

Characterization and Evaluation of the Refractory Properties of Kitibi Clay Deposits, Iwo, Southwestern Nigeria

Charles Adebayo Oyelami

charles.oyelami@fuoye.edu.ng

Federal University Oye Ekiti

Tesleem Olalekan Kolawole

Osun State University

Olamide Elizabeth Sanusi

Federal University Oye Ekiti

Adebayo Olaniyi Afolabi

Federal University Oye Ekiti

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Abstract

The properties of the Kitibi clay deposit were evaluated to determine its suitability for industrial applications. Twenty (20) samples were collected from excavation sites in Kitibi Village in Osun State. The characterization process included mineralogical, chemical, and geotechnical analyses using techniques such as X-ray Diffraction (XRD), X-ray Fluorescence (XRF), specific gravity, moisture content, particle size analysis, Atterberg limits, compressive strength, water absorption test, and bulk density. The results revealed that the liquid limit of the clays ranged between 38.3% to 53.7%, the plastic limit ranged between 19.7% to 25.7%, and the plasticity index ranged from 18.6% to 32.4%. The clays have high moisture content (7.9% – 18.4%), are well-graded, and exhibit medium to high plasticity, pointing to the presence of clay minerals like montmorillonite and illite. The engineering properties of the samples indicate that the samples have high porosity (11.59% to 14.44%), low void ratio (13.11% to 16.88%), and low compressive strength (0.96- 1.40N/mm²). The chemical composition of the clays is similar to that typical for kaolinite. However, the potassium oxide content is unusually high (3.21% to 5.55%). Mineralogically, kaolinite is the dominant clay mineral while smectite occurs in small amounts, and the non-clay mineral identified includes quartz, mica, feldspar, and sillimanite. The evaluation demonstrates that the clays meet the required standards for use in various industrial applications such as ceramics, bricks, landfill liners, and refractories in environments with low mechanical stress. The clays must also be washed before use to reduce the potassium oxide content.

INTRODUCTION

Clay is a fine-grained, naturally occurring material primarily composed of hydrous aluminosilicates, including kaolinite, illite, and montmorillonite (Kumari and Mohan, 2021). Clays are broadly classified into two based on the formation, residual clay bodies are products of intense *in situ* chemical weathering and hydrothermal alteration processes of parent over which they were formed. Transported clays (sedimentary in origin) are products of diagenetic and hydrothermal modification of rocks and their eventual deposition in favourable depositional sites ((Tong, 2000; Chatterjee 2009; Christidis 2011; Schroeder and Erickson 2014; Kogel 2014; Liu et al. 2021; Aromolaran and Adebayo, 2022). Its ultra-fine particle size (less than 2µm) and unique properties make it a significant component of the surface environment of the Earth. One of the key characteristics of clay is its plasticity when wet, allowing it to be molded and shaped, and its ability to harden upon drying or firing. This makes clay a versatile material for pottery, ceramics, and construction materials such as bricks and tiles. Different types of clay, including ball clay, fire clay, plastic clay, and kaolin, serve various industrial applications (Alexandra *et al.*, 2013). Due to its widespread use and importance, clay is considered one of the most significant earth materials.

Kaolinitic clays are especially valued because of their relatively low concentrations of fluxing oxides such as iron oxide (Fe₂O₃), potassium oxide (K₂O), and sodium oxide (Na₂O), which tend to reduce the fusion temperature of refractory materials. The presence of these impurities can significantly impair the thermal resistance and structural integrity of the clay at elevated temperatures (Singer & Singer, 1979). In addition to chemical composition, key physical and engineering properties; including bulk density, apparent porosity, linear shrinkage, permeability, and cold crushing strength, are essential parameters in determining the suitability of clay deposits for refractory use (ASTM, 2015; Norton, 1974).

The discovery and utilization of locally sourced raw minerals for industrial purposes have attracted greater attention in recent decades, especially in developing nations. The reliance on imported refractory materials in Nigeria has raised manufacturing costs and put more strain on the foreign exchange reserves of the country. As a result, considerable research has been focused on assessing the refractory appropriateness of native clay deposits (Akinyemi, 2000; Nwajagu, 1994). Many of these materials have promising refractory qualities, such as sufficient mechanical strength and thermal resistance, according to earlier research on Nigerian clay deposits from areas like Edo, Ekiti, and Kwara States (Folorunso *et al.*, 2014; Omowumi, 2001).

This paper therefore characterizes the Kitibi clay deposit in Osun State, southwest Nigeria, by investigating the mineralogical, chemical, and geotechnical properties of the samples to determine its suitability as an industrial raw material.

STUDY AREA

The study area is located in Egbedore Local Government Area of Osun State, and is geographically positioned between latitudes N 07° 42' 40" and N 07° 42' 38.7" and longitudes E 004° 21' 38.1" and E 004° 21' 32.1". It is accessible via the Osogbo-Iwo Road, which connects it to Osogbo, the state capital, located approximately 20km away. The topography of the area can be described as gentle characterized by rolling hills and valleys. The altitude of the area ranges between 150 meters and 300 meters above sea level. The topographical features of the area are shown in Fig. 1. The study area falls within the tropical savanna climate with distinct wet and dry seasons. The rainy season occurs between March to October, while the dry season and occasional Harmattan span from November to February (Oyelami *et al.* 2023). The total annual rainfall ranges between 1,200mm and 1,500mm with peaks in July and October. The annual temperature in Kitibi generally range from 22°C and 34°C throughout the year, with February and March being the hottest months before the onset of the rainy season (NIMET, 2019).

GEOLOGY OF THE STUDY AREA

Kitibi is mostly underlain by the crystalline basement complex of southwestern Nigeria, particularly the migmatite-gneiss-quartzite zone. Prominent lithologies include porphyroblastic gneiss, quartz schist, and quartzite complexes (Fig. 2). Geologically, the age of the rocks in the study area dates back to the Precambrian. The rocks have undergone intense weathering. The sampling points are rich in feldspar, quartz, mica (muscovite), tourmaline, and garnet.

METHODOLOGY

Clay soil samples were collected from existing excavation sites. A detailed flowchart outlining the methodology employed in this study is presented in Fig. 3. A total of 20 soil samples were gathered from the sampling points in Kitibi Village (sample reference KT).

The clay samples within the excavation sites tended to have variable physical properties like colour over short distances, prompting the collection of two (2) different samples (labeled a and b) from each point. Samples were sealed in carefully labeled plastic bags and prepared for transportation.

The clay samples were air-dried simply by atmospheric exposure for about two weeks prior to laboratory testing. Laboratory tests carried out were grouped into soil classification tests, geotechnical tests, and mineralogical tests. The classification tests include specific gravity, grain size distribution analysis and Atterberg limits. Geotechnical tests include compaction tests compressive strength, unit weight, porosity and CBR. All tests were carried out according to the British Standard BS 1377 (1990) procedures with little modifications where necessary. Chemistry and mineralogy were carried out using X-ray Fluorescence and X-ray Diffraction respectively.

