Geochemical And Geological Characterisation Of Kaolinite Deposits Around Kaoje, Kebbi State, Nigeria

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Abstract: Kaolin deposits in Kaoje have been analysed for their geochemical and geological (physical) characteristics in evaluating their quality for utilisation in local Industries. Physical (grain size) analysis show a moderate proportion of clay and silt size particles for the samples obtained (K1= 47.0 wt. %, K2= 41.8 wt. %, and K3= 50.2 wt. % respectively). Chemical data show that the Kaolin is composed mainly of SiO_2 and Al_2O_3. Other oxides being present in various amounts include K_2O, Fe_2O_3, and CuO. Also, Ca, Cr, Zr, As, and Ni occur in trace amounts and their depletion shows the extent of Kaolinisation. The physical and chemical characteristics of the Kaoje kaolinite indicate that they are suitable for industrial use.

Index Terms: Characterisation, Geochemical, Geological, Kaoje, Kaolinite, Kebbi State, Nigeria.

1 Introduction

Kaolin or China clay is a hydrated aluminium silicate ($Al_2Si_2O_5$ $(OH)_4$); it is used industrially for the production of many materials with economic significance. They are found in commercial quantity in most sedimentary basins as a product of weathering or hydrothermal alteration of rocks contains alumino-silicate minerals. They are primarily composed of aluminum, silicon, oxygen, ferrous and ferric iron, and hydroxyl groups. Other elements such as potassium, calcium, phosphorus, sodium, magnesium also occur in various proportions. Impurities such as quartz, feldspar, tourmaline, ilmenite, zircon, etc., are associated with them, which were derived from the parent rock. The most important members of the kaolin family include dickite, nacrite, allophone, and hallosite (Gary, 2008). Physically, they occur usually as white to near white in colour; they are earthy to dull with plastic touch. Also, the occurrence of iron content in kaolin clay determines its colour. The characteristics and chemical composition of a kaolin deposit usually determines its industrial utilisation. Kaolin is used in most manufactured products. Prominent uses include paper filling and coating; paint, plastic, adhesive and ink pigment; rubber reinforcing agent; ceramic raw materials for porcelain, dinnerware, tiles and enamels; catalyst for petroleum cracking and auto exhaust emission catalytic control devices; cosmetics base; and digestive coating remedy. Kaolin has abundant industrial applications, and this made it a unique industrial mineral because it is chemically inert over a relative wide pH range. It is suitable for moulding mixture in cast iron and steel foundry, and insulator refractories where the most important properties are plasticity, strength and fired colour. In Nigeria, Kaolin deposits are found in the Anambra, Chad, and Sokoto Basins. Others are the Benue Trough and the Niger Delta Basin. In the Northern part of the country, they are found in Bauchi, Borno, Gombe, Katsina, Kaduna, and Kebbi States respectively. In the southern part, they are found in Anambra, Enugu, Ondo, and Oyo States respectively. In Kebbi State, they are found in parts of Dakingari, Kaoje, Giro and Koko. Generally, they occur either sedimentary or residual in origin and are usually associated with granitic rocks. Despite their abundance in Nigeria, the major problems associated with the quarrying of kaolin in these areas include caving in of holes, influx of ground water particularly in the rainy season and the presence of impurities such as quartz, feldspar, tourmaline, muscovite, etc. Thus, the objective of this paper is to carry out a comprehensive and detailed geological and geochemical characterisation of kaolinite deposits occurring in parts of Kebbi State in evaluating their quality for and determining their suitability for application in the Ceramic Industry. This will provide basis for decision-making in terms of their selection for industrial application by small and large-scale ceramic producers.

2 Description of the study area

The study area is in Kebbi State and corresponds to Latitude 11.10° N and Longitude 4.15° E (Figure 1). The area lies within the Sokoto Basin, North-Western Nigeria. The population distribution of the area is less than 310 persons per square kilometre. The availability of potable water is the major factor that determines the population distribution. The study area is an agrarian community, as in other parts of the tropics, rainfall shows marked seasonal variation, with an average annual precipitation of about 750mm. The rainfall is concentrated in a short wet season which extends from mid-May to mid-September whilst the dry season lasts for more than seven months; November to March/April. The drainage of the area is largely controlled by the Sokoto (Rima) River and some other smaller drainage networks. The vegetation is of a typical Sudan savannah.

