Geophysical and Geochemical Assessment of Afuze Bentonitic Clay: Implication for Mud Drilling Additive in Drilling Industry

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**Abstract:** Bentonitic clay is an important material required during drilling operation in oil and water industry. This study seeks to assess the deposit of the Bentonitic clay characteristics using geophysical techniques and geochemical assessment of the bentonitic clay unit in Afuze. Vertical Electrical Sounding (VES) using Schlumberger electrode arrangement were carried out along six traverses to determine the subsurface lithological characteristics of the area. Representative samples of the bentonitic clay layers were collected for X-Ray fluorescence (XRF) analyses and free swelling index parameters. The geophysical results show an appreciable thickness of the bentonitic clay unit among other stratigraphic units and are well defined based on its resistivity characteristic. The geochemical results show that the clay is a Ca-rich bentonitic type with a relatively low swelling properties and distinct to the Wyoming bentonite type. The Afuze bentonitic clay will be suitable for industrial application as drilling additives if beneficiated to increase the Na content in the clay and enhance its rheological properties for effective use in drilling operations.

1. **Introduction**

An impure clay bentonite is an absorbent aluminum phyllosilicate consisting mostly of clay mineral smectite that give bentonitic clay the ability to swell when in contact with liquid [1-3]. Bentonites are formed by sedimentary processes in marine environments and occur as bed between sedimentary sequence or alteration of volcanic ash or tuff [4]. Bentonite is widely used as additive in drilling mud in the construction of oil wells and deep-water wells. Much of its importance in drilling operations is attributed to its rheological properties of viscosity, plasticity and the ability to dry quickly to form mud-cake during drilling operation [2,5].

Few functions of drilling muds include: (1) Mud controls subsurface pressure during drilling operation. (2) Brings rock cuttings to the surface (3) Prevent loss of fluid during drilling operation (4) Assist lithological logging during drilling operation. (5) Cools and lubricate the drill bits. (6) Provide additional support to casing and pipe during drilling. (7) Corrosion prevention during drilling. The Wyoming and Texas bentonitic clay is the standard industrial drilling mud based on its rheological and geochemical properties [6]. Important geochemical properties of a drilling mud are the sodium to calcium (Na/Ca) ratio and the amount of sand to clay content [7].
The proportion of Na/Ca ratio enhances the swelling capabilities of bentonitic clay which physically affects its physical properties. The addition of Na₂CO₃ is one of the known methods of beneficiating and enhancing the swelling ability of bentonite [8,9]. Studies have linked the bentonitic clay swelling properties to its overall rheological and physical properties [10-12]. Swelling index of bentonite involves the combination of water and the bentonitic clay particles forming a swelled hydrated particle [13,14] which is kinetically controlled. Other important properties that affect the swelling behavior of bentonite as reported by [9] are the pH, heat and particles sizes.

Nigeria is a major oil producing country in the world. Hence, involved in extensive drilling activities for oil and gas production, mostly in the Niger Delta region of the country. Bentonite is also used extensively in Nigeria for groundwater drilling. Several hundred-thousand tons of bentonitic clay is consumed each year in Nigeria. Currently, most of the bentonite is imported [2,15]. The utilization of local sources of bentonite will save a lot of the country foreign reserves. Thus, it will encourage local and foreign investments as well as create jobs opportunity and promote economic development in Nigeria [16]. The occurrence of bentonite in Afuze has been reported but relatively little is known about the deposit [17,18]. Hence, this study seeks to investigate the bentonite deposit in Afuze, Edo State of Nigeria to determine its subsurface thickness, lateral extent and geochemical characteristics.

2. Geology and Stratigraphic Settings
The study area lies in the Dahomey basin of southwestern Nigeria. The Dahomey Basm forms the on-shore part of the West African peri-cratonic passive margin basin stretching from eastern Ghana through Togo, and Republic of Benin to the western part of Nigeria [19-21]. Formation of the Dahomey Basin was initiated during Early Cretaceous separation of the South-American and African Plates [20,22]. The Dahomey basin contains extensive section of Cretaceous to Recent sediment up to 3000m thick [22].

