Communication in Physical Sciences, 2025, 12(2) 259-275

# Beneficiation Process of Locally Available Bentonitic Clay: An Efficient Utilization in Drilling Fluid Application in Akwa Ibom State

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**Received: 19 November 2024/Accepted 13 January 2025/Published 05 February 2025**

https://dx.doi.org/10.4314/cps.v12i2.7

***Abstract:*** *This study investigates the enhancement of bentonitic clay obtained from Oron, Nigeria, through a systematic beneficiation process aimed at improving its swelling ability, viscosity, and rheological properties to meet the technical standards required for drilling fluid applications in the oil and gas industry. The beneficiation process includes mechanical purification, chemical treatment with sodium carbonate (soda ash), and ion exchange to activate the calcium-based nature of the clay to a sodium-based form, crucial for its drilling fluid performance. Mineralogical and chemical analyses, including X-ray diffraction (XRD) and scanning electron microscopy (SEM), were used to evaluate the structural changes following beneficiation. The UV-Visible spectra revealed that Eniongo Beach (EBC) absorbed at 430 nm, Usung Beach (UBC) at 544 nm, and Edek Okong Beach (EOBC) at 597 nm, with absorption increasing in the order EOBC > UBC > EBC, indicating variations in particle size and structural complexity. SEM imaging showed that the bentonitic clay samples had micro-sized particles of irregular shapes, and Energy-Dispersive X-ray Spectroscopy (EDS) revealed that the clay was rich in Al, Si, Ba, Mg, and Ca. XRD analysis confirmed the crystalline nature of the clays, with well-resolved peaks corresponding to various inorganic minerals. Rheological testing of the beneficiated clay indicated a significant improvement in its properties, with an apparent viscosity of 10 cP, plastic viscosity of 10.25 cP, yield point of 4, fluid loss of 18 mL, and gel strength of 2/4 lb/100 ft² at 10 sec/10 min. These results demonstrate a marked enhancement in the rheological properties of the clay, aligning with American Petroleum Institute (API) standards for drilling fluids, making the beneficiated Oron clay a viable option for high-performance drilling operations.*

***Keywords:*** *Beneficiation, Bentonitic clay, Mud properties, Drilling fluid*

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## 1.0 Introduction

Drilling fluids also referred to as drilling mud, are fundamental for safe and efficient oil and gas drilling operations (Fadhil and Hadi, 2024). Since their introduction in the early 20th century with rotary drilling, these fluids have evolved to meet the demands of increasingly complex drilling environments, such as deep wells and unconventional reservoirs (Omomo *et al*., 2024). Several functions of drilling fluids have been extensively documented in the literature, including cooling and lubricating the drill bit, aiding in support of the drill pipe, transporting cuttings to the surface, stabilizing the wellbore, preventing well blowouts, controlling formation pressure, minimizing formation damage, and facilitating data acquisition (Asadimehr, 2024; Hammas Rasol *et al*., 2024; Shmoncheva *et al*., 2024; Stanciu, 2024). Based on the work published by Faisal *et al*. (2024), the most desirable properties of drilling fluid are rheological and filtration loss. Consequently, they developed and tested green uncoated and polymer-coated magnetite nanoparticles for application in water drilling. Heir products showed enhanced performance when compared to conventional products. Zhang *et al*. (2020) also confirmed the rheological properties of drilling fluids as a basic determinant of its functional applications. They also stated that the rheological properties are affected by pH, temperature, type of electrolyte and concentration of active materials such as clay. Their study indicated that different clay materials regarding identity and concentrations exhibited different fluid properties and hence their suitability in different types of drilling.

Bentonite, a clay material formed from the weathering of volcanic ash, is a vital component of many drilling fluid systems. Its functionality is attributed to the presence of smectite-type layer silicates, predominantly montmorillonite, which provide high surface area, cation exchange capacity, and the ability to form viscous slurries in water. These properties are influenced by the composition and processing of bentonite deposits. The clay is classified as sodium or calcium bentonite based on the dominant exchangeable cation, with sodium bentonite exhibiting superior swelling and rheological properties. While sodium bentonite is preferred for drilling fluid applications due to its high yield and viscosity, calcium bentonite can be modified through ion exchange to enhance its properties.

In Nigeria, significant bentonite deposits exist across the country, including in the Northeastern (Borno, Yobe, Adamawa), Northwestern (Sokoto, Kebbi, Zamfara), and Middle Belt regions (Benue, Kogi, Nasarawa). These deposits are predominantly calcium-based, necessitating beneficiation to meet industry standards. Beneficiation involves processes such as cation exchange, acid activation, and thermal treatment to enhance properties like swelling capacity, plasticity, and filtration control. This transformation is crucial for achieving the specifications set by the American Petroleum Institute (API) and the International Organization for Standardization (ISO) for drilling muds. Studies on Nigerian bentonite have highlighted its mineralogical composition, industrial applications, and beneficiation techniques. Characterization studies using X-ray diffraction (XRD) and X-ray fluorescence (XRF) consistently identify montmorillonite as the dominant mineral. However, raw Nigerian bentonites often fail to meet the API standards for drilling muds, particularly in terms of swelling capacity and fluid loss control.

