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Geochemical, Mineralogical Properties and Industrial Applicability of Kaolin in Isan Ekiti, Nigeria

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Abstract

This study investigates geochemical and mineralogical property of kaolin in Isan Ekiti state, using X-Ray fluorescence and X-Ray diffractometer. The X – Ray Fluorescence of Samples is the major indicator, shows that the percentage Silicon oxide (SiO2) for both samples ranges from 50.35% to 49.76% with an average of 50.055%, Aluminum oxide (Al2O3) ranges from 24.02% to 27.25% with an average of 25.6%, Ferric Oxide (Fe2O3) ranges from 3.42% to 5.14%, with an average of 4.28%, Magnesium Oxide (MgO) ranges from 4.54% to 4.24% with an average of 4.38%, Calcium oxide from 0.67% to 0.63% with an average of 0.65%, and Potassium Oxide range from 3.97 to 2.47, with an average of 3.22%. The Results of X – Ray diffractometer for samples shows that Quartz has its peak at (34.65, 2.70, 2.01 and 2.75) 2θ values for a sample while a sample was also identified at (32.57, 3.81, 2.23 and 1.65) 2θ values. Kaolinite has its peak at (8.82, 4.13, 4.01, 2.84, 4.22, 4.52and 1.43) 2θ values for a sample while another sample was also identified at (8.78,4.61, 4.42, 3.63, 6.29, 4.84 and 1.52) 2θ values. The Anatase also has its at (4.76 and 2.32) 2θ values for a sample while a sample was also identified at (3.64 and 3.75) 2θ values. The Kaolinite in the samples ranges from 29.97% to 34.09% with an average of 32.03%, when compared with standard parameter, its suitable and can be used in coated paper, and when properly beneficiated, will be applicable in grades of ceramic production.

Keywords: kaolin, geochemical, mineralogical, coated paper, ceramic.

1. Introduction

Kaolin is an important raw material which has wide-spread industrial applications including water treatment, as porcelain, cement, and ceramics production [1]. Kaolin is often the product of weathering of naturally occurring hydrated aluminum silicates. In many applications, the term kaolin typically includes the raw clay and refined commercial products [2]. It is a clay-rich rock, dominated by kaolinite, a clay mineral that is composed mainly of Al2Si2O5(OH)4. In perfect condition, kaolin has specific gravity that ranges from 2.58 to 2.63 with a refractive index of between 1.56 and 1.62 [3] and feels plastic or slippery when touched. Because it is chemically unreactive under normal conditions, kaolin is in high demand as a raw material in the production of paper, ceramics, paint, chalk, cosmetics, pharmaceuticals, and agrochemicals. Kaolin is found

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in large amounts in many parts of Nigeria. The presence of clay-rich deposits in the southwestern region has long attracted the attention of many researchers [4] and further promoted other studies [5] which investigated their industrial potentials.

These earlier studies focused on the geology of the areas under study and provided the results that kaolin occurs in commercial quantities. By default, many of the industrial properties ascribed to some of the kaolin deposits appear to be influenced by conclusions from similar deposits in other kaolin-rich regions of the world. Thus, the appearing gap in local knowledge may have contributed to the unimpressive appreciation of economic and industrial values of Nigerian kaolin deposits with the implication that local industries rely on imported kaolin while dismissing local sources as not meeting the required industrial specifications. It is reported that Nigeria is endowed with different grades of kaolin with a proven reserve which is close to billions of tonnes [6]

Kaolins are essential fine grained, earthy material, which become plastic and tenacious when moist, and they become permanently hard when baked or fired [7].

Kaolin's composition may be clay and clay-sized crystal of other minerals such as quartz, carbonate, and meta oxides. They are often formed either as product of the chemical weathering of pre-existing Crystal rock and feldspar mineral in warm tropical and subtropical region of the world or as a product of the hydrothermal alteration. Kaolin and clay mineral are economics minerals found useful in manufacturing and environmental industries where they serve as major raw material in the making of ceramic, paint, paper products. Other uses of kaolin included cure of ulcer for cleansing purpose, detoxification, adsorption, skin emulsion and cure against sedentary and cholera [8].

