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FIELD OCCURRENCE AND COMPOSITIONAL CHARACTERISTICS OF THE CLAY HORIZON IN THE PATTI FORMATION, SOUTHERN BIDA BASIN NORTH-CENTRAL NIGERIA

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ABSTRACT

Field geological traversing and compositional analyses (chemical and mineralogical) were conducted on the clay horizon within the Patti Formation in the Southern Bida Basin, North-central Nigeria, to determine its mineralogical and chemical composition and potential economic uses. This study addresses the growing need for local raw materials in the ceramic and refractory industries, crucial for regional economic growth. Field observations reveal a stratigraphic setting of basal shale, claystone, and sandstone, with clay thickness ranging from 0.8 to 2.7 meters. The clay is whitish, plastic, and greasy to the touch. X-Ray Diffraction (XRD) analysis shows the clay is predominantly kaolinite (58.8%), with quartz (32.60%) and muscovite (6.12%). X-Ray Fluorescence Spectrometry indicates major oxides include SiO_2 (57.41%), Al_2O_3 (24.56%), and Fe_2O_3 (0.56%). The Al_2O_3 content, critical for ceramic production, is within the suitable range (19.62-32%). The SiO_2 and Fe_2O_3 contents also meet industry standards for ceramics (44.9%-70.0% SiO_2 and 0.5%-8.6% Fe_2O_3). The clay's composition further satisfies refractory material requirements, highlighting its industrial potential. This research contributes to the identification and development of valuable local resources.

Keywords: Clay, Geochemistry, Weathering, Ceramics, Patti Formation

INTRODUCTION

Clay is a naturally occurring earth material composed mainly of fine-grained minerals, which becomes plastic on addition of water, and becomes hard when dried or fired, (Ombaka, 2016). Clays result from the weathering or alterations of rocks mainly of igneous origin. They can form insitu (residual clays) or transported away from the parent rock where they are formed and deposited in a sea or lakes as loess or alluvial deposits. Clay minerals occur as very minute flaky crystals which have SiO_4 tetrahedral sheets. Most of them occur as platy particles in fine grained aggregate which when mixed with water yield materials which have varying degrees of plasticity. Important differences among the clay minerals, however lead to their subdivision into several main groups. The common types of clay minerals include: kaolinite, halloysite, montmorillonite, illite, nontronite, hectorite and allophane. All clay minerals are of secondary geologic origin i.e. they are formed as alteration products of alumino-silicate rocks in an environment in which water is present (Ijagbemi, 2002). Colloidal suspensions form when clays are immersed in fresh water and flocculation occurs when they are immersed in saline water. Clay minerals have different color, from white to dull grey or brown to deep orange-red depending on the clay (Kumari and Mohan, 2021)

Clay is one of the most common industrial minerals in Nigeria; it has been reported in several locations in every region of the country. Industrial minerals such as clays are raw materials used for ceramics, agriculture, building infrastructure, and mitigation of environmental problems. There are some properties of clay such as plasticity, chemical composition, refractory property, strength and shrinkage that determine its suitability in several industries. The size and shape of particles of clay minerals and aggregate characteristics affect the physical properties of industrial clays. The small crystal size yields a large specific surface area for most clay minerals.

The study area, Agbaja and its environs is situated in the Lokoja area of Kogi State, Nigeria and falls within the sedimentary Bida basin of Nigeria. Its lies between latitudes 7^0 53' to 7º 59′ N and longitudes 6^0 32′ to 6^0 43′ E. It covers an area of about 50km². The surface geology of the area is primarily capped by ironstone, a characteristic feature of the Agbaja Formation, underlain by loose silty soil. Beneath this cover lies the Patti Formation, which is a key unit of the Southern Bida Basin's stratigraphy, composed of shale, claystone, and sandstone layers.

Bida basin is a linear intracratonic sedimentary basin located in the central part of Nigeria. The basin is a NW-SE trending intra-cratonic basin which extends northwest from the confluence of Benue and Niger Rivers at Dekina/Lokoja axis. It is separated by the crystalline Basement Complex terrain from the early Cretaceous to Tertiary Illo and Gundumi Formations of the Sokoto basin at Shegwa around Kainji reservoir (Rahaman *et al.*, 2018).

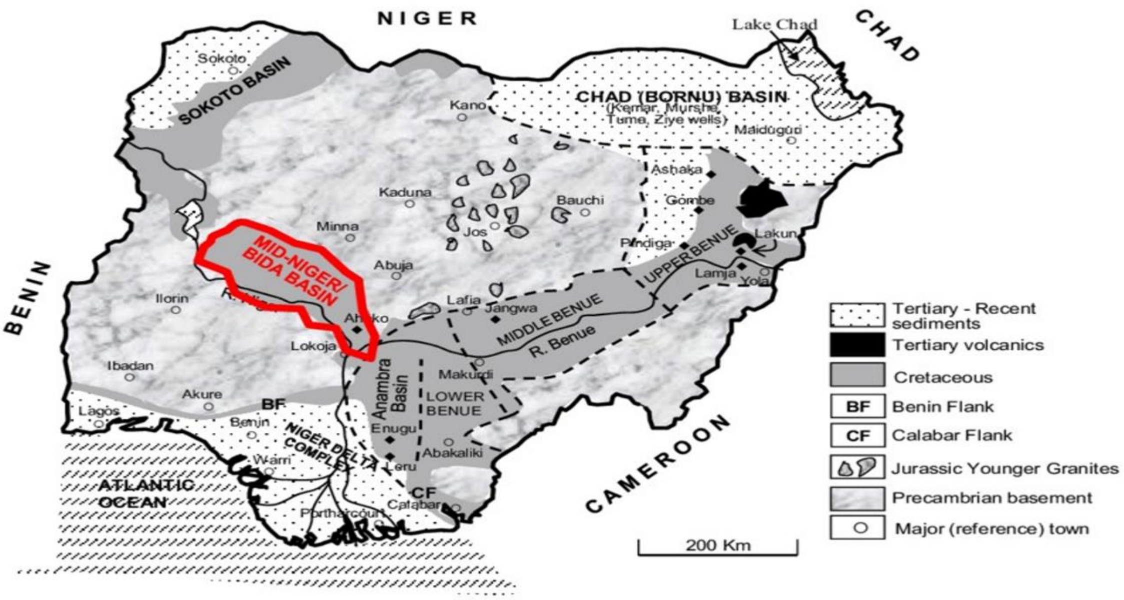

Figure 1: Geological Map of Nigeria showing the Bida basin. (Obaje, 2013)

The historical geological evolution of the Patti Formation is closely tied to the broader tectonic and sedimentary history of the Bida Basin. During the Maastrichtian, the Bida Basin experienced a combination of fluvial and shallow marine depositional environments, leading to the accumulation of fine-grained sediments that now constitute the Patti Formation (Obaje, 2009). These depositional processes were influenced by regional tectonic activities, including the subsidence of the basin and the subsequent accommodation space created for sediment deposition.