Research has demonstrated that beneficiation using sodium carbonate, starch, and other additives significantly improves these properties. For instance, sodium carbonate treatment enhances swelling and rheological behaviour, while starch improves filtration control. Studies by Dewu et al. (2011) and Ahmed et al. (2012) confirm that combining additives such as potash and starch yields better overall performance. Despite these advances, challenges such as limited infrastructure, reliance on imported bentonite, and insufficient funding hinder the full exploitation of local resources. Although significant progress has been made in the beneficiation and application of Nigerian bentonite, gaps remain. Existing studies primarily focus on enhancing the clay's basic properties without addressing its performance in unconventional drilling environments, such as high-pressure and high-temperature (HPHT) wells. Additionally, the economic viability of large-scale beneficiation processes remains underexplored, and there is limited research on integrating beneficiated bentonite into international markets. A comprehensive approach is needed to optimize local bentonite for advanced drilling applications while addressing sustainability and economic empowerment.The primary aim of this study is to evaluate the beneficiation potential of locally available bentonitic clay in Akwa Ibom State for efficient utilization in drilling fluid applications. This research seeks to enhance the properties of the clay to meet industry standards and promote the economic and industrial development of the region.

## 2.0 Materials and Methods

This research focused on analyzing bentonitic clay samples from Oron Local Government Area in Akwa Ibom State, Nigeria, and evaluating their suitability for drilling fluids applications in the oil and gas industry. The study was divided into two primary activities:

***i. Collection of Bentonitic Clays***

The research began with a preliminary survey to identify bentonite deposits in Oron, specifically from Eniongo Beach (EBC), Usung Beach (UBC), and Edek Okong Beach (EOBC). Geological maps, academic research, and government records were consulted to locate the deposits. After obtaining necessary permissions from local authorities, landowners, and relevant government agencies, a geologist was engaged to ensure accurate identification of the bentonitic clay deposits.

***ii. Sampling Procedure***:

Oron is situated in the South-South region of Nigeria within the tropical rainforest belt, specifically between Latitude: 4.75° N and Longitude: 8.25° E, and an altitude of 94 m above sea level. The study area spans approximately 83 square kilometers (about 32 square miles). The sampling process involved identifying outcrop areas where the clay was accessible near the surface, typically at a depth of 6 feet, in areas where calcium, sodium, and magnesium base elements are abundant. Subsurface exploration was conducted using hand augers to access deeper deposits. In-situ field tests were carried out to evaluate the plasticity, color, and texture of the clay to confirm the presence of bentonite.

***Sample Processing and Preliminary Drying***

After extraction, the clay was cleaned to remove impurities

ies such as sand, roots, and debris, followed by preliminary drying under the sun to reduce moisture content, making it easier to transport. A sample of Aqua gel clay from EBC, UBC, and EOBC was then prepared using the following equipment: Multi-Hamilton Beach mixer, triple beam balance, drying oven, mixer cup, spatula, tray, graduated measuring cylinder, hand mortar and pestle, sieve, beakers, and reagents like distilled water. The clay samples were dried at 40°C in a drying oven and spread out on plastic trays.

***Transportation and Environmental Considerations***

The clay was packed into sacks for transportation to the laboratory, ensuring compliance with safety and environmental standards. Workers were equipped with protective gear such as gloves, boots, and helmets. Environmental regulations set by the Oron Local Government were followed to prevent land degradation and contamination of nearby water bodies. After mining, the site was rehabilitated through filling and erosion control measures.

***Pulverization and Sieving***

The dehydrated clay sample was then subjected to pulverization using a mortar and pestle. The pulverized clay was sieved to obtain fine powder particles, which were then collected in a beaker and labelled. Specific amounts of fine clay (27.5 g, 31.0 g, and 34.5 g) were weighed using a spatula and placed into separate mixer cups.

***Clay Suspension and Homogenization*:**
Next, 250 ml of distilled water was measured using a 500 ml graduated cylinder and added to each clay sample. The mixture was stirred using the Hamilton Beach mixer for 2-5 minutes to achieve a homogeneous mixture, which was aged for 24 hours to ensure proper hydration. After ageing, the mixture was stirred again to re-agitate and prepare for further characterization.

***Mud Formulation***
After 24 hours of ageing, 20 g of each sample was weighed and dissolved in 1 L of water, with the following concentrations:

- High-concentration mud: 34.5 g of clay plus 250 ml of water
- Medium-concentration mud: 31.0 g of clay plus 250 ml of water
- Low-concentration mud: 27.5 g of clay plus 250 ml of water.

### *2.1 Determination of Chemical and Mineralogical Composition*

The mineralogical and chemical compositions of the raw Oron clay samples were determined using an X-ray Diffractometer (Model Schmadzu 6000). The Wyoming bentonite was used as the standard (control) for comparison. Particle size distribution was analyzed using the hydrometer method, and cation exchange capacity (CEC) was determined following the guidelines in Inglethorpe et al. (1993).

### *2.2 Chemical Beneficiation (Activation)*

Chemical activation (beneficiation) was carried out to convert the clay into sodium bentonite via ion exchange using sodium carbonate as the activating agent, as described by Bindei et al. (1987). Two modes of activation were applied: wet and dry. In the wet method, 2-14% by weight of Na2CO3 was added incrementally to a clay suspension and stirred for 2 hours to ensure proper ion exchange. After activation, the beneficiated clay was oven-dried to reduce moisture content and ground into a powder using a ball mill. The dry method involved blending sodium carbonate with raw clay, allowing ion exchange during hydration.

**Fig. 1: Bentonitic clay deposits**

**Fig. 2: Grounded Bentonitic clay**

### *2.3 Drilling Mud Formulation*

To formulate the drilling mud, 34.5 g of the beneficiated clay was mixed with varying concentrations of sodium carbonate (Na2CO3) and 250 ml of water. The mixture was agitated using a Hamilton Beach Mixer for 10 minutes to ensure uniform hydration. For improved rheological and filtration properties, 1 g of carboxymethyl cellulose (CMC) was added to the mixture. The mud was allowed to age for 24 hours before conducting filtration and rheological tests.

