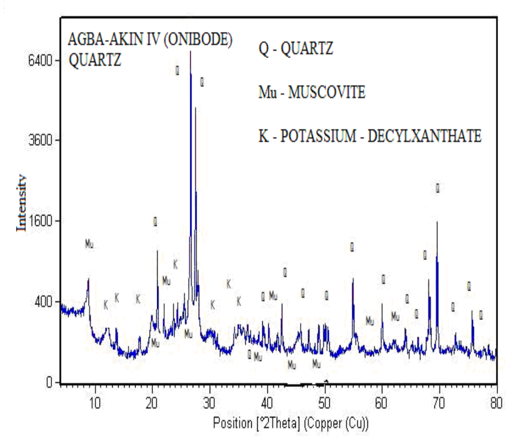

Figure 12: XRD Trace of Agba-Akin 4 Clay.

Figures 1-12: Show the XRD Patterns of Both Oriented and Random Deposits of Representative Clay Samples from Abeokuta Natural Kaolins.

Table 2: Clay Mineral Phases in Natural Clay Deposits (Kaolin) from Abeokuta
*(Non-clay minerals.)

S/N	Various Clay Deposits	Minerals	Peaks	ICDD Based
1	Fajol	*Quartz kaolin *Illite	3.35A° 7.20A° 4.61A°	00 – 079 – 1910 00 – 001 – 0527 00 – 043 – 0685
2	Asero 1	*Quartz kaolin *Illite	3.35A° 7.15A° 9.95A°	01 – 085 – 0797 01 – 078 – 1996 00 – 026 – 0911
3	Asero 2	*Quartz kaolin *Muscovite	3.35A° 7.18A° 5.01A°	01 – 085 – 0930 01 – 083 – 0971 01 – 007 – 0025
4	Ajebo 1	Kaolin	7.19A°	01 – 083 – 0971
5	Ajebo 2	*Quartz kaolin	3.34A° 7.17A°	01 – 083 – 0539 01 – 080 – 0886
6	Ile-Ise Awo 1	*Quartz *Cristobalite *Illite kaolin	3.35A° 3.77A° 8.79A° 7.18A°	01 – 086 – 2237 01 – 076 – 0934 00 – 026 – 0911 01 – 083 – 0971
7	Ile-Ise Awo 2	*Quartz *Microcline *Muscovite *Zeolite	3.24A° 3.19A° 3.16A° 1.28A°	01 – 046 – 1045 01 – 076 – 1239 01 – 007 – 0025 01 – 081 – 2466
8	Ile-Ise Awo 3	*Quartz Kaolin *Illite *Cristobalite	3.24A° 7.24A° 8.80A° 3.56A°	01 – 078 – 1253 00 – 010 – 0527 00 – 026 – 0911 01 – 035 – 0643
9	Agba-Akin 1 (Onibode)	*Quartz *Illite Kaolin *Microcline	3.34A° 8.89A° 7.12A° 3.20A°	01 – 085 – 0796 01 – 075 – 0938 00 – 026 – 0911 01 – 075 – 0938
10	Agba-Akin 2 (Onibode)	*Quartz *Muscovite *Microcline Kaolin	3.25A° 3.35A° 1.78A° 7.38A°	01 – 078 – 1253 00 – 007 – 0025 01 – 083 – 1253 01 – 075 – 0938
11	Agba-Akin 3 (Onibode)	*Quartz *Microcline *Muscovite Kaolin	3.34A° 3.29A° 10.2A° 7.20A°	01 – 078 – 1252 00 – 019 – 0932 00 – 007 – 0042 01 – 075 – 1593
12	Agba-Akin 4 (Onibode)	*Quartz *Muscovite Kaolin	3.35A° 10.0A° 7.26A°	01 – 079 – 1910 00 – 029 – 1488 01 – 080 – 0742

A closer look at the chemical compositions of the twelve (12) clay types from Abeokuta indicates that the loss on ignition varies from 5.1 to 17.7 wt % due to water vapor from dehydroxylation reactions in the clay minerals, carbonate decomposition into CO_2, and oxides as well as burning out of organic matters. This finding is in agreement with Deer et al. (1962).

High silica content was noticed in Fajol clay deposit. This shows that the Fajol clay deposit is SILICEOUS. From the theoretical background of the function of constituents oxides in clay (chemical analysis), clays with silica content of more than 60% are termed siliceous. Ajebo 2 clay shows that Titanium Oxide (TiO_2) is high when compared with others. This may be attributed to the quality of the clay in terms of whiteness for paint, pigment and can act as opacifier. The high aluminum oxide content of Ajebo 1 clay indicates that clays rich in alumina are associated with high clays in the free state as alumina are associated with high clay mineral content in the combined state as alumino-silicates and very seldom is found in clays in the free state.

