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GEOLOGICAL AND RHEOLOGICAL PROPERTIES OF UGIEGHUDU CLAYS, SOUTHERN NIGERIA

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ABSTRACT

The demand for locally sourced drilling mud materials in Nigeria has intensified due to the high cost of imported bentonite. This study appraises the geological, geotechnical, mineralogical, rheological, and filtration properties of clay deposits from Ugieghudu, southwestern Nigeria, to evaluate their suitability for drilling mud applications. X-ray diffraction (XRD) results indicate that the clays are predominantly composed of kaolinite (20–60%) and quartz (20–60%), with minor amounts of vermiculite, orthoclase, muscovite, and iron oxides. Particle size analysis revealed clay contents ranging from 28% to 77%, with liquid limits of 42–80% and plasticity indices of 24–45%, consistent with moderate to high plasticity materials. Specific gravity values range from 2.62 to 2.68, while activity indices classify the clays as inactive to normal, reflecting limited swelling compared to bentonite. Rheological evaluation across temperatures of 30–90 °C showed gel strengths between 4–10 lb/100 ft², plastic viscosities of 2–8 cP, and yield points of 2–8 lb/100 ft², with YP/PV ratios generally within API-recommended limits. Apparent viscosities remained thermally stable, indicating adequate carrying capacity under varying wellbore conditions. Filtration tests produced filter cake thicknesses of 0.4–0.5 cm, mud densities of 8.5–8.65 lb/gal, and alkaline pH values (8.6–8.9), all within acceptable ranges for drilling fluid performance. The integration of mineralogical, index, rheological, and filtration properties suggests that Ugieghudu clays possess baseline characteristics for drilling mud formulations, although their relatively low swelling capacity compared to the Wycombe bentonite implies the need for beneficiation or chemical modification. The findings highlight the potential of these clays as a cost-effective local substitute for imported drilling mud materials, with implications for reducing drilling costs and enhancing resource sustainability in Nigeria's oil and gas sector.

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1.0 INTRODUCTION

Drilling muds are vital to modern petroleum exploration as they servevarious roles such as cooling and lubrication of the drill bit, transportation of drill cuttings to the surface, controlling formation pressures, as wellas stabilizing the borehole wall (Caenn and Chillingar, 1996; Bourgoyne *et al.*, 1991; Shan *et al.*, 2024; Vahid and Mohammad, 2024; Wei *et al.*, 2025; Ettehadi *et al.*, 2022). However, the performance of drilling muds strongly depends on their clay content, since the nature of clays governs essential rheological properties like yield point, viscosity, filtration, and gel strength, among others. Bentonitic clays are widely regarded as the benchmark due to their high swelling

capacity and tendency to provide stable rheological characteristics under diverse downhole conditions (Apugo-Nwosu *et al*., 2011).

However, in Nigeria, known sources of bentonite resources are quite limited, resulting in an unavoidable importation at high cost, placing financial burdens on the oil and gas industry (Afolabi *et al*., 2017). Several indigenous clay deposits across the country, such as those in Afuze, Enugu, Ibulesoro, Abakaliki, Borno, and Ewekoro, have been studied for their potential as drilling mud additives, with variable degrees of success depending on their chemical and mineralogical composition (Aigbedion and Iyayi, 2007; Omole *et al*., 2013). Notably, the appropriateness of locally available clays is often constrained by low montmorillonite content, high quartz content, or unsatisfactory rheological characteristics, although these deficiencies can sometimes be addressed by chemical amendment or beneficiation, such as sodium activation.

The Ugieghudu clays, located in Edo State, southern Nigeria, represent one of the underexplored clay resources that could provide a local substitute for imported bentonite. Although preliminary field observations suggest fine texture and significant clay content, yet their geological and rheological properties have not been systematically characterized. Given the dependence of rheological performance on clay mineralogy, particularly the presence of swelling clays like smectite versus non-swelling clays such as kaolinite there is a critical need to assess the geological characteristics and rheological behaviour of these clays under drilling conditions (Caenn *et al.*, 2017).A systematic evaluation of these properties of Ugieghudu clays will provide essential insights into their potential for drilling mud applications. This will not only contribute to reducing Nigeria's dependence on imported bentonites but also support cost-effective and sustainable exploration practices.

2. DESCRIPTION OF THE STUDY AREA

2.1 Location and Accessibility

The study area (Figure 1) is located in Ugieghudu, situated approximately 51km away from Benin City in Edo state, Nigeria. It falls within latitude 6°30′N – 6°40′N and Longitude 5°54′E – 6°10′E. The region has been described as a tilled plain in the southwestern direction with a local relief of 91 m. The drainage pattern of the study area is dominated by three river systems, namely, the Ikpoba River, Ogba River, and Owigie-Ogbovben River systems. The mean annual discharge of the Ikpoba River for 1982-1983 and 1993-2002 was 1411 mm/yr, which was 1.019 × 109 m^3 with a mean annual baseflow of 1256.23 mm (0. 907 × 109 m3). This constitutes 87.65% of the total flow. It has a mean annual surface runoff of 225.18 mm (0.112 × 109 m3) or 24.4% of the total discharge. The water resources of the region include surface water and underground water, climate and Vegetation. Ugieghudu lies within the Tropical wet and dry climate, with average temperatures typically varying from 25°C to 30°C (77°F to 86°F) throughout the year while higher temperatures are habitually recorded during the dry season. The rainy season usually spans from April to October, with peak rainfall occurring usually between June and September. With mean annual rainfall exceeding 1,500 mm (about 59 inches). The region has high humidity levels, especially during the wet season, contributing to a lush environment. Ugieghudu is part of the tropical rainforest zone, featuring dense vegetation and diverse plant species such as tall trees, shrubs, and various herbs. Economically important plants like oil palm, cocoa, and cassava are prevalent.

