MINERALOGICAL AND GEOCHEMICAL CHARACTERIZATION OF CLAYS AT IGO AND OKHORO DEPOSITS, SOUTHERN NIGERIA: A COMPARATIVE STUDY OF THEIR ECONOMIC POTENTIALS.

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DEDICATION

I dedicate this amazing project specially to God Almighty, My supervisor, Finally to my wonderful parents, for their continuous support and prayers.

ACKNOWLEDGEMENT

God Almighty I want to say a big thank you for standing by me from the beginning of this program to the end.

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ABSTRACT

This study represents a comparative mineralogical and geochemical evaluation of clay deposits from Igo and Okhoro, located within the Benin Formation of Southern Nigeria, with the aim of determining their industrial suitability and economic potential. Field observations revealed that the Igo clay occurs as reddish to brownish lateritic clay interbedded with sands, whereas the Okhoro clay is predominantly light grey with brown patches and is more quartz-rich. X-ray Fluorescence (XRF) analysis of the Igo samples shows high concentrations of silica (SiO_2: with mean value 68.57%) and alumina (Al_2O_3: with mean value 22.59%), with relatively low levels of fluxing oxides. In contrast, the Okhoro samples contain lower silica (mean 59.25%), comparable alumina (mean 21.86%), but noticeably higher iron oxide (Fe_2O_3: up to 7.34%). Trace element concentrations in both locations were generally low, indicating minimal impurity influence on industrial applications. The X-ray Diffraction (XRD) data reveal that the Igo clays are dominated by kaolinite (24.5–45%) and quartz (36–62%), with significant amounts of feldspar minerals (orthoclase and albite) and muscovite. Okhoro samples, however, are overwhelmingly quartz-dominated (88.6–98.04%) with only minor kaolinite (0.98–9.42%) and no detectable feldspars, signifying a highly mature, intensely weathered sediment. These mineralogical differences indicate that Igo represents a sub-mature kaolinite-quartz-feldspathic clay, while Okhoro represents a super-mature quartzose deposit. Comparisons with industrial specifications show that both clay types meet some requirements for refractory bricks, though beneficiation is needed to adjust fluxing oxide levels. Igo clays, due to their higher kaolinite content and natural feldspar fluxes, exhibit stronger potential for ceramic applications, including tiles, earthenware, and fillers for paint or rubber after processing. Okhoro clays, because of their extreme quartz dominance , are more suitable as construction fillers, low-grade refractory blends, or materials for brick manufacturing. Overall, the Igo clay deposit displays broader and more economically valuable industrial potential than the Okhoro deposit, which is limited by its mineralogical maturity.

CHAPTER ONE

INTRODUCTION

Background Study

Clay are naturally occurring material composed primarily of fine-grained minerals, and very small rock fragments, which can generally exhibit plastic properties when appropriate water contents is introduced and will harden when dried or fired, thereby losing its plasticity. Clay usually contains ***phyllosilicates***, and may contain other materials that impart plasticity and harden when dried or fired. It is a very common substance, making up about half of the earth's sedimentary rocks.

Clay is a fine-grained minute soil particle with diameters below 0.005 mm and particle size below 2 micrometers. It is composed of mineral that has gone through mechanical and chemical weathering. Clay a soil composed of many mineral particles, as such can be considered to be neither a mineral nor rock.

Clay is formed from component minerals which originated from silicate rocks containing low carbon acid and other diluted solvent which had undergone progressive weathering. Clays contains minerals that has high specific surfaces and allows a very strong physical and chemical interactions with dissolved species.

Clay have been mined since ancient times and as of today both clay and it's minerals are most important raw materials used by the manufacturing and pharmaceutical industries.

Clay minerals refer to layered silicate minerals and minerals that give plasticity to clay and harden when dried or fired. Clay minerals are layered silicates, usually formed by chemical weathering of other silicate minerals on the Earth's surface. They are most commonly found in shale, the most common type of sedimentary rock. In cool, dry, and temperate climates, clay minerals are fairly stable and important components of soil.. Clay minerals act as "chemical sponges" which hold water and dissolved plant nutrients weathered from other minerals. They show colour from reddish brown to brown. Clay can be classified into swelling into swelling and non swelling clay. The swelling clay contains montmorillonite 2:1, and the non swelling clay contains kaolinite 1:1, Illite 2:1.

1.2 AIM AND OBJECTIVES

Aim

The aim here is to help us in understanding and studying the clay gotten from the study area

Objectives

I. Locating outcrops with high clay content via a detailed location map

II. Bring to light the techniques applied in the observatory and evaluation of the acquired clay samples

III. Evaluating the chemical and mineralogical composition of clay using x-ray fluorescence (XRF) and the x-ray diffratometry

IV. Discussing it’s industrial uses.

The under listed objectives are carried out in done

I. Determining the chemical composition of clay using the X-ray fluorescence analysis (XRF)

II. Determining the mineralogical composition of clay using X-ray diffractometer (XRD).

1.3 LOCATION OF AREA OF STUDY

The study area is located in Igo community and okhoro community, Igo community is about 168km from Benin City and okhoro community is 6.5km from Benin city, Edo State, south-southern Nigeria. The study area in igo community lies within latitude of 05^{o} 31' 30.2"E and 06^{o} 16' 17.3"N, and longitude of 05^{o} 31' 28.5"E and 06^{o} 16' 18.1"N and in okhoro community lies within latitude of 05^{o} 36' 10"E and 06^{o} 20' 20"N, and longitude of 05^{o} 41' 50"E and 06^{o} 18' 10"N. The Igo community and Okhoro community area are both within the rainforest region of Nigeria with the rainy season occurring from April to October. The Igo community is characterized by high forest,ever green rainforest and it's likely still more rural with better potentials for less disturbed forest vegetation while the Okhoro community is also characterized by rainforest, it likely has more heavily altered vegetation due to it closeness to urban areas.

The Igo clay deposit and Okhoro clay deposit are both part of the benin formation which is an outcrop within the larger geological framework of the sourthern sedimentary basin of Nigeria. The Igo clay deposits shows a reddish to reddish brown lateritic massive fairly hardened clay and sand. This is often marked with reticulated mudrock, and this result in the underlying more pinkish, yellowish white often gravelly pebbled sands, clayey soils, sand and clay (Odion et al 2023). The sedimentary sequence are poorly bedded with discontinuous clay horizons at various depths. The deposit is part of the the thick sequence of the benin formation which undelies much of the benin region with estimated thickness of 800m, which forms the uppermost layer of the Niger delta basin. While the Okhoro clay deposit shows a light grey with brownish patches of clay overlying with reddish sand respectively (O.Odia-oseghale et al 2024) . The brownish and reddish coloration can be attributed to oxidation Season (U.Ohwo,2024). The top soil ranges from brownish to reddish sand and the study area are accessible by major rooads, minor roads and footpaths (A. Oziofu, 2024). The areas have a good road network and most places are built up areas and there are footpaths to the various outcrops (E. Agbongiague, 2024). The benin formation is undelain by sedimentary formmation of the south sedimentary basin. The geology is gennerally marked by top reddish earth, composed of ferruginized or lateralized clay sand.

1.4 OCCUPATION OF THE STUDY AREA:

Majority of the people living both in Igo and okhoro communities are predominantly farmers and traders. Both communities are located in Edo state, where agricultural activities forms the backbone of the local economy.

1.5 LOCAL GEOLOGY OF THE AREA:

The geological setting of Igo community is part of the southern Nigeria basin, it contains largely coarse sand, with clay to shale interbeds.The geology of Igo community is typically of a sedimentary dominated basin environment with clay to sand interbeds, lateritic weathering, and industrially sigificant clay deposits. The sedimentary sequence are poorly bedded with discontinuous clay horizons at various depth. While the Okhoro community is also part of the southern Nigeria basin, the clays here are found to be dominated by the clay mineral kaolinite. The geology of Okhoro community also sits on a sedimentary dominated basin with clay and sandy interbeds. The clays here are chemically favorable and the sands provide aquifer capacity. The parent material is likely felsic in origin, and the landscape supports both water supply infrastructure and industrial clay exploitation.

1.6 LITHOLOGICAL DESCRIPTION OF THE BENIN FORMATION:

The Benin formation also known as the coastal plain sands is the youngest of the three principal lithostratigraphic units that makes up the Niger delta sequence (Short,1967). Stratigraphically, it overlies the agbada formation and undelies the surface alluvium and recent deposits of quaternnary age (Doust, 1990). It may range from miocene to recent or from late oligocene in some areas, and the thickness varies from about 200m near the delta top to over 2000m in the depocentre of the delta (Omatsola,1990). It covers much of the Niger delta region, extending westward to benin city, eastward to the imo river, and southward to the atlantic coast. The Benin formation is predominantly arenaceous, composed mainly of coasrse to medium grained sanstones with intercalations of gravel, pebbly sands, minor clay lenses, and shale beds (Avbovbo,1978). It's loosely consolidated and highly porous in most areas, reflecting a dominantly continental depositional environment (Amajor,1981).The benin formation consists of sequence of sedimentary rocks such as sanndstones which are coarse to medium granied, conglomerates which are coarse grained, silstones often fine grained or laminated and shales that contains organic matter. It represent the continental depositional environment of the deltaic system and it is dominantly fluvial in origin.