RESULTS AND DISCUSSION

PHYSICAL/INDEX PROPERTIES

The results of the index properties are presented in Table 1, along with their corresponding specific gravities. The soils were classified according to the Unified Soil Classification System (USCS), which shows the Kitibi clays to be predominantly silty clays.

Soils from the study area have a high moisture content, which is consistent with the high porosity and low permeability of clays, implying that the samples can be easily molded into any shape (Ademila and Adebajo, 2017; Hassan, 1990). The soils are all well-graded. The number of fines (particle sizes < 0.075mm) ranges between 32.3% to 54.3% with an average of 41.5% (Fig. 4). According to literature, the clay samples can be utilized as barrier soils in landfills, and in brick making and pottery (Rowe et al., 1995; Benson et al., 1994; Daniel, 1993; Declan and Paul, 2003; Houben and Guillard, 1994; Delgado and Guerrero, 2006; Adebayo, 2013; Oyelami and Van Rooy, 2016a; Oyelami and Van Rooy, 2016b). The coarse particles (corresponding to sand and gravel particle sizes, > 0.075mm) content range between 45.7% and 67.7% with an average of 58.5%. The sand particles in the samples allow easy movement of water in the soil (Mitchell and Soga, 2005), making them suitable as base and sub-base materials in road construction, construction of embankments and levees, groundwater recharge system and filter layers.

Table 1 Index Properties of the Soil												
SAMPLE ID	MOISTURE CONTENT (%)	SPECIFIC GRAVITY	GRAVEL (%)	SAND (%)	SILT (%)	CLAY (%)	AMOUNT OF FINES (%)	AMOUNT OF COARSE (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX	LINEAR SHRINKAGE (%)
KT 1a	12.10	2.656	11.30	48.40	27.60	12.70	40.30	59.70	49.80	24.50	25.30	8.30
KT 1b	14.20	2.644	14.70	42.00	27.40	15.90	43.30	56.70	-	-	-	-
KT 2a	12.40	2.673	10.50	47.60	26.50	15.40	41.90	58.10	-	-	-	-
KT 2b	16.40	2.665	9.60	43.60	29.20	17.50	46.70	53.30	42.80	22.90	19.90	6.10
KT 3a	14.20	2.653	12.90	32.80	29.50	24.80	54.30	45.70	48.30	23.60	24.70	7.60
KT 3b	13.40	2.653	11.90	34.50	30.20	23.40	53.60	46.40	-	-	-	-
KT 4a	16.50	2.643	8.30	49.90	28.50	13.40	41.90	58.10	-	-	-	-
KT 4b	13.40	2.663	10.50	48.50	26.50	14.50	41.00	59.00	53.70	24.40	29.30	9.00
KT 5a	18.40	2.651	7.20	49.10	30.00	13.60	43.60	56.40	50.00	24.60	25.40	8.80
KT 5b	12.40	2.652	10.40	45.80	30.70	13.10	43.80	56.20	-	-	-	-
KT 6a	8.70	2.642	11.30	52.50	25.80	10.40	36.20	63.80	-	-	-	-
KT 6b	7.90	2.646	13.10	51.50	24.40	11.00	35.40	64.60	46.70	23.20	23.50	6.90
KT 7a	14.40	2.647	7.10	60.00	24.60	8.30	32.90	67.10	44.50	21.40	23.10	6.50
KT 7b	13.60	2.633	8.80	58.90	24.20	8.10	32.30	67.70	-	-	-	-
KT 8a	14.20	2.653	11.20	56.20	24.50	8.10	32.60	67.40	-	-	-	-
KT 8b	13.40	2.653	14.10	52.90	24.50	8.50	33.00	67.00	-	-	-	-
KT 9a	14.20	2.662	14.40	41.70	30.00	13.90	43.90	56.10	38.30	19.70	18.60	5.80
KT 9b	15.20	2.664	12.10	41.30	29.00	17.50	46.50	53.50	-	-	-	-
KT 10a	14.50	2.667	11.20	43.90	27.20	17.70	44.90	55.10	-	-	-	-
KT 10b	33.10	2.655	9.10	48.90	26.50	15.50	42.00	58.00	58.10	25.70	32.40	9.20

The moisture content for the samples range from 7.9% – 18.4% (Table 1). These high values are consistent with the high porosity and low permeability that is characteristic of clays (Ademila

and Adebajo, 2017), and indicate that the clay samples will be easy to mould into any shape

(Hassan, 1990).

The clay samples were classified according to the Unified Soil Classification System (USCS) showing samples to be predominantly silty clays. The clays samples for the study area are all well-graded according to the Fig. 4, which implies that they would be expected to have low porosity and permeability. Grain size distribution, porosity and permeability are important index properties of clays that determine their suitability for various applications, like refractory materials. It was observed that the amount of fines (clay and silt sized particles) ranged from 32.3% to 54.3% while the amount of coarse particles (sand and gravels) ranged from 45.7% to 67.5% (Fig. 4).

Other physical properties include the following ranges of consistency of representative samples: liquid limit ranges between 38.3% to 53.7%, plastic limit between 19.7% to 25.7% while plasticity index ranged from 18.6% to 32.4% (Table 1). The plasticity chart in Fig. 5 show that the soils are inorganic clays with majority having medium plasticity. These soils are therefore considered suitable for refractories and ceramics as their consistency values fall within the acceptable range given by Grimshaw (1971).

Declan and Paul (2003) stipulated that the liquid limit of clays used for barrier lining should be less than 90%. Thus, the soils are expected to exhibit low hydraulic conductivity and are suitable for use as barrier soils (Ademila and Adebajo, 2017). Soils generally used for brick making are typically characterized by a suitable combination of clay and silt content (Delgado and Guerrero, 2006, Oyelami and VanRooy, 2016a). This makes the samples suitable for brick making as their plasticity allows for easier shaping and molding during brick production. Kitibi clay samples are also suitable for geotechnical applications such as embankment filling.

The specific gravity of the clay soils falls within a range of about 2.633–2.673, with an average specific gravity of 2.654. Lambe and Whitman (1991) classified sands as materials with SG of 2.63–2.67, silts with SG of 2.65–2.7, clay and silty clay with SG of 2.67–2.9. The soils from the study area are silt and sand on the basis of their specific gravity. This indicates denser materials, which affect the loading condition and settling characteristics of the soil (Holtz and Kovacs, 1981).

