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ASSESSMENT OF KAOLIN DEPOSITS IN OGBADIBO AND OTUKPO LOCAL GOVERNMENT AREAS OF BENUE STATE USING NUCLEAR ANALYTICAL TECHNIQUE AND THEIR POSSIBLE APPLICATIONS IN INDUSTRY

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ABSTRACT

An assessment of the kaolin deposits in Ogbadibo and Otukpo Local Government Areas of Benue State, Nigeria**,** was carried out using X-Ray Fluorescence Spectrometry–Fundamental Parameter (XRF-FP)**.** This was to determine the elemental compositions and physicochemical characteristics and geological formation differences as well as their industrial suitability. Kaolin is versatile industrial clay which has found important applications in paper coating, ceramics, paints and plastics due to its high opacity, soft texture, and chemical inertness. Thus, knowledge of their composition as well as the purity and impurity concentrations would be of economic advantage to local industries which oftentimes import their raw materials. In addition, it will increase the economic base of the state. In this work four (4) kaolin samples were collected, oven-dried at 105°C, pulverized, homogenised, and pelletized with 15% boric acid binder and analysed at the National Steel Raw Materials Exploration Agency **(**NSRMEA), Kaduna. The results obtained revealed that silicon oxide (SiO_2) and aluminium oxide (Al_2O_3) were the dominant oxides in both locations, confirming kaolinite ($Al_2Si_2O_5(OH)_4$) as the major mineral phase.

Keywords: Aluminosilicate, Assessment, Lower Benue Trough, Feldspars, Kaolinite, Quartz, Stratigraphy

INTRODUCTION

Kaolin is a clay mineral that forms from the chemical weathering of rock rich in feldspars. It is a clay mineral with a soft consistency and earthly texture. It is easily broken and can be moulded or shaped, especially when wet. It is usually white, with occasionally red, blue, or brown colour. Kaolinite has a low shrink swell capacity, making it ideal for many industrial applications. Clay is an abundant fine textured earthly powder produced by weathering and breaking down granite and rocks. It is richly found in soil, sedimentary rocks and hydrothermal deposits (Ekpunobi, *et al.,* 2013). Expandable clay swells up when water is added to it, while non-expandable clay does not. The fundamental reason for the application of certain clay minerals is that their physical and chemical properties are dependent on their structure and composition. Clay and clay minerals are of economics values and have been found useful in manufacturing and environment industries where they serve as major raw materials in the making of ceramics, paint, paper plaster, pharmaceutical products etc. Other applications of clays include: cure of ulcers, for cleansing purposes, detoxification absorption, skin enhancement (cosmetics), agriculture due to its desirable properties and cure against dysentery and cholera (Industrial and medical applications of clay, ceramic, pharmaceutical, cosmetics, agriculture , dysentery, cholera; (Mpuchane, *et al.*,2008). Study reveals that they are good for the production of quality bricks. Clay material has high resistance to wear, high strength at high temperature, good chemical stability and good electrical insulation properties (Guggenheim and Martin, 1995). A clay material can be used to make a refractory material which is a material that will withstand high temperature sufficient to permit its uses in a furnace lining or heating. In addition, some organic pigments from kaolin absorb ultra violet light thereby preventing it from damaging the binder in paint information. Pigment is one of the essential components of paint and it serves three main functions which include the optical function, opacity and gloss [UV absorption and pigment function in pigment formation (Chark, 2013)]. Kaolin is primarily made up of kaolinite mineral (Hydrated aluminosilicate $Al_2Si_2O_5(OH)$), and can also contain various other minerals, such as muscovite, quartz (SiO_2), feldspar, anatase (Titanium dioxide TiO_2). The importance of Kaolin is remarkable as one of the most abundant clay rock in soil and sediments. Its properties are such that it interacts with other soil element to contribute to the mechanical stability of the soil column.

In Nigeria, there are kaolin deposits, but of particular interest in this work are the deposits at Ogbadibo and Otukpo Local Government Areas which have not been fully studied to determine their suitability in industrial manufacturing and economic values to the Country. In addition, some kaolin deposits have associated with them minerals which are very harmful to human beings. A typical example is the deposits at Kankara and Dutsima mine sites which have been found to contain Arsenic (Sani et al, 2024), a toxic element capable of causing cancer. Thus, there is need to investigate these deposits to establish the mineral composition of the mines as well as their economic values.