Previous research in the Southern Bida Basin, such as the works by Ojo et al. (2020) and Ayuba et al. (2024), has provided a general overview of the stratigraphy and sedimentology of the basin. However, there remains a significant gap in the detailed understanding of the mineralogical and chemical properties of the claystone units within the Patti Formation, particularly in the Agbaja area along Lokoja/Agbaja road cut.

The basin is geographically divided into the northern and southern Bida basins and comprises of about 3km thick Campanian to Maastrichtian continental to shallow marine sediments. Their lateral stratigraphic equivalents in the northern Bida basin consist of the basal Bida Formation (conglomerate, sandstone), Enagi Formation (siltstone, claystone and sandstone) and Batati Formation (Ironstone).

The southern Bida basin comprises of the basal Campanian Lokoja Formation (mainly conglomerate and sandstone), Maastrichtian Patti Formation (shale, claystone and sandstone) and the youngest Agbaja Formation (Ironstone).

The Lokoja Formation unconformably overlies the Basement. The Lokoja Formation is immature mineralogically and texturally, and consists of massive clast to matrix supported conglomerate that fine upwards to conglomeratic-sandstone, medium grained sandstone and siltstone. Overlying the Lokoja Formation is the Patti Formation which is made up of shale, sandstone, ironstone and claystone (Ojo *et al.*, 2020; Ayuba *et.al*, 2024). The geological conditions of the Patti Formation are indicative of a Maastrichtian age sedimentary environment characterized by alternating depositional regimes that led to the formation of these distinct lithological units. The Patti Formation is particularly significant due to its claystone horizons, which have potential industrial applications, particularly in ceramics and refractory materials.

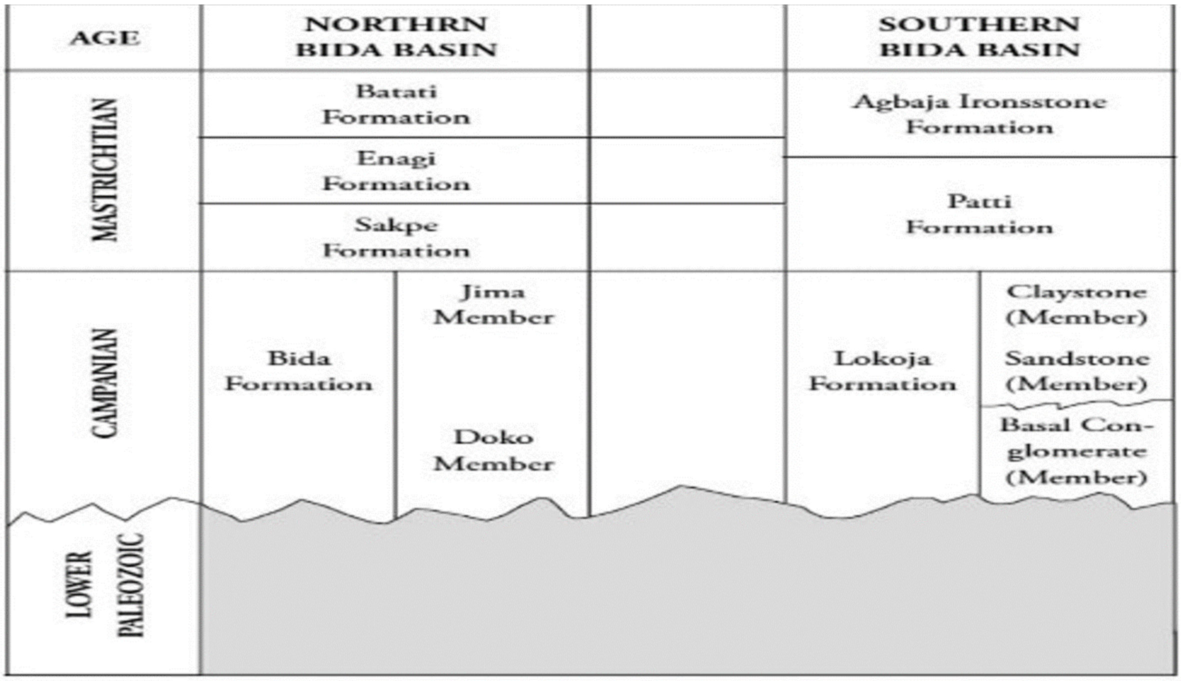

Figure 2: Lithostratigraphic units of the northern Bida basin and the southern Bida basin. (After Akande *et al.,* 2005)

The structural style of the Middle Niger basin (Bida basin) is portrayed by a system of NW-SE trending faults at the boundaries of the basin with the surrounding crystalline Basement terrain (Rahaman *et al.,* 2018). No prominent morphological features, lineaments or intrusions were observed within the sedimentary basin (Salawu *et al.*, 2020). In contrast, the underlying Basement is characterized by prominent structural features, including the lateral continuity of the NNE-SSW trending Kalangai–Zungeru-Ifewara shear zones formed during the Pan-African orogeny (Salawu *et al.*, 2020).