ENGINEERING PROPERTIES

The engineering properties of the clay soils investigated during this study are summarized in Table 2. The table shows the engineering tests, such as porosity, compressive strength, dry unit weight, and water content of the clay samples. Porosity of the samples range from 11.59% to 14.44%, with calculated void ratios of 13.11% to 16.88%. Low porosity clays have porosity less than 40% and are typically more compact and have lower permeability; moderate porosity clays have porosity within the range of 40% to 50% and are common in many natural clay deposits; high porosity clays have porosity greater than 50% and have higher void ratios and are more permeable (Mitchell and Soga, 2005). On this basis, Kitibi clay samples are relatively low in porosity. This suggests that the clays are quite dense and do not allow passage of water, which helps to prevent water seepage and potential structural instability (Craig, 2004).

Table 2
Summary Table of the Engineering Properties of the Clay Samples

SAMPLE 1D	WATER CONTENT (%)	POROSITY (%)	DRY UNIT WEIGHT (kN/m ³)	COMPRESSIVE STRENGTH (N/mm ²)	VOID RATIO (%)
KT 1a	0.51	13.14	19.57	1.23	15.12
KT 1b	0.45	13.01	19.57	1.08	14.96
KT 2a	0.51	14.16	19.32	1.23	16.50
KT 2b	0.44	13.48	19.70	1.23	15.58
KT 3a	0.56	13.42	19.56	1.21	15.50
KT 3b	0.43	14.13	19.66	1.37	16.46
KT 4a	0.59	14.44	19.59	1.37	16.88
KT 4b	0.51	13.78	19.68	1.24	15.98
KT 5a	0.44	12.48	19.61	1.22	14.26
KT 5b	0.47	12.73	19.65	1.39	14.59
KT 6a	0.43	12.29	19.41	1.40	14.01
KT 6b	0.56	13.12	19.60	1.23	15.10
KT 7a	0.60	12.17	19.37	1.24	13.86
KT 7b	0.48	11.91	19.59	1.08	13.52
KT 8a	0.52	12.26	19.48	0.98	13.97
KT 8b	0.47	12.58	19.54	0.96	14.39
KT 9a	0.54	12.18	19.61	1.09	13.87
KT 9b	0.60	11.80	19.55	1.08	13.38
KT 10a	0.52	11.59	19.57	1.02	13.11
KT 10b	0.48	13.08	19.81	1.04	15.05

On this basis, the clays can be useful in applications like landfill liners, base material for construction, bricks, and ceramics making. There are various porosity ranges for refractory clays. Chester (1973) suggested an acceptable range of 10% to 30% porosity for refractory clays, while Grimshaw (1971) suggested a range of 2% to 30%. According to Shuaib-Babata et al. (2018), the lower the porosity, the easier the refractory gets warped. On this basis, the clays will make good insulators and last better as refractories in environments with low mechanical stress.

The compressive strength was determined after air and moisture curing. A summary of the compressive strength test results (Table 2) shows a range of 0.96-1.40N/mm². It has been suggested that the standard range for unfired refractory clays is 2MPa to 10MPa (Carter and Norton, 2007). Based on the compressive strength results, the clays may be suitable only in insulation layers or environments with minimal mechanical stress. They may also find application as filler materials and landfill liners.

CHEMICAL COMPOSITION OF THE CLAY SAMPLES

Table 3
Chemical Composition of Representative Clay Samples

SAMPLE ID	KT 1a	KT 2b	KT 3a	KT 8b	KT 9a	KT 10b
SiO ₂ (%)	65.33	64.07	70.23	70.26	68.82	72.98
TiO ₂ (%)	0.01	0.04	0.02	0.02	0.02	0.02
Al ₂ O ₃ (%)	22.30	23.21	18.28	16.07	19.85	16.44
Fe ₂ O ₃ (%)	0.51	0.54	0.64	0.33	0.44	0.43
MnO (%)	0.03	0.02	0.09	0.04	0.13	0.03
MgO (%)	0.09	0.06	0.04	0.03	0.05	0.07
CaO (%)	0.02	0.05	0.01	0.07	0.00	0.04
Na ₂ O (%)	0.17	0.20	0.16	0.17	0.13	0.24
K ₂ O (%)	3.79	4.61	3.81	3.98	3.21	5.55
P ₂ O ₅ (%)	0.01	0.01	0.02	0.01	0.02	0.02
Cr ₂ O ₃ (%)	0.00	0.00	0.00	0.00	0.00	0.00
CuO (%)	0.00	0.00	0.00	0.00	0.00	0.00
NiO (%)	0.00	0.00	0.00	0.00	0.00	0.00
V ₂ O ₅ (%)	0.00	0.00	0.00	0.00	0.00	0.00
ZrO ₂ (%)	0.00	0.00	0.00	0.00	0.00	0.00
LOI (%)	7.24	6.72	6.23	8.35	6.91	3.80
Total	99.51	99.53	99.54	99.32	99.60	99.60
SiO ₂ /Al ₂ O ₃	2.93	2.76	3.84	4.37	3.47	4.44

As shown in Table 3, the clay samples are mainly aluminosilicates with silica having the highest proportion of the oxides present in the clays, ranging between 64.07% to 72.98%. Alumina (Al₂O₃) in the samples ranges between 16.07% to 23.21%. According to Gupta (2008) and Adamu et al. (2018), clay containing between 51% – 70% and 55% – 75% can be used as refractory bricks and fired clay, respectively (Table 4). Other oxides present in the clay samples include K₂O, Fe₂O₃, Na₂O, MnO, MgO, and CaO. The alumina content of KT 1a and KT 2b fall slightly below the internationally acceptable standard for fired clay and refractory bricks of between 25–45% and 25% – 40% respectively while the remaining samples fall well below the minimum international standard of 25%. However, all the samples can be described as moderate alumina clays since the values fall between 13% – 30% (Aliyu et al., 2012). The iron oxide (Fe₂O₃) in majority of the samples (KT 1 – KT 3) fall within standard range of 0.5% – 2.0% for fired clay and 0.5% – 2.4% for refractory bricks while other samples fall slightly below the standard acceptable ranges (Gupta 2008). The low values of CaO and MgO indicates that the clays can be used for refractories (Hassan, 2005). This means that the clay samples are mostly suitable as refractories chemically, except for the proportion of K₂O which is slightly higher than the recommended 2% for fired clays requiring that the clay be soaked and washed before use to increase its refractoriness. Therefore, reducing the potassium oxide in the samples will increase their refractoriness (Omotoyinbo and Oluwole, 2008). The clay samples are fit for kiln linings, furnace linings, and so on. The concentrations of primary oxides in the clays suggest an acidic environment of formation for the clay samples.

This indication is also corroborated by the low concentrations of basic oxides like CaO, Na₂O, and MgO. An overview of the chemical compositions of the surrounding basement rocks (quartzite and quartz schist) shows a similarity to those of the clay samples. Moreover, the clay samples were collected from a residual clay deposit, which implies that they originated from the underlying basement rocks (Olaolorun and Oyinloye, 2010). The low LOI (3.8–8.35%) value indicates low organic content in the clay samples.