Some studies have been carried out by earlier workers as follows, Ali and Kadhal (2016) carried out the elemental composition and health benefits of kaolin in South Eastern Nigeria using X-Ray Fluorescence Analysis and observed that the kaolin was characterised with exceptional high concentration of Iron, Potassium, Aluminum and Magnesium. They concluded that continuous consumption of this can result to bioaccumulation and can also pose serious health hazard to its consumers. Although, researchers have studied kaolin using different techniques, however none of them applied XRF-FP. The XRF-FP is a good analytical spectrometer widely used for geochemical characterization because it provides powerful non-destructive and reliable analytical technique used to determine the elemental composition of a wide range of materials. It is non-destructive, minimal to no sample preparation, rapid results and high throughput, cost effectiveness, flexibility of Fundamental Parameters method. When compared with other nuclear analytical techniques, it stands out very well. For instance, while instrumental neutron activation analysis

(INAA) has higher sensitivity and is less matrix dependent, it requires a nuclear reactor and a long turnaround time. In addition, INAA is a generally more destructive than XRF-FP. Compared with PIXE, PIXE is more sensitive to light elements, is generally restricted surface analysis and is not portable. Furthermore, XRF-FP is a better choice to Inductively Couple Plasma Mass Spectrometry (ICP-MS) in that ICP-MS, though has higher sensitivity (in ppt), ICP-MS cannot be used for the analysis of solid samples and is a destructive method. So, XRF-FP stands out as a good choice. This work therefore is aimed at analysing the compositions of the kaolins from Ogbadibo and Otukpo LGA, their possible industrial applications as well as the health implications of their mining to both the miners and the inhabitants of the areas. Furthermore, the studies on kaolin in Owukpa in Ogbadibo LGA has not been documented in the literature.

MATERIALS AND METHODS

The Climate and Geology of Otukpo and Owukpo

Otukpo is a prominent town and Local Government Area (LGA) in Benue State, North-Central Nigeria, located between latitudes 7°05′N and 7°15′N and longitudes 8°05′E and 8°20′E. The area lies within the Lower Benue Trough, a major sedimentary basin in Nigeria that is well known for hosting significant deposits of kaolin and other industrial minerals (Location within the lower Benue Trough and mineral potential: Obaje, 2009). Climatically, Otukpo experiences a tropical wet and dry climate, typical of the Guinea savanna belt, with a rainy season from April to October and a dry season from November to March. The high humidity and prolonged rainfall during the wet season encourage deep chemical weathering, which plays a crucial role in the formation of kaolin deposits (Nwajide, 2013).

Geologically, the area is underlain by Cretaceous sedimentary sequences of the Southern Benue Trough, with igneous intrusions and weathered felsic rocks. Kaolin in Otukpo is predominantly of residual origin, resulting from the intense chemical weathering and hydrothermal alteration of feldspar-rich parent rocks such as granite and arkosic sandstones (Residual origin of kaolin from feldspar-rich rocks: Ekosse, 2010). Economically, kaolin from Otukpo is suitable for a variety of applications, including ceramics, paper coating, paint, and water treatment. However, beneficiation is often required to meet high-grade industrial specifications (Ekosse, 2010).

Owukpa is a rural community located in Ogbadibo Local Government Area of Benue State, Nigeria, positioned along the eastern margin of the Anambra Coal Basin (Owukpa geology and Anambra Basin stratigraphy: Obaje, 2009). Owukpa is located between latitude 7.25^0N to 7.35^0N and longitude 8.30^0E to 8.15^0E. It lies within the tropical Guinea savanna climatic zone, experiencing two distinct seasons: a rainy season from April to October and a dry season from November to March. The combination of high rainfall and warm temperatures facilitates deep chemical weathering, which can promote the formation of kaolin from feldspar-rich parent materials (Weathering potential for kaolinite formation in Owukpa: Nwajide, 2013).

Geologically, Owukpa is primarily known for its coal-bearing sedimentary formations of Cretaceous age, which are part of the larger Anambra Basin stratigraphy (Reyment, 1965; Obaje, 2009). While kaolin occurrences in the community have not been extensively documented in literature, the weathering of feldspathic sandstones and shale sequences in similar depositional environments elsewhere in Nigeria has been shown to yield residual kaolinite deposits (Ekosse, 2010). This suggests that the potential for kaolin in Owukpa exists and warrants systematic geological investigation.