2.2 Geological Settings

Ugieghudu is located in Edo State, Southern Nigeria, and falls within the geologically significant Niger Delta Basin. This region is part of a larger sedimentary basin that plays a critical role in Nigeria's geology due to its vast mineral and hydrocarbon resources. The study area falls within the Imo Shale group, Figure 2, which is of Paleocene age, with exposures featuring clayey stone and iron-rich sandstone (Nwajide, 2013). The Imo Shale consists of thick, fine-textured, dark/bluish-grey clayey shale, with occasional admixtures of clayey

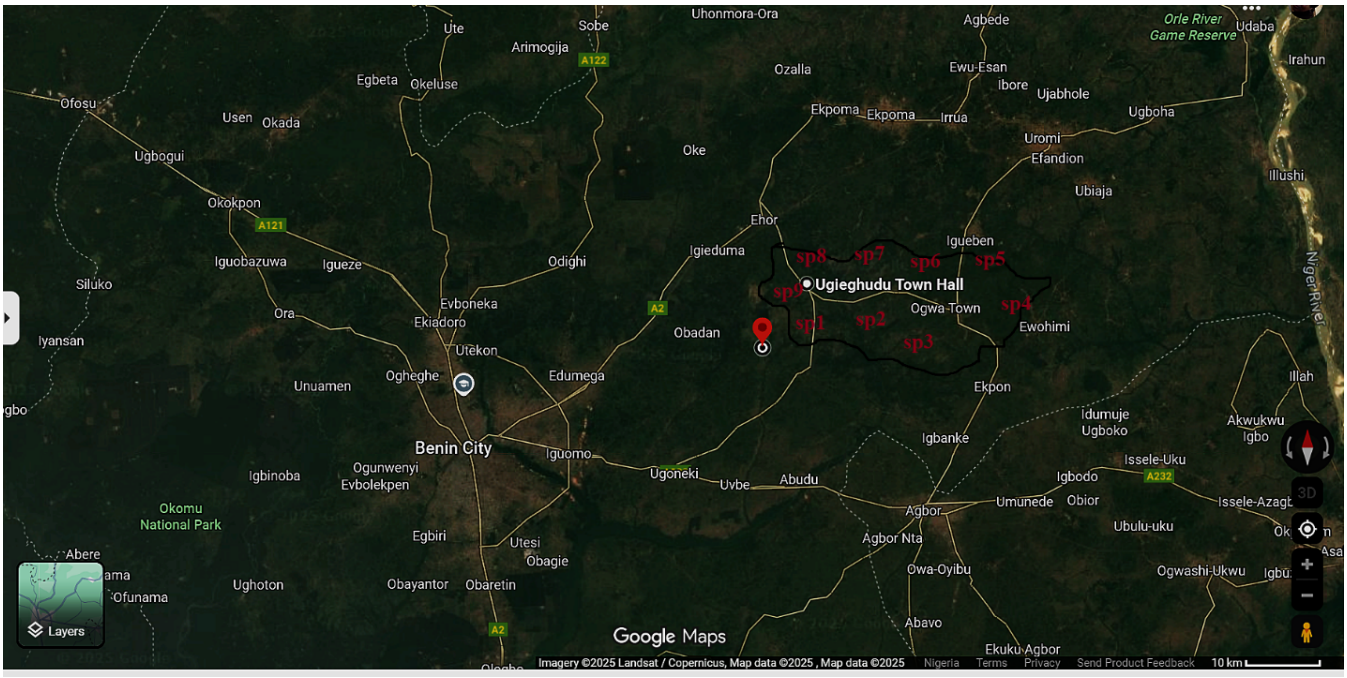


Figure 1. Map of the Edo State showing the study area

ironstone and sandstone bands. The formation becomes more sandy and sandstone towards the top, where it consists of alternations of sandstone and shale (Anyanwu and Arua (1990). Nwajide and Reijers (1996)interpreted the Imo Shale to reflect a shallow-marine shelf in which foreshore and shore face sands are occasionally preserved. They further inferred that in the Niger Delta, the subsurface Palaeocene deposits are essentially of (deep) marine origin and are equivalent to the Imo Shale. This shaley clay is significantly present in the study area of Ugieghudu, Edo State, Nigeria.

3.0 Methodology

Bulk samples of clay soils were collected at various depths and at different intervals from the representative clay bodies extensively distributed in various parts of the study area. A plastic scoop and clean sampling bags were used for collection at each sampling site. To avoid contamination, samples were immediately labelled upon collection. The geographic coordinates of the sampling sites were accurately recorded using a global positioning system (GPS), and these locations were then projected onto a topographic map. Thereafter, the soils were subjected to index (particle size analysis, Atterberg limits, specific gravity). The particle size analyses were conducted in accordance with the specification of the British Standard Institution (Tricker, 1991) by using wet sieving and hydrometer analysis methods for particles of size $\geq$ 80 and $\leq$ 80 µm, respectively. An electric soil shaker was employed for the sieve analysis (mechanical analysis), while the sedimentometry (hydrometer analysis) followed the principle of Stokes' law of sedimentation of individual spherical grains falling freely at steady velocity under the influence of gravity. The liquid limit (LL) of the clayey soil samples was measured with the Casagrande apparatus, while the plastic limit (PL) was measured by the rolling technique, all according to the standard specified by ASTM D4318 (2018). Thereafter, the plasticity index was determined by the arithmetic difference between the liquid and Plastic limits. In addition, mineralogical composition was determined by X-ray Diffraction (XRD) using powdered clay samples. The samples were oven-dried, pulverized, and sieved to <75 µm. The diffractograms were obtained using a CuKα radiation source, and the resulting peaks were analyzed with standard mineral databases (JCPDS files). The relative proportions of minerals such as kaolinite, quartz, illite, vermiculite, and feldspars