MAP STUDY AREA

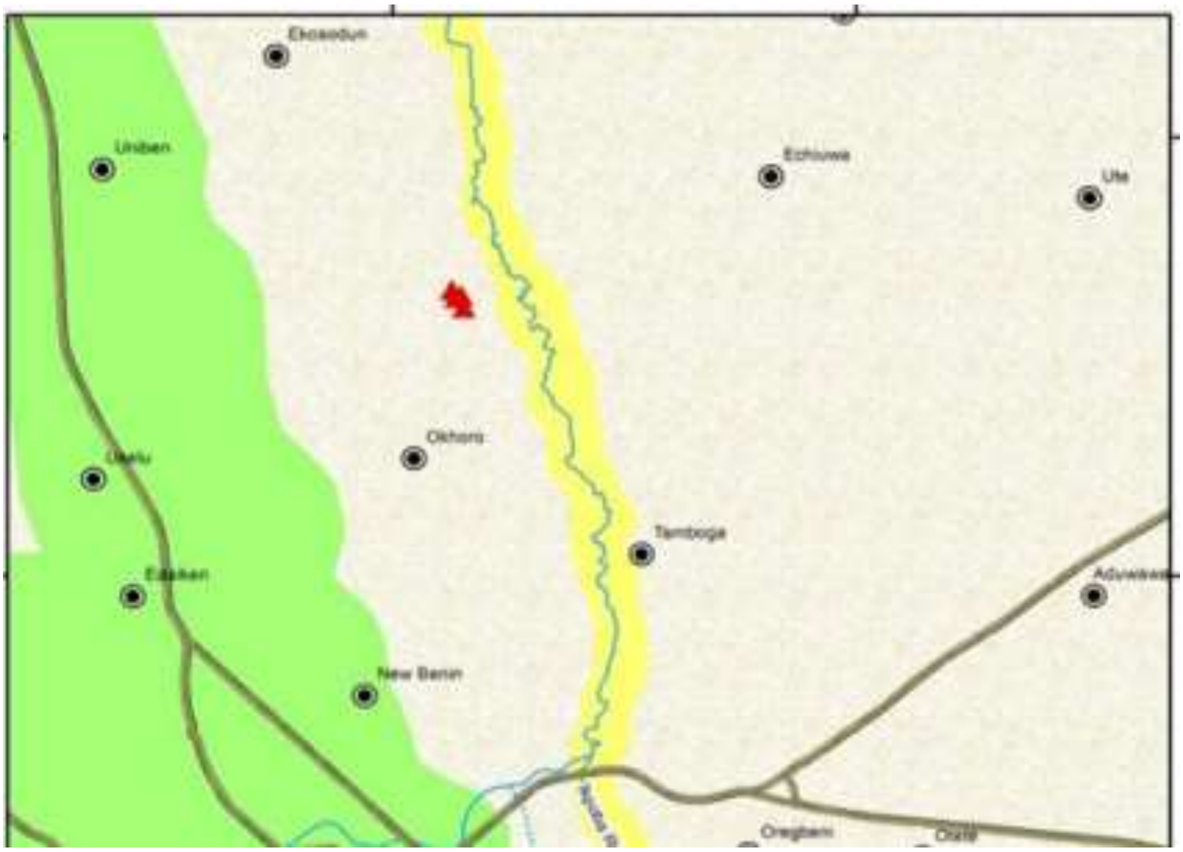


Figure 1: Map of study area, Okhoro Community, Edo State

(Abongiague,2024)

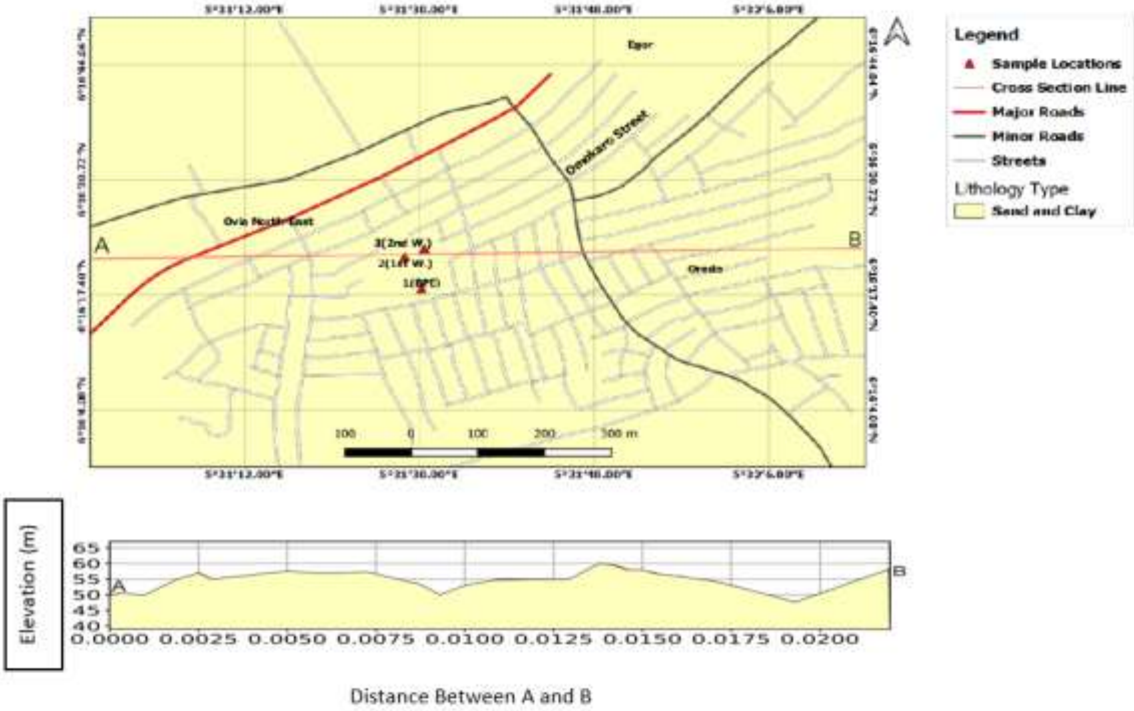


Figure 2: Location map of study area, Igo Community, Edo States

CHAPTER TWO

LITERATURE REVIEW AND GEOLOGICAL SETTINGS

Clay is natural material formed by the progressive deterioration of rocks in silicate layers containing low carbon acid and other diluted solvents with a particles size of less than 2um which are plastic with a content of water which shrink on drying, expands on wetting and hardens when fired (Edozuino et al., 2016). The term clay is applied to materials having particles size of less than 2 micrometer and to the family of minerals that have the same chemical composition and common structural characteristics (Velde 1995) Clay are common among the world most important soil (Murali *et.Al.,* 2018). This deposit of clay can occur as primary or residual and secondary or transported clay (kankara). Clay's are classified according to it structures, chemical composition occurrence, the difference between the type of clay is explained by the octahedral and tetrahedral arrangements of clay structure (Oziegbe et Al 2019). The gritty feel of most clay from hand specimen is attributed to the clay sand mixture which is an indication of proximal overbank environment (Akhireubulu *et.al.,* 2010). Clay particles varies according to different field of studies for this reason, ordinary microscope is not enough to provide an in depth knowledge of the crystal structures of clay. X-ray fluorescence analysis, X-ray diffraction analysis are best employed to study the crystal structures of clay.(Obaje et al 2013).

Clay have been mined since Stone Age and today, clay and it's minerals are among the most important raw material used by the manufacturing industries. It is also one of the material used by the metallurgical industries (Dansarai *et al.,* 2020). This clay minerals are important industrial minerals whose application is dependent on it's physical, mineralogical and chemical composition (Adewole *et al.,* 2020). Clay's like bentonite has varieties of uses, special use of bentonite where its absorbing properties are employed to provide water tight sealing is for underground repository in granite. (Anamarija *et al*., 2012). Bentonite clay is a type of clay that is important during drilling operations in oil and water. Clays are used in the manufacturing of ceramic, paint paper, they are also used for medicinal purpose.

2.1 REGIONAL GEOLOGY OF NIGER DELTA BASIN

The Niger delta basin is located in southern Nigeria and extends offshore into the gulf of guniea. It is one of the world’s largest delta systems and a prolific hydrocarbon province (Stauble,1967). The Niger delta basin developed during the late cretaceous to cenozoic in response to the breakup of Gondwana and opening of the southern atlantic ocean (Chukwu,1991). It evolution is linked to rifting and subsequent passive margin subsidence along the west Africa margin. The tectonic history sets the stage for the thick stratigraphic package, growth faulting systems, and sedimentary architecture which in turn control reservoir, seal annd trap development (G.A,1991). The stratigraphy of the Niger delta basin is classified into three main formations, which represent a coarsening upward sequence from deep marine to continental environment (short,1967).

i. AKATA FORMATION (Paleoocene Recent):
ii. Lithology: dark grey to blue grey shales and silty claystones, with minor sands and turbidite deposits.
iii. Environment of deposition: deep marine to prodelta.
iv. Significance: forms the source rock and regional detachment surface for growth faults and diapirs.
v. Thickness: up to 7,000m in the depocentre.
vi. AGBADA FORMATION (Eocene Recent):
vii. Lithology: alternating sandstones and shales deposited in delta front and delta plain environments.
viii. Environment of deposition: deltaic to shallow marine.
ix. Significance: The main reservoir sequence in the Niger delta.
x. Thickness: up to 4,500m.
xi. BENIN FORMATION (Oligocene Recent):
xii. Lithology: coarse, unconsolidated sands and gravel with minor clay lenses.
xiii. Environment of deposition: continental to alluvial coastal plain.
xiv. Significance: forms the topmost formation and part of the regional overbuden or seal.
xv. Thickness: up to 2,000m.

In the Niger delta basin, the delta prograded southward into the atlantic, depositing sediments in environments ranging from continental fluvial plains to deep marine settings. The delta also exhibits a tripartite structural zonation (Evamy et al,1978). The extensional zones are characterized by listric normal growth faults formed due to gravity sliding of sediments and the faults deep seaward and sole out in the ductile Akata shale (B.D,1978). The translational zones are dominated by shale diapirs, faulted rollovers, collapsed growth structure and the differential loading and mobilization of Akata shales caused complex deformation (Evamy,1978). The compressional zones are formed by folds, thrusts, and imbricate fault systems as sediments are compressed at the toe of the delta.