The Nigeria sector of the Dahomey basin is bounded in the north by the Precambrian Basement rock and the south by the Bight of Benin [23,24]. The stratigraphy of Eastern Dahomey Basin in southwestern Nigeria consists of Abeokuta Group, Ewekoro Formation; Akinbo Formation; Oshosun Formation; Ilaro Formation and Youngest Benin Formation [22,23,25].

The rocks in Afuze are associated to the upper Araromi Formation in the Abeokuta Group of the Eastern Dahomey basm, Southwestern Nigeria [2,26]. The Araromi Formation is the youngest formation in the Abeokuta Group. It is composed of basal fine-medium grained sandstone and overlain by shales, clay, silt-stone, friable sand with interbedded limestones, marl and lignite [22, 25]. Omatsola and Adegoke [23] assigned a Maastrichtian to Paleocene age to Araromi formation based on faunal content. Geological reconnaissance conducted in Afuze coupled with the subsurface investigation show that the area consists of sequence of sedimentary rocks ranging from sandstone, shales, clay (Bentonitic), siltstone and laterite with ferrugenized iron stone that occur at the topmost layer in the area (Figure 1).
Figure 1. Inferred local stratigraphy map of the area under study.

3. Materials and Methods
A reconnaissance survey was carried out in the study area, during which excavated material from wells were studied to provide an insight into the subsurface rock unit at a shallow depth. Road cuts along highways provided exposures that were examined for geological information prior to geophysical data collection.

Electrical Resistivity Sounding (VES) using Schlumberger electrode arrangement were carried out along six traverses to determine the lithological characteristics of the area. The current electrode (AB/2) spacing varied from 1-200m and the potential electrode (MN/2) varied from 0.5m - 10m. The value of any geophysical measurement is by the amount of geological information that can be deduced from the interpretation of the geophysical data [27-29]. The geophysical data were qualitative and quantitative interpreted. The interpretation involves partial curve matching and computer iteration modelling. IPI2WIN and Golden surfer 11 geophysical software’s serve as major tools in the interpretation and modelling with an understanding of geology of the area.

Furthermore, clay samples were collected between Afuze and Uokha town, along Otuo road (Figure 2). Fresh samples were carefully collected from dug pits within the study area for geochemical analysis and other relevant studies. All samples collected were properly handled to avoid contamination. The bentonitic clay from Afuze were prepared and analyzed for major and trace elements using the X-Ray Fluorescence (XRF) spectrometer. Also, the samples were subjected to free swelling test in the laboratory to determine the swelling properties.

Figure 2. Topography and location map of the study area.

4. Results and Discussion
4.1. Geophysical Results
Electrical Resistivity sounding (VES) curves are presented as depth sounding curves (Figure 3). Resistivity and corresponding thicknesses of the layers obtained from computer iteration were used to present geo-electric sections. Three to Four geoelectric layers were obtained from the interpreted geophysical data. The curve types identified ranges from A, AH, HA and KHA curve respectively. The A-curve types are the most preeminent, followed by the AH types and the HA curve types. The general signature of the curves obtained and resistivity parameter suggests presence of clay material in the study area. The geo-electric sections show a 2D cross section of the subsurface lithology across six profiles in the study area (Figure 4).
4.2. Geochemical Results

The geochemical results of Afuze bentonitic clay were analyzed and compared with the standard Wyoming Bentonite as reported by [6,30-31]. Elemental composition of bentonite samples from Afuze is similar in variation to the standard bentonite except for Na$_2$O and CaO constituent (Figure 5). Afuze bentonitic clay is relatively low in Na$_2$O concentration of 0.07% and Wyoming bentonite has concentration of 2.19%. Furthermore, the CaO present in the studied samples is high and ranges from 11.13 - 11.16%, while that of the Wyoming bentonite is 1.77%. It is evident from the geochemical result that Wyoming bentonite is Na-based and Afuze is Ca-based bentonitic clay. The abundance of CaO suggest that Afuze bentonite is typical of Ca-bentonite type which does not originate from the alteration of volcanic ash but rather of sedimentary origin.
4.3. Free Swell Index Results
The free swelling potential ranges from 40.5 - 52.6 as showed from the free swell results (Table 1). The result suggests that the Afuze bentonitic clays are not the very swelling types compared with the Wyoming bentonites with free swell range of 397 and 401 [30,31]. The Wyoming type of bentonite can swell 3 to 4 times its original state when in contact with water [31]. The swelling potential of Wyoming bentonitic clay is characterized by Na based bentonite clay [32] as against low swelling potential of the Afuze Ca bentonitic clay as shown in figure 6.