This study focuses on the claystone units within the Patti Formation in the Southern Bida Basin, aiming to explore key research questions: What are the mineralogical and chemical compositions of these claystone units? How do these compositions compare with industry standards for ceramics and refractory materials? What geological processes have influenced the formation and distribution of these units? To answer these questions, detailed field geological mapping of the study area is conducted to determine the occurrence and distribution of claystone units. Mineralogical analysis using X-Ray Diffraction (XRD) is performed to identify the types and proportions of clay minerals present, and geochemical analysis using X-Ray Fluorescence Spectrometry (XRF) is utilized to determine the major element composition of the claystone. By comparing these findings with industry standards, the study evaluates the claystone's economic potential and suitability for industrial use. By filling these knowledge gaps, the research will contribute to a better understanding of the Patti Formation's claystone units and their potential for industrial exploit

MATERIALS AND METHODS

Field methods

This involves a systematic field reconnaissance of the area. Detailed field mapping was carried out to identify the rock types in the area and their stratigraphic succession. The field mapping involved open traversing along road cuts and river channels. Stratigraphic profiles were carefully documented using descriptive notes focusing on the variation in textural and lithological properties of each horizon in the formation. Specific criteria for identifying rock types, such as color, grain size, mineral composition, and stratigraphic position, were consistently applied during the mapping process.

Sample Collection and Materials Used

Samples of the clay were primarily collected from exposures at road cuts and stream channel. In stream channels, samples were collected from a depth of 6cm and deeper. Although this depth might typically be shallow, great care was taken to ensure that only fresh, unweather material was sampled. Field observations, such as the color, texture, and consistency of the samples, were used to confirm that the samples had not been affected by surface weathering.

A geological hammer was used to break down the rock samples, and each layer's characteristics were carefully documented. The GPS device used for location data was a [Garmin GPS 73 Handheld], providing precise coordinates for each sampling point. The depth of sampling was carefully controlled to ensure representative sampling of the clay horizon, avoiding areas of significant weathering. Sample bags were used to securely store and label the rock samples, ensuring that each sample could be accurately traced back to its location of origin. Field notes, including observations and sketches, were meticulously recorded in a notebook, providing a comprehensive record of the sampling process

Laboratory Analysis

This includes chemical and mineralogical analysis of the clay samples to determine the elemental and mineralogical composition. The samples were pulverised to 0.07 mm size for XRD and XRF Analyses. Each sample was stored in a polythene sample bag before being sent to the lab for examination.

X-Ray Fluorescence (XRF)

Thirteen (13) clay samples were subjected to X-Ray Fluorescence analysis to determine the major elemental composition using the Linear Calibration method. The samples were prepared following standard procedures, ensuring homogeneity and proper surface preparation. The analysis was performed under varying conditions. Low atomic number, Group A elements were analyzed at 4 kV with no filter. Low atomic number, Group C elements used 12 kV with an Al filter. Medium atomic number, Group B elements were measured at 20 kV with a Pd Medium filter. High atomic number, Group A elements at 40 kV with a Cu thin filter, and high atomic number, Group B elements at 50 kV with a Cu thick filter. All measurements were conducted in air atmosphere with a livetime of 60-100 seconds, ensuring optimal detection of elemental compositions across a broad range of atomic numbers. The procedure followed standard XRF practices to achieve accurate and reliable results. ARL QUANTX EDXRF Analyzer X-Ray Fluorescence machine was use for the XRF analysis.

X-Ray Diffraction Analysis (XRD)

Five (5) samples were subjected to X-Ray Diffraction (XRD) using the Powder (ARL 'XTRA) equipment with the aim of identifying and quantifying clay mineral composition. Laboratory analysis was carried out at the Umaru Musa Yar'Adua University, Katsina Central Laboratory. X-Ray Diffraction (XRD) was employed in this study to analyze five clay samples, with the aim of identifying and quantifying clay minerals. The analysis was done to show details about mineralogy, crystal structure, chemical composition, and physical properties of the clay minerals present.

The X-Ray tube machine is allowed to be warm –up ON for one hour before it is used for analysis while the settings are done in the computer system. X-Ray Diffractometer consist of three basic elements: an X-Ray tube, a sample holder, and an X-Ray detector at opposite direction that rotates through and angel of operation.

RESULTS AND DISCUSSION

The results of the field geological traversing of the study area, litho stratigraphic logging, mineralogical and chemical analyses and their interpretation are presented in this section

Field Occurrence

Field geological mapping of the study area (Figure 3), reveals three distinct rock types: Migmatic-Gneiss Complex, older Granite and Cretaceous and Younger sediments (claystone, sandstone siltstone and ironstone). The Cretaceous and Younger sediments dominate the region of study area, constituting approximately 75% of the map area Detailed stratigraphic profiles of the Patti Formation were also established as shown in (figure 3).

The Lokoja/Agbaja road cut exposes the Lokoja Formation, Patti Formation and Agbaja Formation. The claystone of the Patti is white to milky, averaging 1.8 meters in thickness and displays sand-sized quartz grains and shrinkage cracks. The clay thickness at the middle of the horizon is about 2.7 meters. The clay occasionally displays brown stains from iron-enriched water percolation. The sandstones horizon in the Patti Formation is friable and has a medium - coarse grained texture, moderate sorting.