PETROLEUM SYSTEM OF THE NIGER DELTA BASIN

1. Source rock: Akata formation shales include marine origin, rich in type II kerogen.
2. Reservoirs: The Agbada sand and shales alternations provide numerous reservoir units.
3. Seals: The shale intervals within the agbada and the thicker shales of the Akata formation, serves as internal seals and the Benin formation may serve as overbudden.
4. Traps: Growth fault rollover anticlines, fault closures, stratigraphic pinch outs, and toe thrust structures.

2.2 TYPES OF CLAY MINERALS

Some of the most common clay minerals include ***kaolinite***, ***smectite***, ***illite***, and ***chlorite***.

2.2.1 Kaolinited

This clay mineral is a weathered product of feldspar. It has a white, powdery appearance. Kaolinite is named after the region of Kaolin, China, where porcelain (also known as porcelain) was invented from a local clay mineral. The ceramic industry uses it extensively. Because kaolinite is electrically balanced, its ability to adsorb ions is lower than that of other clay minerals.

2.2.2 Smectite

This clay mineral is a weathering product of mafic silicates and is stable in arid, semi-arid, or temperate climates. They are also known as montmorillonite. Smectite has the ability to absorb large amounts of water in a sponge-like manner and form a waterproof barrier which greatly reduces permeability. It is widely used in drilling, civil engineering, chemical and environmental industries where it is known as bentonite.

2.2.3 Illite

The mineral composition is similar to muscovite, with finer grains. It is formed from weathered products composed of feldspar and acid silicates. It is named after the country. Native to Illinois, it is a major clay mineral in Midwestern soils.

2.2.4 Chlorite

This clay mineral is a weathering product of basic silicates and is stable in the following environments: Cool, dry or mild climate. Occurs with illite in soils of the Midwest. It is also found in some metamorphic rocks, such as chlorite schist. Clay is a very common material, shale is formed largely from clay. Shale and clays are of both sedimentary origins. Naturally occurring deposits includes silt and clay. Clay can be differentiated from silt because of it's particle size and its mineralogy. Clay can be classified by it's structure, chemical composition, it's origins and It's mode of occurrence.

2.3 FORMATION OF CLAY

Clay deposit are of two types which are:

1. Primary or residual clay deposit
2. Secondary or transported clay deposits.

1) **PRIMARY OR RESIDUAL CLAY DEPOSIT:** They are mostly formed by surfaces weathering either chemical decomposition of rocks such as granites which contains silica and alumina, by the dissolution of rocks such as limestone containing clayey impurities which when insoluble are deposited as clay and by the integration and dissolution of shale. A common process of clay formation is the decomposition of feldspar. Residual clays always remains at the site of it's formation.
2) **SECONDARY OR TRANSPORTED CLAY DEPOSIT:** These are clays that have been transported from their original location by water

erosion and deposited in a new sedimentary environment. This type of clay deposit are associated with low energy depositional environment such as lakes and any sedimentary basin.

Clay and it's minerals occurs under a limited range of geologic conditions, the environment of it's formation includes soil horizons, continental and marine sediment. Extensive alteration of rocks to clay can produce relatively pure clay deposit that are greatly of economical value. Examples bentonite which is used as drilling mud.

2.4 FEATURES OF CLAY GEOLOGY

Clay plasticity is when the clay is wet and it's hard nature is in his dried form. Clay exhibit varying moisture content, which are minimal when wet and molded and greatest when the molded clay is dry enough to hold its shape. The plasticity of kaolin is 36% to 40%; Fluid limits range from 58% to 72%.

The plastic properties of clay are due to the content of minerals such as aluminum, which is a hydrous mineral. The chemical composition of clay minerals and their ability to retain nutrients and cations such as potassium and ammonia are important to soil fertility. Most clay minerals are minerals that can take up water to an extent, increase in volume during absorption of water and shrink back to their original volume that can produce cracks or other textures such as popcorns when dried. Clay occur under a limited range of conditions in geological space (and time and temperature). They are found mostly on the Earth’s surface. Geologically, its occurrence is mainly associated with the weathering of rocks. Some are forms at sediment boundaries, such as deep sea or lake bottoms. A certain amount of clay is formed when aqueous solution and rock interact, At some depth in the sedimentary layer or at a later stage of magma cooling (i.e. hydrothermal changes).

Although hydrothermal alteration is not very large, it is geologically important because it often accumulates useful heavy metals such as gold. When geologists find rocks that have been changed to clay by hydrothermal alteration, they determine that this has occurred great depth. Extensive changes in rocks caused by hydrothermal water The changes can lead to the formation of pure clay deposits that can yield economic benefits.

2.5 OCCURRENCES OF CLAY

Sedimentary rocks make up about 5% of the Earth's crust which covers approximately 80% of the Earth's surface, with clays (including shale) making up more than 40% of sedimentary rocks. Clay deposits are collected by water (e.g. marine clays, alluvial clays, lacustrine clays), wind (aeolian clays), or ice (e.g. glacial clays, tillage clays or rocky clays), but clays are marine. The most common deposits generally consist of a mixture of clays and coarser materials, usually dominated by the clay mineral illite. Clay minerals form in two main ways:

i. By weathering the parent mineral in situ to form clay-rich residual soils, they are often dominated by the clay mineral kaolinite and are particularly common in tropical weathered landscapes.

ii. By ascending fluids, it occurs due to fluid uplift, i.e. due to hydrothermal changes in the host rock. Cornwall A good example is pottery clay. Feldspar from local granites was converted into clay minerals, mainly of the kaolinite group.

2.6 CLAY DEPOSIT IN NIGERIA

Nigeria is endowed with clay rich states. Clay are gotten from majority of the states in Nigeria and are deposited in most states in larger quantities. Clay deposits can be found in the following state: Abuja, Awka ibom, Anambra, Bauchi, Benue, Borno, Crossriver, Delta, Edo, Lagos, Nasarawa, Ogun, Ondo, Oyo , Sokoto etc.

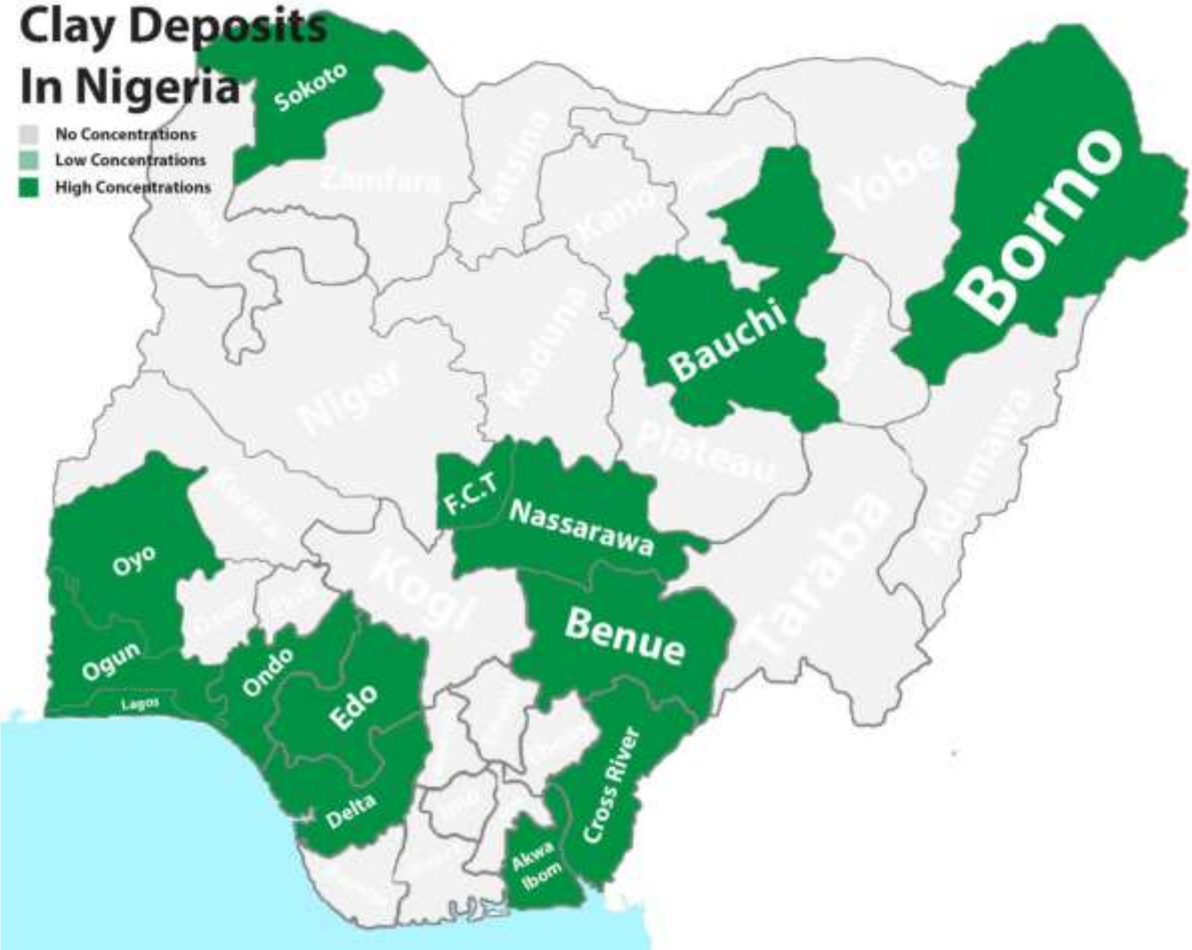


Figure 3: Map showing locations of clay deposits in Nigeria (?)