#### *2.3.1 Drilling Mud Testing Procedures*

***Plastic Viscosity, Apparent Viscosity, Yield Point, and Gel Strength Determination*:**

The viscometer (Ofite 900 model) was used to measure these parameters following the manufacturer's guidelines. The mud was decanted into the sample cell, and the rotor sleeve was immersed in the mud to the inscribed line. After stabilizing for 10 seconds, readings at 600 rpm (θ600) were recorded, and plastic viscosity, yield point, and gel strength were calculated in centipoise (cP) and pounds per hundred square feet (lb/100ft²), respectively.

### *2.3.2 Fluid Loss Determination*

The API filter press was used to determine fluid loss or water loss at a low temperature. The sample mud was poured into the filter cell, which was then placed in the frame. A graduated cylinder was positioned under the drain tube to collect the filtrate, and a 100 psi (690 kPa) pressure was applied. After 30 minutes, the fluid loss volume was recorded in millilitres (ml).

### *2.3.3 pH Determination*

pH determination was carried out using pH test paper. A strip of indicator paper was immersed in the mud, and the color change was compared with the standard colour chart provided with the test strips. The pH of the mud was reported to the nearest 0.5 unit.

## 3. 0 Results and Discussion

The results presented in **Table 1** provide a detailed comparison of the properties of Oron Bentonitic clay with the API standard requirements for drilling fluids. The comparison shows that most properties of Oron Bentonitic clay fall within the acceptable range specified by the API. For example, the mud density (8.6125 lb/gal) is slightly below the API standard range of 8.65–9.60 lb/gal, while plastic viscosity (10.25 cP) is close to the lower end of the API requirement of 8–10 cP. The yield point of 18.125 lb/100ft² is significantly higher than the minimum value based on the relationship with plastic viscosity (3 x PV), highlighting the potential of Oron clay as a drilling fluid with a higher yield point than the standard. However, fluid loss (25.125) exceeds the API limit of 15 mm, indicating that the fluid might not perform optimally in certain applications without modification. The pH level of 7.698 is slightly below the API's minimum of 9.5, which may affect the fluid's stability and performance in some conditions. Additionally, the sand content (0.25%) and screen analysis (max 10%) values suggest that Oron clay is relatively low in undesired impurities. Its marsh funnel viscosity (36 sec) falls within the acceptable range of 32–56 sec/q+, indicating a moderate fluid flow rate. The mud yield (60 bbl/ton) is well below the API standard of 91 bbl/ton, indicating a lower yield but still within acceptable operational ranges. Overall, while Oron Bentonitic clay exhibits promising drilling fluid properties, some adjustments may be needed to meet certain API specifications, particularly in fluid loss, pH, and mud yield.

**Table 1: Comparing the API standard for drilling fluids with that of Oron bentonitic clay**

| Drilling Fluid Property (lb/gal) | Oron bentonitic clay | Numerical value requirement (API) Agwu *et al.* (2015) |
|---|---|---|
| **Mud density** | 8.6125 | 8.65-9.60 |
| **Plastic viscosity (cP)** | 10.25 | 8 – 10 |
| **Yield point (Ib/100ft$^2$)** | 18.125 | 3 x Plastic viscosity |
| **Fluid loss (Water)** | 25.125 | 15 mm Maximum |
| **pH level** | 7.698 | 9.5min – 12.5max |
| **Sand content %** | 0.25 | (1 – 2) % Maximum |
| **Screen analysis %** | | 10% (maximum) |
| **Moisture content (ppm)** | 0.325 | $Ca^{2+}$ (ppm) 2.50 (maximum) |

| | | |
|---|---|---|
| **Marsh funnel viscosity (seconds)** | 36 | 32 – 56 sec/q+ |
| **Mud yield (bbl/ton)** | 60 | 91 (maximum) |
| **API filtrate (ml)** | 28 | 30 (minimum) |
| **Montmorillonite** | | 70 – 130 |
| **Vermiculite** | 150 | 100 – 200 |
| **Illite** | 10 | 10 – 40 |
| **Chlorite** | 6 | 10 – 40 |
| **Kadinite** | 5 | 3 – 15 |
| **Marsh funnel viscosity for water** | 28 | 26 sec/q+ ± 0 |
| **n-Factor (power law index)** | 0.5 | 1 (maximum) |
| **YP/PV ratio** | 1.768 | 3.0 (maximum) |

**Table 2** presents a comparative analysis of the mineral composition of Wyoming Bentonite and Oron Beach Clay. The results show distinct differences in mineral content between the two clay samples. Wyoming Bentonite has a higher percentage of smectite (60%) compared to Oron Beach clay (26.76%), which may contribute to its superior swelling and gel-forming properties, making it more suitable for certain drilling applications. Oron Beach clay, on the other hand, contains a higher proportion of gismondine (41.50%), which may influence its chemical reactivity and behavior in drilling operations. Additionally, the presence of **s**erpentine (5.50%) and kaolinite (4.00%) in Oron clay is notable, as these minerals may contribute to specific chemical interactions or modifications in the behavior of the drilling fluid. The quartz content in Oron Beach clay (9.73%) is lower than that of Wyoming Bentonite (19.4%), which may suggest differences in particle size and overall performance in filtration or sedimentation processes. The presence of barite and sanderite in Wyoming Bentonite (19.4% and 10%, respectively) gives it a distinct mineral profile, suggesting its potential for use in specific applications requiring additional density. In conclusion, while both clays show potential for use in drilling fluids, their different mineral compositions may determine their suitability for varying applications and may require tailored processing to optimize performance.

