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COMPOSITIONAL AND RHEOLOGICAL ANALYSIS OF DRILLING MUD FORMULATED FROM UGHELLI NORTH CLAY

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Abstract: *helps in ascertaining its suitability especially as it pertains to drilling mud formulation. Compositional and physical analysis of mud is important because it helps us to understand the mud's properties, composition and behaviour which is in turn helpful to us in order to select a suitable clay for mud formulation. This research is focused on characterization of the properties of the locally sourced mud from Ughelli North clay deposit. The study evaluated the mud pH, mud density, rheological properties and sand concentration. The declining trend in plastic and apparent viscosities, coupled with a largely stable but low yield point, suggests that the Ughelli North clay may have limited capacity to maintain rheological stability over extended periods.*

Keywords: *Drilling Mud, Clay Deposits, Characterization, Compositional Analysis, Physical Analysis, Rheological Properties and Metal Concentrations*

INTRODUCTION

Drilling mud formulation refers to the process of creating a mixture of fluids and additives used in drilling oil and gas wells. Drilling mud formulation is crucial for a number of reasons, such as cooling and lubricating the drill bit, removal of cuttings and debris, maintaining and controlling well pressure, supporting the walls of the well,etc (Kelessidis, 2007). The fundamental constituent of any drilling mud is the mud or clay used in the formulation (API, 2009). Clay is a type of fine-grained earth material that is plastic when moist but hardens when heated or dried. It is composed of tiny particles of minerals, usually silicates that are less than 0.05 millimetres in diameter (Odewole et al. 2022). Clay minerals regarded as pure clay are mainly white or brightly coloured, while the presence of impurities like a little amount of iron oxide is responsible for the reddish or brownish colours of natural clay. The composition of clay varies largely with geographical location (Lydia et al. 2019). They are various types of clay, such as the China clay also called Kaolinite, Bentonite, Illite, Montmorillonite, vermiculite, and lastly the chlorite (Irabor and Okunkpolor, 2020). On account of the differences in the behaviour of clays when they absorb water, they are also loosely classified as expanding (montmorillonite which swells to several times its original size on absorption of water) and non-expanding (kaolinite) (Taylor and Smith, 1986).

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Clays have several applications in construction, agriculture, paper, pharmaceutical, ceramic, petroleum industries etc. Its application in the petroleum industry includes the formulation of drilling mud (Lydia et al. 2019). Clay is suitable for the formulation of drilling mud because of some of it's unique abilities such as it's high plasticity, high absorption capacity, cation exchange capacity, and it's thermal stability, etc. Interestingly, Nigeria has large proven reserve deposits of clay minerals which are estimated to be several billions of tonnes, a large number of these deposits are yet to be characterized (Shuaib-Babata et al. 2019). The entire process of characterising these clay deposits is not only complex but also important as it helps in ascertaining its suitability especially as it pertains to drilling mud formulation. The major analysis usually carried out on clay includes; chemical analysis, physical analysis, rheological analysis, laboratory analysis, mineralogical analysis or a combination of them (Ikubuwaje, et al. 2019). Chemical analysis of clay is important because it helps us to understand the clay's properties, composition and behaviour which is in turn helpful to us in order to select a suitable clay for mud formulation, while the Laboratory analysis of clay has quite a number of importance such as property determination, accurate identification, behavioural prediction, geotechnical evaluation, etc.

