



Reserve Estimation and Assessment of Industrial Properties of Werram Kaolin Deposit, Plateau State, North Central Nigeria

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Abstract

Werram is a small community in the Jos Plateau State of Nigeria. The area is underlain by Cenozoic basaltic lavas. *In situ* decomposition of the basaltic lavas have formed a sedimentary kaolin deposit under study. An area of 8.2 hectares was chosen for a detailed geological investigation based on the result of an earlier reconnaissance survey. The objectives of the study were to estimate the kaolin reserve and investigate the potential industrial applications particularly in the ceramic industry. A total of 20, 6-inch boreholes were carefully sited on a 100m² grid. The drilling was undertaken by 2 Banka drill teams supplied by the defunct Nigerian Mining Corporation. The proven reserve is 1.57 million cubic metres. Generally, the kaolin occurs as light grey with variable iron oxide stainings. The samples had fired colours ranging from shades of white to shades of red at the maximum temperature of 1000°C. The average loss on ignition recorded is 12.06±5.57%. This attested to the inorganic nature of the kaolin thereby making it a good ceramic raw material. The average silica and alumina content obtained from the analysis are (51.77±14.70%) and (24.38±11.24%) respectively. The fluxing oxides (Fe₂O₃+MgO+CaO+Na₂O+K₂O) content in the kaolin is 8.78%. This is against the average value of 15 for some clays. The low flux value gives the clay a refractory behaviour which is an advantage in ceramic products. The clay has a low plastic limit (21.55±10.73) which will impact on its low drying and firing shrinkages. These values meet the requirements in the ceramic industry.

Keywords: Kaolin, Reserve, Natural colour, Fired Colour, Plasticity, Firing shrinkage, Loss on Ignition

1.0 Introduction

Kaolin minerals occur widely as products of hydrothermal alteration and weathering and as constituents of sediments. Kaolin is composed mainly of kaolinite, Al₄(OH)₈[Si₄O₁₀], and other related clay minerals such as nacrite and dickite (Baker and Uren, 1982). They have been reported from weathered rocks of various geologic ages. Their distributions, modes of occurrence and properties have been the subject of many studies. These minerals are important raw materials for the ceramic, paper, cosmetic, pharmaceutical and other industries. Kaolinites are commonly altered rocks related to young volcanic activities (Togashi and Fujii, 1972). The economic importance of kaolin minerals has been discussed (Fujii, 1976; Eze, 2015). Each industrial application of kaolin requires some specific properties.

1.1 Location and Geology of the area

Werram lies about 54 kilometres south of Jos in Plateau State of Nigeria. It is situated along Jos-Akwanga express road. The area is bounded by latitudes 9° 34' and 9° 37'N and longitudes 8° 47' and 8° 50'E. Access to the deposit from the all season asphalt road is by an 11km laterite road. Even without definite roads, access to the kaolin deposits could be made on conventional four-wheel drive vehicles through the savannah grasses. Werram has the characteristic topographic features of a plateau; the terrain is generally flat with flat-topped hills overlain by thick cap of resistant iron stones. The average altitude of the area is about 1,300m. The area that witnessed the Cenozoic volcanism and the rock type is represented by the Fluvio-Volcanic series consisting of basaltic lavas (Falconer *et al.*, 1926). Two main basaltic subtypes have been distinguished based on their periods of emplacement

and textural differences. They are termed as the Older (Tertiary) and the Newer (Quaternary) Basalts (MacLeod *et al.*, 1971; Lar and Tsalha, 2005). The basaltic lavas have been altered to variegated pink to white clays to a depth of as much as 50m in some places. Basaltic lavas capped by lateritic ironstone form some isolated flat-topped hills known as Werram Hills (Wright, 1971). Relict structures such as spheroidal weathering patterns and amygdalae are preserved in some places.