Table 1. Results of the free swell index.

|                | Afuze 1 | Afuze 2 | Standard Commercial Bentonite [30] |
|----------------|---------|---------|------------------------------------|
| FREE SWELL INDEX | 40.5    | 52.6    | 397-401                            |

Figure 6. Free swell index of Afuze bentonitic clay compared with Wyoming bentonitic clay.

5. Conclusions
The study assessed bentonitic clay in Afuze using geophysical and geochemical techniques. The study area has considerable amount of bentonitic clay occurrence as deciphered from the resistivity variations.
and geoelectric sections. Furthermore, geochemical investigation was conducted on the clay samples and a laboratory experiment was conducted for its natural swelling index. Afuze bentonitic clay shows high Ca and a relatively low Na content. Afuze bentonite exhibit very low free swelling properties and the chemical constituent suggest it is of sedimentary origin. Afuze bentonitic clay will be suitable for industrial application if beneficiated using sodium carbonate to enhance its rheological properties for effective use in drilling operations. It is therefore recommended that further research on rheology and beneficiation be carried out on the Afuze bentonitic clay.

References

[1] Abdullah M, Asad, S, Mohammad A and Raquibul H 2013 Suitability of bentonite clay: an analytical approach. International Journal of Earth Science 2013 88-95
[2] Senbore S and Akande V 2016 Geological and Geophysical Evaluation of Bentonitic Clay, Afuze, Edo State, Nigeria AJOSR 1(1) 90 – 102
[3] Hao L, Bing X and Yue-fen Q 2017 Effect of Bentonite on the Pelleting Properties of Iron Concentrate. Journal of Chemistry Article ID 7639326, 6 p https://doi.org/10.1155/2017/7639326
[4] Clarence R and Earl S, 1926 The Minerals of Bentonite and Related Clays and Their Physical Properties, Journal of The American Ceramic Society. 9(2) 77-96
[5] Ajugwe C, Oloro J and Akpotu D 2012 Determination of the rheological properties of drilling fluid from locally sourced clay from various geographical areas. Journal of Engineering and Applied Science 4
[6] Nweke M, Igwe O and Nnabo, P 2015 Comparative evaluation of clays from Abakaliki Formation with commercial bentonite clays for use as drilling mud. African Journal of Environmental Science and Technology 9(6) 508-518
[7] Omole O, Malomo S and Akande S 1989 The suitability of Nigerian black soil clays as drilling mud clays. Nature and technical properties. Appl. Clay Sci. 4 357–372
[8] Muhammad A.M 2011 Improvement of Rheological Properties of Bentonitic Clays Using Sodium Carbonate and a Synthetic Viscosifier, International Archive of Applied Science and Technology 2 43-52
[9] Musaab M, Nasser S, Hussein I, Benamor A, Omaizi A, Sultan S and Mahmoud A 2017 Effects of sodium carbonate addition, heat and agitation on swelling and rheological behavior of Ca-bentonite colloidal dispersions, Applied Clay Science 147 176-183
[10] James O, Adediran M, Adekola F, Odeburunmi E and Adekeye J 2008 Beneficiation and Characterization of a Bentonite from North-Eastern Nigeria. Journal of the North Carolina Academy of Science, 124(4) 154–158
[11] Omole O, James A, Falode O, Malomo S and Oyedeji A 2013 Investigation into the rheological and filtration properties of drilling mud formulated with clays from Northern Nigeria. Journal of Petroleum and Gas Engineering 4(1) 1-13
[12] Musaab M, Ibnelwaleed H, Mustafa N, Mohamed M, Abdullah S and Abdelbaki B 2019 An Investigation of the Swelling Kinetics of Bentonite Systems Using Particle Size Analysis Journal of Dispersion Science and Technology 41(6) 817-827
[13] Montes–h G, Duplay J, Martinez L and Mendoza C 2003 Swelling–shrinkage kinetics of MX80 bentonite. Applied Clay Science 22 279-293
[14] Takakura S and Takagi T 2011 Technical development of bentonite exploration methods. Geophys. Explor. 64, 309-318
[15] Ayonmike C and Okeke B 2015 The Nigerian local content act and its implication on technical and vocational education and training and the nation’s economy. Int. J. Educ. Lear. Dev. 3(1), 26–35
[16] Afolabi R, Orodu O and Efeovbokhan V 2017 Properties and application of Nigerian bentonite clay deposits for drilling mud formulation: Recent advances and future prospects. J Applied Clay Science 143 39–49
[17] Aigbedion, I and Iyayi, S 2007 Formation evaluation of Oshioka field using geophysical well logs. *Middle-East J. Sci. Res.*, 2, 107