**Table 2: Summary of mineral composition of the clay samples**

| ***Wyoming* Bentonite** | | **Oron Beach clay** | |
|---|---|---|---|
| **Mineral** | **Composition (%)** | **Mineral** | **Composition (%)** |
| **Smectite** | 60 | Smectite | 26.76 |
| **Barite** | 19.4 | Quartz | 9.73 |
| **Sanderite** | 10 | Kaolinite | 4.00 |
| **Gismondine** | 7.9 | Gismondine | 41.50 |
| **Muscovite** | 6.9 | Serpentine | 5.50 |
| **others** | 5.8 | Others | 16 |

Table 3 presents the particle size distribution data for Oron clay and Wyoming bentonite, showing the proportions of silt, sand, and clay at two different time readings: 40 seconds and 2 hours. At 40 seconds, Oron clay shows a higher percentage of clay (65%) compared to silt (24%) and sand (15%). After 2 hours, the clay content decreases to 44%, while the silt content reduces slightly to 15%, and the sand content increases to 32%. This indicates that Oron clay primarily consists of fine particles, which influences its water retention and swelling characteristics. The shift in particle distribution over time suggests that processes like flocculation or particle aggregation might be occurring, causing a reduction in clay particles and an increase in sand content.

Wyoming bentonite, on the other hand, exhibits a more balanced distribution at 40 seconds, with clay at 47%, silt at 33%, and sand at 20%. After 2 hours, the clay content decreases to 33%, the silt content decreases to 23%, and the sand content increases to 33%. Like Oron clay, Wyoming bentonite shows a shift towards a higher proportion of sand over time, suggesting a similar aggregation or dispersion process. This shift indicates that Wyoming bentonite may undergo more dispersion in the presence of water or during sedimentation, which leads to the aggregation of finer particles and a corresponding increase in sand particles.

Oron clay, with its higher initial clay content, has greater potential for use in applications requiring high colloidal stability, water retention, or viscosity. The higher clay content could also enhance its performance in thickening fluids and applications such as drilling muds, where fine particles are desirable. Both samples, however, demonstrate a trend of increasing sand content over time and decreasing clay and silt fractions. This suggests that both clays exhibit similar settling or aggregation behaviour when exposed to water. Wyoming bentonite, with its lower initial clay content, might not provide the same structural or rheological benefits as Oron clay in certain applications.

The shift from a higher proportion of clay to sand over time in both samples reflects their behaviour when exposed to water, with finer particles (clay) possibly aggregating or flocculating while the coarser particles (sand) become more prominent due to settling or redistribution. This trend could influence the rheological properties of the materials, making Oron clay more suitable for processes that require fine particulate material. In contrast, Wyoming bentonite may be less stable in certain applications due to its higher sand content and lower clay proportion. In conclusion, Oron clay has a higher initial clay content and maintains a larger proportion of clay over time compared to Wyoming bentonite, which could make it more effective in applications requiring high viscosity and better suspension properties. However, the shifts in particle size distribution for both clays indicate that their behavior can be dynamic, and further investigation is needed to fully understand the factors influencing their performance in different environments.

**Table 3: Particle Size**

| Sample | 40 seconds reading | 2hours reading | % Silt (<0.002mm) | % Sand (0.002-0.05mm) | % Clay (0.05-2mm) |
|---|---|---|---|---|---|
| **Oron clay** | 44 | 32 | 24 | 15 | 65 |
| **Wyoming** | 33 | 23 | 33 | 20 | 47 |

Table 4 presents the chemical composition of Wyoming and Oron bentonitic clays. For Wyoming bentonite, the major components are $SiO_2$ (43.60%), $Al_2O_3$ (14.20%), and $Fe_2O_3$ (14.50%), while Oron clay contains higher amounts of $Al_2O_3$ (20.10%) and $SiO_2$ (48.50%). The higher $SiO_2$ and $Al_2O_3$ content in Oron clay suggests a stronger silicate network, which could influence its performance as a drilling fluid due to the structural properties associated with higher levels of aluminosilicates. Additionally, Oron clay contains more iron oxide ($Fe_2O_3$, 17.59%) compared to Wyoming (14.50%), which may enhance its catalytic activity in certain chemical reactions. The presence of other minor oxides such as $Na_2O$ and $K_2O$ in both samples also shows differences in their ionic content. Notably, Oron clay contains a significant amount of "other" compounds (20.10%), which could include trace elements or impurities affecting its performance in different applications. In comparison to the chemical composition of both clays, Oron clay has a higher overall metal oxide content, potentially leading to higher rheological properties in its applications compared to Wyoming bentonite.

Table 5 compares the physical properties of Oron raw bentonite and its beneficiated form. Beneficiation improves the swelling index of Oron clay from 15.00 mL/2g to 20.00 mL/2g, suggesting an enhancement in its water retention and ability to form a gel-like structure, which is crucial for drilling fluids. However, the moisture content decreases slightly from 10.50% in raw bentonite to 8.22% in beneficiated bentonite, indicating a reduction in water content due to the beneficiation process. The particle size distribution also shifts from coarse to fine, which can improve the clay's dispersion in liquids, making it more effective for applications requiring fine particle sizes for better suspension and viscosity control. The bulk density of the beneficiated bentonite slightly decreases from 0.85 g/cm$^3$ to 0.78 g/cm$^3$, indicating a reduction in the overall mass per unit volume after beneficiation. This decrease could enhance the flowability of the drilling fluid when used in its beneficiated form.