Table 1: Major kaolin deposits in Nigeria and estimated reserves (modified from Gushit et al., 2010)

State	Major Locations	Estimated Reserve (million tonnes)
Abia	Isikwuato, Nneochi, Obingwa, Umuahia area, Ikwuano	Very large
Anambra	Anambra-East, Ayamelum, Ekwusigo, Njikoka, Aguata, Ihiala, Nnewi-South	4.2
Bauchi	Alkaleri, Bauch, Damban, Darazo, Ganjuwa, Kirfi, Misau, Ningi	18
Benue	Obi, Ogbadibo, Apa, Oturkpo	10
Borno	Gwoza, Chibok, Damboa	Large
Edo	Esan, Ovia and Etsako areas, IkpobaOkha, Akoko-Edo, Egor, Igueben, Oredo, Orhionmwon, Uhunmwonde, Owan-East	Very large
Enugu	Enugu	50
Kaduna	Maraban-Rido	5.5
Katsina	Batagarawa, Batsari, Dan-Musa, Danja, Dutsin-Ma, Ingawa, Kankara, Kankia, Safana, Malumfashi, Musawa,	Very large
Kebbi	Bagudo, Suru, Wasagu / Danko	Very large
Kwara	Baruten, Edu, Ifelodun, Ilorin, Ilepodun, Isin, Kaiama, Pategi	Large
Niger	Bosso, Edati, Gbako, Katcha, Lapai, Lavun, Mashegu, Mokwa, Paikoro, Shiroro, Wushishi	Very large
Ogun	Abeokuta area, Ado-Odo/Ata, Idarapo, Ifo, Igbado area, Ijebu area, Ipokia, Obafemi-Owode, Odeda, Odogbolu, Remo-North	Large
Ondo	Irele, Odigba	Not available
Oyo	Atisbo, Ifedayo, Iseyin, Saki West and East.	1.5
Plateau	Barkin-Ladi, Bassa, Bokkos, Jos-North, Kanke, Pankshin	8.0
Zamfara	Gumi, Gusau, Kaura-Namoda, Maradun, Maru, Talata-Mafara, Zurmi	Not available

2.7 USES OF CLAY

Clay can be used for varieties of things such as:

1. FARMING: Clay soil particles are compact in nature, hence it tends not to hold enough air, which is the basic requirements of many plants. Hence all plant can be grown using clay soil. However most plants like apples, willow, etc can be grown using Clay soil. Clay can also be used for other varieties of plants by adding different gypsum and compost so that these plants can benefit from the nutrients and moisture content of clay.

2. CONSTRUCTION: Clay soil has always been used in construction because of its properties. You can burn it to make an Adobe brick. The bricks are then laid together with mortar. Clay composition for house construction. Most of the figures were produced. Build a house out of clay. Garden sculptures made from clay soil are often left unglazed, allowing them to weather and age naturally over time. Earthen dams are created by adding suitable clay materials to porous soil to prevent water infiltration. Adding clay can reduce water loss in canals. The main raw materials for Portland cement are clay and limestone. Clay is used as a drilling fluid in oil drilling rigs.
3. LANDSCAPING: Clay soil is made up of small particles. It is very dense and does not allow water or air to pass through it easily, this water retention ability makes it ideal for use in landscaping. It can be used to create varieties of landscapes features such as beds, borders and pathways
4. MEDICINAL USE: The mineral content of clay soil helps to provide relief for an upset stomach and wound infection. Clay soil has minerals with Antimicrobial properties that are resistant. Most clay minerals are used for treating skin infections.
5. CERAMICS: Clay soil can be molded into a variety of shapes. The shape and structure when mixed with water. clay soil Plastic after mixing with water. You can make flower pots and tubes out of clay. and

other useful items for household use. Glue too It is used to make ceramic tiles that can be used on counters, floors, and on walls.

6. POTTERY: Making pottery using clay soil was a source of income since the ancient times. When you mix clay with water, you get a thick mass which can then be formed into a flower pot or other shape. These molded shapes are then placed in the oven where it is fired to suck all the moisture out of the mold and harden it.

CHAPTER THREE
MATERIALS AND METHODOLOGY

3.1 MATERIALS

They consist of;

3.1.1. Field materials

i. Global positioning system (GPS):This is an instrument used to locate the exact position on the map. This radio based navigation system provides accurate 3D positioning, velocity and time 24 hours a day, everywhere in the world and compatible with all weather.

ii. Measuring Tape: This instrument was used to measure clay diapirs in the formation and from where samples were taken.

iii. Field note: The field was used to write down important information that was observed in the study area such as vegetation type, drainage pattern etc.

iv. Pick hammer: This was used to loosen the clay materials embedded in the sand.

v. Cutlass: This was used to clear the path that led to where the samples were collected as the place was a rugged area filled with uneven grasses.

vi. Samples bags: The clay materials were kept in this bag.

vii. Pen, markers and Camera: The pen was used for writing on the field note, the marker was used to differentiate the samples of one location from another. The camera was used to take pictures of outcrops, structures and other geological interest.

viii. Safety boot and long sleeves to protect the feet and skin against the grasses and insect.

3.1.2. Laboratory Materials

1. X-ray fluorescence spectrometer: The equipment used to determine the chemical composition of the clay samples.
2. X-ray diffractometer: the laboratory equipment used to determine the mineralogical composition of the clay samples.

3.2 METHODOLOGY

1. Samples collection: The clay used for this research was collected from Igo community and Okhoro community.
2. Samples preparation: The clay in Boulder form from the site was first reduced to smaller particles size and further milled to fine powder and the clay samples was then dried.
3. Chemical analysis: chemical analysis of the powdered clay samples was determined using XRF instrument where the samples was dried at 1100 degree centigrade (because moisture have been added due to storage before analysis) for 8hrs prior to analysis. Rational analysis were then conducted using sulfuric acid to determine the various oxides percentage present.

4. Mineralogical analysis: The powdered clay sample was dried in an oven and the mineralogical data was obtained on powdered sample using XRD instrument.
5. Laboratory analysis used for clay materials.

   Analysis used for the clay samples are:

   i. X-ray fluorescence (XRF)
   ii. X-ray diffractometry (XRD)

3.2.1. X-RAY FLUORESCENCE (XRF)

X-ray fluorescence (XRF) analysis of the samples obtained from Igo and Okhoro community was performed in the geochemical laboratory. This was performed using an X-ray fluorescence spectrometer, an instrument used for routine and relatively non-destructive chemical analysis of rocks, minerals, minerals, etc. deposits and liquids. It works on the principle of spectral wavelength dispersion. It is similar to electron microscopy (EPMA). However, XRF is in principle cannot performs analysis at small spot sizes (2 to 5 microns) typical of EPMA operations and is therefore typically used for volumetric analysis of larger fractions of geological material.. The Stability and simplicity as well as relative ease and low cost of sample preparation makes X-ray spectrometry the most widely used method for the analysis of the major and trace elements which can be found in rock fragments and sediments.

3.2.1.1. Procedure for Determination of Percentage Elemental Composition of Clay Sample Using X-ray fluorescence:

I. PULVERIZATION OF THE ROCK SAMPLE

Dry the sample using oven at a temperature of 60°for 30 minutes if it is a wet sample or otherwise. Break the dried Samples into pieces using the various equipments, these are diamond cutting machine, jaw crusher disk Miller and finally vibrating cup Miller(Herzog model)by setting various equipments are 6-8rpm. Having out the powdered sample of particle size 100mesh(0.15 microns)The sample is ready for XRF machine.

II. PELLETIZATION OF ROCK SAMPLES

The powder samples are mixed with binder which can be either sodium or lithium tetra borate (BORAX). The borax and the sample are mixed in a ratio of 4:1 gram to analyze. This implies that 1g of Samples is weighed using metre balance and mixed with 4g of the borax. This is mixed evenly and properly using an Herzog vibrating cup Miller at a speed of 8 rpm. The mixture is then loaded into a cup of size 22mm by 40mm made of aluminum materials The pelletizing machine operates by allowing the stroke in an up and down movement. Only the pressing force is set at 6 rpm. The cup containing the mixed sample is placed on the stroke and allowed to go down the limitation point. On the returning of the stroke with plug already plugged at the loading point, the pressing force pressed the cup against fixed point and a pellet is formed. The pellet is now ready for XRF analysis.

III. SETTING OF THE XRF EQUIPMENT.

The necessary parameters is now set in accordance to standards. These parameters include a pressure value set at 16 Pa (pascals), climate chamber for opening and lifting of the cassette (holder with granule samples). The voltage mostly recommended is 45v and the current recommended current level is 40A. The instrument is allowed to operate for at least 4 to 8 hours to allow the standards and other mechanical parts responsible for the analysis to stabilize and initialize.

IV. LOADING AND RUNNING OF SAMPLES

The sample is Placed in the CASSETTE with the surface side facing downwards. A spring attached to the cassette is used to manually secure it by turning it clockwise to prevent sediment from falling or scattering on the goniometer during downward analysis. The loading and cassette points are directly opposite the goniometer positions for ease of analysis. Analysis begins immediately after the cassette has been lifted down with which resulted in the closure of the opening valve.

V. GENERATION OF RAW DATA

After approximately 20 minutes the analysis is complete and data collection is performed automatically followed by a manual deletion technique of the results into a save file where the results can be obtained in ionic, carbonate, oxide or non-ionic format. Results are issued when the concentration of the relevant parameter is greater than or equal to that of an already calibrated and installed station.

3.2.1.2. Application of XRF Analysis

X-ray fluorescence is a form of geochemical analysis which is widely used in a wide range of applications and research such as: Soil surveys, mining (e.g. determination of ore content and their grade), cement production, ceramic and glass production, metallurgy (e.g. quality control). Environmental studies (e.g. particulate matter analysis of filters) Petroleum industry (e.g. sulfur content of crude oil and distillate). field analysis in geological and environmental studies. It is also useful in igneous, sedimentary and metamorphic petrology.