In order to improve the mineralogical and chemical properties of Bentonite from Gombe State, Nigeria, Ahmed et al. (2012) used a variety of beneficiation techniques, such as sieving, calcination, and acidification. They found that both raw and beneficiated samples had montmorillonite peaks, with higher peaks seen after beneficiation. However, calcination broke down sodium montmorillonite, leaving magnesium montmorillonite as the dominant phase, and acidification further enhanced the purity of the clay by eliminating ferric oxide. Igwe et al. (2016) evaluated the Abakaliki clay's chemical, mineralogical, and geotechnical characteristics and found that illite and montmorillonite were the two most common minerals, with low kaolinite percentages. The clay did not fulfil API specifications for drilling mud because of its low Na2O concentration and inferior rheological qualities, even though it was malleable and had natural pH values. Nevertheless, the study showed that it may function much better with additions like sodium carbonate and carboxymethyl cellulose. This is consistent with the requirement for methodical assessment and adjustment of regional clays in order to meet the required requirements. A thermochemical treatment technique was presented by Ogolo et al. (2023) to change potassium-based Bentonite into sodium-based Bentonite. The study significantly improved rheological characteristics, such as viscosity, yield point, and thixotropy, using raw clay samples from Pindinga and Ubakala. The clay's appropriateness for drilling applications was improved by the addition of soda ash and magnesium oxide to the treatment process, demonstrating the possibility of cutting-edge treatment techniques to overcome the drawbacks of local Bentonite.

Overall, the study showed promising results in enhancing the properties of locally sourced Bentonite for drilling purposes. Further research and development in this area could lead to more efficient and cost-effective solutions for the oil and gas industry. More locally sourced clay samples need to be characterized in order to determine their suitability for drilling operations, as the chemical composition of the clay determines its chemical and physical properties and, consequently, its application.

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Aim of the Study

The aim of this study is to conduct and report a compositional and physical characterization of locally sourced drilling mud from ughelli north clay deposit.

Objective of the Study the objectives of this study are:

i. To analyse the rheological and physical properties of drilling mud derived from Ughelli North clay.
ii. To determine the pH stability and mud weight variations over time for clay-based drilling fluids. iii. To evaluate the elemental composition of Ughelli North clay for industrial suitability.

Location and Geology of the Study Area

The local clay material used in this study was obtained from Oviri-Ogor community in Ughelli North Local Government Area of Delta State, South-Southern Nigeria. Its geographical coordinates are approximately longitude 5° 59' 24" E, latitude 5° 30' 36" N, and an elevation of 65 ft above sea level. The topography within 2 miles of OviriOgor is predominantly flat, with a maximum elevation change of 95 feet and an average elevation above sea level of 75 feet. Within 10 miles, the topography remains flat (120 feet), and within 50 miles, it contains only slight variations in elevation (350 feet).
The area within 2 miles of Oviri-Ogor is covered by trees (48%), water bodies (20%), and crop-land (15%). Within 10 miles, the land cover consists of trees (50%), shrubs (18%), and water (12%). Within 50 miles, trees (42%), crop-land (25%), and grassland (10%) dominate the landscape. Oviri-Ogor is located in the typical Niger Delta region, characterized by the Benin, Agbada, and Akata geological formations. The region is a lowland sedimentary area with flat terrain in a coastal fluviatile-tide environment. The soil profile includes fine brownish-Gray topsoil underlain by clayey and silty formations, typical of the deltaic environment. These features make Oviri-Ogor a representative site for evaluating clay properties for industrial applications, including drilling mud formulation.

Materials

The various materials employed during the experimental study includes:
Clay sample, plastic plates for storing the sample, digital weighing balance, water, highspeed blender, mud balance, digital stopwatch, Marsh cup, pH papers, viscometer, sand content kit, gloves, lab coat, safety shoe, measuring cylinder.

Sample Collection and Preparation

Fresh clay samples were taken from a 4-foot-deep trench that was dug out with the intention of concentrating on particular horizontal strata that are frequently home to salt, calcium, and magnesium base components. To aid in the pulverization and sifting processes that followed, the materials were ground into finer particles and oven-dried. To create a 63 µm fraction that complied with API requirements for Bentonite, the dry materials were crushed into a fine powder using a mortar and pestle and sieved using a Rota shaker.

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Figure 1: Clay sample obtain from site

The Wet Mixing Method was utilized to prepare the mud used in this investigation.This process entails combining the components of drilling mud with a liquid (either water or oil) to form a uniform slurry; in this study, water was utilized. Due to its many benefits, including a quicker mixing time, improved mud consistency, less dust generation during preparation, improved hydration of additives, etc., the wet mixing technique is recommended over the dry mixing approach.