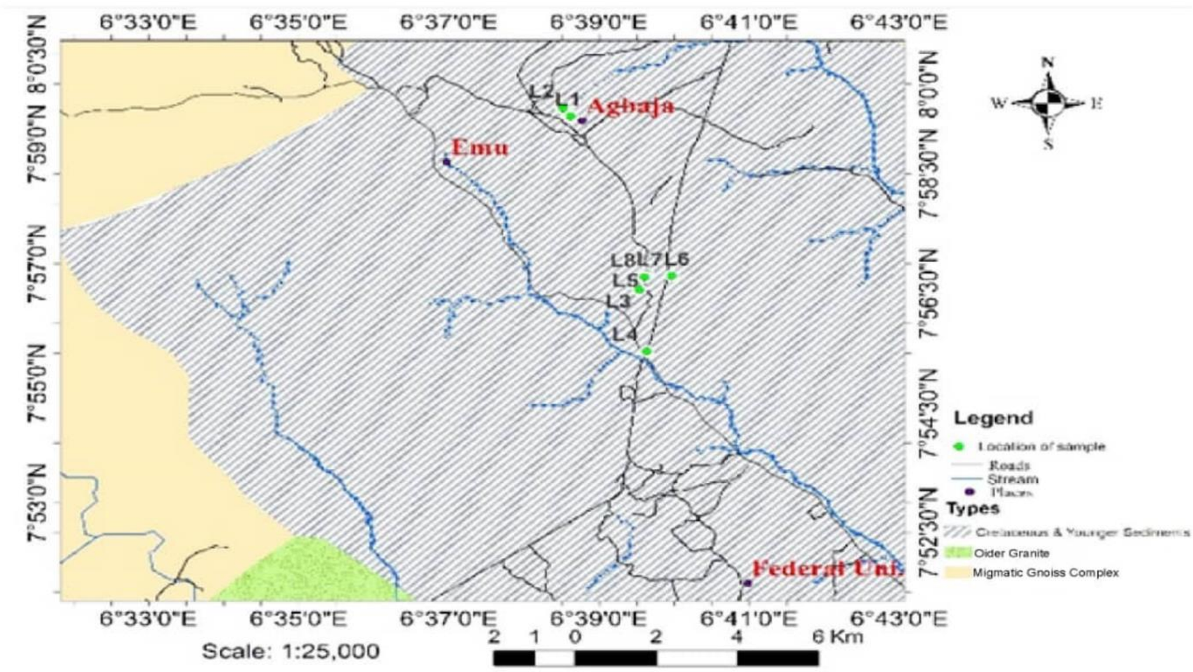

Figure 3: Geological map of the study area showing the rock types

Stratigraphic Details and Layer Description

The stratigraphic sections of the study area are presented below, with a focus on the thickness, distribution, and characteristics of the identified sedimentary layers. The sequence of layers, in stratigraphic order, is as follows: Sandy-clay, medium-grained sandstone, claystone, coarse sandstone, siltstone and ironstone. The stratigraphy reveals distinct layers based on color, texture, and structure as shown in figure 4 below. The detailed description of each layer is as follows

Sandy Clay Layer:

Underlying the sandstone is the sandy clay horizon, which has a thickness of about 1.0 meter. This layer is characterized by a reddish-brown color and a fine, earthy texture with some plasticity and an argillaceous smell. In some locations, the clay appears whitish, suggesting variations in mineralogical composition. The primary minerals identified include kaolinite and quartz, with trace amounts of feldspar and iron oxides.

Clay Layer

The claystone layer which is of interest in this research has been correlated with its corresponding mineralogical and chemical data for a more integrated understanding of the stratigraphy.

The clay deposit in the study area is part of the sedimentary sequence within the Patti Formation.

The claystone typically has gradational contacts with the overlying and underlying units, reflecting a steady transition between depositional environments. The claystone likely represents deposition in a very low-energy setting, such as a floodplain, or distal deltaic environment. The high kaolinite content suggests intense chemical weathering in a tropical to subtropical climate, where fine sediments were transported by slow-moving water and deposited in still or standing water bodies.

Reflecting a steady transition between depositional environments, the lower contact transition gradually medium-grained sandstone, indicating an increase in energy, while the upper contact with the overlying unit suggests a return to slightly more energetic conditions

The claystone forms a distinct unit within the sequence, characterized by its fine-grained, homogenous nature with high kaolinite content (58.80%), moderate quartz (32.60%), and minor muscovite (6.12%) and orthoclase (2.34%).

The claystone layer, varying in thickness from 0.9 meters, with a maximum exposed thickness of 2.7 meters along Lokoja/Agbaja road cut, location 3.

Sandstone Layer

The sandstone layer is well-developed, with a thickness ranging from 1.5 to 2.0 meters. This unit is composed of medium to coarse-grained, well-cemented sand grains, with a color that varies from yellowish-brown to reddish-brown. It also contains minor amounts of silt which contribute to its textural diversity. The sandstone layer overlies the clay layer and underlies the siltstone unit in the stratigraphic sequence. The mineralogical composition is dominated by quartz, with minor feldspar and iron oxides, correlating with the observed coarse texture.

Siltstone Layer

The siltstone layer in the study area are characterized by a fine-grained texture and range in thickness from 0.7 to 1.6 meters. The color of these layers varies from gray to brown, and they exhibit well-defined bedding planes, indicative of a quiet depositional environment. The siltstone is composed of fine silt-sized particles, with a minor clay and sand content.

Sedimentary Ironstone Layer

The sedimentary ironstone in the study area is part of the Agbaja Formation and overlies the Patti Formation. This layer consists of alternating beds of iron-rich sedimentary rocks, interbedded with siltstone, sandstone, and claystone. The ironstone exhibits a reddish-brown color and coarse-grained texture, reflective of its high iron content. The lithological characteristics of this layer include significant amounts of hematite and goethite, contributing to its iron-rich.

The distribution and thickness of each layer at the location are shown in the stratigraphic section illustrated in (figure 4).