1.2 The Kaolin Deposits

Werram kaolin deposit is a residual formed from *in situ* decomposition of the older basalts, which were lavas now decomposed to clay. The lateritized older basalt are overlain by a thick cap of lateritic ironstone which form flat-topped hills in the environment. Hosterman (1960) has reported a kaolin deposit in Washington formed from basalt similar to the deposit in Werram, Plateau State. The deposit has well exposed sections due to previous mining of tin from alluvial deposit in the area. The exposed sections show the kaolin as a massive body overlain by a ferruginous top soil which constitute the overburden in all places.

Generally, the kaolin occurs as light grey to white with variable iron oxide stainings which resulted in the colouration of the kaolin in some places. Relict structures and textures of basaltic lavas such as spheroidal weathering patterns, amygdalae and feldspar laths (both now pseudo morphed by white kaolinite) are preserved in some places. Relicts of the basalt bombs are represented by round kaolin pods which occurs sporadically within the deposits.

2.0 Method of investigation

Some 27 hectares of suspected mineralized area were investigated at the reconnaissance survey level on an initial grid of 400m × 400m using banka drill crews. Based on the results of the reconnaissance survey an area of 8.2 hectares was delineated for detailed study. Banker drilling was executed on a grid of 100m × 100m to determine the thickness and areal extent of the mineralization with a view of estimating the reserve. The drilling was undertaken by 2 banka drill teams supplied by the defunct Nigerian Mining Corporation. The deposit was divided into two blocks coded Werram I and

Werram II for operational convenience of the two banka drill teams. Banka drilling was considered sufficient tool for the exploration more so as unskilled labour was readily available in the area. This type of drilling has been found suitable for the prospecting of shallow alluvial ore deposits and tailings, bauxite and lateritic iron ore. The use of drill casings made it possible for the most valuable information to be obtained from the bore hole.

A casing was fitted with a casing shoe, placed in a shallow hole in the ground and fitted with a working platform for the drillers on top of the casing. The entire system was then rotated slowly by another set of men. In this way, the casing was forced down by a combination of the weight of the platform, the jerking movement of the drilling tool, and the reduction of friction resulting from the rotation of the casing. A bailer was used to remove the sample from the casing and for obtaining accurate samples that was ensured by not allowing the end of the bailer to go below 20cm above the casing shoe. Each hole was drilled to at least one metre below the base of pure kaolin. Free and representative samples were collected at intervals of 0.5m or at every noticeable change in physical characteristics. Bulk samples were analyzed for plasticity, fired colour and chemical constituents.

3.0 Results and Discussion

3.1 Reserve

The drilling campaign showed that the deposit is laterally homogenous but grades into the parent rock with purity decreasing with depth. The overburden is very variable in thicknesses and typically consists of dark brown lateritized topsoil, and underlying this overburden in many places, is a thin layer of slightly lateritized mottled purple-red clay. This layer which was also classed as part of the overburden often contains lenses of kaolin and usually grades into the massive kaolin. Contacts between the overburden and the kaolin are usually gradational. The overburden is as high as 24m in some places, but generally, the average thickness is about 2m in Werram I and 1.5m Werram II. Werram I and Werram II have average kaolin thicknesses of 8.00m and 6.00m respectively and stripping ratio of 0.25 for each block (Table 1). A total of 1.5 million cubic metres of kaolin is proven for the Werram deposit.

Table 1: Proven Reserve of Kaolin in Alkalari

Block	Area (hectares)	Average Overburden (m)	Average Kaolin Thickness (m)	Stripping Ratio	Reserve (m ³)	Reserve Classification
Werram I	6.8	2.00	8.00	0.25	136,5440	Measured
Werram II	1.4	1.50	6.00	0.25	210,840	Measured
Total	8.2				1,576,280.00	Measured