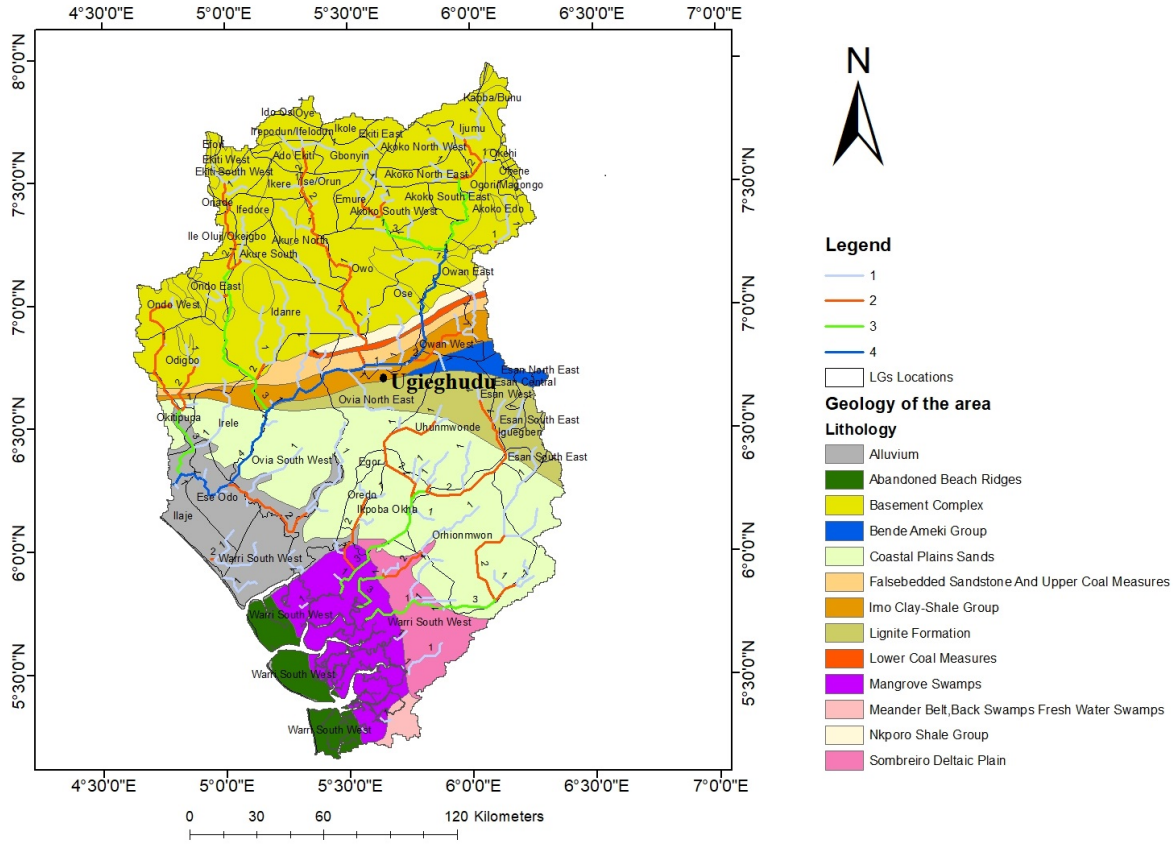


Figure 2. Geological map of part of South-western Nigeria showing the Imo clay in Ugieghudu area

were quantified based on peak intensities. The chemical composition of the clays was determined by X-ray Fluorescence (XRF) spectrometry. Samples were dried, ground, and pressed into pellets using a hydraulic press. The pellets were then irradiated in an XRF spectrometer equipped with an Rh anode X-ray tube. Major oxides, including SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, TiO_2, MnO, and P_2O_5, were quantified from fluorescence intensities using calibration curves derived from certified reference standards (ASTM C114, 2022). The rheological parameters of the prepared drilling muds were determined using a Rotational Viscometer (Fann Model 35, API standard) at varying rotational speeds (600, 300, 200, 100, 6, and 3 rpm). From these readings, the plastic viscosity (PV), yield point (YP), and apparent viscosity (AV) were calculated according to the procedures specified by API (2010). Gel strength was measured at 1 second and 10 minutes by allowing the mud to remain static and then recording the maximum dial deflection once rotation resumed. The various laboratory tests were conducted at controlled temperatures of 30°C, 50°C, 70°C, and 90°C using a mud heater to simulate downhole condition. Filtration performance was assessed using a Low-Pressure, Low-Temperature Filter Press at 100 psi and ambient temperature. The filter cake thickness was evaluated with a vernier caliper after undergoing filtration for thirty minutes. Mud density was measured by utilizing a standard mud balance, while pH was determined with a standard calibrated pH meter.

4.0 RESULTS AND DISCUSSIONS

4.1 Index Properties

The various grain size classes observed in the soils are shown in Table 1 which indicates that the soils contain variable quantities of sand, silt, clay, and gravel. A position plot of the sampled soils on the ternary diagram according to Sheperd (2010) shown in figure 4 reveals that the clay soils are classified as

