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Qualitative Analysis of Fine Grained Deposits from Obogoro Community in Bayelsa State, Nigeria

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Abstract: Ten samples of fine grained deposits that occur in Obogoro community, Bayelsa state, Nigeria, were subjected to qualitative analysis using XRD for whole rock analysis and Atterberg's Limit to determine the mineralogy and engineering properties of the deposits. The deposits are found to be made up of four major primary minerals, which are: quartz, ranging from 62% to 77%, with an average of 70%; orthoclase (K- feldspar), with a range of 7% to 15%, and an average of 11.5%; albite (plagioclase feldspar) is also one of the primary minerals that occur in the analyzed sediments. It has a range of 4% to 21%, and an average of 11.5%; and the white mica: muscovite with a range of 3% to 10%, and an average of 6.75%. Typical clay minerals were not observed but only the four primary minerals. This is attributed to incomplete weathering that may have been facilitated by mineral stability and geochemistry of the environment of deposition. The mineralogy depicts an acid igneous rock origin for the sediments. The Atterberg's Limit analysis shows that the Liquid Limits range from 32.7.0% to 57.6%, Plastic Limits range from 20.4% to 29.2% for five samples that passed the test; and the Plasticity Index ranges from 11.2 to 31.6 for the five samples that passed the Plastic Limit test. The analyzed samples fall above the A-Line of the Plasticity chart (CL) and <50% Liquid Limit divide line (ML), indicating that the fine grained deposits are silt to inorganic clays according to ASTM D2487 -11 derived from an acid igneous rock source.

1. Introduction

Clays are fine grain sedimentary rock with complex composition. They are secondary minerals resulting from the alteration and weathering of rocks mainly of igneous origin. On the Wenthworth scale they are less than 1/256 or 0.002 mm in diameter. A deposit is called clay if it has more than 50% of its constituent of this size grade (Pettijohn, 2004; ASTM D2487 -11)[3][6]. Clays are composed of hydrous aluminum sheet silicates and most of them are naturally plastic and slake when wet (Pettijohn, 2004)[6]. The chemical composition of clay is mainly silica, alumina, feldspars, water and other accessory minerals. Clays form as the end product of weathering, abrasion, chemical and biochemical additions that may have been precipitated and deposited. According to

Turker (1989)[9], the origin of clays is in 3 fold, which are: Inheritance – these are detrital clays formed from the weathering of silicate crystalline rocks; 2) Neoformation – these are formed in-situ either by precipitation or from amorphous silicate materials; 3) Transformation – these are formed by the modification of detrital clay by ionic exchange or cation rearrangement. Four clay mineral groups are recognized. They are: the kaolinite group, smectite or montmorillonite group, illite or muscovite group and the chlorite group which are formed by different chemical processes and environment (Pettijohn, 2004)[6]. The type of clay mineral formed is a reflection of the climate, drainage, source rock and other sedimentary processes that interacted.

The Limit of Consistency (Atterberg's Limit) is used to determine the sensitivity and response of fine grained sediments to moisture in liquid and ambient air that it interacts with as the sediment pass from liquid to plastic and to semi solid. Some of the limits evaluated in this work are: Liquid Limit (LL), Plastic Limit (PL) and the Plasticity Index (PI) of the deposit.

Clays are raw material in several industries. They are used in the construction industry for bricks, tiles, production of cement, etc. They are also in the agricultural industry, pharmaceutical industries, pottery and many more.

The fine grained sediments that overlie Obogoro community in Bayelsa state are referred to as clay by the indigenes. Fine grained sediments like clays are better studied with XRD by analyzing the whole rock sample. This project aims to look at the mineralogical components of the fine grained deposits that occur in Obogoro community in Bayelsa state, using XRD, in other to determine the mineralogy, infer the source, the type of clay mineral and its properties and as well determine some of its engineering properties.