2.1 Geology of the study area

The Sokoto Basin is an intracratonic rift structure which evolution is related to tectonic epirogenic movements and rifting of tectonically stabilised crust during the Palaeozoic. The movements became evident from the beginning of Palaeozoic and continued until the Upper Cretaceous when the opening of the Goa Trench was achieved (Kogbe, 1978; Obaje et al., 2004). The Sokoto Basin is located in the North-western part of Nigeria, it covers the present day Kebbi, Sokoto, and Zamfara States. The Basin is dominated by gently undulating plain attaining an average elevation varying from 250 to 400 m above sea-level. The sediments of the Sokoto Basin were accumulated during four main phases of deposition. The overlying continental Gwandu Formation forms the Post-Paleocene Continental Terminal. These sediments dip gently and thicken gradually towards the northwest, with a maximum thickness of over 1,200 m near the frontier with Niger Republic. Throughout the study area, the Tertiary marine sediments of the Sokoto Group are overlain

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disconformably by a thick series of deposits consisting predominantly of red and mottled massive clays, with sandstone intercalations. These sediments belong to the Gwandu Formation, with the type section and the type area in the Gwandu Emirate of Kebbi State (Kogbe, 1972). Outcrops of the formation cover almost 22,000 km^2 in parts of the Sokoto Basin. These sediments also outcrop extensively in Niger Republic and northern Benin Republic. The non-marine origin of the Gwandu Formation is certain, and the sediments can be correctly attributed to a continental environment (Kogbe, 1976; Obaje, 2009). The best outcrops of the Gwandu Formation occur around Birnin-Kebbi and Argungu. The sediments consist of massive white clays interbedded with coarse and medium-grained red sandstones and mudstones with occasional peat bands. The type section encountered in Kaoje area shows a typical lithologic characteristic of the Gwandu Formation. In the study area, the lateritic capping is a hard ferruginous sandstone layer which is easily eroded into a network of gullies. These are underlain by red sandy clays and white massive mudstones, which are invariably stained pale brown or pink. The mudstone with sandstone intercalations extends monotonously throughout the sections. The sands at the surface are quite red in colour, often showing colour banding and poor stratification. The mudstones often show a nodular structure with nodules suggestive of local turbulence in the depositional environment.

3 METHODOLOGY

3.1 Field work

Reconnaissance survey was carried out in the outskirts of Kaoje in identifying the occurrence of Kaolinite deposits and establishes the local geology of the area. In furtherance to this, a detailed and systematic sampling of the exposed Kaolinite outcrops were carried out at designated locations using handheld shovel and geological hammer as appropriate on the identified outcrops.Subsequently, three vertical representative profiles were selected from the kaolinite outcrop. Three (3) samples each weighing about 1.0kg were taken from each location at the vertical interval of two metres with the aid of a geological hammer. All the samples were labelled accordingly and put into sampling bags for subsequent laboratory analyses. The samples were dried and pulverised using clean agate mortar and pestle. The prepared samples were analysed for the geochemical composition and some physical (Granulometric) characteristics.

3.2 Physical analysis

Kaolinite samples were taken from the various sites for particle size analysis. The samples were ground into powder and passed through 2 mm sieve. 50 g of the samples were weighed into different conical flask. 50 ml of 5% sodium hexametaphosphate was added along with 100 ml of distilled water. The mixture was stirred with a stirring rod and left to settle for 30 min. It was later stirred for 15 min with the multimixer machine and transferred to the glass cylinder where more distilled water was added to the 1000 ml mark on the cylinder. The top of the cylinder was covered with a lid and inverted several times until all the soil was in suspension. The cylinder was placed on its flat surface and the time was noted. Soil hydrometer was placed immediately into suspension, and the first reading on the hydrometer was taken 40 seconds after the cylinder settled down. The temperature was assumed constant throughout the first set of hydrometer readings. The second set of readings was taken when the suspension remained between two to three hours.

3.3 Geochemical analysis

Three different Kaolinite samples (K1, K2, and K3) were selected for X-ray fluorescence (XRF) spectrometry analysis. The samples were collected at an average depth of two metres from the top of the outcrop and at a regular spacing of a ten meters horizontally. Sample preparation, as well as major and trace element analysis were carried out by X-ray fluorescence spectrometry and instrumental neutron activation analysis as outlined in Gary (2008). Also, mineralogical investigations by X-ray diffraction were carried out as described by Bundy (1993), and Murray and Keller (1993).

4 RESULT AND DISCUSSION

4.1 Particle size distribution

The grain size distribution of Kaoje kaolinite (Table 1) shows a moderate proportion of clay and silt size particles (>46.3wt (%) passed through 0.75 μm sieve). Kaolinite grain size is an important parameter for assessing its suitability for various industrial applications. In this regard, the grain size of kaolinite determines its ceramic strength, shrinkage, and its glossiness (Aref and Lei, 2009). Also, Nyakairu and Koeberl (2001) stated that fine-grained minerals such as kaolinite are very important in the manufacturing of paper, pulp filler, and coatings. Furthermore, kaolinite is an essential material in pharmaceutical and ceramic Industries. Lastly, Heinskanen (1996) argue that the grain size of kaolinite ranges from between1μm - 50μm. Thus, the Kaoje kaolinite deposits falls within this category and could be useful specifically in the ceramic and paper industries.