Sample Collection and Preparation

A total of four (4) samples were collected from two (2) different locations each at a depth of 5 metres at the mine sites. The distribution of the kaolin deposits was considered to be evenly distributed in each of the two areas studied and as such 2 samples per location were considered a good representation of each deposit. Furthermore, the sample depth of 5 meter corresponds to the depth where the cluster was well established. The specific sample locations are Owukpa in Ogbadibo Local Government Area and Otukpo in Otukpo Local Government Area of Benue State. All samples were put in well labelled polythene bags at the point of collection. The coordinates of points of collection as read using Global Positioning System (GPS) are latitude 7.13 degree north and longitude 8.13 degree east for Otukpo, and latitude 7.19 degree north and 8.13 degree east for Owukpa.

The four samples were then re-bagged after removing impurities from them; they were then dried with oven at a temperature of 105 degree centigrade for 24 hours to remove moisture and then ground into fine and homogeneous powder using mortar and pestle. The homogeneous 6g samples were labelled and then taken to the National Steel Raw Material Exploration Agency (NSRMEA) laboratory for analysis.

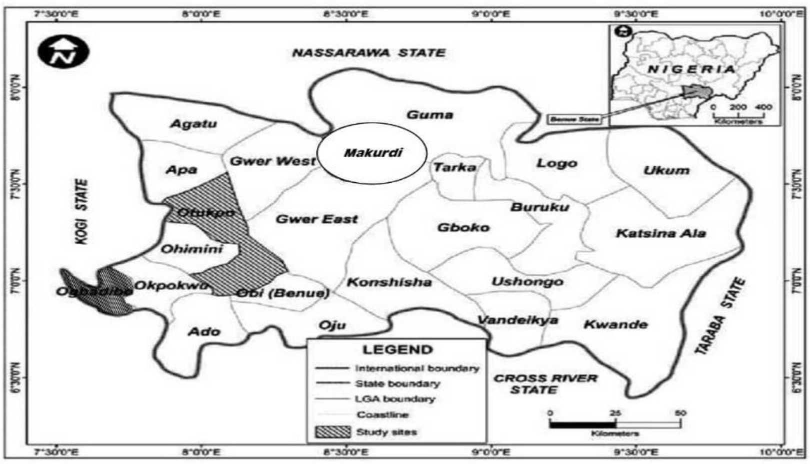

Figure 1: Map of Benue State, showing the Two different Local Government of Ogbadibo and Otukpo, in Relation to the Scope of the Study

Experimental Procedure for X-Ray Spectrometry-Fundamental Parameter

The X-Ray Fluorescence (XRF) spectrometer was calibrated using certified reference materials with compositions of major, minor and trace elements similar to kaolin. Calibration curves were prepared for major oxides like silicon oxide (SiO_2), aluminium oxide (Al_2O_3), iron oxide (Fe_2O_3), titanium dioxide (TiO_2), potassium oxide (K_2O), sodium oxide (Na_2O), magnesium oxide (MgO), and calcium (CaO).

The kaolin samples were oven dried, ground, and sieved to a particle sizes of 75 micrometer to ensure homogeneity. The homogenized 6 g samples were mixed with fifteen percent (15%/wt) of boric acid to form pellet of 32 mm diameter after they have undergone hydraulic press of 15 tons. During the pelletization 60 seconds was maintained as dwelled time to obtain stable and smooth pellets. The pressed pellet samples were then loaded into the X-Ray Fluorescence Spectrometer with operating conditions set as follows:

i. X-ray tube voltage: 40 KV
ii. Current: 30mA
iii. Atmosphere: Vacuum
iv. Detector type: Solid State Detector
v. Counting time: 30 seconds per sample

The composition of each of the samples was then determined by the X-Ray Fluorescence Spectrometer which gave the results of the major oxides, minor oxides and trace elements composition of the kaolin.

The analysis was carried out in triplicate for each sample to ensure accuracy and reproducibility. Data were processed using the instrument's built-in software, and elemental concentrations were expressed in weight percent (wt. %) for major oxides and parts per million (ppm) for trace elements. Data interpretation followed ASTM standard practices for XRF in clay materials (ASTM C114-18, 2018).

RESULTS AND DISCUSSION

The concentrations of the oxides obtained from our analysis are presented in Table 1 while in Table 2, we present the standard industrial concentrations of oxide found in the kaolin samples.