The study is to investigate the geochemical and mineralogical studies of kaolin in Isan Ekiti, Ekiti State, and determine its industrial applicability.

1.1 Geology of Nigeria

The geology of Nigeria, as detailed in [9], is made up of three main rock groups: mainly Precambrian basement crystalline metamorphic-igneous-volcanic rocks; Mesozoic to Tertiary sediments, granites and volcanic; and Quaternary alluvial deposits.

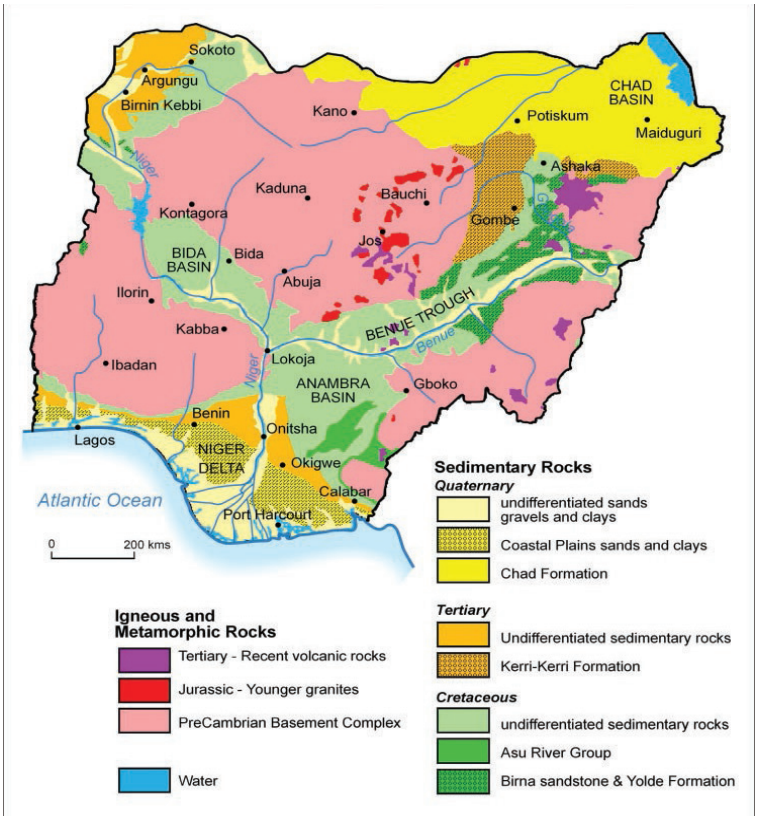

Fig. 1: Generalized geological map of Nigeria (After, MacDonaldetal.,2005).

Precambrian Basement Complex rocks underlie three parts of Nigeria i.e., North-central area including the Jos

Plateau; South-west area adjacent to Benin; and south-east area adjacent to Cameroon. The rocks of the North-central area are composed of gneisses, migmatites, granites, schists, phyllites and quartzites. Then arrow, tightly folded north-south trending schist belts of northwestern Nigeria include igneous rocks, pelitic schists, phyllites and banded iron stones. The migmatite-gneiss complex of amphibolite, diorites, gabbro, marbles and pegmatite form a transition zone between the schist belt of Northwestern Nigeria and the granites of the Jos Plateau to the East. There, extensive Precambrian Age Older Granites crop out extensively. These have been intruded by Jurassic age Younger Granites are for characteristic ring complex structures. The Precambrian Basement rocks of southwestern Nigeria, as found in the Dahomeyan (Benin) Basin, consist of migmatites, banded gneisses and granite gneisses, with low grade metal sedimentary and metal volcanic schists, intruded by Pan-African age granites and charnockites [10]. The migmatites and gneissic metal sediments are often intruded by pegmatite veins and dykes [11]. Older granites, granodiorites and syenites, with dolerite dykes, also form part of the Precambrian basement of SW Nigeria. The Precambrian Basement rocks of south-eastern Nigeria occur in three blocks along the border with Cameroon (Fig. 1). The crystalline basement rocks include biotite-hornblende gneiss, kyanite gneiss, migmatite gneiss and granites and are well fractured [12].