The sample of treated clay was gathered in a beaker and properly marked with masking tape. Using a weighing scale, 21.0 g of the fine clay sample were then transferred into different mixer cups and labelled appropriately. A 500 ml measuring cylinder was used to measure 350 ml of distilled water, which was then added to the corresponding clay sample. A Hamilton Beach mixer (type 936-1) was used to combine the mixture until it became homogeneous. To guarantee full hydration, the resultant homogeneous mix was let to mature for a full day. Prior to conducting characterization tests, the mixture was mixed once more to agitate the mud following the ageing period. The type of tests conducted on the sample include mud density, mud pH, sand content, and rheology test, along with chemical analysis in search of heavy metals present such as zinc, lead, manganese, and copper, etc.

Mud Weight Characterisation

To determine the mud density, a mud balance was utilized. The calibration of the mud balance commenced with the use of fresh water to verify the integrity of the mud balance. Subsequently, the cup was filled to its brim with the specially formulated mud sample. Following this, the cup was tapped vigorously to release any trapped air bubbles. The lid was then securely placed and rotated to ensure a proper seal. Any excess mud that overflowed through the vent was wiped off from both the lid and the body of the cup. The balance was then positioned on its base, and the rider was adjusted along the graduated arm until equilibrium was achieved. The mud weight in the 4 unit was recorded.

Mud Rheology Characterisation

The mud was vigorously agitated before conducting the test. Subsequently, the agitated mud was carefully transferred into the rheometer cup and immersed within the rotor sleeve precisely up to the

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specified mark. It was then secured in place by tightening the locking screw on the left side of the apparatus,the knob was adjusted in other to obtain readings for 3rpm ,300rpm ,and 600rpm . These measurements at different speeds provided the basis for calculating the plastic viscosity and yield point. Plastic viscosity (PV) and yield point (YP) were derived using the Bingham plastic model, expressed mathematically as:

$PV, cP = \theta_{600} - \theta_{300}$

$YP, lb/100\ ft^2 = \theta_{300} - PV$

Plastic viscosity was calculated as the difference between the 600-rpm and 300-rpm readings, indicating the resistance of mud to flow under mechanical forces. Yield point, a measure of the mud's ability to carry cuttings at low flow rates, was determined by subtracting the PV from the 300-rpm reading.

PH Characterisation

The indicator was torn out and placed on the mud for sufficient time to soak,it was brought out after a while and the colour change in the pH paper was read by it with the ones provided on the hydrion dispenser chart and the value was recorded.

Sand Content Characterisation

The sample is initially filtered through a 200-mesh sieve to segregate sand from finer particles. Subsequently, the sample undergoes a thorough rinsing process to guarantee that only sand remains on the sieve. The sand is then carefully transferred to a calibrated sand content tube filled with water, and post agitation, it is allowed to settle. The sand content is then determined directly from the graduated markings on the tube, usually represented as a percentage.

Chemical Analysis Technique:

Atomic Absorption Spectroscopy for Metal Analysis

In this study, AAS was employed to measure the concentrations of four specific metals: lead (Pb), magnesium (Mg), copper (Cu), and zinc (Zn). The process follows from the preparation of the clay sample, which is digested using a mixture of strong acids (commonly nitric and hydrochloric acids) to break down the matrix and release the metals into solution. The resulting solution is filtered to remove undissolved solids and diluted to a suitable concentration. The digested sample is then introduced into the AAS instrument, where it is atomized using either a flame or graphite furnace, depending on the detection limits and metal of interest. Actually, lead which is a heavy metal, often requires the enhanced sensitivity of a graphite furnace. Magnesium, copper, and zinc— classified as essential and trace elements—can be effectively analysed using a flame atomizer. A hollow cathode lamp specific to each metal emits light at characteristic wavelengths (217 nm for lead, 285 nm for magnesium, 324 nm for copper, and 213 nm for zinc). The metal atoms in the atomized sample absorb this light, creating a measurable decrease in intensity.