3.2.1.3. Strengths and Limitations of X-ray Fluorescence (XRF)

1. **Strengths**

X-ray fluorescence is particularly well and suited for investigations that involves

i. Bulk chemical analysis of major elements (Si, Ti Al, Fe, Mn, Mg, Ca, Na, K, P) in rocks and sediments.

ii. Bulk chemical analysis of trace elements (>1ppm, Ba, Ce, Co, Cr, Cu, Ga, Nb, Ni, Rb, Sc, Sr, Rh, Zr, Zn) in rocks and sediments.

2. **Limitations**

In theory, XRF is able to detect X-ray emissions from all elements, which vary depending on the wavelength and intensity of the incident Xrays, but in practice most commercial instruments have very limited ability to accurately and accurately measure the abundance of elements with Z=11 in most natural earth materials. XRF analysis cannot distinguish differences between isotopes of an element. Due to this factor, this analysis is usually performed using other instruments. XRF analysis cannot distinguish between ions of the same element in different valence states. So these analysis of rocks and minerals are done with techniques such as wet chemical analysis or Mossbauer spectroscopy.

3.2.2. X-RAY DIFFRACTOMETRY (XRD).

The x-ray diffractometry (XRD) analysis on the samples obtained from Igo and Okhoro community was carried out in the lab using an X-ray diffractometer.

Procedure for Determination of Percentage Mineralogical Composition of Rock Samples Using;

i. PULVERIZATON OF THE ROCK SAMPLES

   Dry the sample by using an oven at a temperature of 60°C for 30 minutes if it is a wet sample or otherwise. Break the dried sample into pieces with the various equipment; Jaw crusher, diamond cutting devices, disc Miller and a vibrating cup Miller by setting the various equipment at 6-8 rpm. Having obtained the powder samples of particulate size 100 mesh (0.15 microns) the sample is ready for XRD machine.

ii. SETTING OF THE XRD EQUIPMENT

This is usually run between 0° and 20° theta Bragg angle depending on the type of minerals in question. The running rate per second is between two to ten per second.

The voltage recommended is 40v and the current recommended level is 30A.The silt used for aperture are sizes 0.01 and 0.03 microns.

iii. LOADING AND RUNNING OF SAMPLES

The sample is spread out on a sample holder made of aluminum material which is a smooth surface. The holder is neatly placed on the loading dock of the point on the goniometer lever containing the damping lever. The window indicating readiness and having properly closed the analysis starts. The pronounced peaks or diffractograms being displayed expresses the mineralogical composition at various angle of the degree theta.

3.3 QUALITY ASSURANCE/QUALITY CONTROL

The following quality assurance procedures apply in this study.

1. The field data and information obtained were documented on field data sheets.
2. All instrument and equipment were used in accordance with the operating instructions and guidelines as supplied by the manufacturer, unless otherwise specified in the initial work plan.

PLATE 1: Clay sample from the exposed Benin formation, Igo Community.

LATE 2: Clay sample from the exposed Benin formation Okhoro Community.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the findings from the mineralogical analyses conducted on clay samples collected from Igo and Okhoro. The results are systematically presented and discussed with respect to the geological context, mineral composition, and the potential economic benefits of the clay deposits. A comparative analysis between the two locations is provided to highlight their distinct properties and industrial suitability.

4.2 Field Observations and Sample Description

The clay deposits in Igo and Okhoro are located within the Benin Formation, Southern Nigeria. The study area is accessible via major and minor roads, with footpaths leading to the outcrops. The Igo clay deposit showed intercalations of clay and reddish, lateritic sand. In contrast, the Okhoro deposit was characterized by light grey clay with brownish patches, overlaid by reddish sand. The brownish and reddish colorations observed at both sites are attributable to the oxidation of iron minerals. The topsoil in the area ranges from brownish to reddish sand, consistent with the typical ferruginized or laterized clay sands of the Benin Formation as described by Agbongiague et al. (2024).

4.2.1 QUATITATIVE XRF ANALYSIS

Table 1: Major Element composition of clay samples from Igo

MAJOR ELEMENTAL COMPOSITION	IGO 1	IGO2	IGO 3	IGO 4	IGO 5	MEAN%
SiO_2	65.93	73.32	65.83	68.79	68.99	68.57
Al_2O_3	25.96	19.54	25.38	20.62	21.44	22.59
K_2O	0.13	0.14	0.15	0.38	0.22	0.20
Fe_2O_3	1.99	1.68	1.99	2.72	2.09	2.09
CaO	0.38	0.42	0.88	0.73	0.59	0.60
TiO_2	3.44	3.02	3.67	4.12	3.39	3.53
MgO	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.05	0.04	0.06	0.05	0.05	0.05
P_2O_5	0.08	0.05	0.05	0.12	0.00	0.06
TOTAL	97.96	98.21	98.01	97.53	96.77	97.69

Table 2: trace elements of clay samples from Igo

TRACE ELEMENT	IGO 1	IGO 2	IGO 3	IGO 4	IGO 5	MEAN %
SnO_2	0.00	0.00	0.00	0.00	0.00	0.00
BaO	0.04	0.00	0.00	0.00	0.00	0.008
CuO	0.04	0.04	0.04	0.05	0.04	0.04
v_2O_5	0.21	0.18	0.19	0.25	0.24	0.21
ZnO	0.01	0.02	0.01	0.02	0.02	0.02
ZrO_2	0.23	0.26	0.23	0.01	0.29	0.20
NiO	0.01	0.01	0.01	0.01	0.01	0.01
CoO	NIL	0.01	NIL	0.02	0.01	0.008

4.2.2 Geochemical Interpretation

From the table above, The result show high concentration of silica content with an average weight of 68.57.wt % and high concentration of alumina content with an average weight of 22.59.wt %. Hence, the silica content is higher than the alumina content in the igo clay samples. The ferric oxides(Fe_20_3) has an average weight of 2.09.wt % and titanium dioxide($Ti0_2$) also have an average weight of 3.53.wt %.

Generally, when Ca0 content is low Mg0 will be high. The result above shows that th e Ca0 content is higher than the Mg0 across all the clay samples. This suggests that the igo clays likely have more calcium minerals present than magnesium minerals . Compared to the okhoro clay samples, The geochemical data for Okhoro clays, as reported by Agbongiague et al. (2024), provides a benchmark, showing high SiO_2 and very low concentrations of fluxing oxides like K_2O and Na_2O. This profile aligns with its mineralogy and confirms an advanced stage of chemical weathering.

All trace element have relatively low or no content value, this shows that when used as raw materials for products they will have no impact negatively on the finished products.

MAJOR ELEMENTAL COMPOSITION	**OKHORO 1**	**OKHORO 2**	**OKHORO 3**	**MEAN %**
SiO_2	59.99	58.19	59.57	59.25
Al_2O_3	21.68	22.47	21.44	21.86
Fe_2O_3	6.36	7.31	7.34	7.00
CaO	0.12	0.04	0.16	0.11
TiO_2	1.34	1.20	1.25	1.26
MgO	0.20	0.19	0.18	0.19
MnO	0.09	0.06	0.08	0.08
P_2O_5	NIL	0.05	0.05	0.03
K_2O	0.08	0.24	0.09	0.14

Table 3: Major element of clay sample at Okhoro (Agbongiague et al., 2024).

MAJOR ELEMENTS	MEAN % IGO	MEAN % OKH	Refractory bricks (Parker,1967)	Rubber (Keller,1964)	Ceramics (Singer and Sonjai, 1964)	Brick clay (Murry 1960)	Additives (Payne, 1961 Paint)
SiO2	68.57	59.25	51-70	44.9	67.5	38.67	48.68
Al_2O_3	22.59	21.86	25-44	32.35	26.5	9.45	9.45
K_2O	0.20	0.14	-	0.28	1.10-3.10	2.76	2.76
Fe_2O_3	2.09	7.00	0.5-2.40	0.43	0.5-1.20	2.7	2.7
CaO	0.60	0.11	0.1-0.2	Tr	0.18-0.30	15.84	15.84
TiO_2	3.53	1.26	1.0-2.80	1.8	0.1.-1.0	-	-
MgO	0.00	0.19	0.2-0.7	Tr	0.1-0.19	8.5	85
MnO	0.05	0.08	-	0.01	-	-	-
P_2O_5	0.06	0.03	-	-	-	-	-

Table 4: Major element of studied clay compound with chemical industrial specifications.

The Igo clay and okhoro clay can be most suitable for refractory bricks only when some beneficiation is done on them.

4.2.3 Geochemical Interpretation

From the table above, The result show high concentration of silica content with an average weight of 68.57.wt % and high concentration of alumina content with an average weight of 22.59.wt %. Hence, the silica content is higher than the alumina content in the igo clay samples. The ferric oxides($Fe_20_{3)}$ have an high content with an average weight of 2.09.wt %. This could be as a result of high perculation of ferric waters down to the clay from the ferrogenize lateritic body overlying the clays. The titanium dioxide($Ti0_2$) also have an high content with average weight of 3.53.wt %. This could be as a result of heavy mineral presence and weathering intensity.

Generally, when Ca0 content is low Mg0 will be high. The result above shows that th e Ca0 content is higher than the Mg0 across all the clay samples. This suggests that the igo clays likely have more calcium minerals present than magnesium minerals . Compared to the okhoro clay samples, The geochemical data for Okhoro clays, as reported by Agbongiague et al. (2024), provides a benchmark, showing high SiO_2 and very low concentrations of fluxing oxides like K_2O and Na_2O. This profile aligns with its mineralogy and confirms an advanced stage of chemical weathering.

All trace element have relatively low or no content value, this shows that when used as raw materials for products they will have no impact negatively on the finished products.

4.2.4 Mineralogical Composition (XRD Analysis)

The mineralogical composition of the clay samples from Igo and Okhoro, as determined by X-ray Diffraction (XRD) analysis, is summarized in Table 2. The analysis identified a suite of minerals, with quartz and kaolinite being the dominant phases across all samples.