Table 4
Chemical Composition of Refractory Clays by International Standard (Modified after Gupta, 2008)

Constituents	Fired Clay (%)	Refractory Clay (%)	Sample (%)	Remarks
SiO ₂	55–75	51–70	64.07–72.98	Mostly Suitable
Al ₂ O ₃	25–45	25–40	16.07–23.21	Not Suitable
Fe ₂ O ₃	0.5–2.0	0.5–2.4	0.33–0.64	Partly Suitable
K ₂ O	< 2.0	-	3.21–5.55	Not Suitable
MgO	< 2.0	-	0.03–0.09	Suitable

A representation on a $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-Fe}_2\text{O}_3$ ternary diagram showed that all samples were localized along the $\text{SiO}_2\text{-Al}_2\text{O}_3$ axis toward SiO_2 . (Fig. 6). This further indicates that these samples are primarily composed of silica (SiO_2) and alumina (Al_2O_3), with minimal amounts of hematite (Fe_2O_3). This composition type is typical for certain clays like kaolinite. The presence of kaolinite and low concentration of iron oxide (< 1%) makes the clay samples suitable for paper filling and coating. The clay can also be used in the paint industry.

MINERALOGICAL PROPERTIES

The X-ray diffraction scan for the clay samples shows that the clays are predominantly composed of kaolinite with some percentage of quartz, K-feldspar, rutile, mica, plagioclase, sillimanite and smectite as shown in Table 5. The analysis revealed that kaolinite (22% – 60%) is the highest relative amount of clay minerals present in the clay samples with smectite occurring in trace quantities in KT 9a. The total clay content for the samples ranges 22% – 60%.

Table 5
Mineral Composition of Representative Clay Samples

Mineral Constituent (%)	KT 1a	KT 2b	KT 3a	KT 8b	KT 9a	KT 10b
Quartz	20	25	20	30	33	32
K-feldspar/Rutile	30	20	-	39	16	30
Kaolinite (1)	38	44	60	22	22	26
Mica	12	11	12	9	8	12
Plagioclase	-	-	8	-	-	-
Sillimanite	-	-	-	-	15	-
Smectite (2)	-	-	-	-	6	-
Clay Minerals (1 + 2)	38	44	60	22	30	26

The presence of sillimanite in KT 9a indicates high alumina content in the sample and the nature of the parent rock in the study area. Sillimanite is an aluminosilicate mineral that forms typically in metamorphic rocks. The presence of smectite in trace amounts also indicates the presence of swelling clays like montmorillonite.

The high silica content is attributed to the residual nature of the clay deposit. Also, the kaolinite peaks of the samples are more broadened than less sharpened (Fig. 7). Peak broadening is normally expressed in terms of the peak width at half height (Brindley and Kurtossy, 1961; Langford & Wilson, 1978; Dinnebie & Billinge, 2008). It is known to be associated with disordered kaolinite. The distorted crystallinity of the kaolinite is suggestive of intense weathering. The quartz content of the clay samples can be related to the grittiness of the clay and the dominance of sand fraction. This indicates that the clay is suitable for brick making as quartz enhances the strength of bricks.

ECONOMIC VALUE

The characterization of the clay samples revealed that they are useful for lining of sanitary landfills, thermal insulators, lining of low and medium-temperature melting furnaces, liquid metal ladles, and portions of blast furnaces (Yami et al., 2007). The clays have iron oxide content that is high enough to impart a beautiful reddish colour to them when fired, making them attractive for some applications like ceramics, bricks, and pottery making. However, the high potassium oxide content of the clay samples must be reduced by soaking and washing the clays before use (Mark, 2010).

The clay samples may also be used as raw materials in ceramics making, replacing the need for importation of raw materials or finished products from abroad. They can also be potential raw materials for industries like the paper and paint industries (Shuaib-Babata et al., 2018).

CONCLUSIONS

Kitibi clay deposit in Iwo, southwest Nigeria was studied and characterised based on geotechnical and mineralogical properties. Geotechnical data reflects a typical residual clay categorised as silty clay with poor porosity and making it a suitable refractory clay. Results of mineralogical analysis showed kaolinite as the dominant clay mineral with quartz, K-feldspar, rutile, mica, plagioclase, sillimanite and smectite; reflecting the chemistry of the parent rock and the intense weathering of the clay deposit. Chemical composition of the clay samples are mainly aluminosilicates with silica having the highest proportion of the oxides present in the clays. The chemical composition indicated that the clay samples are mostly suitable as refractories chemically, except for the proportion of K_2O which is slightly higher than the recommended 2% for fired clays requiring that the clay be soaked and washed before use to increase its refractoriness. Other oxides present in the clay samples include K_2O , Fe_2O_3 , Na_2O , MnO , MgO , and CaO .

In terms of industrial application, the studied clay samples also belong to medium to high-plasticity clays which supports its use as refractory raw materials for furnace and kiln lining, and as a suitable potential raw material for ceramics, paper, paints, and other industries. Equally, based on the results, the sampled clay may be suitable for thermal insulation in many applications, specifically in environments with low mechanical stress and reduced exposure to fumes and vapour, for lining of sanitary landfills, base and sub-base material, absorbent and filler.

The clays are found to be good materials for refractory applications after being soaked and washed to reduce the alkali oxide content and increase refractoriness. They could replace imported clays in applications like the production of earthen wares, paper, paints, and insulating refractories for casting and melting low temperature iron and steel. If carefully utilized, it will assist in addressing the economy of the country by reducing dependence on foreign raw materials.

Declarations

Conflict of Interest: The authors declare no competing interests.

Authors' Contributions Charles A. Oyelami conceived and designed the experiments, wrote the paper; Sanusi Olamide Elizabeth, Charles Oyelami performed the experiments; analysed and interpreted the data; contributed reagents, materials, analysis tools or data; and wrote the paper. . Tesleem O. Kolawole/Adebayo O. Afolabi, was parts of the field work; performed the experiments; analysed and interpreted the data; contributed reagents, materials, analysis tools or data; and wrote the paper.