Ile-Ise Awo 1 and 2 has the highest iron oxides (Fe_2O_3) content, which primarily determine the fired color of the clay, the increasingly red coloration of Ile-Ise Awo 1 and 2 fired clay (5.9 wt%) was due to their iron oxides that were greater than 4%. The presence of alkali oxides such as potassium oxide (K_2O) and sodium Oxides (Na_2O) in all the twelve (12) selected clay deposits in Abeokuta indicate their excellent fluxing ability during firing at comparatively low temperatures, to form glasses of complex composition towards giving a vitreous structure to ceramics bodies such as found in these twelve (12) clay deposits in the study area (Abeokuta). Although Agba-Akin 3 has the highest potassium oxide (K_2O) present compared with the rest but then, these trace elements are in agreement with previous clay/ceramic research works (Herbillon et al, 1976; Brindley 1980).

These results have the characteristics of common clay minerals (Grim, 1968) as in form of muscovite clay mineral in the illite group for Fajol and Asero while Asero 2 clay has montmorillonite clay mineral in form of the smectite. Ajebo 1 clay has kaolinite clay mineral in the halloysite group which present ~99.99% kaolin that can be used for utilization potentials for porcelain stoneware tiles for industrial development of Ogun-State, while Ajebo 2 has kaolinite clay mineral in the halloysite group which presents ~70% kaolin and 30% quartz peak.

Ile Ise Awo has 1 and 3 has muscovite clay mineral in the Illite group, while Ile Ise Awo 2 has glauconite clay mineral in the illite group, while Agba Akin 4 has muscovite clay mineral in the illite group. Agba Akin 1 has vermiculite clay mineral in the vermiculite group, compared to Agba Akin 2 and 3 having Sepiolite clay mineral in the Sepiolite group.

CONCLUSION

The wide variety of soils in Abeokuta is as a result of the interaction between parent rocks, climate and physiography of Ogun State. This is reflected in the wide variety of clay minerals as discovered in this study. The soil map of Ogun State has been used to define the clay mineral deposits. From a geological point of view, twelve clay minerals from five deposits are distinguished. The clay minerals concerns are: kaolin while some other clay deposits studied contain muscovite, quartz, illite, microcline, and zeolite minerals.

In conclusion the mineralogical characteristics of natural clay (kaolin) studied from Abeokuta, five clay deposits can be classified: Ajebo 1 clay deposit has pure kaolinite clay mineral of the 1:1 layer with Ajebo 2 belonging to the halloysite clay mineral with 2:1 layer. Fajol, Ileise-awo 3, Agba-Akin 4 has muscovite clay mineral of the 2:1 layer while Asero1, Ileise-Awo 1, Ileise-Awo 2,has illite clay mineral as in 2:1 layer. Asero 2 has montmorillonite clay mineral of the 2:1 type. Agba-Akin 1 has vermiculite of the 2:1 layer. Agba-Akin 2 and Agba-Akin 3 has sepiolite clay mineral of the 2:1 type.

Given their mineralogy and chemical characteristics, these clays could be used in various ceramics (tiles, bricks pottery, etc.).

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REFERENCES

1. Grim, R.E. 1968. *Clay Mineralogy*. Mc Graw-Hill, New York, NY. 596.

2. Caillere, S., S. Henin, and M. Rautureau. 1982. *Mineralogie des argyles*. Masson: Paris, France.

3. Hurst, V.J. and A.C. Kunkle. 1985. “Dehydroxylation Rehydroxylation, Stability of Kaolinite”. *Clays and Clay’s Minerals*. 33:1-14.

4. Bailey, S.W. 1988a. “Hydrous Phyllosilicates”. American Mineralogical Society: Washington, DC.

5. NEEDS Document. 2004. National Planning Commission: Abuja, Nigeria. ISBN 0-9741/04-81.

6. Adegoke, O.S. 1980. “Guide to the Non-Metallic Mineral Industrial Potential of Nigeria”. *Proceedings of the Raw Materials Research and Development Council*. 110-120.

7. Mc Graw-Hill Encyclopaedia of Science and Technology. 1992. Mc Graw Hill: New York, NY. 3:752-761.

8. Ahmed, K.S. and P.B. Onaji. 1986. *The Effects of Beneficiation on the Properties of Some Nigerian Clay*. Nigerian Society on Chemical Engineering. 6(2):119-129.

9. Nnuka, E.E. and C. Enejo. 2001. “Characterization Nahuta Clay for Industrial and Commercial Applications”. *Nigerian Journal of Engineering and Materials*. 2(3):9 -12.

10. Deer, W.A., R.A. Howie, and J. Zussman. 1962. *Rock-Forming Minerals. Vol 3: Sheet Silicates*. Longman: London, UK.

11. Brindley, G. 1980. *Crystal Structures of Clay Minerals and Related Their X-Ray Identification*. Mineral Society Monograph No 5: London, UK.

12. Herbillon, A.J., M.M. Mestdagh, M. Vievoye, and E. Deroname. 1976. "Iron in Kaolinite with Special Reference to Kaolinite from Tropical Soil”. 11(3):201-220.

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