3.2 Natural and Fired Colour

Colour is one of the factors that determine the market value of ceramics and in some cases it may be considered more important than the quality of the ceramics. The natural and fired colours were expressed in the Munsell Colour Chart to expressed the values of the hue, value and chroma; the three variables that combine to give the colour. The clay natural colour affects the appearance of the finished ware. The metallic oxides present in the clay affect the colour of the clay. Most important among the oxides is iron oxide. Iron oxide occurs in many natural forms which include magnetite (Fe₃O₄), hematite (Fe₂O₃), limonite (Fe₂O₃.xH₂O), goethite (Fe(OH)₃), ferrous oxide (FeO), pyrite (FeS₂), ferrous sulfate (FeSO₄.7H₂O) and siderite (FeCO₃), all of which can affect the colour of a clay body. Generally, the kaolin occurs as light grey to white, with variable iron oxide stainings which resulted in the colouration of the kaolin in some places.

Five bulk samples selected based on the colour variations in the field were fired to 110°C, 750°C, 850°C, 950°C and 1,000°C (Table 2). The fired

colour of clay is determined by the oxides, mostly iron oxide. The fired colour of clay may be different from the natural colour of the clay. Regardless of its natural colour, clay rich in iron burns red when exposed to an oxidizing fire, due to the formation of ferrous oxide (Khan, 1998). This trend was observed in some parts of the deposit represented by samples WS4 and WS5. Metallic inclusions such as iron or manganese often ‘bleed’ out from the body and into the glazes on the surface. Manganese dioxide can cause black/brown specking in the fired clay (Lawrence and West, 1982). The effect of other oxides on colour usually depends on their relative proportion to iron oxide. When ferric oxide is low (1-3%) and Al₂O₃ is up to 25%, there is a modifying effect by the alumina. With this combination, the fired colour is faint pink to white at a temperature of 1000°C (Worrall, 1986). This is true for kaolin from most parts of the deposit.

Other factors that affect ceramics fired colour are the specific oxides found in the clay and its percentage found in the clay body and the firing temperature. High iron content clay bodies fired to

Table 2: Natural and Fired Colour of Werram Kaolin

Samples	Natural Colour	750°C	850°C	950°C	1000°C
WS1	Light gray	Moderate Orange pink 10R 7/4	Moderate Orange pink 10R 7/4	Moderate Orange pink 10R 7/4	White N9
WS2	Very light gray	Very Pale Orange 10R 8/2	Very Pale Orange 10R 8/2	Very Pale Orange 10R 8/2	White N9
WS3	Light gray	Pale Pink 5RP 8/2	Pale Pink 5RP 8/2	Pale Pink 5RP 8/2	Bluish White 5B 9/1
WS4	Light gray	Light Brown 5YR 5/6	Moderate Reddish Orange 10R 5/6	Moderate Reddish Orange 10R 5/6	Moderate Reddish Orange 10R 6/6
WS5	Light gray	Pale Red 10R 6/2	Pale Red 10R 6/2	Pale Red 10R 6/2	Pale Red 10R 6/2

cone 012 (850°C) will appear light red/brown or dark pink in their fired color. The same clay body will darken considerably when fired higher to cone 01(1150°C) (Lawrence and West, 1982).

Karaman *et al.* (2006) established a relationship between the fired brightness colour component and the compressive strength of clay products. Dark and pink colours are generally stronger than light fired colour. The samples showed fired colours ranging from shades of white to shades of red at the maximum temperature of 1000°C

3.3 Plasticity

The plasticity and linear shrinkage results are presented in Table 3. One important distinguishing property of clays is their ability to develop plasticity when mixed with water. Plasticity may be defined as the property of a material, which permits it to be deformed under stress without rupturing and to retain the shape produced after the stress is removed. The method used in this study was to determine the liquid limit, plastic limit and plasticity index. Each clay mineral will show a range of values for water of plasticity since particle size, crystallinity of the clay mineral, and exchangeable cation composition also exert an influence on the plasticity.