**Table 4: Chemical composition**

| Chemical compound | Wyoming (%) | Oron bentonitic clay |
|---|---|---|
| $Al_2O_3$ | 14.20 | 20.10 |
| SiO2 | 43.60 | 48.50 |
| $Na_2O$ | 3.22 | 0.11 |
| K2O | 0.93 | 1.75 |
| CaO | 7.05 | 2.05 |
| $TiO_2$ | 1.30 | 2.14 |
| MnO | 0.11 | 0.10 |
| $Fe_2O_3$ | 14.50 | 17.59 |
| NiO | 0.02 | 0.02 |
| CuO | 0.14 | 0.06 |
| MgO | 2.40 | 1.26 |
| BaO | 11.0 | ND |
| PbO | 0.06 | ND |
| RuO | 0.56 | ND |
| ZnO | ND | 0.03 |
| SrO | ND | 0.03 |
| $ZrO_2$ | ND | 0.11 |
| $Cr_2O_3$ | ND | 0.05 |
| Others | ND | 20.10 |

**Table 5: Physical properties of bentonite before and after beneficiation**

| Property | Oron Raw Bentonite | Beneficiated Bentonite |
|---|---|---|
| Moisture content (%) | 10.50 | 8.22 |
| Particle size distribution | Coarse | Fine |

| Property | Oron Raw Bentonite | Beneficiated Bentonite |
|---|---|---|
| Swelling index (mL/2g) | 15.00 | 20.00 |
| Bulk density (g/$cm^3$) | 0.85 | 0.78 |

Table 6 highlights the rheological properties of drilling fluids prepared with Oron raw and beneficiated bentonites. The apparent viscosity of Oron raw bentonite is 10 cP, which increases to 18 cP after beneficiation, surpassing the API specification of ≥15 cP, indicating that the beneficiated bentonite improves the fluid's ability to resist flow. The plastic viscosity also increases from 8 cP to 12 cP, suggesting that the treatment of Oron clay increases its resistance to flow, which could be advantageous for the maintenance of suspension in drilling fluids. The yield point of raw Oron bentonite is 4 lb/100 $ft^2$, which rises to 22 lb/100 $ft^2$ in the beneficiated form, indicating a significant improvement in the gel strength and the ability of the fluid to carry cuttings from the wellbore to the surface. Additionally, the fluid loss decreases from 18 mL in the raw form to 10 mL in the beneficiated form, which indicates improved filtration control and less fluid loss into the surrounding formation, a desirable property for efficient drilling. The gel strength also increases substantially from 2/4 lb/100 $ft^2$ to 8/12 lb/100 $ft^2$, suggesting that the beneficiated bentonite produces a stronger gel structure over time, which enhances its ability to suspend particles and maintain wellbore stability during drilling operations.

In comparison to previous results, the enhancement in rheological properties observed with the beneficiated Oron bentonite aligns with its increased swelling index and finer particle size distribution from Table 5. This indicates that the beneficiation process not only improves the particle distribution but also significantly improves the material's performance as a drilling fluid, with higher viscosity and gel strength, which are critical for suspension and transporting drilled cuttings. These results also contrast with the chemical composition data in Table 4, where Oron clay's higher alumina and silica content may contribute to these improved rheological properties. Overall, the comparison between raw and beneficiated Oron bentonite demonstrates the substantial improvements in its application as a drilling fluid, which are likely due to both its altered chemical composition and physical properties. These findings suggest that Oron clay, particularly in its beneficiated form, can serve as a promising alternative to Wyoming bentonite in drilling fluid formulations, offering enhanced rheological performance and better control over fluid loss and suspension capabilities.

**Table 6: Rheological properties of drilling fluid prepared with bentonite**

| Property | API Specification | Oron Raw Bentonite | Beneficiated Bentonite |
|---|---|---|---|
| Apparent viscosity (cP) | ≥15 | 10 | 18 |
| Plastic viscosity (cP) | - | 8 | 12 |
| Yield point (lb/100 $ft^2$) | 3–50 | 4 | 22 |
| Fluid loss (mL) | ≤15 | 18 | 10 |
| Gel strength (10 sec./10 min) (lb/100 $ft^2$) | - | 2/4 | 8/12 |

Table 7 preents a performance comparison between the raw and beneficiated Oron bentonite drilling fluids in terms of various operational parameters. For suspension stability, Oron raw bentonite shows a percentage of 78%, while the beneficiated form demonstrates an improved value of 92%. This increase suggests that the beneficiation process enhances the bentonite's ability to maintain a stable suspension, a crucial characteristic in drilling fluids, as it ensures that cuttings and other solid particles are effectively suspended and prevented from settling during the drilling process.

In terms of hole cleaning efficiency, the raw Oron bentonite drilling fluid achieves 60%, while the beneficiated form improves this value to 85%. This increase reflects the better performance of the beneficiated fluid in efficiently removing drilled cuttings from the wellbore. Improved hole cleaning is vital for maintaining an efficient drilling operation, as it helps prevent issues such as stuck pipes and increased torque. The significant enhancement in hole cleaning efficiency of the beneficiated bentonite indicates that the refinement process increases the fluid's ability to perform this critical function.

The cutting carrying index, which measures the fluid's effectiveness in carrying cuttings to the surface, also shows improvement. The raw Oron bentonite drilling fluid has a cutting carrying index of 0.6, while the beneficiated bentonite fluid shows an increased value of 1.1. This higher index indicates that the beneficiated bentonite can carry a greater amount of cuttings at a given flow rate, which contributes to a more efficient drilling operation by preventing clogging and maintaining fluid circulation.

Regarding mud weight, the raw Oron bentonite drilling fluid has a mud weight of 8.6 lb/gal, while the beneficiated bentonite fluid has a slightly higher mud weight of 8.8 lb/gal. The increase in mud weight could be attributed to the finer particle size distribution and higher swelling index of the beneficiated bentonite, which may contribute to a slightly denser fluid that offers better control over formation pressures during drilling.

When comparing these results to the earlier parameters obtained for the Oron clay, the improvements in suspension stability, hole cleaning efficiency, and cutting carrying index align with the enhanced rheological properties observed for the beneficiated bentonite in Table 6. The higher viscosity and gel strength observed in the beneficiated bentonite are consistent with its enhanced performance in these drilling fluid applications. Additionally, the increase in suspension stability and hole cleaning efficiency indicates that the beneficiated bentonite is more effective in maintaining fluid properties under operational conditions.