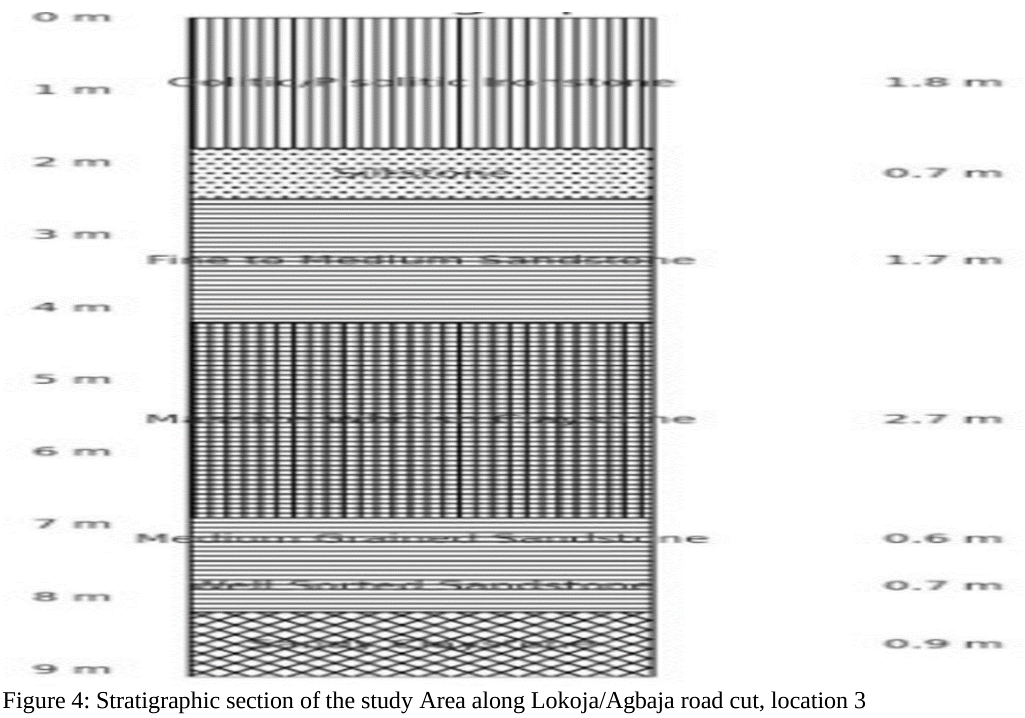

Figure 4: Stratigraphic section of the study Area along Lokoja/Agbaja road cut, location 3

Major Element Geochemistry

The average major elemental oxide composition (in percentage weight) of the clay samples of the study area are as follows; SiO_2 (57.41%), Al_2O_3 (25.32%), Fe_2O_3 (0.56%), MgO (0.22%), CaO (0.07%), Na_2O (.0.14%), K_2O (0.10%), TiO_2 (1.05%) and loss on ignition (14.86). The high content of silica and alumina suggest an alluvial source for the clay deposit. The other oxides are found in notably small concentrations. The low Fe_2O_3 (0.65%) and CaO (0.07) is attributed to the absence of marine carbonate in the associated sedimentary sequence. Low Na_2O, MgO and K_2O amounts (0.14, 0.22 and 0.10 respectively) suggest low salinity of the water where the claystone was deposited, which is an indicative of low salinity origin of the water in which the clay was formed.

Table 1: Major Element Composition of the Clay Horizon in the Patti Formation of the study Area

Elemental Oxides (% wt)	Sample Location													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**Mean**
SiO_2	74.20	74.14	52.22	52.83	52.79	63.09	55.40	53.47	54.60	53.64	53.64	53.58	52.78	57.41
Al_2O_3	14.90	14.96	27.68	26.84	28.94	23.33	27.38	27.33	27.80	28.77	27.76	27.21	26.36	25.32
Fe_2O_3	0.70	0.74	0.59	0.67	0.37	0.68	0.54	0.79	0.49	0.36	0.48	0.08	0.79	0.56
CaO	0.10	0.09	0.08	0.07	0.07	0.08	0.09	0.03	0.05	0.08	0.08	0.07	0.05	0.07
MgO	0.20	0.15	0.23	0.23	0.20	0.18	0.23	0.23	0.24	0.23	0.23	0.23	0.23	0.22
K_2O	0.10	0.07	0.42	0.08	0.10	0.06	0.05	0.08	0.06	0.06	0.07	0.08	0.09	0.10
Na_2O	0.10	0.05	0.14	0.15	0.20	0.13	0.17	0.14	0.14	0.14	0.15	0.13	0.14	0.14
TiO_2	0.90	0.94	1.16	0.96	0.98	1.03	1.22	1.14	1.22	1.03	0.99	0.89	1.23	1.05
MnO	0.01	0.02	0.01	0.01	0.02	0.06	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02
P_2O_5	0.15	0.08	0.09	0.15	0.13	0.15	0.06	0.07	0.08	0.09	0.09	0.07	0.09	0.10
LOI	8.64	8.76	17.38	18.01	16.20	11.21	14.85	16.71	15.30	15.59	16.49	16.35	18.23	14.86
Total:	99.90	100	100	100	100	100	100	100	100	99.00	100	100	100	99.85

Mineralogical Composition

The mineralogical composition of the clay samples was determined using XRD analysis, Figure 5 to 8 illustrates the XRD patterns of clay samples obtained from Locations 1, 2, 3 and 4 respectively. The XRD gives a mineral composition of the clay as follows; the presence of quartz (32.6%), kaolinite (58.8%), muscovite (6.12%), and orthoclase (2.34%).

The presence of muscovite is an indication that the weathering process is still at the incipient stage. In tropical regions, muscovite undergoes decomposition to form kaolinite during the advanced stages of weathering, as reported in various weathering profiles.

In summary, the coexistence of muscovite, quartz, and kaolinite suggest a sequence of weathering, where muscovite-bearing rocks underwent initial breakdown, leaving behind muscovite and quartz. Further weathering led to the formation of kaolinite, indicating more advanced stages of alteration. The X-Ray Diffractogram indicates that the clay is primarily Composed of kaolinite as shown in X-Ray Diffractograms in figure 5 to 8 below. The XRF results supports the identified mineralogical phases as a result of the high aluminum (Al_2O_3) and silica (SiO_2) content in the clay which are major elemental components of quartz, kaolinite, muscovite and orthoclase identified in the mineral components of the clay.