1.2 Physical properties of Kaolin

Grayish White, clay sized, easily broken in dry condition, in wet condition very sticky, easily to form as desired and elastic (not easily broken). In the location field , the clay is often mixed with sandstone lithology and gravel cricket with matrix and fragment in the form of quartzite fraction which are weathered regoliths which are deposited simultaneously with the clay [13].

1.3 Chemical Properties of Kaolin

All clays are mineral absorb positive carton by virtue of the unsaturated negative ions in the surface layers and to a less extent some finely grained illites absorb cation within the lattice [8].

The kaolin is made up of abundantly, quartz and silicate mineral $Al2Si2O5(OH)4$ structure per alumina-silicate producing bulky congested particles of $SiO4$ tetrahedral sheets and $AlO2(OH)4$ octahedral sheets [14].

1.4 Industrial and Domestic Uses of Kaolin

The ceramic industry is a big user of kaolin clay in white ware, insulators and refractory. Some tests are used to evaluate kaolin for use in ceramics. These include plasticity, shrinkage modules or rupture, absorption, fired colour, coating rate and chemical analysis. The paper industry is another major consumer of kaolin. Kaolin is used both as filler and as a coating. The most important size fraction of kaolin used in coating clays is less than 2 microns. Coating clay used for publication paper contains 80% of very fine particle. In petroleum and related cracking industries, kaolin is used as a catalyst in the process to break down long chain hydrocarbon to gasoline. Kaolin is also used in the production of pencils. The amount of kaolin present ranges from 20% to 50%. Kaolin is often added to cement as a whitener during the manufacturing process [15].

1.5 Mineralogical Properties of Kaolin

The mineralogical properties of kaolin, kaolinite and quartz are the most abundant minerals. Other accessory minerals are hematite, k-feldspar, illites and calcite. The Crystal size of kaolinite calculated from the Scherrer equation, is about 20-25nm [16].

2 Materials and Methods

2.1 Sample Collection

The study area lies within Ekiti state in Isan Ekiti, located on latitude 7O 46″ N and 70 53″ N and longitude 50 00″ E and 5O 07″ E Isan Ekiti.

Mixtures of the fresh representative samples of kaolin from two major division of the deposits were collected on the field using equipment such as digger, shovel, mixed, bagged and tagged sample A and Sample B. The global positioning system instrument 'etrex model' was used to locate the geographical coordinates of the site. The samples were transported to the laboratory for detailed analysis.

2..2 Sample Preparation

Kaolin samples obtained from the field were taken to the laboratory for further analyses. The samples were carefully selected for geochemical analyses. Mineral samples were pulverized at the same laboratory in preparation for the geochemical analysis.

2.3 X – Ray Diffraction

X- Ray diffraction was used for the identification of unknown crystalline materials (e.g. minerals, or inorganic compounds). Determination of unknown solid was critical in the characterization of crystalline materials, and in the determination of unit cell dimension, and measure of sample purity. The samples were analyzed using X-ray diffraction spectrometer (XDS 2400H X-ray diffractometer equipped with a MiniFlex2+ goniometer and detector). This worked by the combination of other components like the water chiller which cooled x-ray tube and maintained a uniform temperature. Compressed air also helped in opening and closing of the cabinet door. The materials to be analyzed were finely ground and sieved to pass through 63 microns' sieve. The pulverized sample was then prepared using prepared blocks and compressed into a flat sample that was later mounted on the sample stage in the XRD cabinet. The sample was analyzed using the Emission Transmission spinner stage with the theta-theta settings. The intensity of diffracted X-ray was continuously recorded as the sample and detector rotated through their respective angles. Peak intensities occurred when the mineral containing lattice plane with d-spacing appropriate to different x-rays at a value of θ. passed through the detector.