To ensure accuracy, the instrument is calibrated using standard solutions of known metal concentrations, and the results are validated with quality control samples. The detection limits and sensitivity of AAS make it ideal for quantifying trace metals like copper and zinc, as well as potentially toxic metals like lead. In this study, the method not only provides critical data on the metal content of

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the clay sample but also offers insights into its suitability for industrial applications, particularly in contexts where the presence of heavy metals like lead must be minimized to meet safety standards. AAS remains a cornerstone in chemical analysis due to its robustness, high sensitivity, and specificity.

Results

Laboratory Analysis

The study evaluated the rheological properties, mud weight, sand content, and pH of drilling mud formulated using clay sourced from Ughelli North, Delta State. Table 4.1 presents the results across the five-day test period which provides insights into the compositional and physical characteristics of the clay as a drilling mud additive.

Table 1 laboratory analysis results Ughelli north clay sample.

Day Test	Ph	Rheological Test (cp)			Mud Weight				Sand Content (%)
		3 rpm	300 rpm	600 rpm	lbs/gal (ppg)	lbs/sq. in/1000ft	lbs/cu. ft (pft^3)	sp. gr	
1	6	1	3.0	4.5	8.8	450	65.5	1.07	Negl
2	6	1	2.5	3.5	8.6	430	65.5	1.05	Negl.
3	5	1	3	3	8.5	440	64	1.04	Negl.
4	4	0	2	2	8.5	450	64	1.03	Negl.
5	4	0	2.0	2.0	8.3	440	63.5	1.01	Negl.

pH Levels

The pH values steadily decreased from 6 on day 1 to 4 by day 5, suggesting acidification of the drilling mud. This change could result from chemical interactions within the mud system or microbial activity, indicating the need for pH stabilizers to maintain a neutral or slightly alkaline condition suitable for most drilling operations.

Mud Weight and Density

The mud weight remained relatively stable, averaging 8.5 lbs/gal, with minor fluctuations. The equivalent pressure gradient ranged between 64 to 65.5 lbs/sq. in/1000 ft, which aligns with typical requirements for controlling formation pressures in standard drilling operations. Specific gravity values declined marginally from 1.07 to 1.01 over the five days, showing that the clay maintains a functional density but may experience slight reductions in solids suspension efficiency over time.

Sand Content:

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The sand content remained negligible throughout the test period, underscoring the effectiveness of the clay in minimizing abrasive particles. This characteristic is advantageous as it reduces equipment wear and promotes smoother drilling operations.

Rheological Properties:

The rheological properties, viscosity at varying shear rates (3 rpm, 300 rpm, and 600 rpm), showed a gradual decline over the test period. On day one, the 3 rpm viscosity reading was 3.0 cp, decreasing to 2.0 cp by day five. Similarly, the 300 rpm reading dropped from 4.5 cp to 2.0 cp, and the 600 rpm viscosity declined from 8.8 cp to 8.3 cp. This reduction indicates a loss of structural integrity over time, suggesting limited long-term stability in maintaining desirable rheological characteristics. However, the initial values show that the clay can produce moderately stable mud at the onset of mixing. The rheological properties of the drilling mud formulated using clay from the Ughelli North deposit were also assessed for plastic viscosity, yield point, and apparent viscosity measurements over test period. These properties, which are critical for evaluating the flow behavior and carrying capacity of the mud, exhibited trends indicating changes in the performance characteristics of the clay.

Table 4.2 Rheological Test Calculation Result

Day	Plastic Viscosity (cp)	Yield point (cp)	Apparent Viscosity (cp)
1	1.5	1.5	2.25
2	1	1.5	1.75
3	0	3	1.5
4	0.5	1.5	1.25
5	0.5	1.5	1.25

Plastic Viscosity (PV):

The plastic viscosity, indicative of the internal resistance of the mud to flow under steady shear, varied across the test period. It started at 1.5 cp on day one, dropped to 1 cp on day two, and reached 0 cp by day three, before slightly recovering to 0.5 cp on days four and five. The initial decline suggests a reduction in the suspension and solids interaction within the mud, possibly due to a breakdown of the clay particles or dilution effects. The partial recovery on subsequent days might be due to minor flocculation or settling dynamics within the mud system.