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Ethics Declaration

Consent to Participate, and Consent to Publish declarations: Not applicable.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Third Party Material

No third party material

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Figures

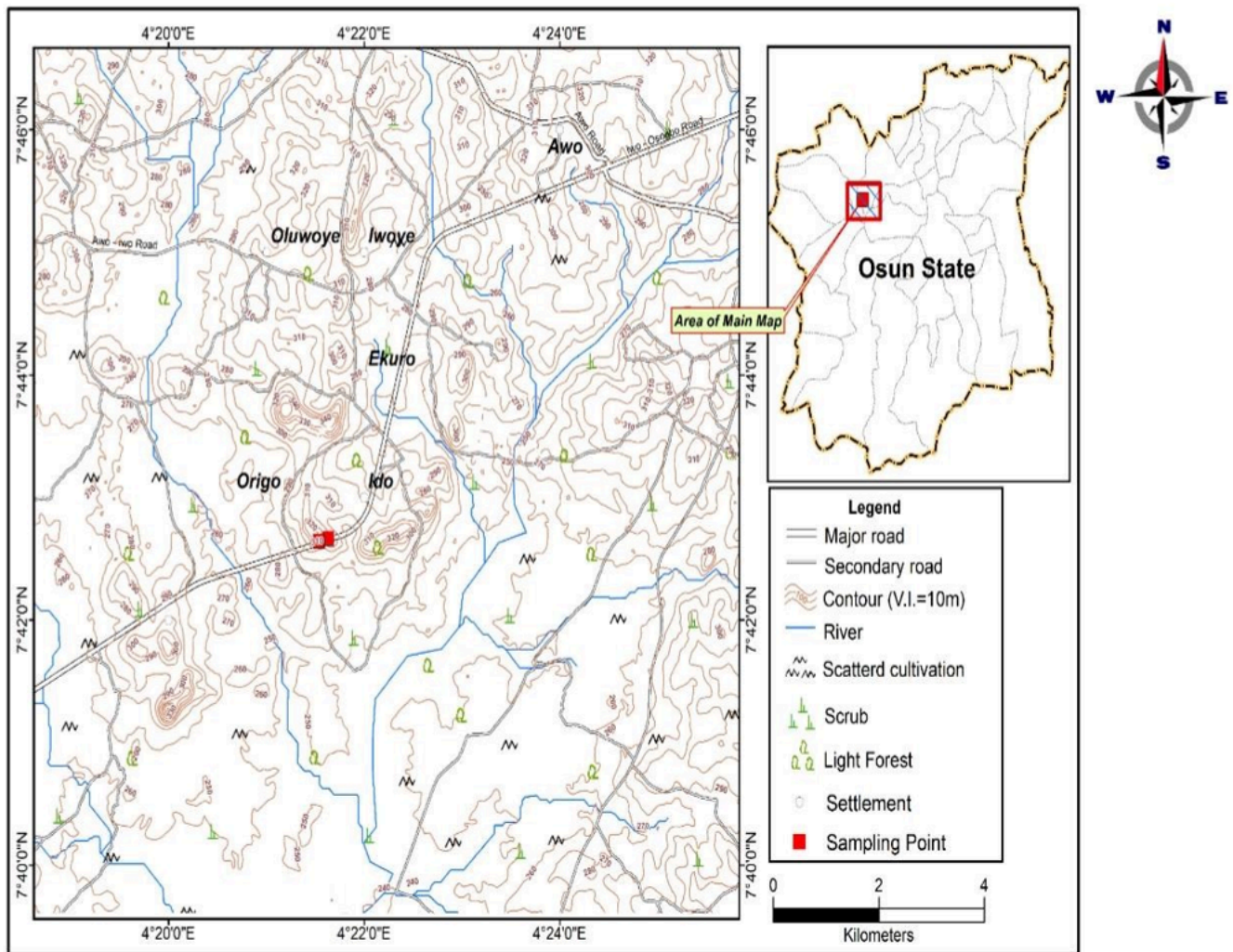


Figure 1

Topographical Map of Kitibi (modified from Topographical Map of Iwo Sheet 247 NE 1:50,000, SRTM 30m and Federal Surveys, 1967)

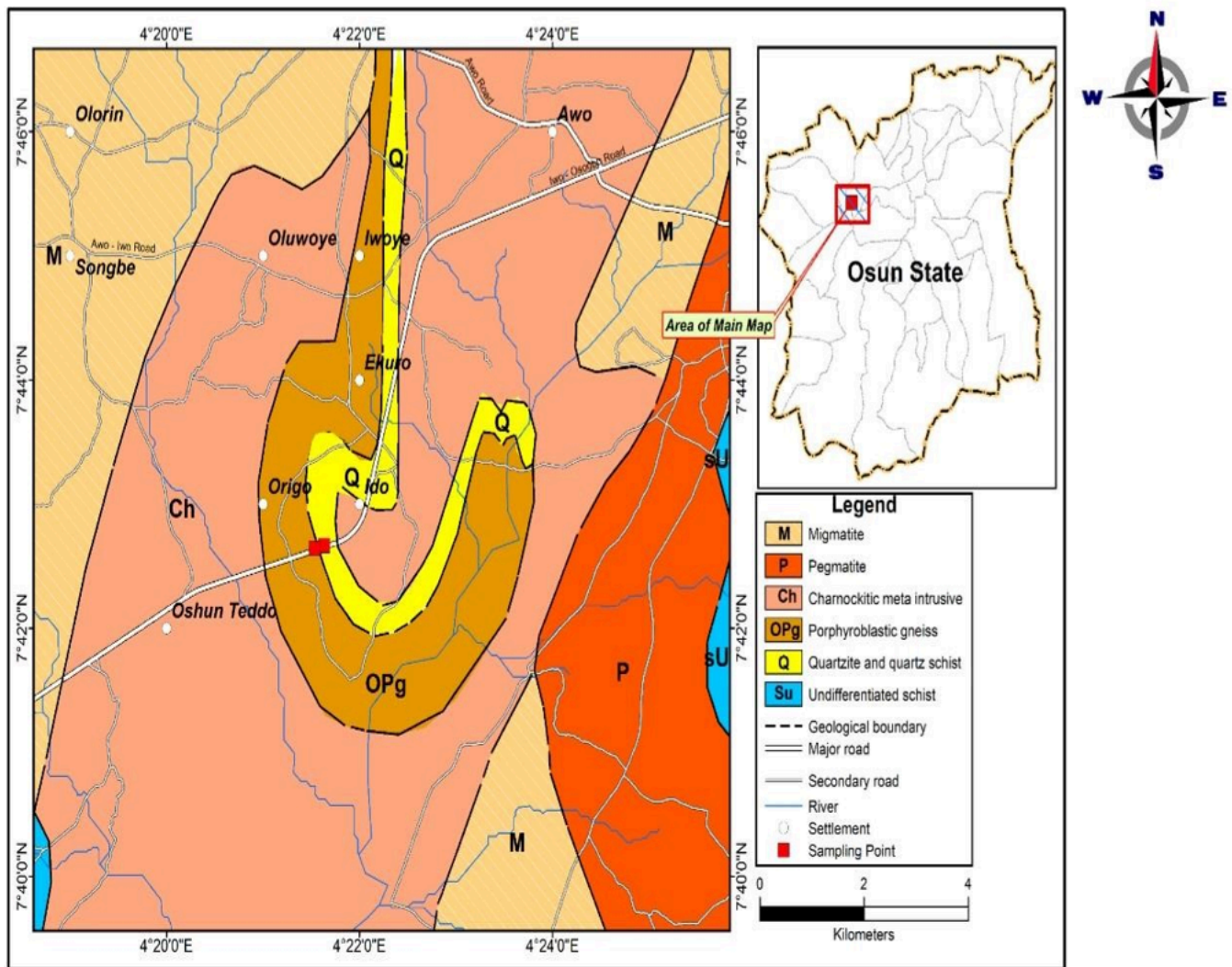


Figure 2

Geological Map of Kitibi (adapted from Geological Map of South West Nigeria (NGSA, 2006))