sandy clays, clayey sand and clays. By implication, the particle size distribution shows that the studied samples from some locations are dominated by clay fractions, ranging from 60–77%, while the silt fractions are relatively low (9–11%) and sand content is generally <30%. Such high clay content is a desirable property for drilling mud preparation, as clays provide the necessary viscosity and gel strength for suspension of drill cuttings. In contrast, other samples from 1A, 1B, 5A, and 5B contain <35% clay and are sand-dominated (>45%). These coarse-grained soils are not ideal for drilling mud unless beneficiated with higher proportions of active clay. Generally, the particle size distribution of the samples shows clay contents ranging between 28% and 77%, with most exceeding the 30% API minimum for drilling mud clays (API, 2010).The specific gravity values (2.62–2.68) fall within the typical range for silicate minerals and clays, suggesting mineralogical stability. The Atterberg limits indicate that the samples with high clay contents (particularly 2A, 2B, 3A, 3B, 4A, 4B, 6A, 6B, 7A, 8A, and 8B) exhibit very high liquid limits (63–80%) and plasticity indices (37–45%), consistent with highly plastic clays. Such soils possess excellent swelling and water retention properties, essential for drilling fluids, as they can develop sufficient mud weight and viscosity. By contrast, samples with lower clay content (1A, 1B, 5A, 5B) show liquid limits below 47% and plasticity indices between 24–26%, categorizing them as low-to-intermediate plasticity soils (Figure 3) with limited capacity to perform as drilling mud. The linear shrinkage values (6.3–13.6%) further support this distinction. Samples 6A and 6B show relatively lower shrinkage, which may indicate less volumetric instability on drying, but the majority of the other clay-rich samples (10–13%) still fall within acceptable limits for drilling mud use. Notably, the plasticity index classifies the clays as moderately to highly plastic, consistent with materials capable of developing thixotropic structures (Onyemaobi and Ogbonna, 2014). Moreover, the liquid limit falls within the acceptable range for drilling mud applications, while the specific gravity (2.62–2.68) is typical of aluminosilicate clays (Osasan and Afere, 2010).

On the basis of clay activity, most of the samples record values between 0.58–0.62, indicating inactive to normal clays. This suggests that although kaolinite may dominate the mineralogy, the clays still demonstrate adequate plasticity. The sand-rich samples (1A, 1B, 5A, 5B) have slightly higher activities ranging from 0.81–0.85, which reflects the smaller proportion of clay still contributing significantly to plasticity, though the total clay available is insufficient for drilling applications. The activity ratios suggest inactive to normal clays, implying moderate swelling potential, a feature consistent with kaolinitic dominance (Mitchell and Soga, 2005). Generally, these properties show that Ugieghudu clays have adequate plasticity and consistency for drilling fluid use, though their activity values are lower than those of bentonitic clays, indicating the need for beneficiation (Akinyemi *et al*., 2016).

Overall, the results suggest that the clay-rich soils from sites 2, 3, 4, 6, 7, and 8 have strong potential as raw materials for drilling mud, given their high clay content, high plasticity, and acceptable shrinkage. These properties imply that the clays can swell adequately in water, build up viscosity, and suspend drill cuttings effectively. Conversely, the sand-dominated soils from sites 1 and 5 would require beneficiation (e.g., blending with bentonite or other swelling clays) before they could be effectively used as drilling mud.

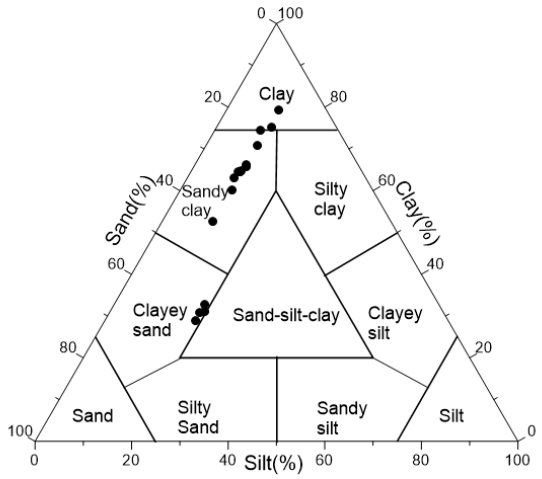


Figure 3. Soil classifications based on the grain size distribution (Sheperd, 2010)

Table 1. Index properties of the studied Clays

e No					gravity	limit	limit	index	shrinkage	y
1A	28.30	18.40	51.20	2.00	2.65	42.70	18.60	24.13	7.90	0.85
1B	29.40	18.80	46.90	3.00	2.66	43.30	18.80	24.47	8.60	0.83
2A	70.60	10.70	18.60		2.67	74.30	32.30	42.00	12.90	0.59
2B	74.40	9.40	16.20		2.68	76.50	33.30	43.34	13.60	0.58
3A	63.10	9.80	27.20		2.67	66.50	28.90	37.59	11.40	0.60
3B	60.10	10.80	29.00		2.67	64.80	28.20	36.63	11.40	0.61
4A	64.80	10.20	25.00		2.64	68.50	29.80	38.70	12.10	0.60
4B	66.10	10.80	23.10		2.63	70.20	30.50	39.68	12.90	0.60
5A	30.10	18.30	49.60	2.00	2.67	44.20	19.20	24.98	8.60	0.83
5B	32.40	18.60	48.10	1.00	2.66	46.50	20.20	26.28	8.60	0.81
6A	73.10	11.10	13.10	2.00	2.64	77.50	33.70	43.80	6.30	0.60
6B	76.90	10.50	9.60	3.00	2.63	79.80	34.70	45.10	6.30	0.59
7A	64.50	10.30	25.20		2.65	63.80	29.70	38.60	12.10	0.60
7B	52.70	10.40	36.90		2.66	57.60	25.00	32.56	10.70	0.62
8A	64.40	9.80	25.80		2.63	67.80	29.50	38.30	12.10	0.59
8B	64.24	10.70	22.80		2.62	70.50	30.70	39.85	12.10	0.62