[18] Raw Materials Research, Development Council 2007 Technical Brief on Mineral Raw Materials in Nigeria - Bentonite. RMRDC, Abuja

[19] Adegoke O S, Ako B D, Enu E I 1980 *Geotechnical investigations of the Ondo State bituminous sands*. Vol. 1. Geology and reserve estimate (Rept. Geological Consulting Unit, Dept. of Geology, University of Ife) 257 p

[20] Whiteman A J 1982 *Nigeria: Its Petroleum Geology, Resources and Potential*, Vol. 2, (Graham and Trotman, London)

[21] Olatinsu O B, Olorode D O, Clennell B, Esteban L, Josh M, 2017. Lithotype Characterizations by Nuclear Magnetic Resonance (NMR): A Case Study on Limestone and Associated Rocks from The Eastern Dahomey Basin, Nigeria. *Journal of African Earth Sciences* **129** 701-712

[22] Billman H G 1992. Offshore Stratigraphy and Eontology of Dahomey (Benin) Embayment. *NAPE Bulletin* **70** 121-130

[23] Omotsola M and Adegoke S 1981 Tectonic Evolution and Cretaceous Stratigraphy of the Dahomey Basin. *J. Min. Geol* **18**(1) 130-137

[24] Omolaiye G E, Oladapo I M, Ayolabi A E 2020. Integration of remote sensing, GIS and 2D resistivity methods in groundwater development *Appl Water Sci* **10** 129

[25] Agagu K 1985 *A Geological Guide to Bituminous Sediments in Southwestern Nigeria*. Unpubl. Report, (Department of Geology, University of Ibadan)

[26] Ikhane P R, Akintola A I, Akintola G O, Okunlola O A, Oyebolu O O, Udo I.U, 2012. Petrography and Geochemical Appraisal of Afowo Sandstone Facies, Dahomey Basin, Southwestern Nigeria *Chemistry and Materials Research* **2**(5) 2224- 3224

[27] Archie G 1944 Electrical Resistivity log an aid in core analysis interpretation. *AM. Assoc. of Petroleum, Geol. Bull.* **2** 350-366

[28] Badmus S and Olatinsu B 2009 Geophysical evaluation and chemical analysis of kaolin clay deposit of Lakiri village, southwestern Nigeria. *International Journal of Physical Sciences* **4** (10) 592-606

[29] Ariyo, S.O., and Adeyemi, G.O. 2016. Hydrogeophysical investigation for groundwater potential of Ishara/Ode-Ramo geological transition zone, southwestern Nigeria. *Arab J Geosci* **9** 631

[30] Rath DL 1989 Origin and characteristics of Wyoming bentonite deposits. Public Information Circular No. 25, *the Geological Society of Wyoming* pp 84-90

[31] Falode O A, Ehinola O A and Nebeife P C 2007 Evaluation of Local Bentonitic Clay as Oil Well Drilling Fluids in Nigeria. *Appl. Clay Sci.* **39** 19-27

[32] Hosterman, J and Patterson S 1992 Bentonite and Fuller's earth resources of the United States. *U.S. Geological Survey Professional Paper* 1522