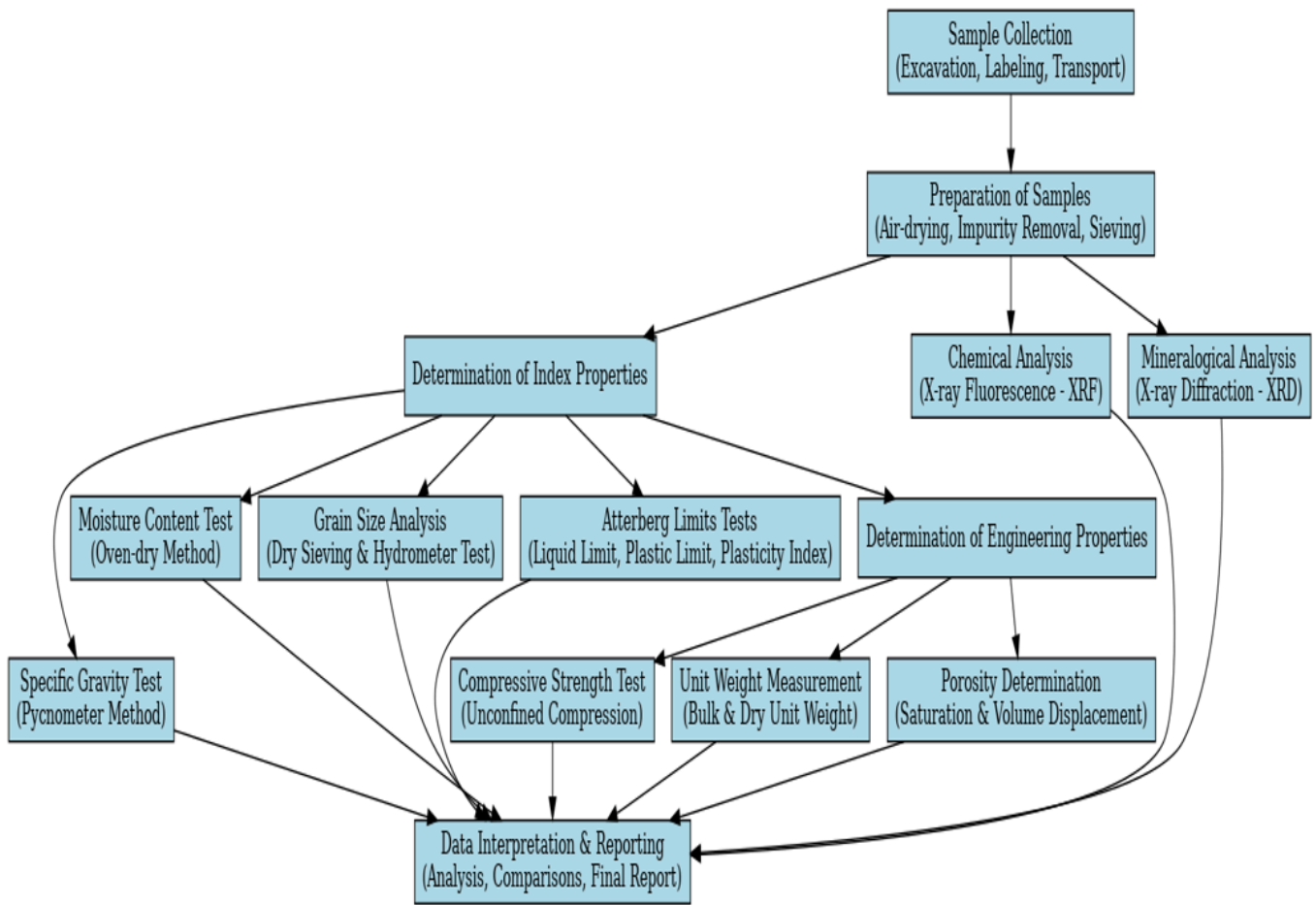


Figure 3

Flowchart for Methodology Used in Kitibi Clay Characterization

PARTICLE SIZE DISTRIBUTION CURVE

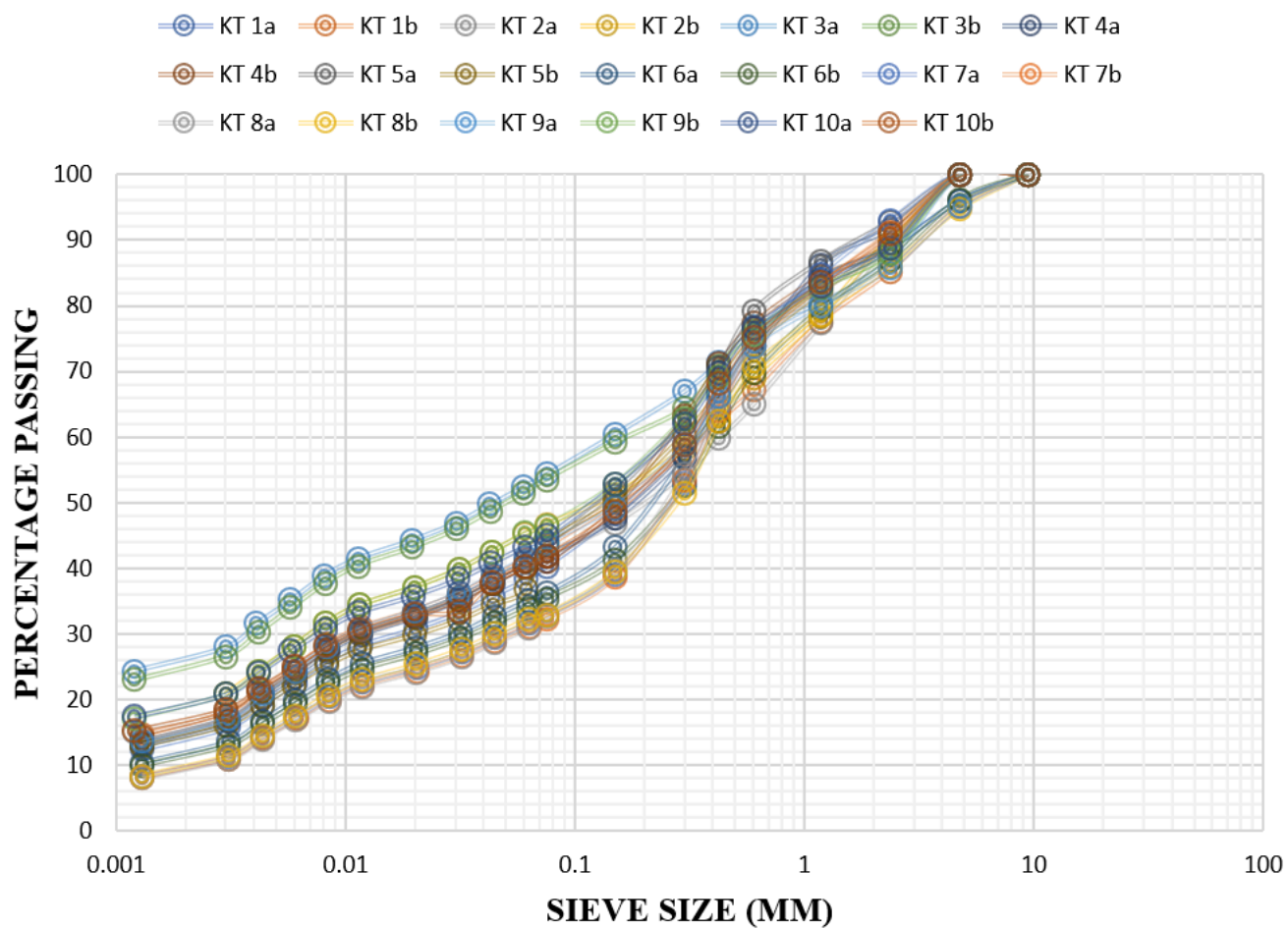


Figure 4