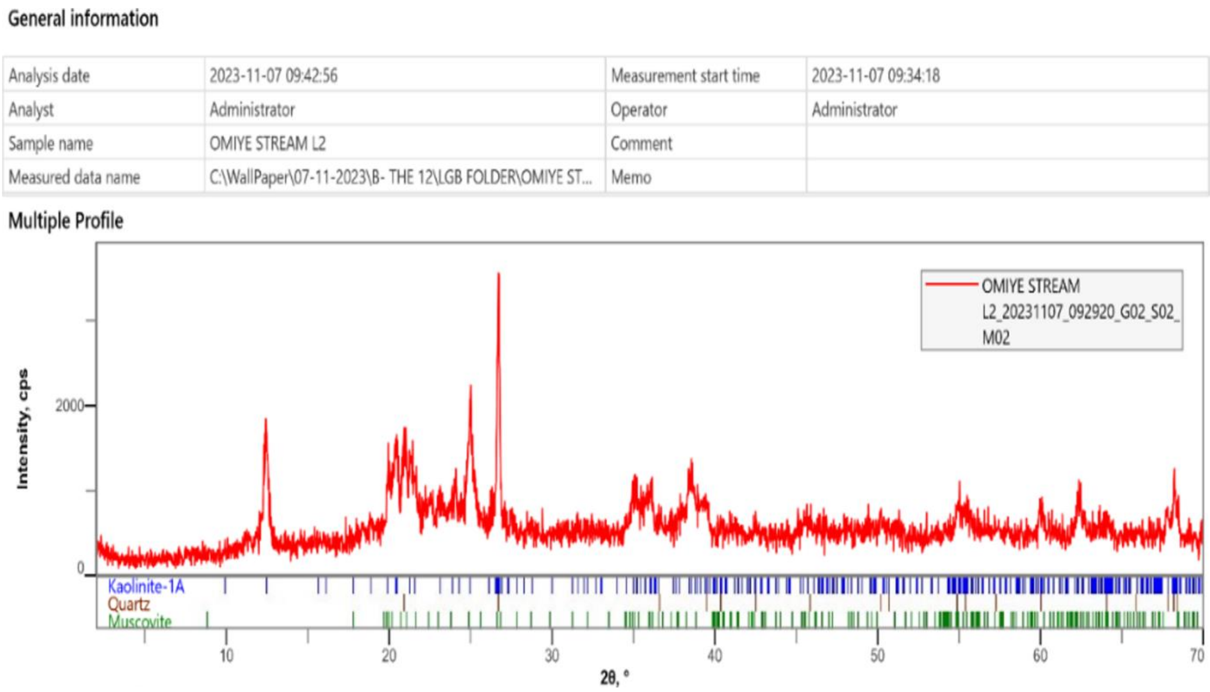

Figure 5: X-Ray Diffractogram of clay in the study area (Sample location 1)

General information

Analysis date	2023-11-07 09:36:33	Measurement start time	2023-11-07 09:30:29
Analyst	Administrator	Operator	Administrator
Sample name	LGB 6	Comment	
Measured data name	C:\WallPaper\07-11-2023\B- THE 12\LGB FOLDER\LGB 6_202...	Memo	

Multiple Profile

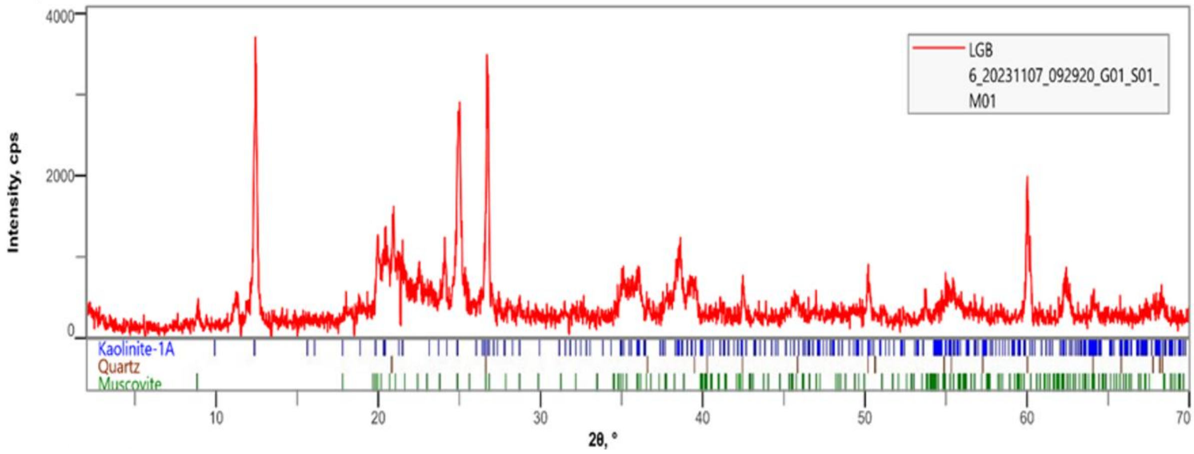

Figure 6: X-Ray Diffractogram of clay in the study area (sample location 2)

General information

Analysis date	2023-11-07 09:34:23	Measurement start time	2023-11-07 09:13:30
Analyst	Administrator	Operator	Administrator
Sample name	LGB 9	Comment	
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Multiple Profile

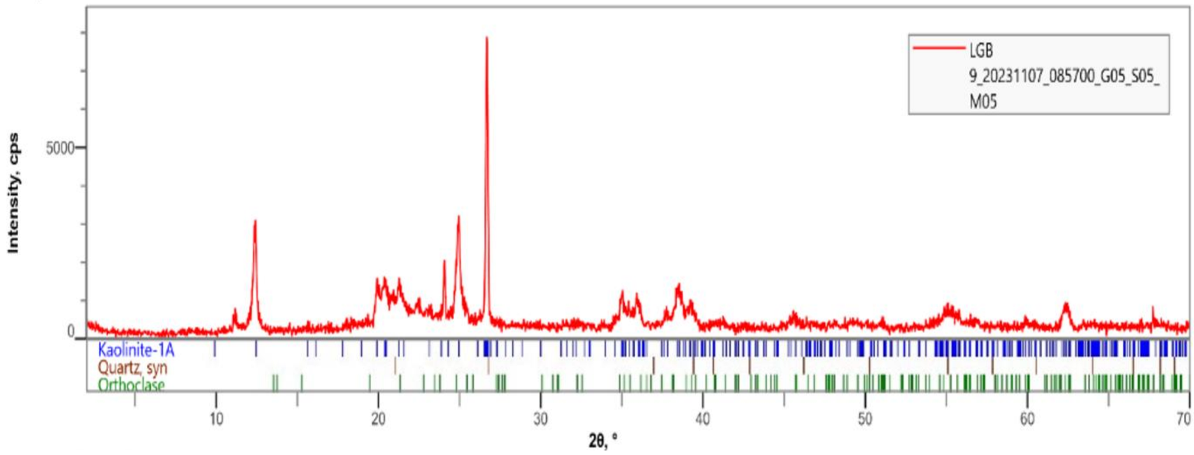

Figure 7: X-Ray Diffractogram of clay in the study area (sample location 3)