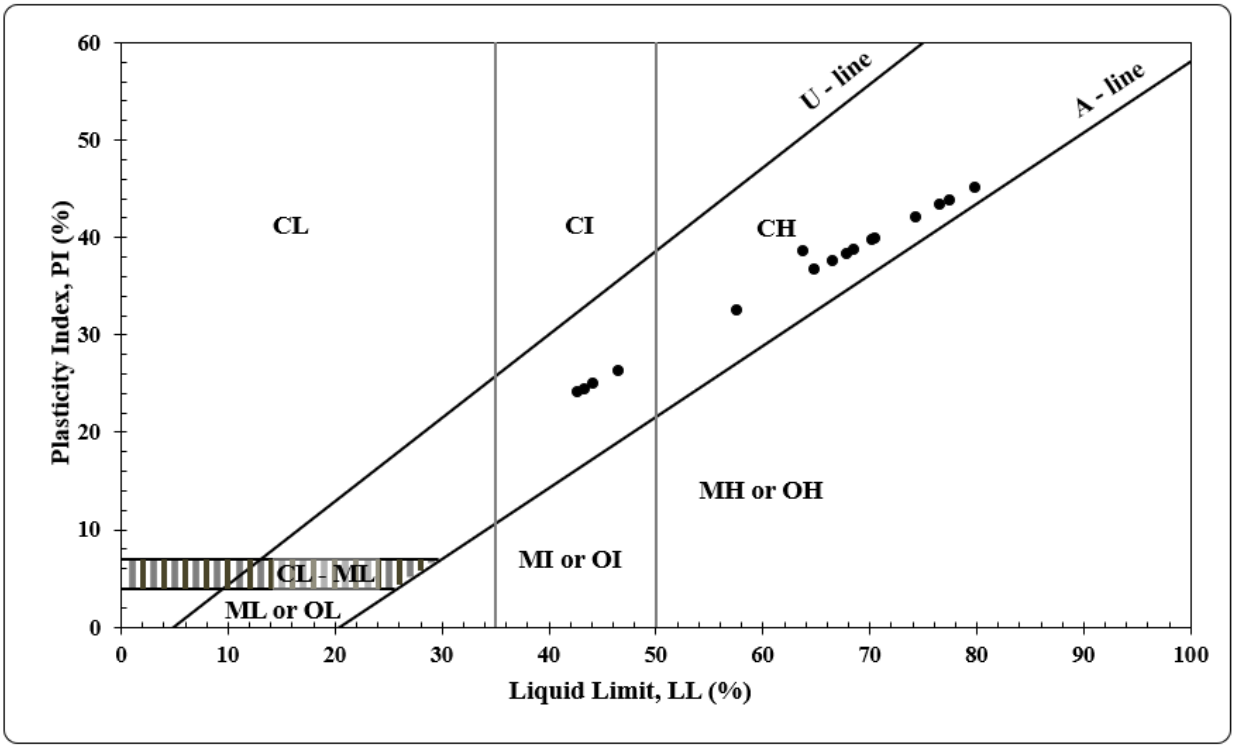


Figure 4. Plots of the studied clay samples on the USCS plasticity chart

3.2 Geochemical Properties

The major oxide composition (Table 2) of the Ugieghudu clay samples reveals that the dominant constituents are alumina and silica, with subordinate proportions of titanium oxide, iron oxide, magnesium oxide,

phosphorus pentoxide, and very low concentrations of alkali oxides (Na_2O, K_2O) and calcium oxide. The dataset shows Al_2O_3 values ranging from 44.0 to 54.9 wt.%, while SiO_2 varies between 36.1 and 46.4 wt.%. These oxides account for over 80–90% of the bulk composition, confirming that the clays are primarily alumino-silicate in nature. The relatively high alumina contents suggest the dominance of kaolinite, consistent with the mineralogical results from XRD. The relatively moderate silica contents indicate the presence of quartz admixtures and perhaps minor contributions from feldspathic minerals.Magnesium oxide (MgO) occurs at concentrations between 0.07 and 2.2 wt.%, suggesting the presence of Mg-bearing phases such as vermiculite or trace chlorite. Sodium oxide and potassium oxide are present in trace amounts (<0.5wt.%), reflecting limited feldspathic or micaceous contributions. Calcium is virtually absent across all samples (<0.02 wt.%), confirming the highly leached and weathered nature of the clay and the absence of carbonates or calcareous impurities. From an application standpoint, the high alumina and moderate silica contents classify the Ugieghudu clays as high-alumina kaolinitic clays, which are favorable for drilling mud formulations due to their stability, low shrink-swell properties, and potential for viscosity control when dispersed in aqueous solutions. The moderate levels of TiO_2 and Fe_2O_3 may influence the rheological properties and density of the drilling mud, but are not prohibitive. However, the absence of expandable clays (e.g., smectite, montmorillonite) as indicated by low MgO and Na_2O, suggests that the clays alone may not meet the swelling and gel-strength requirements of standard bentonitic drilling muds. This limitation implies that Ugieghudu clays may require beneficiation, chemical modification, or blending with commercial bentonite to enhance their rheological performance. In summary, the geochemical composition aligns with the mineralogical data, confirming that Ugieghudu clays are alumino-silicate rich, moderately siliceous, and contain significant proportions of kaolinite and quartz, with minor vermiculite and accessory phases. Their composition makes them suitable as a potential raw material for drilling mud additives, provided the necessary processing steps are undertaken to optimize rheological behavior.

3.3 Mineralogical Composition

The X-ray diffraction (XRD) analysis of the Ugieghudu clay samples revealed a mineralogical composition dominated by quartz and kaolinite, with moderate proportions of vermiculite, and minor amounts of orthoclase, muscovite, iron oxides, and illite (Table 3). Quartz contents ranged