Grain Size Distribution of Clay Samples from Kitibi

PLASTICITY CHART

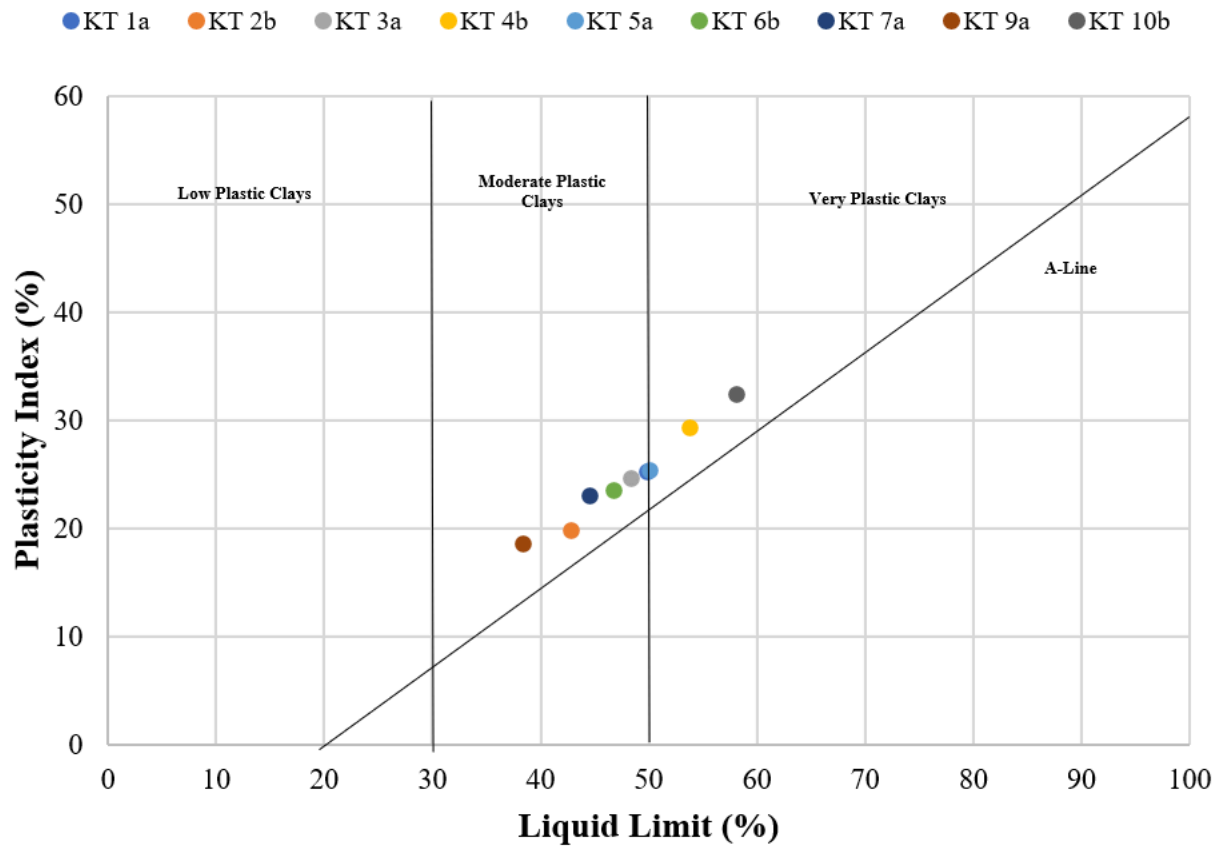


Figure 5

Plasticity Chart of Representative Samples from the Study Area