To minimize effects due to spatial divergence of the reflected beam a soller-aperture (width=1 mm) was mounted in front of the detector entrance slit. The resolution limit of the diffractometer was checked using a reference material. The Full Width-Half-Maximum (FWHM) of all peaks was in the range of 0.045o to 0.07o. There was no significant angle dependence of the peak width; only a slight increase with decreasing peak intensity. Two-theta sets were also checked using these standards.

The two collected rock samples were thoroughly dried in an oven at 31°C for 12 hours. The dried samples were crushed and ground to powder using pestle and mortar and reduced in sizes after crushing, by coning and quartering until desired size and quantity of sample for analysis was obtained. These were kept in air-tight polythene bags for analysis.

The diffractometer operating conditions should be chosen to maximize intensity and to reduce errors arising from counting statistics, even if this leads to some loss of resolution. (Largest practicable divergence and receiving slits; sample spinner).

2.4 X-Ray Fluorescence Spectrometry

Determination of major, trace/rare earth elements of the rock and mineral samples were done using X-Ray Fluorescence. Two rock samples were analyzed using the XRF. The major oxides, trace/rare earth elements of these rock samples were gotten through X-Ray Spectroscopy.

LOI was determined gravimetrically by heating 1g of the powdered sample in a cleaned weighed crucible at 1000oc. After which the crucible and the content was weighed to get the difference in weight before and after heating.

LOI = (a-b/1) x 100%

Where a = weight of crucible + 1g of the sample before heating

b = weight of crucible + 1g of the sample after heating.

3.0 Results and Discussions

3.1 Result of X-Ray Diffraction

The result of X-ray diffraction is shown in tables below.

Table 1. Composition Weight of Kaolin Sample A

Peak	Mineral Present	% Composition by Mass
1	Illite	1.38
2	Kaolinite	29.97
3	Quartz	42.11
4	Hematite	7.08
5	Anorthite	4.00
6	Anatase	11.05
7	Siderite	2.67
8	Smectite	1.66
TOTAL		**99.92**

Table 2. Composition Weight of Kaolin Sample B

Peak	Mineral Present	% Composition by Mass
1	Illite	1.40
2	Kaolinite	34.09
3	Quartz	40.26
4	Hematite	7.39
5	Anorthite	3.57
6	Anatase	7.53
7	Siderite	2.95
8	Smectite	1.61
TOTAL		**98.8**

Table 3. Percentage of Kaolinite used in Different Paper Types

Paper Type	Kaolin wt%
Newsprint	3-10
Uncoated	10-20
Coated	30-40
Lightweight	Up to 40

Source: [17]

Tables 1 and 2 shows the composition by mass of the samples analyzed using X–Ray Diffraction approach. The results show the presence of illite, hematite, anorthite, smectite and more presence of quartz, kaolinite and anatase with very strong X-Ray peaks. Quartz has its peak at (34.65, 2.70, 2.01 and2.75) 2θ values for sample A while sample B was also identified at (32.57, 3.81, 2.23 and 1.65) 2θvalues.

Kaolinite has its peak at (8.82, 4.13, 4.01, 2.84, 4.22, 4.52and 1.43) 2θ values for sample A while it was identified in sample B at (8.78,4.61, 4.42, 3.63, 6.29, 4.84 and 1.52) 2θ values. The Anatase was idntified at (4.76 and 2.32)

2θ values for sample A while that of sample B was also identified at (3.64 and 3.75) 2θ values.

The kaolinite content for the samples ranges from 29.97% to 34.09% with an average of 32.03%, when this value is compared with the specification on Table 3 [17], it shows that the kaolin deposit is suitable for production of coated paper.

3.2 Results of X Ray Fluorescence Spectrometry

The result of X-ray florescence spectrometer is shown in Tables below.