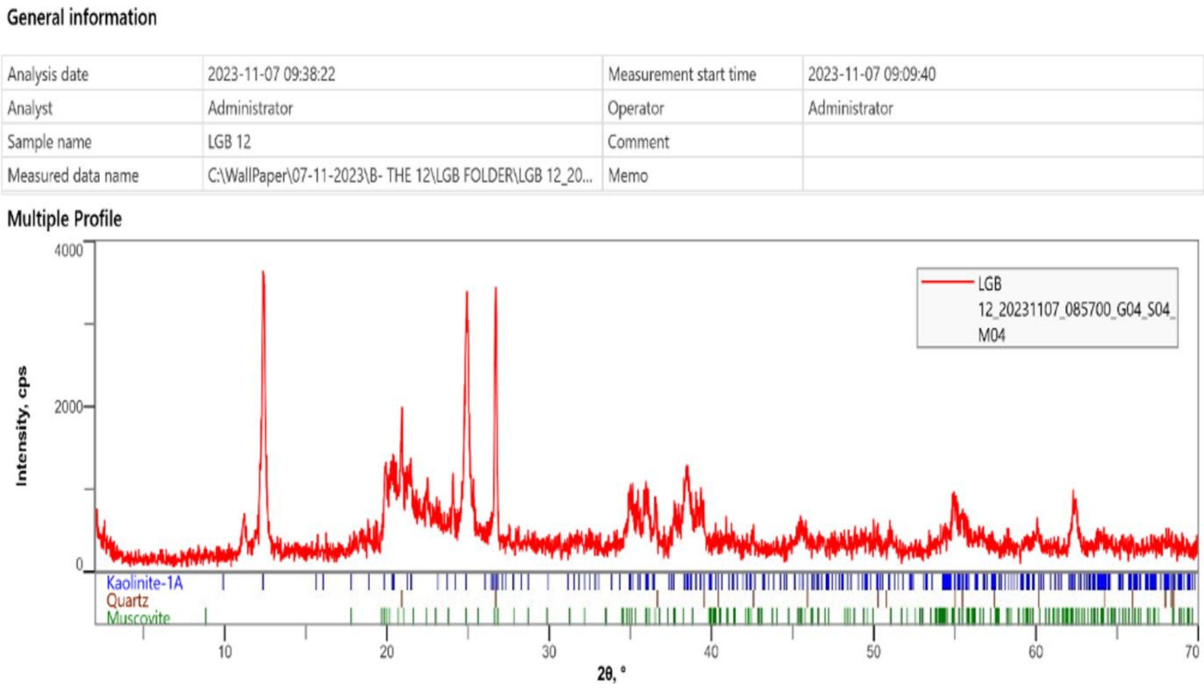

Figure 8: X-Ray Diffractogram of clay in the study area (sample location 4)

Table 2: Mineralogical composition of clay in the study area

Minerals	Sample Number						
	1	2	3	4	5	Range	Mean
Quartz (%)	40.00	35.00	31.00	29.00	28.00	28.00 - 40.00	32.60
Kaolinite (%)	55.00	53.00	57.00	59.00	70.00	53.00 - 70.00	58.80
Muscovite (%)	5.00	11.60	-	12.00	2.00	2.00 - 12.00	6.12
Orthoclase	_	_	11.70	_	_	0.00 - 2.34	2.34
Total	100	99.6	99.7	100	100		99.92

Industrial Applications of Clay in the Study Area

Kaolinite, a clay mineral, demonstrates remarkable effectiveness in adsorbing pollutants across various sectors, due to its small crystal size and large surface area which results in high surface reactivity. One of the most common industrial uses of kaolin is its use as refractory materials, manufacturing of ceramics, porcelain ware, and floor and wall tiles. Its naturally bright white color when pure makes it useful for manufacturing pure white ceramics, porcelain, China, sanitary ware and kaolin pottery.

Ceramics Uses

The key component in kaolinite clay that determines its suitability for ceramics production is primarily aluminum oxide (Al_2O_3). This oxide is essential because it contributes to the clay's plasticity, workability, and firing characteristics, allowing it to be shaped into various forms and to withstand high temperatures during firing. Additionally, other elements and oxides present in clay, such as silica (SiO_2) also play important roles in the ceramic-making process.

The specific percentage composition of aluminum oxide (Al_2O_3) in clay for ceramics production can vary depending on the type of clay and the desired characteristics of the final ceramic product. However, generally, clay used for ceramics production typically contains around 15-25% aluminum oxide (Al_2O_3) by weight. This percentage ensures that the clay has the necessary properties for shaping, firing, and producing durable ceramics. Because kaolin contains low concentrations of iron or alkalis, it is ideal for use in various forms of ceramics. When producing ceramics and white ware, manufacturers usually combine kaolin with additional silica and feldspar, along with a minor amount of another type of clay called ball clay, which is a plastic light-burning clay. The combination of kaolin and these other allows ceramic manufacturers to achieve the ideal plasticity, shrinkage, and vitrification and to properly shape and heat the ware. Kaolin offers high dry strength, meaning that as an additive, it helps reinforce and strengthen the final product which is crucial in manufacturing ceramic ware.

The mineralogical composition specifications for ceramics production can vary depending on the specific type of ceramic being produced, as different ceramics may require different clay compositions. The clay in study area has satisfactory mineralogical composition required in ceramics production. The mineralogical content of clay in the study area is kaolinite (58.8%), quartz (32.60%), Muscovite (6.12%), and orthoclase (2.33%). Generally, ceramics production benefits from a high percentage of kaolinite, which provides plasticity and strength. Kaolinite content of about 25-60% is common. Quartz is often present in clay but excessive amounts can cause issues during firing. Quartz content should generally be kept below 35% according to the Standard Organization of Nigeria.

Feldspar acts as a flux and helps lower the melting point of clay, promoting vitrification. However, excessive feldspar can lead to excessive melting and deformation. Feldspar content should be controlled below 25%.