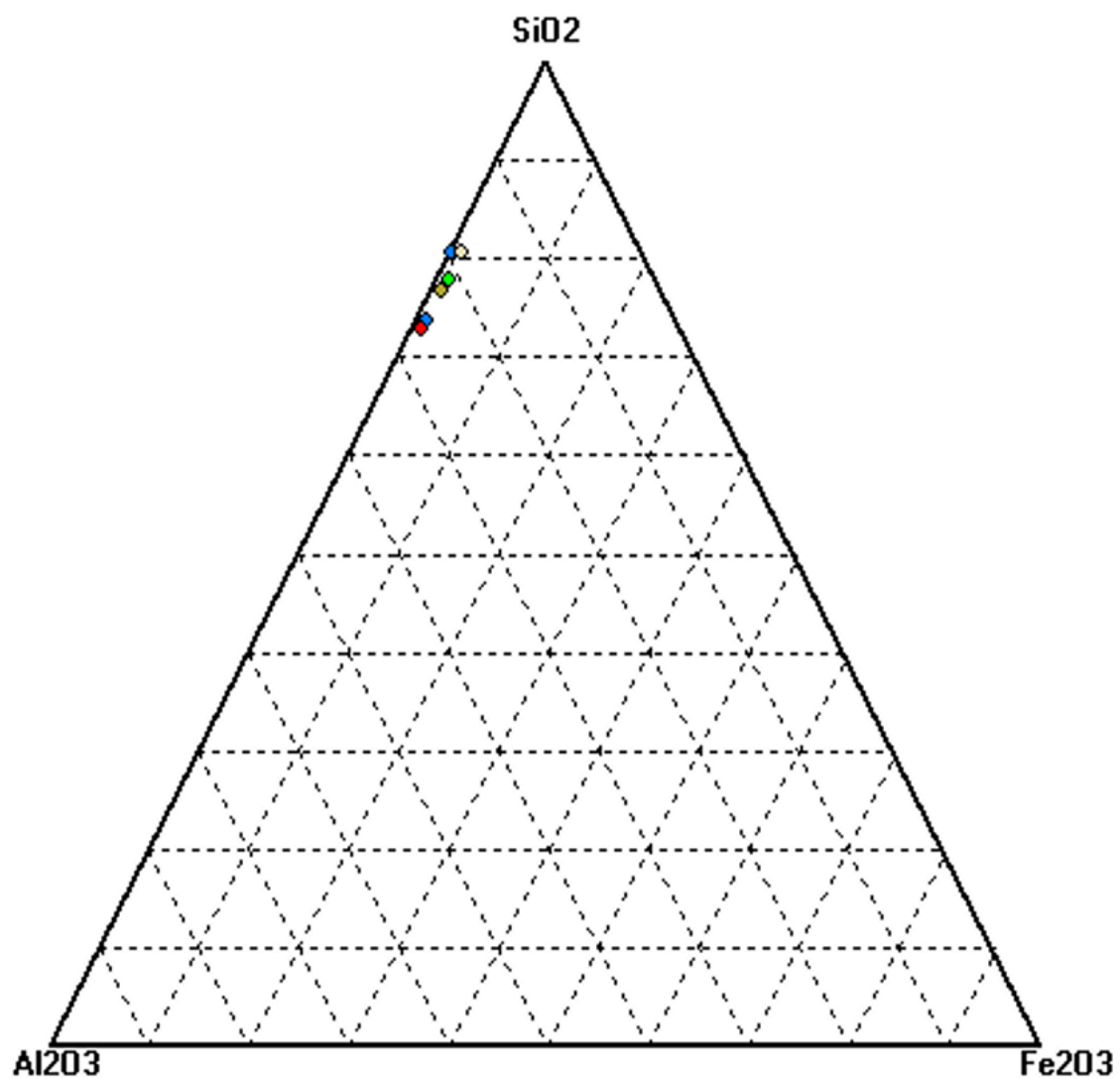


Figure 6

SiO_2 - Al_2O_3 - Fe_2O_3 Ternary Diagram for Representative Kitibi Clay Samples

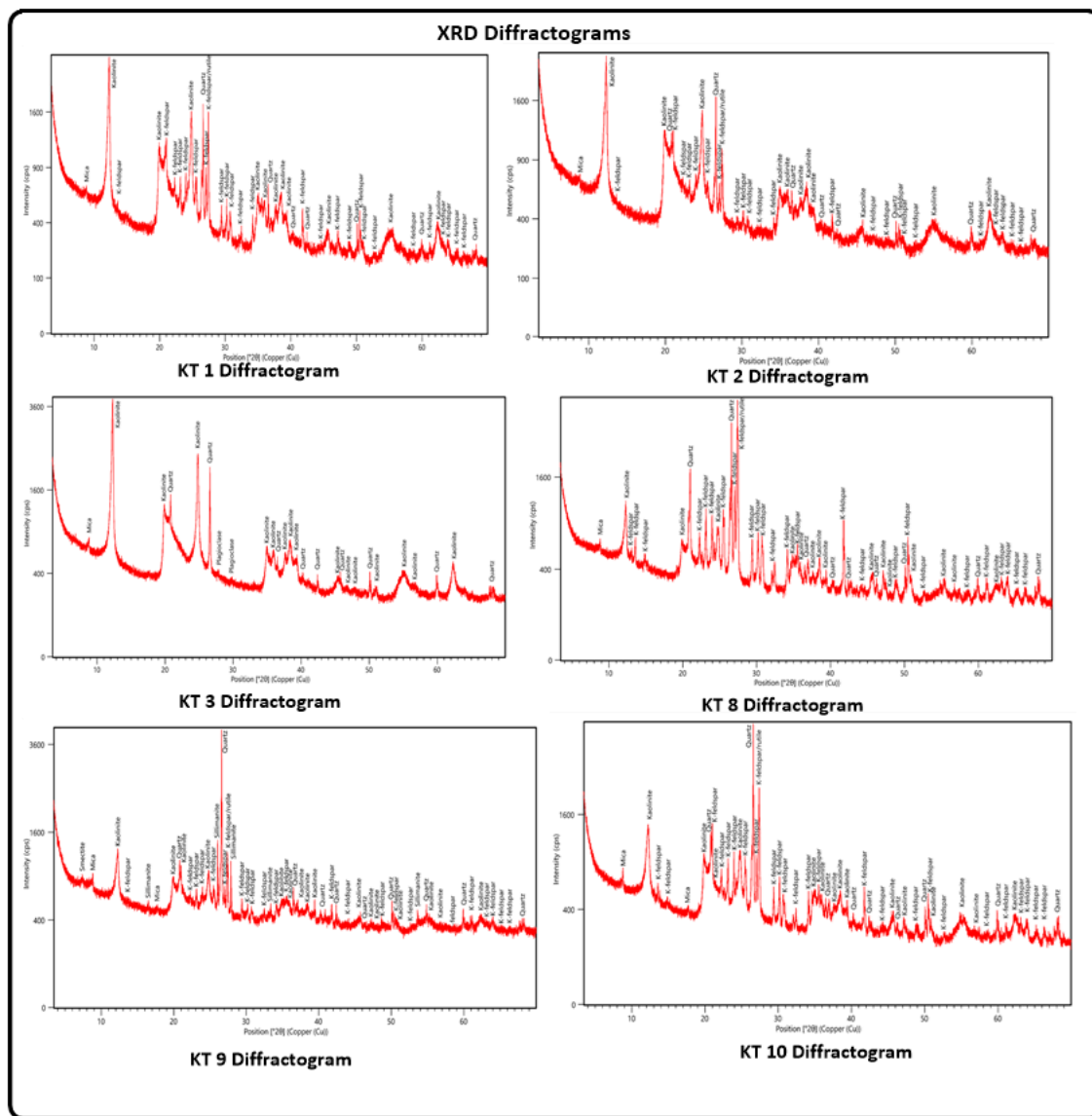


Figure 7

X-ray Diffractograms of Selected Samples