In comparison to literature, these results reflect the expected improvements seen when bentonite undergoes beneficiation processes such as particle size refinement and increased swelling index. Studies have consistently shown that beneficiation can enhance the performance of bentonite as a drilling fluid, improving its ability to suspend solids, carry cuttings, and maintain hole cleaning efficiency. For example, similar improvements have been reported in studies involving the beneficiation of bentonite for use in the oil and gas industry, where the enhanced rheological properties contribute to more efficient drilling operations.

In conclusion, the comparison of raw and beneficiated Oron bentonite in drilling fluid applications shows significant improvements in key performance indicators, including suspension stability, hole cleaning efficiency, cutting carrying index, and mud weight. These improvements highlight the effectiveness of the beneficiation process in enhancing the performance of Oron bentonite as a drilling fluid, making it a potentially more efficient alternative to unprocessed bentonite in drilling operations.

**Table 7: Performance comparison in drilling fluid applications**

| Test Parameter | Oron **Raw Bentonite Drilling Fluid** | **Beneficiated Bentonite Drilling Fluid** |
|---|---|---|
| Suspension Stability (%) | 78 | 92 |
| Hole Cleaning Efficiency (%) | 60 | 85 |
| Cutting Carrying Index | 0.6 | 1.1 |
| Mud Weight (lb/gal) | 8.6 | 8.8 |

The characterization using UV-visble (Fig. 3.0) showed that EBC absorbed at 430 nm, UBC absorbed at 544 nm, and EOBC absorbed at 597 nm. The Max wavelength of absorption followed the trend: EOBC > UBC > EBC. The UV-visible spectrum of the bentonite samples from Eniongo Beach (EBC), Usung Beach (UBC), and Edek Okong Beach (EOBC) reveals distinct absorption characteristics, as shown in Fig. 3.0. EBC exhibits its maximum absorption at 430 nm, UBC at 544 nm, and EOBC at 597 nm. The trend in maximum absorption wavelengths follows the order EOBC > UBC > EBC. This shift in the absorption maxima toward longer wavelengths (redshift) indicates that the electronic structure of the bentonites varies among the samples, likely due to differences in their mineral compositions, particle sizes, and surface properties.

The absorption at 430 nm for EBC suggests smaller particle sizes or a simpler electronic structure, corresponding to a shorter wavelength. The UBC sample, with its maximum absorption at 544 nm, indicates a more complex structure or larger particle sizes, resulting in an intermediate wavelength. EOBC, with the longest absorption wavelength at 597 nm, reflects the most significant structural complexity or particle size among the three samples. These differences in optical properties may correlate with variations in their potential applications, where EOBC, with its redshifted absorption, might be more effective in applications requiring interactions with longer wavelengths, such as photocatalysis or light absorption.

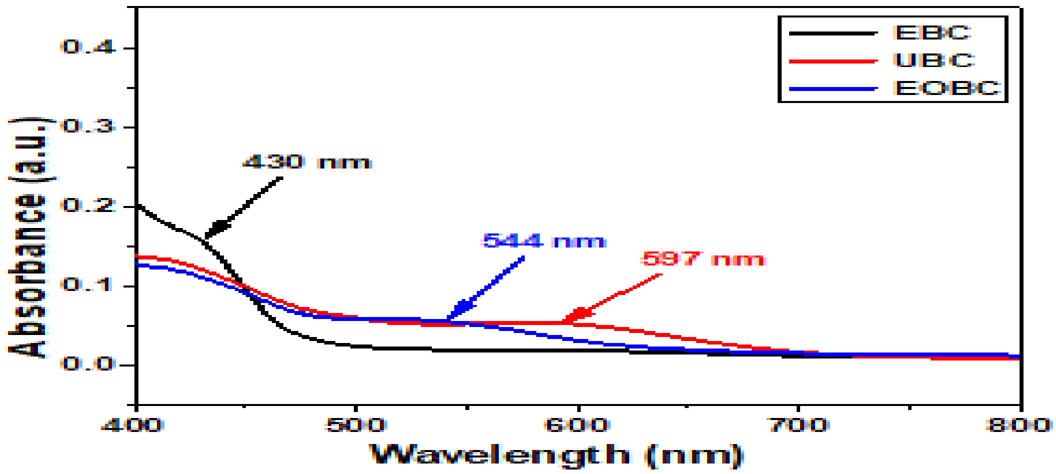


**Fig. 3. Characterisation using UV-Visible**

X-ray diffraction (XRD) patterns shown in Figs. 4a, b and c were carried out on Oron clay and Wyoming Bentonite samples to ascertain their mineralogical composition. The Wyoming bentonite sample comprises sanderite, smectite (montmorillonite), barite, Morimotoinite and muscovite (Table 2.0). Other minerals determined in trace amounts were zinc arsenate, behierite and ammonium chlorate. The smectite leads the Wyoming bentonite by 50%, as estimated. The smectite clay mineral is responsible for the swelling of drilling fluids and its high rheological and filtration properties. The Wyoming bentonite also shows a high amount of barite (20%), a non-clay mineral used in drilling fluid as a weighting agent to increase the density of the drilling fluids, indicating that the Wyoming bentonite has been treated with barite. This was also detected on the Oron locally sourced bentonitic clay sample composed mainly of smectite, quartz, kaolinites, gismondine and serpentine. In Fig. 4.0, all the clays showed well resolved peaks in the XRD spectrum indicating that they are made of crystals. The crystalinity displayed was as a result of the various inorganic minerals contained on the clay.