SAMPLE 1

Figure 4: X-ray diffractogram of IGO 1 sample

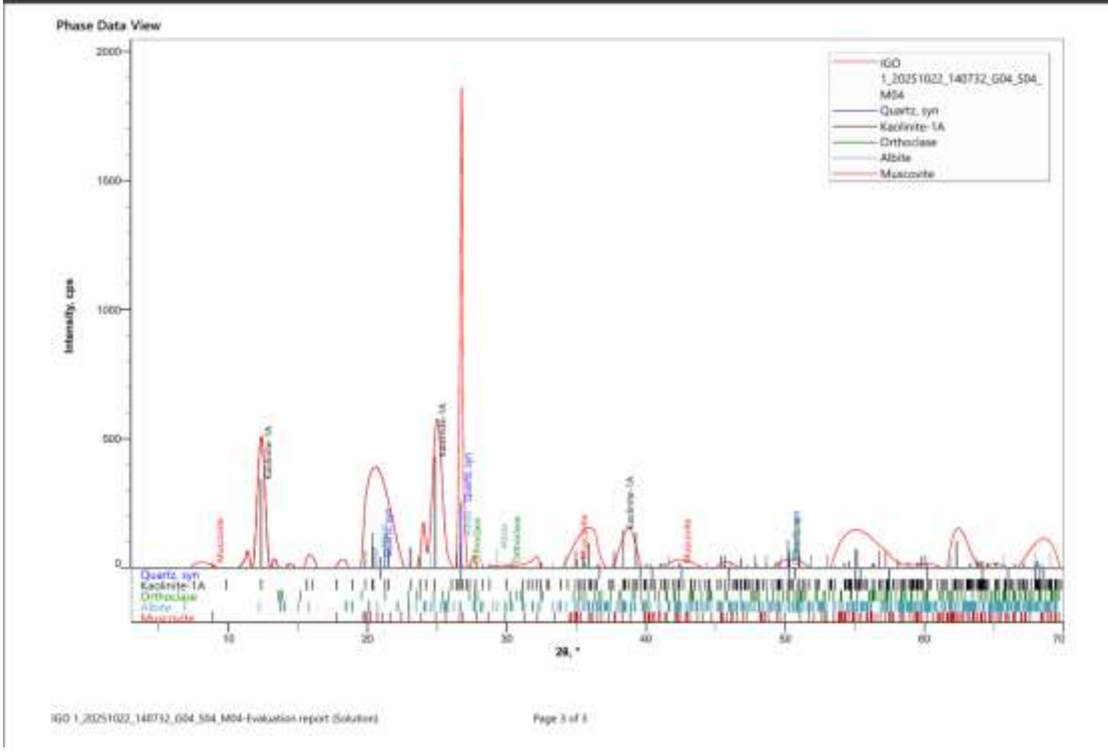
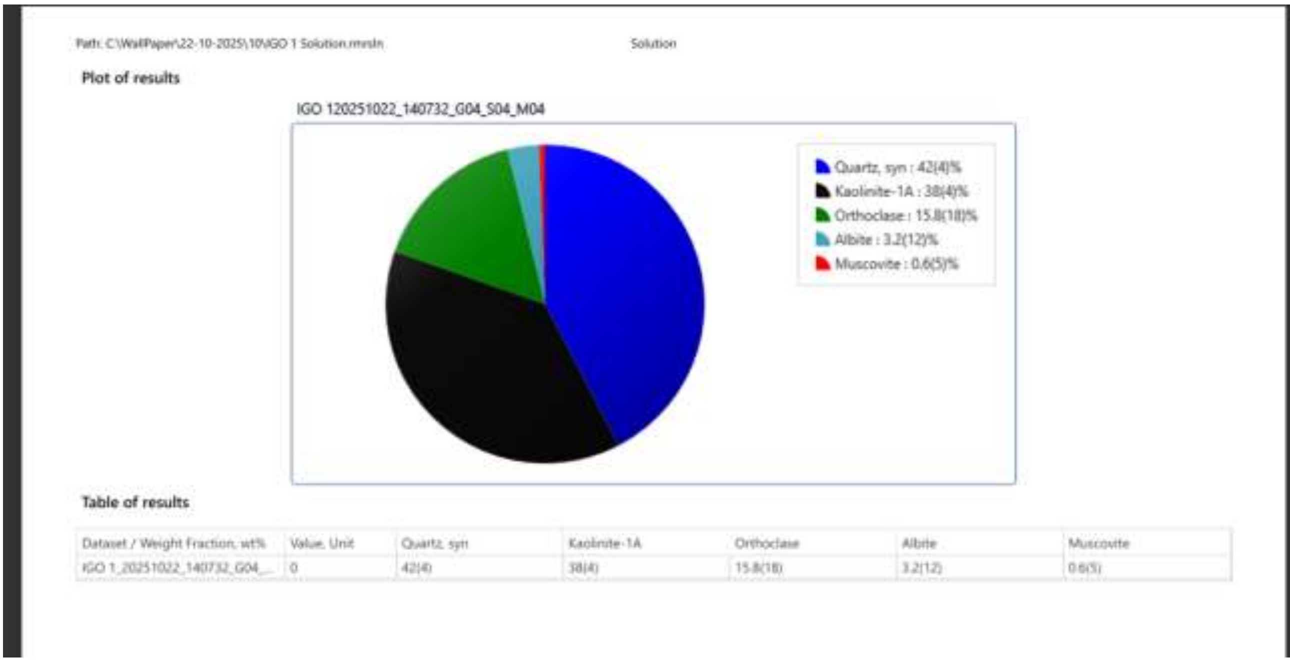


Figure 5: Quantitative analysis report for IGO 1 sample



Dataset / Weight Fraction, wt%	Value, Unit	Quartz, syn	Kaolinite-1A	Orthoclase	Albite	Muscovite
IGO 1_20251022_140732_G04_...	0	42(4)	38(4)	15.8(18)	3.2(12)	0.6(5)

Figure 6: Modal Quantitative composition of IGO 1 sample

(Nigeria Building And Road Research Institute- Mc Lab. ZARIA, KADUNA STATE NIGERIA)