Table1 *Particle size distribution of Koko Kaolinite samples*

Sieve size (mm)	***Samples***			
	K1	**K2**	**K3**	**Mean**
2.36	99.2	97.6	100	98.9
1.18	95.2	92.0	97.6	94.9
0.600	90.2	84.4	93.6	89.4
0.425	34.2	76.8	38.0	49.6
0.300	77.0	68.0	78.2	74.4
0.212	65.4	58.0	67.0	63.5
0.150	53.4	47.4	55.0	51.9
0.075	47.0	41.8	50.2	46.3

4.2 Geochemical analysis

The results obtained from XRF as analysed for their major and minor element oxides (Tables 2, 3, and 4) showed that SiO_2 content for K1, K2, and K3 is 46.1%, 40.68%, and 49.2% respectively. This high silica content can be attributed to the abundance of quartz in the area. Also, Al_2O_3 content for K1 is 20.63%, K2 has 26.3%, and K3 has 24%. This distribution of Aluminium oxide content in the Kaolinite depends upon the intensity of kaolinisation. Thus, incomplete kaolinisation indicates lesser amount of kaolin minerals (Visser and Young, 1990; Sayin, 2007). The Fe_2O_3 content of the Kaoje kaolin ranges from 0.26 to 1.02% (K1 0.26; K2 0.80; and K3 1.02 percentage respectively). The concentration of Iron Oxide in the two locations (K1 and 2) is within the allowed limit while those in K3 exceeds the maximum allowed limit of 1% Fe_2O_3 (Highley, 1984). The presence of iron oxide in these kaolin deposits can be attributed to the breakdown of biotite and other ferromagnesian minerals of the source within the Gwandu Formation. Other constituents such as K_2O, CuO, Cr, Zr, As, and Ni occur in various proportions. Their concentration is insignificant in determining their industrial potentials. This trend is quite similar to other kaolin deposits of Northern Nigeria, Morocco, South-eastern Botswana and Georgia, USA (Ekosse, 2000).

Table 2 *Geochemical analysis of kaolinite K1*

Elements	*Concentration*	*Standard deviation*
Al_2O_3	20.63%	±0.06
SiO_2	46.11%	±0.17
K_2O	-	-
Fe_2O_3	0.80%	±0.45
CuO	0.41%	±0.02
Ca	-	-
Cr	295	±0.20
Zr	781	±0.23
Ni	027	±1
As	391	±2.11

Other values are in ppm

Table 3 *Geochemical analysis of kaolinite K2*

Elements	*Concentration*	*Standard deviation*
Al_2O_3	26.3%	±0.02
SiO_2	40.68%	±0.06
K_2O	0.26%	±0.01
Fe_2O_3	0.22%	±0.03
CuO	-	-
Ca	341	±25.5
Cr	-	-
Zr	234	±11.1
Ni	-	-
As	-	-

Other values are in ppm

Table 4 *Geochemical analysis of Kaolinite K3*

Elements	*Concentration*	*Standard deviation*
Al_2O_3	29.7%	±0.04
SiO_2	44.18%	±0.02
K_2O	0.24%	±0.03
Fe_2O_3	0.26%	±0.06
CuO	-	-
Ca	326	±12.4
Cr	-	-
Zr	221	±02.1
Ni	023	-
As	-	-

Other values are in ppm

Progressive weathering and kaolinisation processes lead to the decomposition of all minerals except quartz in the Kaoje kaolinite deposit. The decreasing trend of SiO_2 suggests an advanced stage of kaolinisation for the Kaoje kaolinite, as the solubility of quartz increases in an alkaline environment (Garbarino et al., 1994). The successive decrease in the SiO_2, Fe_2O_3, TiO_2, CaO, and K_2O concentrations indicates their potentials for higher mobility. The reduction in these oxides is compensated by enrichment in Al_2O_3. Also, during weathering and kaolinisation small amounts of other trace elements enter the kaolinite structure (Murray and Keller, 1993), and this enhances the colouring effect of iron in kaolins (Fischer, 1984). In the Kaoje kaolinite, iron occurs in the form of hydrated oxides adsorbed on small kaolin grains and in secondary iron minerals formed in during the weathering and kaolinisation processes. In small amounts, iron enters the kaolinite structure and replace aluminum in the octahedral layer (Murray and Keller, 1993). Furthermore, the occurrence of Ni, Cr, Zr and As in the kaolin samples can be attributed to the mobilisation of iron oxide. In this respect, race elements are liberated from primary structures during granite weathering and kaolinisation processes and are subsequently removed from the rocks. Additionally, Feng and Kerrich (1990) noted that Cr, Co, Ni, and Zr behave similarly during magmatic processes, but cautioned that they may be fractionated during weathering.

5 CONCLUSION

Compositional features and industrial application of Kaoje kaolinite was evaluated based on physical and geochemical characteristics of the deposit with the aim of determining their suitability as an industrial raw material. Thus, the study concludes that the Kaoje kaolinite deposit predominantly contains Al_2O_3 and Fe_2O_3, as well as other oxides occurring in trace amounts. Also, the findings of this study suggest that the Kaoje kaolinite can be utilised in the manufacture of ceramics, refractory bricks, paper, paint and plaster of Paris (POP). Therefore, the study recommends that more technical and financial inputs are required in exploring, mining and processing of the Kaoje kaolinite deposits in harnessing their full potentials for socioeconomic development of Kebbi state and Nigeria as a whole.

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