Table 4. Result of X Ray fluorescence on Sample A

S/N	Basic Oxides	Formulae	% Composition by Mass
1	Silicon Oxide	SiO_2	50.35
2	Aluminum Oxide	Al_2O_3	24.02
3	Ferric Oxide	Fe_2O_3	3.42
4	Calcium Oxide	CaO	0.67
5	Magnesium Oxide	MgO	4.54
6	Sodium Oxide	Na_2O	0.86
7	Potassium Oxide	K_2O	3.97
8	Sulphide	SO_3	0.11
9	Manganese Oxide	MnO	0.02
10	Lead Oxide	Pb_2O_5	1.08
11	Loss of Ignition	LOI	9.27

Table 5. Result of X Ray fluorescence on Sample B

S/N	Basic Oxides	Formulae	% Composition by Mass
1	Silicon Oxide	SiO_2	49.76
2	Aluminum Oxide	Al_2O_3	27..25
3	Ferric Oxide	Fe_2O_3	5.14
4	Calcium Oxide	CaO	0.63
5	Magnesium Oxide	MgO	4.24
6	Sodium Oxide	Na_2O	0.21
7	Potassium Oxide	K_2O	2.47
8	Sulphide	SO_3	0.23
9	Manganese Oxide	MnO	0.01
10	Lead Oxide	Pb_2O_5	0.02
11	Loss of Ignition	LOI	6.85

Table 6. Composition and properties of Ceramic Grade Kaolin

Compound	Average	a	b	c	Unit
Loss on Ignition	8.06	13.0	12.22	12.1	%
SiO_2	50.06	47	48	48	%
Al_2O_3	25.6	38	37	37	%
Fe_2O_3	4.28	0.39	0.7	1.0	%
MgO	2.46	0.22	0.30	0.30	%
K_2O	1.3	0.8	1.85	2.0	%

CaO	0.8	0.1	0.06	0.07	%
Na_2O	0.21	0.15	0.10	0.10	%
TiO_2		0.03	0.02	0.05	%

Source: [17] (a) ECC Super standard porcelain(b) ECC grolleg; earthware (c) ECC Remblend; sanitary ware

Tables 4 and 5 show the results of the X – Ray Fluorescence analysis of Sample A and Sample B for their chemical composition. The percentage Silicon oxide(SiO2) ranges from 50.35% to 49.76% with an average of 50.06%, Aluminum oxide (Al2O3) ranges from 24.02% to27.25% with an average of 25.64%, Magnesium Oxide (MgO) ranges from 4.54% to 4.24% with an average of 4.38%, Ferric Oxide (Fe2O3) ranges from 3.42% to 5.14%, with an average of 4.28%, Calcium oxide from 0.67% to 0.63% with an average of 0.65%, Sodium oxides from 0.86% to 0.21% with an average of 0.54%, Potassium Oxide range from 3.97 to 2.47, with an average of 3.22%, and Lead oxide ranges from 1.08% to 0.02% with an average of 0.55% weight percentage composition.

Comparing these values of chemical composition with kaolin's industrial standards for the ceramic industry in Table 6. The data shows the proximity of the compositions value obtained with the standard required compositions. The SiO2 composition of 50.06% is more than required compositions for ceramic production shown in Table 6, and values of Al2O3, alumina compositions and other oxides are very close to the industrial requirements for ceramic production described in Table 6, and with appropriate beneficiation process, they will meet up with the required composition.

4.0 Conclusion and Recommendation

The geochemistry of the samples analyzed showed that the chemical composition of the samples is made up of higher concentration of silicon oxide, aluminum oxide, ferric oxide, magnesium oxide.

The mineralogical compositions of the samples are; illite, hematite, anorthite, smectite and higher concentrations of quartz, kaolinite and anatase, the kaolin deposit studied is suitable for production of coated paper. Appropriate beneficiation process is recommended to make the kaolin suitable for production of grades of ceramic.

There is also a need for detailed exploration by investors to determine the grade and tonnage of kaolin ore deposit.

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