SAMPLE 2

Figure 7: X-ray diffractogram of IGO 2 sample

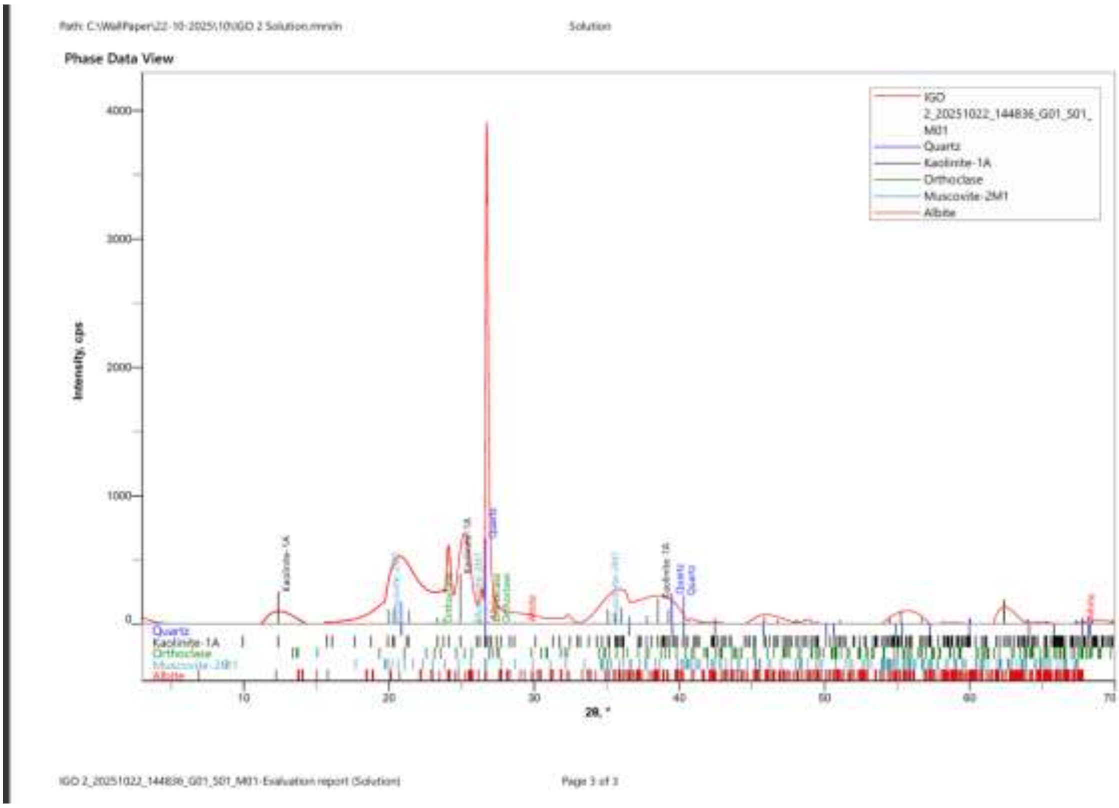


Figure 8: Quantitative analysis report for IGO 2 sample

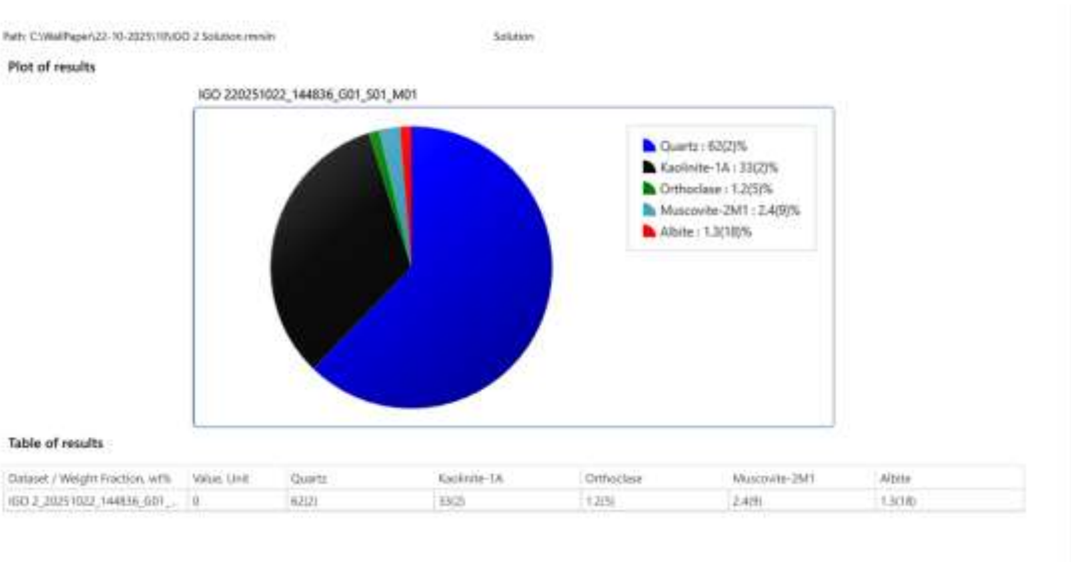


Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Quartz	Kaolinite-1A	Orthoclase	Muscovite-2M1	Albite
IGO 2_20251022_144836_G01_...	0	62(2)	33(2)	1.2(5)	2.4(9)	1.3(18)

Figure 9: Modal quantitative composition for IGO 2 sample

(Nigeria Building And Road Research Institute- Mc Lab. ZARIA, KADUNA STATE NIGERIA)

SAMPLE 3

Figure 10: X-ray diffractogram of IGO 3 samples

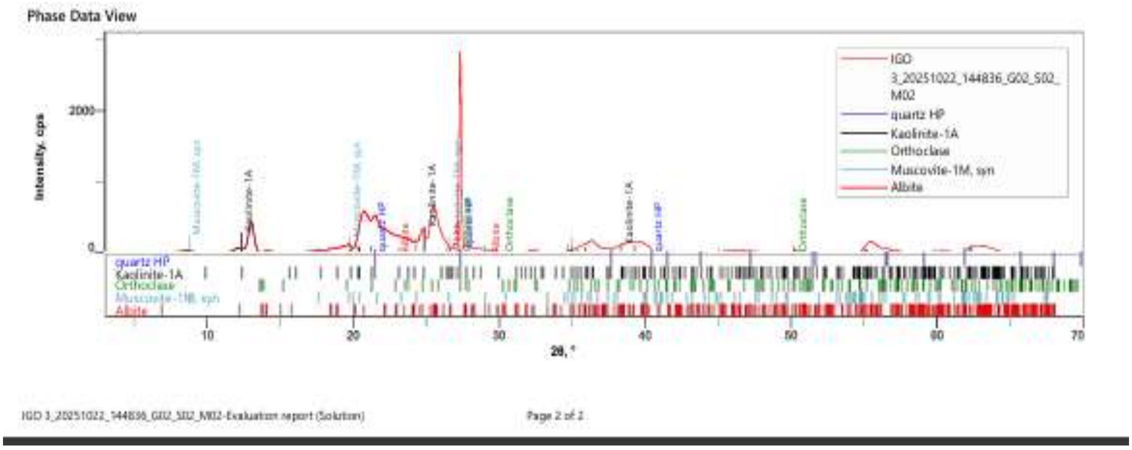


Figure 11: Quantitative analysis report for IGO 3 sample

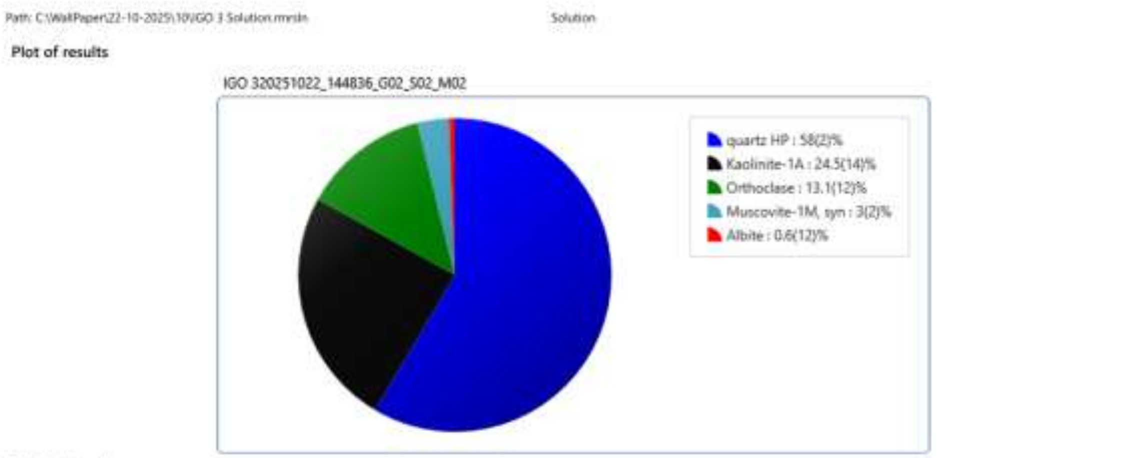


Table of results

Dataset / Weight Fraction, wt%	Value, Unit	quartz HP	Kaolinite-1A	Orthoclase	Muscovite-1M, syn	Albite
IGO 3_20251022_144836_G02_...	0	58(2)	24.5(14)	13.1(12)	3(2)	0.6(12)

Figure 12: Modal quantitative composition of IGO 3 sample

(Nigeria Building And Road Research Institute- Mc Lab. ZARIA, KADUNA STATE NIGERIA)

SAMPLE 4

Figure 13: X-ray diffractogram of IGO 4 sample

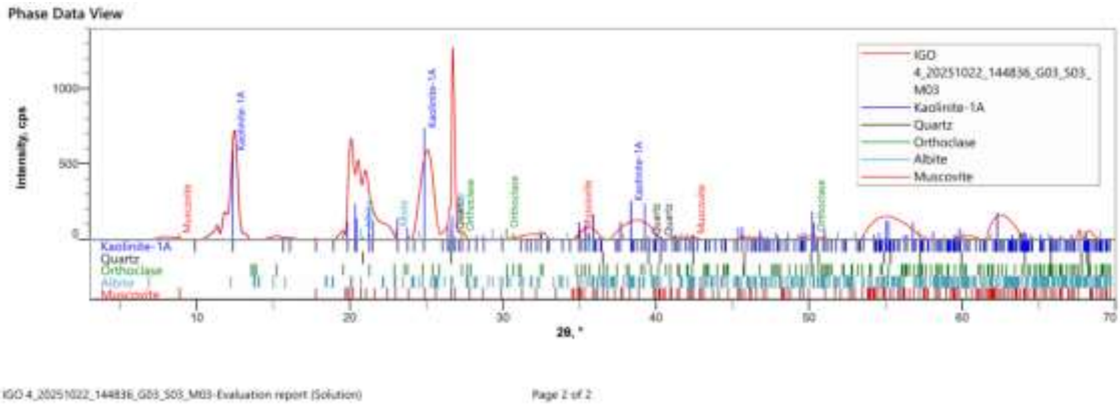


Figure 14: Quantitative analysis report for IGO 4 sample

Path: C:\WallPaper\22-10-2025\10\IGO 4 Solution.rmrsln Solution

Plot of results

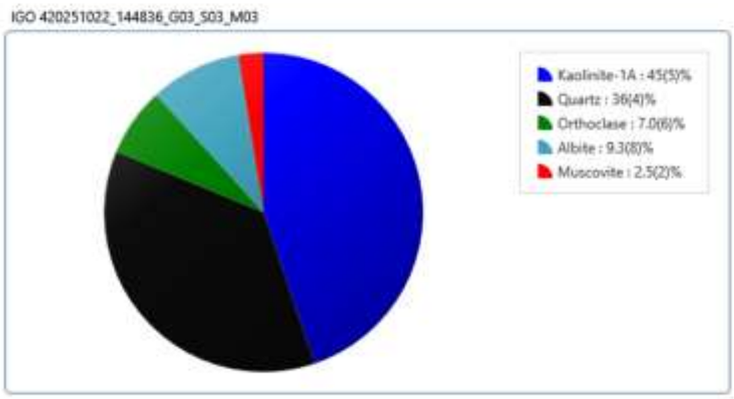


Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Kaolinite-1A	Quartz	Orthoclase	Albite	Muscovite
IGO 4_20251022_144836_G03_...	0	45(5)	36(4)	7.0(6)	9.3(8)	2.5(2)

Figure 15: Modal Quantitative Composition of IGO 4 sample

(Nigeria Building And Road Research Institute- Mc Lab. ZARIA, KADUNA STATE NIGERIA)