Table 1: The Concentration of Oxide Found in the Four Samples of Kaolin, wt. %

S/N	Oxide	Otukpo a1=a	Otukpo a2=b	Owukpa b1=c	Owukpa b2=d
1.	SiO_2	48.098	65.223	66.223	71.369
2.	V_2O_5	0.111	0.110	0.089	0.156
3.	Cr_2O_3	0.035	0.032	0.039	0.105
4.	MnO	0.027	0.028	0.021	0.033
5.	Fe_2O_3	23.421	9.348	7.880	1.404
6.	Co_3O_4	0.110	0.031	0.027	0.012
7.	NiO	0.000	0.002	0.002	0.004
8.	CuO	0.037	0.040	0.044	0.070
9.	Nb_2O_3	0.011	0.015	0.011	0.022
10.	WO_3	0.000	0.003	0.004	0.002
11.	P_2O_5	0.000	0.000	0.367	0.000
12.	SO_3	0.368	0.173	0.405	0.880
13.	CaO	0.236	0.144	0.244	0.202
14.	MgO	0.000	0.513	0.000	0.000
15.	K_2O	1.002	1.524	2.028	0.864
16.	BaO	0.059	0.027	0.084	0.041
17.	Al_2O_3	24.000	19.824	20.138	19.905
18.	Ta_2O_5	0.025	0.016	0.058	0.086
19.	TiO_2	1.844	2.079	1.328	3.229
20.	ZnO	0.009	0.003	0.009	0.002
21.	Ag_2O	0.011	0.026	0.031	0.021
22.	ZrO_2	0.107	0.295	0.380	0.501
23.	SnO_2	0.000	0.000	0.000	0.000

Table 2: Standard Industrial Concentration of Oxides in Kaolin

S/N	Oxides	Typical Range (%)	Significant / Role
1.	SiO_2	45—55	From Silica (Quartz or part of Kaolinite); main filler
2.	Al_2O_3	35—39	From kaolinite; key for ceramic and refractory uses
3.	Fe_2O_3	< 0.5 (usually < 1)	Needs to be low for whiteness
4.	TiO_2	< 1.5 (Ideally < 1)	Impacts whiteness and opacity in ceramics/paper
5.	K_2O	< 1	Alkalis; excessive level: reduce refractory quality
6.	CaO/MgO	< 0.5	Minor impurities; can affect firing properties

Table 1, shows that the two deposits at Owukpa and Otukpo contain major oxides SiO_2 (with values lying between 65 and 71 wt,% at Owukpa and between 48 and 65 wt.% at Otukpo) and Al_2O_3 (with concentrations lying between 19 and 20 wt.% at Owukpa and between 20 and 24 wt.% at Otukpo). From table 2 which contain the standard industrial concentration of oxides in kaolin, the values of these two oxides should lie between 45 and 55 wt.% for SiO_2 and 35 to 39 wt.% for Al2O3. This implies that the concentration of SiO_2 in Owukpa deposits exceeds the requirement for industrial application while that from Otukpo is marginally within the tolerable limits. For Al_2O_3 the concentrations from the two deposits are below the range of values required. This could be as a result of the direct consequence of its sedimentary origin and the intense tropical weathering history of the region. This chemical profile reflects the incomplete kaolinization of parent material, significant contamination from nearby quartz-rich sources, and transportation/deportation processes. (Omang *et al*, 2019). For the minor oxides Fe_2O_3, the concentrations in Owukpa between 1and 8 wt.% while at Otukpo it is between 9 and 23 wt.% which are beyond the limit. (<1). All the other minor oxides (with the exception of CaO, MgO) namely K_2O, and TiO_2, and a lot of trace oxides namely MnO, ZnO, SnO_2, CuO, NiO, WO_3, P_2O_5 SO_3 Cr_2O_5, V_2O_5, BaO, Ta_2O_5, Ag_2O and ZrO_2 all have values which exceed the acceptable limit. High quality kaolin is characterized by low levels of Fe_2O_3 and TiO_2. The remaining two minor oxides CaO and MgO have less than 0.5 as required.

Table 3: Overall Ranking of Industrial Applications of Owukpa and Otukpo Kaolins

Rank	Sample	Location	Best Industrial Application	Reason For Ranking
1st	D (Owukpa B2)	Owukpa	Paint, Plastic, Rubber, Catalyst/Electronics	Highest TiO_2 (3.23), highest ZrO_2 (0.501), lowest Fe_2O_3 (1.404); excellent for advanced and high-tech uses.
2nd	C (Owukpa B1)	Owukpa	Paper and Ceramics	Balanced SiO_2 (66.22) and Al_2O_3 (20.14), relatively low Fe_2O_3 (7.88) and TiO (1.33); best for whiteness and quality product
3rd	B (Otukpo A2)	Otukpo	Cement Production	Presence of MgO (0.513) and moderate Fe_2O_3 (9.35); suitable for cement formulation
4th	A (Otukpo A1)	Otukpo	Metallurgical Uses	Very high Fe_2O_3 (23.42); suitable for iron related applications but poor for high-quality industrial uses