Liquid limit is the value of moisture content at where an extremely small stress causes deformation. The liquid limit for Werram kaolin ranges from 50% to 95% with an average of $77.0 \pm 18.9\%$. This value is significantly higher than the average liquid limit of 49.54% of 20 ceramic kaolin samples reported by Dondi *et al.* (2008). High liquid limit value corresponds to high clay content which is a desirable characteristic of kaolin in most industrial applications.

The plastic limit is the value of moisture content just adequate for powdered clay to form a coherent mass. The plastic limit of Werram kaolin ranges from 9.64% to 33.15% with an average value of $21.55 \pm 10.73\%$. This is lower than the plastic limit of 36 recommended for good ceramic clays by Worrall (1986). Low plasticity implies low drying and firing shrinkages (Eichler, 2001).

Plasticity index (PI), is a measure of the range of moisture content over which the clay behaves plastically. Typical values of Atterberg's plasticity index for kaolinitic clays range from 5% to 22% (Fernando *et al.*, 2010). Grimshaw and Searle (1971) recommended plasticity index of 10-30% for ceramic clays. The high plasticity index ($55.8 \pm 9.4\%$) makes Werram kaoling an excellent ceramic clay. Similar high plasticity index is typical of mature residual and secondary kaolin deposits which are generally fine grained and less well crystallized, both features producing higher plasticity indices (Bain, 1971). This property tends to exclude a hydrothermal origin for the clay. The lowest plasticity indices are generally obtained from hydrothermal kaolin deposits where the clay is both coarse and well crystallized.

3.4 Firing shrinkage

Firing shrinkage is the reduction in length or volume, in percentage of a mass of shaped clay that takes place when the mass is fired at given temperature for at least five hours. Werram clay was fired at five different temperatures of 110°C, 750°C, 850°C, 950°C and 1000°C. The average linear shrinkage increased from 6.22% at 110°C to 8.22% at 1000°C. Chester (1973) recommended linear shrinkage range of 7-10% for refractory clays. The

Table 3: Plasticity and Linear Shrinkage

Samples	Plasticity			Linear Shrinkage				
	L.L	P.L	P.I	110°C	750°C	850°C	950°C	1000°C
WB1	95.00	33.15	61.85	5.56	6.67	6.67	6.67	8.89
WB2	50.00	9.64	40.36	5.56	6.67	6.67	6.67	6.67
WB3	75.00	17.15	57.85	4.44	4.44	4.44	6.67	6.67
WB4	95.00	32.67	64.33	11.11	12.22	12.22	13.33	14.44
WB5	70.00	15.16	54.84	4.44	4.44	4.44	4.44	4.44
Mean± STDev	77.00± 18.91	21.55± 10.73	55.85± 9.39	6.22± 2.79	6.89± 3.18	6.89± 3.18	7.56± 3.37	8.22± 3.82

relatively low firing shrinkage of Werram clay is beneficial in the ceramic industry. The clay will not undergo appreciable shrinkage and is therefore not likely to develop cracks even at very high temperatures. This property makes Werram clay suitable as prime ceramic raw material. Low linear shrinkage limits of less than 7% have been attributed to low feldspar or high quartz content (Eze, 2015).

3.5 Chemistry of the Deposit

Different authors have reported varying SiO_2 content for clays used in the various products in the ceramic industry. Chester (1973) reviewed the SiO_2 content of clays from five different ceramic companies and gave a range of value of 47-48%. Abubakar *et al.* (2014) recommended clays from Dabagi clay deposit in Kebbi State, Nigeria with an average SiO_2 of 64.50% for ceramic works. The mean value obtained from the analysis of five samples of Alkaleri kaolin is $47.99 \pm 6.12\%$ (Eze, 2015). The kaolin deposit in Werram is relatively rich in silica with an average of $51.77 \pm 14.70\%$ (Table 4) which is within the reported range of values for different industrial applications including ceramics (Table 4). In the presence of flux, the silica present in the clay will melt at a lowered melting point during firing to form glaze on the surface of ceramics.