SAMPLE 5

Figure 16: X-ray Diffractograms of IGO 5 sample

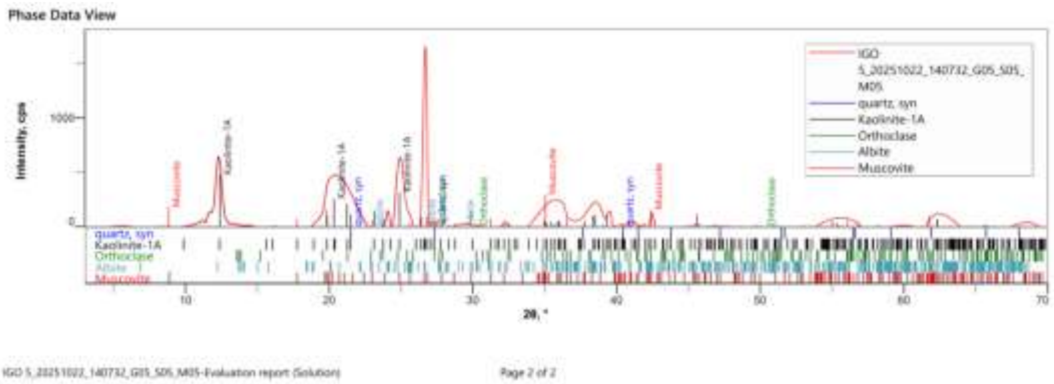


Figure 17: Quantitative analysis report for IGO 5 sample

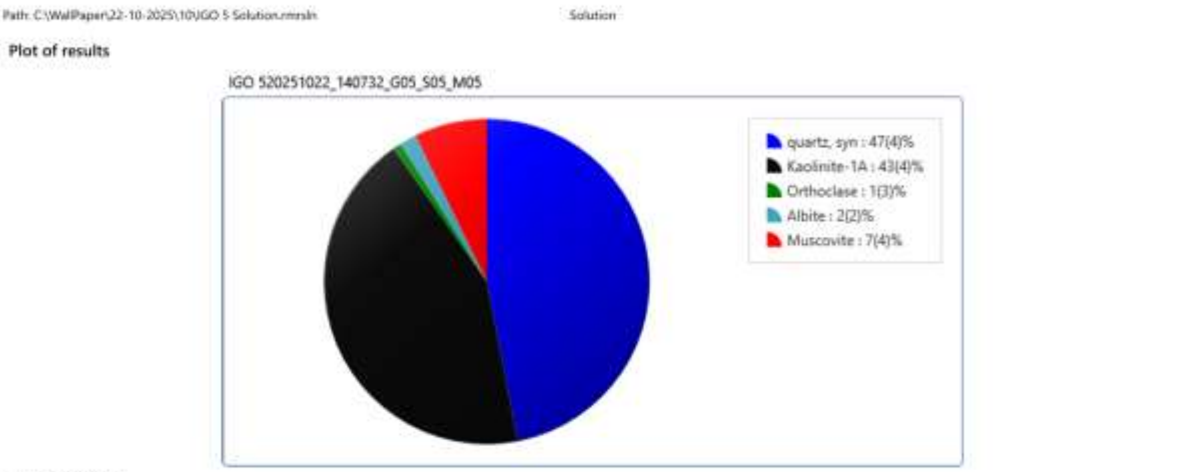


Table of results

Dataset / Weight Fraction, wt%	Value, Unit	quartz, syn	Kaolinite-1A	Orthoclase	Albite	Muscovite
IGO 5_20251022_140732_G05_...	0	47(4)	43(4)	1(3)	2(2)	7(4)

Figure 18: Modal Quantitative Composition for IGO 5 sample
(Nigeria Building And Road Research Institute- Mc Lab. ZARIA, KADUNA STATE NIGERIA)

MINERALOGICAL COMPOSITION

Table 5: Modal Composition (wt%) of Clay Samples from Igo and Okhoro

Sample ID	Quartz	Kaolinite	Orthoclase	Albite	Muscovite
IGO 1	42	38	15.8	3.2	0.6
IGO 2	62	33	1.2	1.3	2.4
IGO 3	58	24.5	13.1	0.6	3
IGO 4	36	45	7.0	9.3	2.5
IGO 5	47	43	1	2	7
OKH-1	98.04	0.98	-	-	-
OKH-2	96.91	1.48	-	-	-
OKH-3	88.6	9.42	-	-	-

Mineralogical data for Okhoro samples (OKH-1, OKH-2, OKH-3) are sourced from Agbongiague et al. (2024) for comparative purposes.

4.3 Interpretation of Results

The XRD results reveal that the Igo clays are mineralogically diverse. Kaolinite content ranges from 24.5% to 45%, while quartz varies between 36% and 62%. Significant amounts of feldspars (Orthoclase and Albite) and micas

(Muscovite) are also present in most Igo samples. Representative X-ray diffractograms for samples IGO-1 to IGO-5 are shown in Table5, highlighting the characteristic peaks of the identified minerals. The mineralogical composition was consistent across most Igo samples, with kaolinite and quartz as the dominant phases. In stark contrast, the Okhoro clays from the literature are overwhelmingly dominated by quartz (88.6% to 98.04%), with a very low kaolinite content (0.98% to 9.42%) and an absence of detectable feldspars. From the table above, the orthoclase, the muscovite, and albite have zero values indicating that the okhoro clay samples are more mineralogically matured than the igo clay samples. Hence, they must have undergone intensive weathering and transportation of sediments than that of igo.

4.3.1 Mineralogical Interpretation

The mineralogical disparity between Igo and Okhoro, despite their proximity within the Benin Formation, highlights significant variability in depositional and weathering environments. The preservation of feldspars at Igo suggests a sediment that was either transported more rapidly from its source (preventing complete chemical weathering) or derived from a different local parent rock with a higher feldspar content. In contrast, the extreme maturity of the Okhoro clays points to an environment of prolonged chemical weathering in a stable, low-energy setting, such as a floodplain or a distal part of a sedimentary basin, where only the most stable minerals (quartz) could persist. The Igo clays, with their feldspars and kaolinite, are kaolinite-quartz-feldspathic in nature. This indicates a less mature sediment, where chemical weathering has not completely degraded all feldspathic minerals. This is consistent with findings by Odia-Oseghale et al. (2023) for clays in the broader Ovia North-East area.

The Okhoro clays, however, are essentially quartzose sands with minor kaolinite. The extreme dominance of quartz and near absence of feldspars point to a highly mature sediment that has undergone intense chemical weathering and physical sorting, leaving behind the most stable mineral, quartz.

4.3.3 Industrial and Economic Significance

The contrasting mineralogy dictates the economic applications of the two clay deposits.

Igo Clays:

The significant kaolinite content (up to 45%) makes Igo clays a promising raw material for the ceramic industry, particularly for earthenware, pottery, and tiles. The presence of feldspar is a major advantage, as it acts as a natural flux, reducing the energy required during firing. This composition makes Igo clays suitable for a wider range of ceramic products compared to Okhoro. Furthermore, with beneficiation to reduce quartz content, these clays could be tested for use as a filler in the paint and rubber industries.

Okhoro Clays:

As identified by Agbongiague et al. (2024), the Okhoro deposits are sandy clays with low plasticity and a mineralogy dominated by quartz. Their direct use in high-value ceramics is limited. Their primary use is as a filler material in construction, such as in cement production, or as a base material for refractory bricks when blended with high-purity clays. They could also be used in less demanding applications like brick making. Their use in cosmetics or pharmaceuticals would require extensive and likely uneconomical processing to remove the abundant quartz.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study successfully characterized and compared the mineralogical composition of clay deposits from Igo and Okhoro within the Benin Formation, leading to clear conclusions regarding their genesis and economic potential.

The primary conclusion is that the Igo and Okhoro clay deposits are mineralogically distinct, representing different stages of sedimentary maturity and weathering history. The Igo clay is a kaolinite-quartz-feldspathic clay, characterized by a significant and valuable kaolinite content (24.5 - 45%) and the consistent presence of orthoclase and albite feldspars. This mineral assemblage indicates a sub-mature sediment derived from a source that underwent a moderate intensity of chemical weathering, which preserved the less stable feldspathic minerals.

In stark contrast, the Okhoro clay is a quartzose sand with only trace amounts of kaolinite (0.98 - 9.42%) and a complete absence of detectable feldspars. This composition is the hallmark of a mineralogically super-mature sediment, resulting from intense and prolonged chemical weathering that destroyed all but the most stable mineral, quartz.

The Geochemical analysis(XRF) of the Igo samples shows high concentrations of silica (SiO_2: with mean value 68.57%) and alumina (Al_2O_3: with mean value 22.59%), with relatively low levels of fluxing oxides. In contrast, the Okhoro samples contain lower silica (mean 59.25%), comparable alumina (mean 21.86%), but noticeably higher iron oxide (Fe_2O_3: up to 7.34%). Trace element concentrations in both locations were generally low, indicating minimal impurity influence on industrial applications.

5.2 Recommendations

Based on the conclusions of this study, the following recommendations are made:

1. For the Igo Clay Deposit:

i. **Beneficiation Studies:** Invest in beneficiation processes (such as sieving, magnetic separation, or chemical bleaching) to reduce the quartz and iron oxide content, which would enhance the clay's quality and whiteness for higher-value ceramic and industrial applications.

ii. **Detailed Geochemical and Geotechnical Analysis:** Conduct further analyses, including XRF for precise chemical composition and Atterberg limits tests to determine plasticity. These data are crucial for attracting industrial investment and optimizing the clay for specific ceramic recipes.

iii. **Firing Tests:** Perform industrial firing tests on the Igo clay to determine its specific behaviour, including shrinkage, water absorption, porosity, and fired colour, to definitively classify its ceramic grade.

2. For the Okhoro Clay Deposit:

i. **Optimization as Filler:** Focus research on optimizing its use as a cheap, locally sourced filler material in cement production, brick manufacturing, and possibly as a base for agricultural soil conditioners.

ii. **Exploration for Purer Layers:** Conduct further geological surveying within the Okhoro area to determine if there are subsurface layers with higher clay content that were not exposed in the sampled outcrops.

3. For Government and Stakeholders:

i. **Policy Development:** The relevant state ministries should recognize the economic value of the Igo clay deposit and develop policies that encourage its sustainable exploitation for local industries, reducing reliance on imported ceramic raw materials.

ii. **Investment in Processing:** Encourage public and private sector investment in small to medium-scale ceramic and brick-making industries in the Igo community to create jobs and add value to the raw material locally.

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