Owukpa kaolin (C and D) rank highest overall due to their lower Fe_2O_3 which gives better brightness and purity, higher SiO_2 for improvement of strength and quality and presence of valuable trace elements (ZrO_2 and TiO_2). Otukpo kaolin (A and B) rank lower because of high Fe_2O_3 especially sample A which can reduces suitability for paper and ceramics.

Discussion

The results obtained (Table 1) shows that Otukpo A1 is more aluminous (24.00 wt.% Al_2O_3) and ferruginous (23.42 wt.% Fe_2O_3), and that may affect its thermal behaviour and suitability in ceramic applications. On the other hand, Owukpa B2 shows the highest silica content (71.37 wt. % SiO_2) and the lowest iron oxide content (1.40 wt. % Fe_2O_3), indicating a purer kaolinite quartz-rich composition, favourable for refractory or paper-grade clay uses.

Potassium-bearing phases such as muscovite and /or feldspar are more pronounced in Owukpa B1 and Otukpo A2, suggesting a moderate level of fluxing minerals. The presence of transition metal oxides (example CuO, MnO, and Co_3O_4) in minor quantities across all samples point to the fact that there are trace mineral impurities which can influence the clay colour upon firing.

Possible Industrial Applications

Paper and Ceramics Application

Kaolin used in paper and ceramics production should have high SiO_2 and Al_2O_3 contents and low Fe_2O_3 and TiO_2 contents for brightness and purity. Excess amount of Fe_2O_3 or TiO_2 often degrade whiteness, making the clay less desirable for paper and ceramics but useful in cement or catalyst substrates (Obada *et al*., 2015). In table 4, we present the comparative results of the four kaolin samples for paper and ceramics making.

Table 4: Samples and their Suitability for Paper and Ceramics

Sample	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	TiO_2 (%)	Suitability
A	48.10	24.00	23.42	1.84	Too high Fe_2O_3
B	65.22	19.82	9.35	2.08	Moderate
C	66.22	20.14	7.88	1.33	Suitable
D	71.37	19.91	1.40	3.23	Good SiO_2, low Fe_2O_3, but high TiO_2. It is suitable

From Table 4, the best deposit for paper and ceramics is sample C which is kaolin from Owukpa B1 because it has high SiO_2, good AlO_3, Fe_2O_3 and TiO_2 concentrations.

Paint, Plastics and Rubber Application

Kaolin used in paint, plastics and rubber industries should have moderate or high TiO_2 for whitening and presence of ZnO, BaO, CaO, and K_2O.

Table 5: Sample and the Suitability for Paint, Plastics and Rubber

Sample	TiO_2 (%)	ZnO (%)	BaO (%)	K_2O (%)	CaO (%)	Suitability
A	1.84	0.009	0.059	1.00	0.236	Basic grade
B	2.08	0.003	0.027	1.52	0.144	Better K_2O
C	1.33	0.009	0.084	2.03	0.244	Best K_2O + BaO
D	3.23	0.002	0.041	0.86	0.202	High TiO_2

The results of their comparison are presented in Table 5, which shows that the best sample for making paints/plastics/rubber is sample D which is kaolin from Owukpa B2 because it has high TiO_2, however sample C which is kaolin from Owukpa B1 is also good because it has good K_2O and BaO values.

Catalyst and Electronics Applications

The key oxides for catalyst and electronics applications are V_2O_5, Nb_2O_2, Ta_2O_5, ZrO_2, WO_2 and TiO_2.

Table 6: Sample and the Suitability for Catalyst and Electronic Applications

Sample	V_2O_5 (%)	Nb_2O_3 (%)	Ta_2O_5 (%)	ZrO_2 (%)	WO_2 (%)	Suitability
A	0.111	0.011	0.025	0.107	0.000	Basic potential
B	0.110	0.015	0.016	0.295	0.003	Moderate
C	0.089	0.011	0.058	0.380	0.004	Good
D	0.156	0.022	0.086	0.501	0.002	Best (Highest in all except WO_2)

Kaolin clays have gained increasing relevance in advanced material applications due to their ability to host trace oxides with catalytic and electronic functionalities. Key amongst these oxides are vanadium pentoxide (V_2O_5), niobium oxide (Nb_2O_5), tantalum pentoxide (Ta_2O_5), zirconium oxide (ZrO_2), tungsten oxide (WO_2), and titanium dioxide (TiO_2). These oxides are known for their high dielectric properties, redox activity, and thermal stability (Christi, G. E, 2011). To assess the suitability of each kaolin sample (A–D) for such applications, Table 6 summarizes the concentrations of these oxides and their corresponding suitability ratings. This shows that Owukpa (B2) is the best followed by Owukpa (B1).