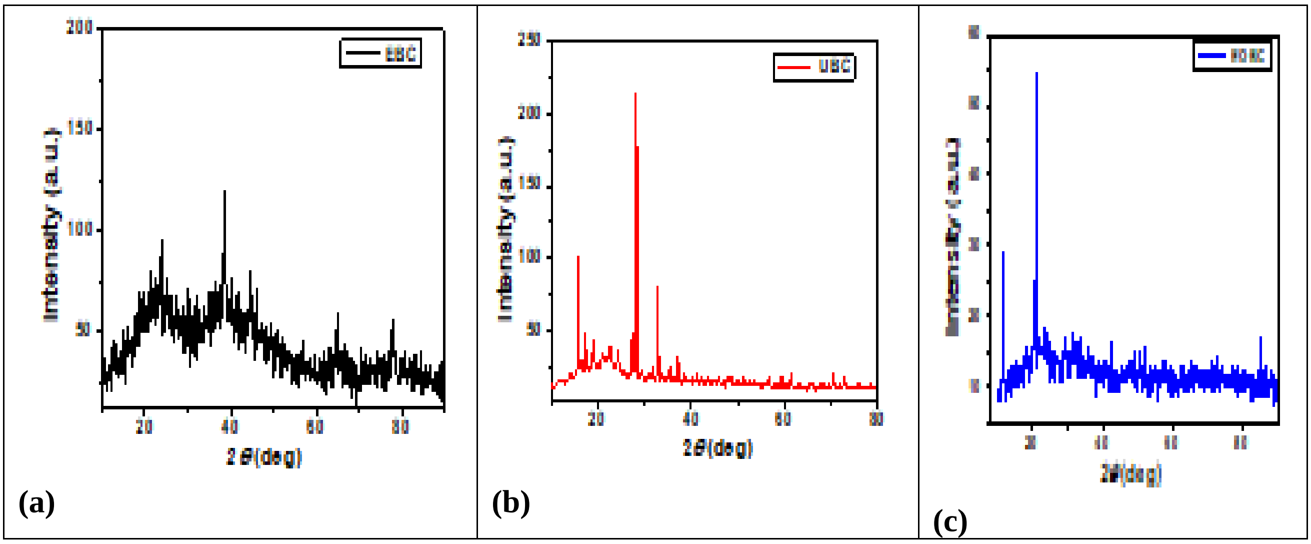


**Fig. 4. Characterisation using XRD**

The particle size distribution analysis was carried out to determine the percentage of particle size present that comprised the composition of the clay sample (silt, sand, and clay). Table 3.0 presents the particle size distribution of the Wyoming and locally sourced Oron bentonitic clay raw samples. The table 3.0 shows that the silt, sand, and clay percentage composition in the Wyoming and Oron locally sourced samples are 33, 20, 47, 24, 15 and 65, respectively.

The chemical composition of the raw locally sourced Oron bentonitic clay and Wyoming bentonite, as obtained using an XRF machine, is presented in Table 2. It can be observed from Table 2 that the $Al_2O_3/SiO_2$ was approximately 1/3 in Wyoming bentonite, as expected of smectites, which is the main component of bentonites. This ratio was higher in Oron bentonitic clay. The obtained value is in agreement with the results reported by Falode *et al*. (2007), Deer *et al*. (1992) and Kirk-Othmer (1980). It can also be noticed that Wyoming bentonite has a higher percentage of $Na_2O$ (3.22%) than oron bentonitic clay (0.11%), indicating that Wyoming bentonite consists of sodium montmorillonite. Oron bentonitic clay, however, has a higher percentage of CaO (2.05%) when compared with $Na_2O$ present (0.11%), which indicates the presence of calcium montmorillonite as expected of Nigerian bentonitic clays (Ademibawa *et al*., 2009). The Wyoming bentonite also shows a high percentage of BaO, indicating the presence of Barite ($BaSO_4$), a non-clay mineral.

Physical Properties (Table 5): Beneficiated bentonite shows improved swelling capacity and finer particle size, essential for fluid consistency. Chemical Composition (Table 4): Reducing $Fe_2O_3$ and CaO enhance bentonite's adsorption capacity, and increased $Na_2O$ content boosts swelling and rheology. Rheological Properties (Table 6. 0): Beneficiated bentonite meets API standards, showing higher viscosity and better gel strength. Application Performance (Table 7): Enhanced stability and cleaning efficiency make the beneficiated clay suitable for high-performance drilling fluids. The SEM images (Fig. 5.0) of (a) EBC; (b) UBC and (c) EOBC showed that the clay are of sizes within the micro range and of no particular particle shape. EDS results showed that the clay are rich in Al > Si > Ba > Mg > Ca.