Table 3: Chemical composition of clay in the study area compared with some standards for industrial application for ceramics (Al-momani, 2000)

Major element oxides	Chemical composition of clay materials for ceramic (%)	Chemical composition of clay in the study area (%)	Remarks
SiO_2	44.90 - 70	53.29	Falls within specified parameters
Al_2O_3	19.62 - 32	25.50	Within acceptable range
Fe_2O_3	0.5 - 8.6	0.56	Within acceptable range
TiO_2	0 - 1.4	0.96	Within acceptable range
CaO_3	0 - 1.0	0.07	Falls within specified parameters
MgO	0.05 - 1.96	0.20	Within acceptable range
K_2O	0.05 - 1.98	1.37	Within range
Na_2O	0 - 1.0	0.13	Within acceptable range

The table above (Table 3) shows that the major element oxide composition of the clay in the study area falls within the standard specifications confirms the suitability of the clay in the study area for ceramic use.

Refractory Uses

Kaolinite is used in the production of refractory materials such as bricks and crucibles, due to its high melting point and thermal stability. The chemical composition of the clay in the study area falls within the specifications required for Refractory use as shown in (table 4).

Table 4: Chemical composition of clay in the study area compared with some standard clays for industrial application (Ituma *et al.*, 2018)

Uses	SiO_2	Al_2O_3	Fe_2O_3	CaO	Remarks
Refractory	51- 70	25- 44	0.5 - 2..4	01- 2.0	Suitable
Glass	80- 95	12 - 17	2 - 3	4 - 5	Not suitable
Paper	45 - 46	34- 36	0.3 - 0.6	0.03- 060	Not suitable
Paint	43- 48	37.9 - 38.4	13.4 - 13.7	0.03- 0.60	Not suitable
study area	57.41	25.32	0.56	0.07	Suitable for refractory

The table above (Table 4) shows industrial specifications chemical data for various industrial uses, including manufacturing of paper, paints, fertilizer, and as refractory. The chemical composition of the clay in the study area does not meet up with the requirements for the manufacture

Environmental Impact and Mitigation Measure

There is a need to highlight the importance of environmental responsibility in mining operations. Mining activities, while essential for resources, the extraction of natural resources through mining can have far- Mining reaching impacts on the environment. The following are the potential environmental impacts associated with mining, along with measures to mitigate them:

i. Land Degradation

- Impact: Mining causes topsoil loss, habitat destruction, and alters the landscape.
- Mitigation: Reclaim land after mining, manage and restore topsoil, and replant native vegetation to stabilize the soil and restore ecosystems.

ii. Water Resource Impacts

- Impact: High water usage, risk of contamination, and disruption of natural water flow.
- Mitigation: Implement closed-loop water systems to recycle water, treat wastewater before release, and adopt water-saving practices.

iii. Air Quality and Dust Emission

- Impact: Dust and emissions from mining and processing reduce air quality and pose health risks.
- Mitigation: Use dust suppression methods (e.g., water sprays), install vegetative barriers, and maintain equipment to reduce emissions.

iv. Energy Consumption and Carbon Footprint

- Impact: High energy demand leads to significant carbon emissions.
- Mitigation: Invest in energy-efficient technologies, use renewable energy sources, and recover and reuse waste heat.

v. Waste Management

- Impact: Generation of waste materials like overburden and tailings can lead to environmental hazards.
- Mitigation: Minimize waste generation, recycle and repurpose materials where possible, and ensure the safe disposal of waste of glass, paper and paint.

CONCLUSION

The study reveals the stratigraphic location of the claystone in the Patti Formation of the Southern part of the Bida Basin.

Field relationship shows that the formation consists of the following lithological horizons; Basal medium - coarse grained sandstone, massive fine-grained claystone, fine - medium grained sandstone, siltstone and ironstone. The study area falls within the Basement Complex terrain and the Cretaceous and Younger sediments.

The Cretaceous and younger sediments dominate the region, occupying approximately 75% of the map area. The sequence of layers, in stratigraphic order, is as follows: Sandy-clay, medium-grained sandstone, claystone, coarse sandstone, siltstone and ironstone.

The claystone layer which is of interest in this research has been correlated with its corresponding mineralogical and chemical data for a more integrated understanding of the stratigraphy.

The clay deposit in the study area is part of the sedimentary sequence within the Patti Formation.

The claystone typically has gradational contacts with the overlying and underlying units, reflecting a steady transition between depositional environments. The claystone likely represents deposition in a very low-energy setting, such as a floodplain, or distal deltaic environment. The high kaolinite content suggests intense chemical weathering in a tropical to subtropical climate, where fine sediments were transported by slow-moving water and deposited in still or standing water bodies.

Reflecting a steady transition between depositional environments, the lower contact transition gradually medium-grained sandstone, indicating an increase in energy, while the upper contact with the overlying unit suggests a return to slightly more energetic conditions

The claystone forms a distinct unit within the sequence, characterized by its fine-grained, homogenous nature with high kaolinite content (58.80%), moderate quartz (32.60%), and minor muscovite (6.12%) and orthoclase (2.34%).

The claystone layer, varying in thickness from 0.9 meters, with a maximum exposed thickness of 2.7 meters along Lokoja/Agbaja road cut, location 3.

The claystone is white to milky color, with an average thickness of 1.8 meters. Toward the middle of the horizon the thickness of clay reaches a maximum of 2.7 meters. The Litho-stratigraphic succession in the study area, starting from the top layer reveals oolitic/pisolitic ironstone (1.8 m), siltstone (0.7 m), coarse grained sandstone (1.7 m), massive whitish claystone (2.7 m), medium grained rained sandstone (0.6 m), Well- sorted sandstone (0.7 m), sandy- clay (0.9 m) and medium - coarse grained sandstone.

3. XRF analysis of the clay samples reveal a relatively high composition of silica (SiO_2) (57.41%) and alumina (Al_2O_3) (25.32%) with other oxides present in minor amounts.

4. XRD analysis identified the presence of quartz (32.60%), kaolinite (58.80%), muscovite (6.12%) and orthoclase (2.34%) in the clay samples.

5. The chemical composition of the clay in the study area meets the specifications for ceramics, and refractory materials (Ituma et al., 2018). Mining activities, while essential for resources, the extraction of natural resources through mining can have far- Mining reaching impacts on the environment.by understanding these potential impacts and implementing the corresponding mitigation measures, we can minimize the environmental footprint of mining activities.

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