Metallurgical and Cement Use

For metallurgical and cement uses, the oxides needed are Fe_2O_3, MnO, MgO, CaO, and SO_3. Kaolin clays, while traditionally associated with ceramics and refractories, can also play significant roles in metallurgical and cement manufacturing processes depending on the presence and concentration of certain oxides. The oxides of major relevance to these applications include ferric oxide (Fe_2O_3), manganese oxide (MnO), magnesium oxide (MgO), calcium oxide (CaO), and sulfur trioxide (SO_3). (Role of Oxides in cement and metallurgy: Murray, 2007).

Table 7: Sample and the Suitability for Metallurgical and Cement Uses

Sample	Fe_2O_3	MnO	MgO	CaO	SO_3	Suitability
A	23.42	0.027	0.000	0.236	0.368	High Fe_2O_3
B	9.35	0.028	0.513	0.144	0.173	Good MgO
C	7.88	0.021	0.000	0.244	0.405	Moderate Fe_2O_3
D	1.4	0.033	0.000	0.202	0.880	Low Fe_2O_3

To evaluate the metallurgical and cement potentials of the four kaolin samples, Table 7 presents the relevant oxide contents and suitability ranking. From this ranking sample A (Otukpo 1) is the best followed by sample B (Otukpo 2).

Table 8: Chlorine Concentration in Oxide and Element

Sample	Site	Cl (Oxide Mole)	Cl (Element Mole)
A	Otukpo A1	0.486	55.418
B	Otukpo A2	0.541	67.655
C	Owukpa B1	0.589	71.240
D	Owukpa B2	1.092	94.885

From Table 8, Owukpa samples, especially sample D, show the highest chlorine concentration. (see also Appendix A) The presence of chlorine in kaolin samples, Table A in Appendix, particularly in Owukpa B2, is significant and impacts both processing safety and end-use suitability. While it does not rule out their usefulness, it requires additional purification steps and limits high value industrial applications without treatment.

Possible Origins of Chlorine in the Kaolin Deposits

The presence of chlorine in kaolin deposits is usually minor, but it can provide useful Information about the geochemical history, environment of formation, and post-depositional processes of the clay. The possible origins of chlorine in kaolin deposits include: Marine influence (Sedimentary origin), hydrothermal fluids, weathering of chlorine-bearing minerals, groundwater and Surface water contamination, evaporate association, anthropogenic (human induced) sources and Fluid inclusion and adsorption mechanisms.

Implications of Chlorine in Processing Industries

The presence of chlorine in kaolin deposits has significant implications for industrial processing, primarily through equipment corrosion, reduction in product quality, environmental concerns, and increased processing cost. Although, chlorine can be used internationally to bleach kaolin, its unwanted presence generally acts as an impurity which can promote severe equipment corrosion and this will require complex removal techniques. In addition, it will posse potential health risk because of the creation of toxic chlorinated byproducts. Thus, although chlorine is not structurally bound in kaolinite, it acts as a deleterious impurity, particularly in high temperature and high-purity applications, necessitating careful control and removal during beneficiation.

CONCLUSION

Comparative features and industrial applications of Ogbadibo and Otukpo Local Government Areas of Benue State kaolin clay were analysed based on the elemental composition of each of the kaolins. The four deposits contain significant amounts of SiO_2 and Al_2O_3, confirming the presence of kaolinite and quartz, which are typical of high-quality kaolin deposits. Sample C (Owukpa B1) and Sample D (Owukpa B2) show higher SiO_2 and lower Fe_2O_3, making them more suitable for paper, ceramics, and coating applications where brightness and whiteness are critical, however, they also have high chlorine content which could pose health hazard. This work shows that Owukpa samples (C and D) have overall better industrial quality in terms of oxide balance, purity, and versatility across multiple sectors. The dominance kaolinite as the principal mineral phase further contributes to its desirable physicochemical properties, including low shrink-swell capacity, good plasticity, and chemical inertness. Government should ensure that environmental impact assessments be done before large scale kaolin mining or processing in area with

Chlorine or Iron content. Therefore, the Owukpa kaolin deposit in Ogbadibo holds significant economic potential and can serve as a viable raw material for both local industries and export purposes if properly processed and beneficiated.