Table 2. Geochemical Properties of the clays

	L2A	L5A	L8A	L4A	L1B	L3B	L5B	L7A	L4B	L2B	L6B	L8B	L7B
SiO_2	37.485	45.307	46.36	38.11	36.11	38.24	35.488	39.94	38.074	40.15	39.204	42.328	43.651
MgO	1.837	1.903	2.142	2.197	2.101	0.072	2.019	1.824	2.151	0.012	1.997	1.946	2.189
Na_2O	0.0532	0.0758	0.068	0.074	0.074	0.072	0.0714	0.055	0.0812	0.065	0.0696	0.0649	0.0855
P_2O_5	1.3955	1.7308	1.902	1.516	1.406	1.467	1.3875	1.585	1.484	1.492	1.5158	1.6005	1.786
Al_2O_3	54.9	47.017	44	53.171	53.48	53.7	53.888	51.3	53.9	52.53	51.7	49.245	46.679
CaO	0	0.01089	0.011	0	0.016	0.0078	0.0088	0.0115	0	0	0	0.0162	0.0032
K_2O	0.2977	0.1421	0.433	0.393	0.188	0.217	0.107	0.2512	0.3972	0.2729	0.3977	0.246	0.339
TiO_2	1.5721	1.994	2.501	2.051	1.709	2.189	2.105	2.51	2.149	1.341	2.6872	2.649	2.659
MnO	0.0139	0.0016	0.02	0.012	0.021	0.0145	0.02	0.0177	0.0132	0.0154	0.0192	0.0186	0.0253
Cr_2O_3	0	0.002	0	0	0	0.001	0.0016	0.0012	0.002	0.001	0.0009	0.0011	0.001
Fe_2O_3	2.35	1.769	2.3	1.801	5.3	1.987	4.885	2.412	1.735	2.097	2.38	1.867	2.563
ZrO_2	0.0091	0.032	0.022	0.013	0.013	0.023	0.019	0.01	0.013	0.0116	0.0151	0.0174	0.019
Total	99.913	99.985	99.759	99.338	100.41	97.990	100.00	99.917	99.999	97.987	99.986	99.999	100

between 20–60%, with the highest values recorded in samples 6A (60%) and 6B (55%), while the lowest concentrations were observed in samples 8A and 7B (20%). Kaolinite occurred abundantly across the samples, with values ranging from 20% in samples 8B, 6A, and 6B, to as high as 55–60% in samples 8A, 7B, and 7A. Vermiculite was present in moderate amounts (8–15%), showing relatively consistent values across all samples. Orthoclase and muscovite were detected in minor concentrations (2–5%), while iron oxides appeared only in samples 8B and 6A (3% each). Illite was uniformly distributed at 2% across all the samples. The mineralogical distribution suggests two dominant mineral phases: quartz and kaolinite. The relatively high quartz content in some samples (6A and 6B) indicates significant sandy fractions and reduced plasticity, which may affect the rheological behaviour of the clays when used in drilling mud formulations. High quartz content generally contributes to abrasiveness and may lead to faster wear of drilling equipment. In contrast, the samples with higher kaolinite content (8A, 7B, and 7A) indicate enhanced plasticity and good dispersion in aqueous media, which are desirable characteristics for drilling mud preparation. Kaolinite is also known for its low shrink-swell capacity, making it stable under varying moisture conditions, though its contribution to viscosity buildup is relatively modest compared to smectite-rich clays such as bentonite.

The moderate presence of vermiculite (8–15%) across the samples is significant. Vermiculite, being a 2:1 clay mineral with high cation-exchange capacity and swelling behaviour, can improve water retention and enhance the rheological properties of the clay slurry. Its presence therefore, increases the potential of Ugieghudu clays for drilling mud applications, compensating partly for the limited swelling capacity of kaolinite. Similarly, the minor proportions of muscovite and orthoclase reflect residual feldspathic and micaceous materials, which are less reactive but indicate limited weathering of the parent rock materials. The trace amounts of illite are consistent across all samples and may slightly contribute to plasticity and potassium ion availability. The occurrence of iron oxides in samples 8B and 6A suggests localized geochemical enrichment, which could affect the colour, density, and chemical stability of the clay.

Overall, the mineralogical results indicate that Ugieghudu clays are kaolinite–quartz dominated with a useful proportion of vermiculite. From a drilling mud perspective, the relatively high kaolinite and vermiculite contents suggest that the clays can serve as potential drilling mud additives, particularly for viscosity and fluid loss control due to their dispersive ability and moderate swelling when exposed to alkaline conditions (Olatunde *et al*., 2012; Bello *et al*., 2015). However, the significant quartz fractions in some samples could reduce the overall performance by limiting swelling capacity and increasing abrasiveness, as they can dilute swelling potential and lower rheological strength (Aigbedion and Iyayi, 2007). This implies that while the clays may not fully replace commercial

Table 3. Mineralogical composition of the clay soils

Samples	8B	8A	7B	6A	6B	7A
Minerals						
Quartz	55	20	20	60	55	23
Kaolinite	20	55	60	20	20	55
Vermiculite	15	13	8	10	13	15
Orthoclase	3	5	5	3	5	3
Muscovite	2	5	5	2	5	2
Iron	3			3		
Illite	2	2	2	2	2	2

bentonite, they can be beneficiated, blended with sodium-based bentonite, or chemically modified to meet API standards for drilling fluid applications (Ehirim and Akpokodje, 2012).

3.4 Rheological Properties

The results of the rheological tests are presented in Tables 4 and 5. The rheological tests conducted across a temperature range of 30–90 °C highlight the thermal stability of the muds. The gel strengths (4–10 lb/100 ft²) remained within functional ranges, suggesting sufficient thixotropy to suspend cuttings during static periods (Caenn *et al*., 2017). However, compared to bentonitic muds, some samples exhibited lower gel strength at elevated temperatures, reflecting the thinning effects associated with kaolinite-rich muds (Amadi *et al*., 2019).

The plastic viscosity (2–8 cP) values reflect the fine particle fraction and dispersive tendencies of kaolinite (Darley and Gray, 1988). The yield points (2–8 lb/100 ft²) produced YP/PV ratios mostly within the API-recommended range (0.75–1.5), indicating adequate carrying capacity for drill cuttings (API, 2010). The apparent viscosity values also remained stable across the tested temperature range, showing resilience under thermal variations encountered during drilling. Nonetheless, some samples showed declining viscosity at higher temperatures, underscoring the potential need for chemical conditioning in high-temperature wells (Bello *et al.,* 2015).