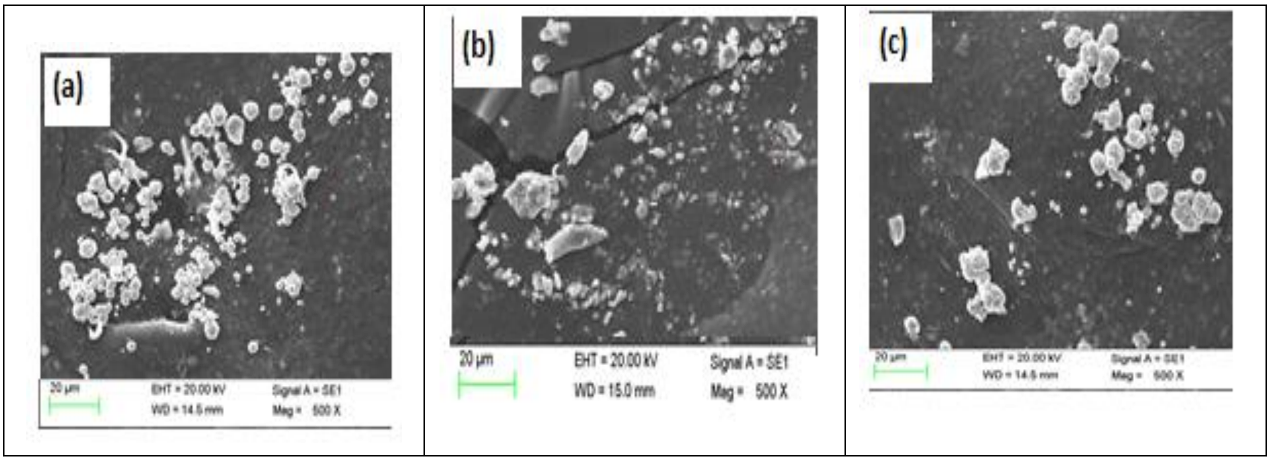


**Fig. 5. Characterisation using SEM/EDS**

The SEM images reveal distinct morphological differences among the bentonite samples from Eniongo Beach (EBC), Usung Beach (UBC), and Edek Okong Beach (EOBC). The bentonite from EBC shows a relatively aggregated structure with irregularly shaped particles of varying sizes. These particles appear clustered, forming a porous and loosely packed structure, which suggests good adsorptive properties due to its porosity and irregular surface that provide active sites for ion exchange or adsorption. In contrast, the UBC sample appears more compact, with larger, smoother particles and fewer visible voids or spaces. This compact nature indicates lower porosity, which could reduce adsorption capacity compared to EBC, but the smoother surfaces may reflect a higher degree of crystallinity or lower levels of impurities, potentially making it less chemically reactive.

The EOBC sample exhibits smaller, more dispersed particles with fewer clusters and a more even distribution compared to the other samples. This dispersed morphology may enhance the surface area, improving the material's adsorption efficiency, and the smaller particle size suggests a higher level of mechanical processing or natural weathering. These differences in particle size, aggregation, and surface structure could result from variations in environmental conditions, such as mineral composition, sedimentation processes, and exposure to erosion at the respective beaches. Overall, the bentonite from EBC may be better suited for water treatment or adsorption applications due to its porous structure, UBC may be more appropriate for uses requiring compact materials like drilling muds or sealants, and EOBC may excel in applications needing higher surface area, such as catalysis.

## 4.0 Conclusion

This study focused on the characterization and performance evaluation of Oron and Wyoming bentonites, both in their raw and beneficiated forms, to assess their suitability for drilling fluid applications. The analysis included UV-Visible spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM), and particle size distribution, among other methods. The UV-Visible spectra revealed distinct differences in absorption maxima, with EBC showing absorption at 430 nm, UBC at 544 nm, and

EOBC at 597 nm, indicating variations in particle size and structural complexity. The XRD results showed that both Wyoming and Oron bentonites primarily consist of smectite, with Wyoming bentonite containing significant amounts of barite, which enhances its use as a weighting agent in drilling fluids. The particle size distribution analysis revealed that the Oron bentonite sample had a higher clay content compared to Wyoming bentonite, suggesting better adsorption capacity and potential for use in water treatment applications.

The chemical composition analysis indicated that Wyoming bentonite had a higher percentage of sodium oxide, which is characteristic of sodium montmorillonite, while Oron bentonite had a higher percentage of calcium oxide, indicative of calcium montmorillonite. This difference affects the swelling properties and rheological behavior of the bentonites, with sodium montmorillonite typically showing higher swelling capacity. Beneficiated bentonite showed significant improvements in swelling capacity and particle size, which are essential for achieving better fluid consistency and performance in drilling applications. Rheological analysis demonstrated that beneficiated bentonite met API specifications, with improved viscosity and gel strength compared to raw bentonite. Furthermore, performance comparisons in drilling fluid applications revealed that the beneficiated bentonite exhibited better suspension stability, hole cleaning efficiency, and cutting carrying index than raw bentonite.

SEM images revealed differences in the particle morphology of the bentonite samples, with EBC showing an aggregated structure with irregularly shaped particles, UBC appearing more compact with larger, smoother particles, and EOBC exhibiting smaller, more evenly distributed particles. These differences in morphology could affect the adsorption efficiency, swelling capacity, and reactivity of the bentonites in various applications.

In conclusion, the study demonstrates that beneficiating bentonite enhances its physical, chemical, and rheological properties, making it more suitable for high-performance drilling fluid applications, as well as other potential uses in catalysis, water treatment, and adsorption. The differences in the mineralogical composition, particle size, and morphology of the various bentonite samples highlight the importance of selecting the appropriate material for specific applications based on its unique characteristics.

Based on the findings of this study, it is recommended that further optimization of the beneficiation process be carried out to improve the performance of bentonite for industrial applications. Additionally, the differences in optical, morphological, and chemical properties of the bentonites suggest that these materials should be tailored for specific uses, such as water treatment, drilling fluid formulation, and catalysis. Further research into the long-term stability and environmental impact of using beneficiated bentonites in various applications is also recommended.

**Acknowledgements**

We wish to sincerely appreciate the financial assistance granted us by the Tertiary Education Trust Fund (TETFUND) through the Management of the University of Uyo, Uyo for the execution of this research.

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## Compliance with Ethical Standards Declaration

### Ethical Approval

Not Applicable

**Competing interests**

The authors declare that they have no known competing financial interests

**Funding**

This research was sponsored by TETfund under Institutional Based Research (IBR).

### Authors' Contributions

IEU, AIE and ANO were involved in the experimental aspect of the work as well as the interpretation while IDE, IBA, IEU and ANO were involves in computation and proff reading of the manuscripts. All authors were involved in the development of the draft manuscript