REFERENCE

Adewuyi, O. I. (2015). Analysis of kaolin deposit in Nigeria, Academic Research Work, afribary .com

Ajanaku, K. O., Olanrewaju A., and Swapan, K. D. (2016) Oriental Journal of Chemistry. 32 (3) 1571 -1582

Ali. H and Kasham, V. A. (2016). X-Ray Fluorescence Analysis (XRY) of Kaolin in the South Eastern Nigeria, Journal of Basic and Applied Research ISSN 2413-7014, vol. 2, 160-165.

Aliu, Okpo Jeminatu, Itiowe, Kiamuke and Avwenagha, Enivwenayi Oghenero (2021). Geochemical Composition, Mineralogy, Geotechnical Characteristics of Some Clay Deposits. Global Journal of Geological Sciences vol. 2021, 41-51

Baker, C. J. and Uren, R.E. (1982). Kaolin in New South Wales, Geological Survey of New South Wales 231

Balan E; Allard T; Bolzot B; Morin G; Muller J. P. (1999) Structural characterization of kaolinite and illite by Raman Spectroscopy. Clays and clay minerals (47)5, 605-613, https://doi.org/10.1346/CCMN.1999.0470512

Bassey, C. E., Ukaegbu, V. U., and Akpan, A. E. (2013) Geology and Occurrence of industrial minerals in the Lower Benue Trough, Nigeria. Journal of Geology and Mining Research, 5(3), 47-53. https://doi.org/10.5897/JGMR12.018

Benjamin, Odey Omang, Ayodele Owolabi, Ebenezer Agayina Kudamnya, Joseph O. Odey (2019) Characterization of Kaolin Deposits in Okpella and Its Environs, Southern Nigeria. International Journal of Geosciences 10, 312-327

Bernard J. H., Rost R, (1992) Encyclopaedic knowledge of clay Science 13(4), 293-306

Brindley, G. W., and Nakahira, M. (1959). The Kaolinite-Metakaolinite Transformation. Journal of the American Ceramic Society, 42(7), 314-318. https://doi.org/10.1111/j.1151-2916.1959.tb 13577

Churchman, G.J, Whitton J. S, Claridge G. C. C, Theng BKG (1984), Intercalation method using formamide for differentiating halloysite from kaolinite: Clays and clay minerals, v. 32, p. 241-248

Clack, M. D. T (2013) Paints and Pigments Review http://www.nzic.org.nzchemprocess/polymer/10D.pdf

Devidal, J, Dandurand, J and Gout, R (1996). Gibbs free energy of Czech Silikatovy Svaz, Praha, 443 pp.ed, John Willey and sons, Inc, New York, 681 pp

Ekosse, G. (2010). The origin, geochemistry and mineralogy of kaolinte clays of Camerroon, Nigeria and South Africa. Clay Minerals, 45(2), 111-127. https:doi.org/10.1180/claymin.2010.045.1.111

Ekpunobi, U. E., Duru, C. B., Ogbuagu, A. S. and Obumsel, E. O. (2013) Analysis and Characterization of clay deposits in Idemili River, South Eastern Nigeria, Pelagia Research Library, Der Chemica Sinica, 4, 6-9.

Frost, R. L (1998), Hydroxyl deformation in kaolin, Clays and Clay Minerals. Cambridge University Press 46 (3) 280-289

Grim, R. E. (1968), Clay Mineralogy (2nd ed.), McGraw--Hill.

Guggenheim, S. and Martin, R. T. (1995) Definition of Clay and Clay Mineral: Joint report of AIPEA Nomenclature Committees, Clays Clay Miner 43: 255-256 DOI: 1346/CCMN.1995.0430213

Ike, C. D., William, G., Igboko, N., Kenneth, O., Birol, O. and Mohammed, M. R., (2021) Faisal Islam Chowd, Journal of Applied Science and Process Engineering Volume 8 Number 2.

Inegbenebor, A. I., Inegbenebor, A. O., Mordi, R. C., Kalada, N., Falomo, A. and Sanyaolu, P (2016) Determination of the Chemical Compositions of Clay Deposits from Some Part of south West Nigeria for Industrial Application. International Journal of Applied Science and Biotechnology, Volume 4 (1): 21-26.