Table 4. Rheological Properties of the clay soils

RHEOLOGICAL PROPERTIES OF SAMPLES @ 30 °C								
(Rpm)	1B	2B	3B	4B	5B	6B	7B	8B
Gel strength @1.0-sec	5	5	5	7	7	6	7	10
Gel strength @10 min	4	4	3	6	5	4	6	7
Plastic viscosity	3	2	4	4	4	6	5	8
Yield point	4	5	3	4	6	3	3	4
Apparent viscosity	5	4.5	5.5	6	7	7.5	6.5	10
RHEOLOGICAL PROPERTIES OF SAMPLES(A) @ 50 °C								
Gel strength @1.0-sec	6	10	9	7	9	7	9	7
Gel strength @10 min	5	8	7	5	7	6	8	6
Plastic viscosity	5	4	5	5	6	3	7	5
Yield point	3	8	4	5	5	6	5	6
Apparent viscosity	6.5	8	7	7.5	8.5	6	9.5	8
RHEOLOGICAL PROPERTIES OF SAMPLES(A) @ 70 °C								
Gel strength @1.0-sec	7	7	7	8	7	7	10	9
Gel strength @10 min	6	5	6	6	5	6	8	7
Plastic viscosity	3	5	4	5	4	5	6	5
Yield point	6	3	6	6	6	5	8	8
Apparent viscosity	6	6.5	7	8	7	7.5	10	9
RHEOLOGICAL PROPERTIES OF SAMPLES(A) @ 90 °C								
Gel strength @1.0-sec	6	9	6	7	9	8	8	7
Gel strength @10 min	5	7	4	5	7	6	7	6
Plastic viscosity	4	6	4	8	6	6	8	6

Yield point	3	3	4	1	6	4	5	6
Apparent viscosity	5.5	7.5	6	8.5	9	8	10.5	9

Table 5. Rheological Properties of the clay soils

RHEOLOGICAL PROPERTIES OF SAMPLES(A) @ 30 °C								
(Rpm)	1A	2A	3A	4A	5A	6A	7A	8A
Gel strength @1.0-sec	6	5	7	8	4	6	5	5
Gel strength @10 min	5	4	6	7	3	5	4	4
Plastic viscosity	5	4	5	5	3	5	5	3
Yield point	2	3	5	7	4	4	3	6
Apparent viscosity	6	5.5	7.5	8.5	5	7	6.5	6
RHEOLOGICAL PROPERTIES OF SAMPLES(A) @ 50 °C								
Gel strength @1.0-sec	8	6	5	8	6	6	6	5
Gel strength @10 min	7	5	4	7	5	5	5	4
Plastic viscosity	4	4	5	5	3	4	3	7
Yield point	4	5	5	4	5	5	6	2
Apparent viscosity	6	6.5	7.5	7	5.5	6.5	6	8
RHEOLOGICAL PROPERTIES OF SAMPLES(A) @ 70 °C								
Gel strength @1.0-sec	7	8	8	8	6	8	6	7
Gel strength @10 min	6	7	7	7	5	7	5	6
Plastic viscosity	3	3	4	5	3	4	3	7
Yield point	4	6	6	4	4	4	5	1
Apparent viscosity	5	6	7	7	5	6	5.5	7.5
RHEOLOGICAL PROPERTIES OF SAMPLES(A) @ 90 °C								
Gel strength @1.0-sec	7	6	8	7	6	5	6	6
Gel strength @10 min	6	5	7	6	5	4	5	5
Plastic viscosity	2	2	4	5	3	3	3	5
Yield point	4	7	5.5	3	3	4	5	4
Apparent viscosity	4	5.5	6.75	6.5	4.5	5	5.5	7

A comparison of rheological Properties of the Clays with API Standards shown in Table 6 indicates that the gel strength and plastic viscosity values are within acceptable API ranges. This shows that the clays can build gels and resist flow sufficiently under pressure. Also, apparent viscosity and yield points are consistently below API thresholds, suggesting that the clays alone cannot provide adequate cuttings transport or hole cleaning during drilling. These clays can form a base material for drilling muds but would require activation or beneficiation (e.g., sodium carbonate treatment, blending with bentonite, or polymer additives) to meet full API standards. The thermal stability up to 90 °C is encouraging, showing that the clays will not undergo significant viscosity collapse in deeper wells.

Table 6. Comparison of Rheological Properties of Ugieghudu Clays with API Standards

Parameter	API standard Range	Observed Range	Compliance and Remarks
Gel Strength (1-sec)	2–10 lb/100 ft²	4–10 lb/100 ft²	Within API range – good for suspension during circulation start-up.
Gel Strength (10-min)	4–15 lb/100 ft²	3–8 lb/100 ft²	Mostly within range, but a few low values indicate weaker cuttings suspension under static conditions.
Plastic Viscosity (PV)	2–10 cP (depending on mud type)	2–8 cP	All within range – low PV is favourable for pump efficiency and reduced pressure losses.
Yield Point (YP)	15–30 lb/100 ft² (for unweighted muds)	2–8 lb/100 ft²	Much lower than API requirement – indicates limited carrying capacity; would need clay beneficiation or additives.
Apparent Viscosity (AV)	≥15 cP (for effective hole cleaning)	5–10.5 cP	Below API standards – shows insufficient hole-cleaning ability unless modified.
YP/PV Ratio	1.0–2.0	0.4–1.6	Some samples meet the ratio requirement, but most remain below optimal API levels.