The alumina content ($24.38 \pm 11.24\%$) of Werram clay falls within the range of 25-44% recommended for ceramics by Chester (1973). Clays having higher

percentage of alumina shrink considerably on firing (Ries, 2007).

A low iron content of less than 0.9% is necessary in order to achieve fired brightness at temperatures of 1000°C and above (Highley, 1984). The iron oxide content of $2.85 \pm 1.97\%$ in Werram kaolin may inhibit the kaolin from attaining brightness on firing. High level of iron oxide usually imparts reddish colour to clay when fired (which may however be attractive to some users).

Firing behaviour is mainly affected by the “fluxing oxides” ($\text{Fe}_2\text{O}_3 + \text{MgO} + \text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}$). The fluxing oxides content in the kaolin is 8.78% as against the average value of 15 for some clays. The low flux value gives the clay a refractory behaviour which is an advantage in ceramic products. High concentration of fluxing oxides impacts dark colour after firing. While some people want bright colour ceramics, others interpret dark colour as mark of durability.

3.6 Loss on Ignition

The average loss on ignition recorded is $12.06 \pm 5.57\%$. This attested to the inorganic nature of the kaolin thereby making it a good ceramic raw material. Bloodworth *et al.* (1993) put the loss on ignition value of ceramic-grade kaolin as 13.0%, 12.2% and 12.1% for three different samples studied. Loss on ignition (LOI) is a commonly used

Table 4: Chemistry of the Deposit

Samples	SiO_2 (%)	Al_2O_3 (%)	FeO_3 (%)	TiO_2 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)	L.O.I. At 950°C
WS1	51.6	31.91	1.88	1.01	1.26	0.45	0.02	0.2	11.2
WS2	48.4	30.29	3.97	1.74	1.05	0.61	0.04	0.13	13.3
WS3	39.6	35.51	6.26	1.73	1.05	0.3	0.16	0.17	13.8
WS4	44.6	37.5	1.72	1.4	0.77	0.4	0.07	0.02	13.3
WS5	55.4	27.56	1.33	1.67	0.91	0.5	0.02	0.04	10.7
WS6	51.4	27.4	2	3.1	2.24	0.2	0.26	0.09	11.5
WS7	84.4	6.64	0.39	1.97	1.96	0.6	0.18	0.04	3.2
WS8	62.6	20.78	1.32	0.4	1.68	2.62	0.94	1.16	6.6
WS9	51.06	21.68	4.22	3.1	1.68	2.62	0.7	0.65	12.2
WS10	28.6	4.51	5.43	1.06	31.5	1.21	0.63	0.2	24.8
Mean \pm STD ev	51.77 ± 14.70	24.38 ± 11.24	2.85 ± 1.97	1.72 ± 0.86	4.41 ± 9.53	0.95 ± 0.92	0.30 ± 0.33	0.27 ± 0.36	12.06 ± 5.57

method to determine the organic matter content of clay by oxidation at an elevated temperature in a muffle furnace by measuring the weight loss. Organic matter is oxidized at 500-550°C to carbon dioxide and ash (Heiri *et al.*, 2001).

4.0 Conclusion

The proven reserve of the kaolin deposit in Werram is not sufficient to sustain a large scale ceramic company for an economic life. It can however be used to augment any such industry located close to the larger deposits in the nearby Bauchi State. The average linear shrinkage, silica and alumina content, loss on ignition and plastic limit of the kaolin are considered good for a ceramic-grade kaolin. The kaolin can be studied in details for any other preferred industrial use outside ceramics.