Mitchell, J. K. (1993), Fundamental of Soil Behaviour 2nd ed. Wiley, New York.

Moore, D. M and Reynolds, R. C., (1997), X-ray Diffraction and Identification and Analysis of Clay Minerals. 2nd Edition, Oxford. (Oxford University Press, New York), 378 P.

Mpuchane S., G., Ekosse, B., Gashes, I., Morobe and Coetzee S. (2008) Mineralogy of Southern African Medicinal and Cosmetic Clays and their Effects on the Growth of Selected test microorganism. Fresen Environ. Bull. 15:547-557.

Murray, H. H. (2007) Applied clay mineralogy, occurrences, processing, and application of kaolins, bentonites, palygorskite-sepiolite, and common clays, developments in clay science, 2, 1-177.

Obada, D. O., Oke, S. A., and Oyetunji, A. (2015) Characterization and Evaluation of Selected Kaolin Clays in the Lower Benue Trough, Nigeria. Nigerian Journal of Technology, 34(2), 360-365.

Obaje, N. G (2009) Geology and mineral resources of Nigeria. Springer. https:doi.org/10.1007/978-3-540-92685-6

Oboh, I. O., and Ighalo, J. O. (2020) A Comprehensive Review of the Applications of Kaolin as a Green and Sustainable Adsorbent, Journal of Cleaner Production, 275, 123367 https://doi.org/10.1016/j.jclepro.2020.123367

Olusola, J. O., Suraju, A. A. and Nurudeen, A., (2024), Geochemical and Mineralogical Studies of Kaolinitic Clays in Parts of Ilorin, Southwestern Basement Rock Area, Nigeria. University Journal of Geosciences 2 (7): 212-221.

Reyment, R. A. (1965). Aspects of the geology of Nigeria: The stratigraphy of the cretaceous and Cenozoic deposits Ibadan University Press.

Skoog, D. A., Holler, F. J., and Crouch, S. R. (2018). Principles of Instrumental Analysis (7th ed.). Cengage Learning.

Spark, K. M., Johnson, B. B., Wells, J. D (1995) Characterizing trace mental adsorption on oxides oxyhydroxides, European Journal of Soil Science. Volume 46, Issue 4, P. 621-631

Suraj G., Iyer, C. S. P., Rugmini, S., Lalithambika, M., (1998). Adsorption Structure at 1.5 k, Clays and Clay Mineral 41, 738-744

Umar, I. M., Bamidele, R. A. and Olasunkanmi, A. O. (2019). Industrial potential of kaolin selected deposits in Nigeria. International Journal and Engineering Research, 10(5), 456-465.

Willard, H. H., Merritt, L. L., Dean, J. A., and Settle, F. A. (1988). Instrumental methods of analysis (7th ed.) Wadsworth Publishing.

APPENDIX

Table 9: The Concentration of Elements Presents in the Sample (ppm)

S/N	ELEMENT	OTUKPO A1=A	OTUKPO A2=B	OWUKPA B1=C	OWUKPA B2=D
1.	O	0.000	0.000	0.000	0.000
2.	Mg	0.000	0.132	0.000	0.000
3.	Al	47.698	51.464	52.132	40.281
4.	Si	385.424	678.759	679.811	560.614
5.	P	0.000	0.000	7.419	0.000
6.	S	12.487	6.438	14.624	23.011
7.	Cl	55.418	67.655	71.240	94.885
8.	K	150.337	247.706	317.193	96.238
9.	K	46.516	30.341	49.102	29.684
10.	Ti	691.478	833.914	507.489	892.013
11.	V	53.359	56.650	43.298	55.071
12.	Cr	25.444	25.427	29.631	55.320
13.	Mn	24.581	30.245	22.252	24.809
14.	Fe	21453.030	10655.360	8836.016	1177.336
15.	Co	126.629	44.599	37.508	13.042
16.	Ni	0.000	2.101	3.066	4.645
17.	Cu	34.885	63.051	70.375	104.148
18.	Zn	9.727	5.830	15.998	3.499
19.	Zr	90.478	425.889	559.902	687.309
20.	Nb	8.8777	20.829	16.014	28.846
21.	Ag	0.968	3.974	4.742	2.921
22.	Sn	0.000	0.000	0.000	0.000
23.	Ba	8.140	4.006	11.809	4.220
24.	Ta	6.716	7.302	26.489	36.486
25.	W	0.000	1.515	1.802	1.060