3.5 Filtration Properties

The filtration characteristics and basic mud properties of the Ugieghudu clay-based drilling muds are summarized in Table 7 and 8. The results revealed that the filter cake thickness for all the samples ranged between 0.4 and 0.5 cm, values that lie within the American Petroleum Institute (API) standard of ≤0.5 cm for water-based drilling fluids. This signifies that they will exhibit good wall-building capacity and low permeability (Caenn and Chillingar, 1996). This observation indicates that the clays developed thin, compact, and relatively impermeable filter cakes. Such filter cake characteristics are highly desirable because they help minimize fluid invasion into the formation, reduce the risk of differential sticking of the drill string, and generally ensure efficient drilling performance. The consistently thin filter cakes across all the samples suggest that the clays possess good colloidal and filtration control properties, which are essential requirements for drilling mud formulations.

The mud density values of the samples varied from 8.5 to 8.65 lbs/gal, which aligns well with the API-recommended range for unweighted freshwater drilling muds (8.6–9.0 lbs/gal). These densities are typical of muds suitable for shallow to intermediate-depth drilling operations where pore pressures are relatively low. While such densities are not sufficient for overpressured or deep reservoirs, they provide a good baseline for formulating drilling fluids that can later be adjusted with weighting agents such as barite to meet specific downhole pressure conditions (Olatunde *et al*., 2012).

The pH values of the clays ranged between 8.6 and 8.9, which falls within the preferred alkaline range of 8.5–10.5 for drilling fluids. An alkaline pH is advantageous in drilling operations because it promotes clay dispersion, enhances the swelling

potential of bentonitic clays, suppresses bacterial activity that could degrade organic additives, and provides corrosion control for metallic drilling equipment. The natural alkalinity observed in the Ugieghudu clay-based muds therefore, reduces the need for extensive chemical conditioning and points to an inherent geochemical advantage for their utilization. Based on the comparison with the international standard, the results of filter cake thickness, mud density, and pH indicate that the Ugieghudu clays exhibit promising baseline properties that conform to international drilling mud standards.

Therefore, the results of filter cake thickness, mud density, and pH demonstrate that the Ugieghudu clays exhibit promising baseline properties that conform to international drilling mud standards. The ability to form thin and compact filter cakes indicates good filtration control; however, their densities and pH levels fall within acceptable operational ranges, promoting dispersion, bacterial control, and corrosion resistance (Akinyemi *et al*., 2016). These findings suggest that the clays could serve as effective base materials for drilling mud, particularly for shallow to medium depth wells in onshore environments. However, in line with the earlier rheological evaluations, the clays may still require beneficiation through sodium activation or the addition of polymers to enhance yield point and viscosity, thereby ensuring adequate cuttings transport in the borehole. Nevertheless, their strong performance in terms of filtration and basic mud properties underscores their potential as a viable local substitute for imported bentonite in Nigeria's oil and gas drilling sector.

Table 7. Filtration properties

	1A	**2A**	**3A**	**4A**	**5A**	**6A**	**7A**	**8A**
Filter Cake Thickness (cm)	0.4	0.5	0.4	0.45	0.5	0.5	0.4	0.45
Mud Density (lbs/gal)	8.65	8.5	8.65	8.6	8.5	8.55	8.6	8.5
pH	8.7	8.6	8.9	8.75	8.8	8.7	8.9	8.6
	1b	2b	3b	4b	5b	6b	7b	8b
Filter Cake Thickness (cm)	0.4	0.45	0.3	0.4	0.5	0.3	0.4	0.35
Mud Density (Lbs/Gal)	8.9	8.6	8.9	8.6	8.8	8.3	8.7	8.5
pH	8.9	8.6	8.9	8.6	8.3	8.7	8.5	8.8

Table 8. Comparison of Filtration Properties with API Standards

Parameter	API Recommended Range	Observed Range (Samples 1A–8A)	Compliance and Remarks
Filter Cake Thickness	≤0.5 cm (thin, tough, impermeable)	0.4–0.5 cm	All within range – indicates good filtration control and minimal formation damage.
Mud Density	8.6–9.0 lbs/gal (for freshwater, unweighted muds)	8.5–8.65 lbs/gal	Within range – densities are consistent and appropriate for shallow to intermediate wells.
pH	8.5–10.5 (alkaline muds preferred)	8.6–8.9	Within recommended alkaline range – ensures clay dispersion, microbial control, and corrosion protection.

Conclusions

This study evaluated the geological and rheological properties of Ugieghudu clays with respect to their potential use in drilling mud applications. The particle size distribution of most of the samples shows clay contents exceeding the 30% API minimum for drilling mud clay, while the plasticity index is consistent with materials capable of developing thixotropic structures. Also, the liquid limit falls within the acceptable range for drilling mud applications, while the specific gravity is typical of aluminosilicate clays. The activity ratios (0.58 - 0.85) suggest inactive to normal clays, implying moderate swelling potential, a feature consistent with kaolinitic dominance. These properties show that the studied clays have adequate plasticity and consistency for drilling fluid use, though their activity values are lower than those of bentonitic clays, indicating the need for beneficiation. The mineralogical analysis revealed kaolinite-rich compositions, supported by index properties indicating sufficient clay content, plasticity, and activity within acceptable ranges. However, the relatively high quartz content suggests that while the clays contain essential base minerals for drilling mud formulation, they may require enhancement through additives such as sodium carbonate or polymers to optimize performance. Rheological evaluation demonstrated adequate gel strength, yield point, and viscosity across varying temperatures, while filtration tests showed compliance with API standards for filter cake thickness, density, and pH. These findings establish that Ugieghudu clays possess the fundamental qualities required for drilling mud formulation. Although their performance is somewhat lower than bentonitic clays in terms of swelling and rheological response, their thermal stability, plasticity, and filtration characteristics underscore their potential as viable local substitutes. With beneficiation and chemical additives, these clays could contribute significantly to reducing Nigeria's reliance on imported bentonite, thereby lowering drilling costs and enhancing local content in the oil and gas sector. From the observations presented in the foregoing sections, beneficiation as well as further performance testing of the clays and field application trials are recommended.

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