References

- Abubakar, U. A., Birnin Y., Frauq, U. Z., Nom S. S. and Sharif, N. 2014, "Characterization of Dabagi clay deposit for its ceramics potential", *African Journal of Environmental Science and Technology* **8(8)**, 455-459.
- Bain, J. A. 1971, "A Plasticity Chart as an Aid To The Identification and Assessment of Industrial Clays", *Clay Minerals*, **9(I)**, 1-17.
- Baker, C. J. and Uren, R. E. 1982, *Kaolin in New South Wales*. Geological Survey of New South Wales: 231
- Bloodworth, A. J. Highley, D. E. and Mitchell, C. J. 1993, *Industrial Mineral Laboratory manual: Kaolin*. British Geological Survey *Technical Report WG/93/1*. Mineralogy and Petrology Series., Keyworth Nottingham, United Kingdom: 75.
- Chester, J. H. 1973, *Refractories, Production and Properties*. The Iron And Steel Institute: London, UK. **3-13**, 295-314.
- Dondi, M., Iglesias, C., Dominguez, E., Guarini, G. and Raimondo, M. 2008, "The effect of Kaolin properties on their Behaviour in Ceramic Processing as illustrated by a Range of Kaolins from the Santa Cruz and Chhubut Provinces, Patagonia (Argentina)", *Applied Clay Science* **40**, 143-158.
- Eze, C. L. 2015, "Geological Investigation of Alkalari Kaolin Deposit, Bauchi State, Nigeria and the Assessment of Its Ceramic Properties", *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)* **6(5)**, 346- 352.
- Eichler, A. 2001, "Tetragonal Y-doped zirconia: structure and ion conductivity", *Physical Review B*. **64**, 1-8
- Falconer, J. D., Raeburn, C., and Bain, A.D. 1926, "*The southern plateau tin fields*", Geological Survey of Nigeria, Bulletin, No. 9.
- Fernando A. A., Hazim, A. A. and Dachamir H. 2010, "Measuring and modeling the plasticity of clays", *Materials Research* **13(3)**, 1-6.
- Fujii N. 1976, "General review on kaolin clay deposits in Japan", *7th Sym. Genesis Kaolin, International Gorilla Conservation Programme Tokyo*: 1-16
- Grimshaw, R.W. and Searle, A. B. 1971, *The Chemistry and Physics of Clays and Allied Ceramic Materials*. Wiley-Interscience, California: 1024.
- Heiri, O., Lotter, A. F. and Lemcke, G. 2001, "Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results", *Journal of Paleolimnology* **25**, 101-110.
- Highley, D. E. 1984, *China clay*. Her Majesty's Stationery Office, London: 65.
- Hosterman, J. W. 1960, "*Geology of the clay deposits in parts of Washington and Idaho*", U. S. Geological Survey Bulletin, **1270**, 285-292.
- Karaman, S., Gunal, H. and Ersahin, S. 2006, "Assessment of clay bricks compressive strength using quantitative values of colour components", *Construction and Building Materials* **20**, 348-354.
- Khan M.A. 1998, "Brief summary of ceramic stains, test methods and applications", *International Ceramic Review* **47(5)**, 299 - 302.
- Lar, U. A. and Tsalha, M. S. 2005, "Geochemical Characteristics of the Jos Plateau Basalts, North central Nigeria", *Global Journal of Geological Sciences* **3(2)**, 187-193.
- Lawrence, G. W and West, R. R. 1982, *Ceramic Science for the Potter*. Chilton Book Co.; 2 edition: 297.
- Macleod, W. N., Turner, D.C., and Wright, E. P. 1971, "*The geology of the Jos Plateau*", Bulletin of the Geological Survey of Nigeria No. 32

- Ries, H. 2007, *Clays, Their Occurrence, Properties, and Uses - With Especial Reference to Those of the United States*. Carruthers Press: 528.
- Togashi, Y. and Fujii, N. 1972, "Study on the Itaya kaolin deposit, Yamagata Prefecture, Northeastern Japan", *Bulletin of Geological Survey, Japan*, **23**, 595-612.
- Worrall W. E. 1986, *Clays and Ceramic Raw Materials*. Springer Science and Business Media, New York: 239.
- Wright, E.P. 1971, "The Basement Complex", *Bulletin of the Geological Survey of Nigeria*, No. 32, 12-47.