Yield Point (YP):

The yield point, reflecting the initial stress required to induce flow, was steady at 1.5 cp on days one, two, four, and five, with a notable increase to 3 cp on day three. This spike might indicate temporary gelation or an increase in particle interactions, potentially caused by changes in the ionic composition or the hydration state of the clay. The generally low yield point values imply that the mud exhibits low shear thinning behavior, which could be advantageous in minimizing pressure surges during pumping operations.

Apparent Viscosity (AV):

Apparent viscosity, the combined measure of plastic viscosity and yield point at a given shear rate, showed a decreasing trend over time. Starting at 2.25 cp on day 1, it dropped to 1.75 cp on day 2 and

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stabilized at 1.5 cp by day 3, declining further to 1.25 cp on day 4 and 5. This reduction reflects a gradual decrease in the mud's overall flow resistance, possibly linked to the breakdown of the clay structure or a reduction in the active surface area of suspended particles.

Chemical Analysis:

Table 3 summarized the results of the chemical analysis conducted on Ughelli North Clay, focusing on the concentration of key trace elements. The analysis provided measurements of manganese, lead, copper, and zinc, expressed in milligrams per kilogram (mg/kg).

Table 3: Chemical Analysis results of Ughelli north clay

S/N	Parameters	Ughelli North Clay
1	Manganese (mg/kg)	3.299
2	Lead (mg/kg)	0.537
3	Copper (mg/kg)	5.888
4	Zinc (mg/kg)	0.511

The manganese concentration of 3.299 mg/kg suggests a moderate level, typical for clays from sedimentary environments. Manganese plays a role in influencing the rheological properties of drilling mud by contributing to the overall mineralogical structure. The detected level is not hazardous and aligns with typical values for industrial clays. The lead concentration of 0.537 mg/kg indicates a relatively low level, which is beneficial for minimizing toxicological risks in industrial applications. This value is below the safety thresholds set for clay used in non-food-related industrial processes, implying that the clay is suitable for use in drilling muds without significant environmental concerns. Similarly, Copper, a trace element, is present at 5.888 mg/kg in the clay sample. This concentration is moderately high, reflecting the geochemical composition of the source region. Copper can enhance the functionality of drilling muds by contributing to thermal conductivity and chemical stability. However, it also necessitates monitoring due to its potential environmental impact when present in excess. Another essential trace element detected in the mud was Zinc at a concentration of 0.511 mg/kg, which is a low concentration. This level aligns with typical background concentrations in clay deposits. Zinc can impart some degree of anti-corrosion properties to drilling muds, but its low level here suggests it may have a limited direct impact on the clay's performance in such applications.

Conclusion and Recommendations

This research is focused on characterisation of the properties of the locally sourced mud from Ughelli North clay deposit. The study evaluated the mud pH, mud density, rheological properties and sand concentration. The Ughelli North clay demonstrated promising initial performance for use in drilling muds, particularly regarding low sand content and reasonable rheological properties. However, the observed decline in pH over time suggests a need for further conditioning or treatment to enhance long-term stability. The declining trend in plastic and apparent viscosities, coupled with a largely stable but low yield point, suggests that the Ughelli North clay may have limited capacity to maintain rheological stability over extended periods. While the mud exhibits manageable flow properties initially, the reduction in viscosity highlights the need for supplemental viscosifiers or stabilizing

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agents to enhance its performance. The yield point values, though consistent, are relatively low, indicating limited carrying capacity for cuttings at low flow rates. The results also indicate that the Ughelli North clay contains low to moderate levels of metals, with no significant toxicity concerns for industrial applications. The low levels of lead and zinc minimize environmental risks, while the moderate levels of manganese and copper suggest potential contributions to the physical and chemical stability of the drilling mud. However, additional treatment or the inclusion of additives may be necessary to optimize the clay's performance depending on the specific application requirements. It is further imperative that further research should focus on exploring the incorporation of nano-particles into drilling fluids to evaluate their potential for improving mud rheology, wellbore stability, and filtration control while reducing the environmental footprint of drilling operations, and also investigating the interactions between clay particles and polymer additives to understand their combined effects on viscosity, and stability of drilling muds, enabling better control over mud properties.

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