2. Study Area

The study area of this project covers Obogoro community within Yenagoa Local Government Area of Bayelsa state, Nigeria, and is geographically located between latitudes N04°55'15'2 and N04°55'15'4'' and longitudes E006°15'22.5'' and E006°15'24.3''. It lies within the saltwater and freshwater swamp geomorphic units of the Niger Delta Sedimentary Basin of Southern Nigeria. (Figure 1)

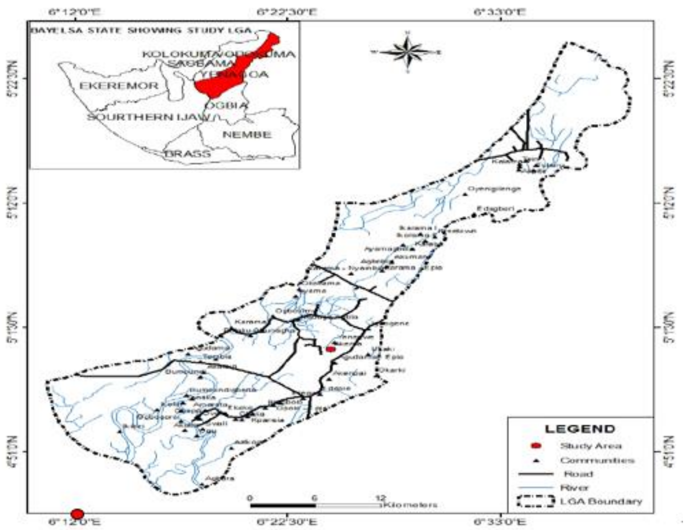

Figure 1: Map of Study Area.

3. Geology of The Niger Delta

Obogoro community is one of the communities within the lower reaches of the Niger Delta basin where Quaternary deposits are accumulating. Three lithostratigraphic units are recognized in the subsurface geology of the Niger Delta Basin. They are from base to top: The Akata Formation, Agbada Formation and the Benin Coastal Sands. The Akata Formation has a thickness greater than 3129 ft. (Whiteman, 1982). It is basically made up of thick deep marine shales which are the major petroleum source rock of the basin. Above the Akata, lies the parallic Agbada Formation with thickness which ranges from 1400 – 9600 ft. (Whiteman, 1982)[10]. It has intercalations of shale and sands at the base and grades upwards to be sandier. It is the major reservoir unit of the Niger Delta Basin. The Benin Formation which consists of the major aquifers in the region overlies the Agbada Formation. Above the Benin Formation are the Quaternary deposits in the region, which are made up of gravel sand, silt and clay at different locations and environment (Allen, 1965)[1] Table 1.

Table 1: Stratigraphic Column of the Niger Delta [Allen, 1965].[1]

Geologic Unit	Lithology	Age
Alluvium (General)	Gravel, sand, clay, silt	Quaternary
Freshwater Backswamp, Meander Belt	Sand, clay, some silt gravel	
Mangrove and Salt Water/Backswamps	Medium fine sands, Clay and some silt	
Active /Abandoned Beach Ridges	Sand, clay, and some silt	
Sombreiro – Warri Deltaic Plain Sand	Sand, clay, and some silt	
Benin Formation Coastal Plain Sand	Coarse to medium sand with subordinate silt and clay lenses	Miocene
Agbada Formation	Mixture of sand, shale and silt	Eocene
Akata Formation	Shale	Paleocene

4. Literature Review

Crystalline rocks are mostly made up of the following primary minerals: Quartz, feldspars, micas, amphiboles, pyroxenes, and the olivines, while, other minerals that are formed from the decomposition of these minerals are called secondary minerals. Examples are clay minerals, carbonates, zeolites etc. (Read, 1984)[8].

According to Plummer et al., (2003)[7], weathering is a process where rocks are broken down. Weathering of rocks goes on in two realms: physical and chemical weathering. Physical weathering refers to the disintegration or fragmentation of rocks by physical processes, whereas, chemical weathering involves the reaction of rocks at the earth or near earth surface with water or gasses in the atmosphere, leading to the formation of new minerals that are now thermodynamically stable under the new conditions of temperature and pressure. The processes in chemical weathering produce clays, oxidized and dissolved sediments. High rainfall, high temperature, environment of high organic decomposition are the main factors that facilitate chemical weathering.

Clay mineral groups are the kaolinite group, illite group, smectite group, (monmorilonite is the major component of the smectite group), and the chlorite group. Illite and smectite are formed in moderately intense weathering condition in immature sands. When there is prolonged and intense leaching, kaolinite is produced (Boggs, 2006)[4]. Kaolinite can also form by the pneumatolysis, the action of gasses on the feldspar (Read, 1984)[8]. Quartz, feldspars, micas, iron oxides and some other minerals are also associated with occurrence of clay minerals (Read, 1984) [8].

Muscovite is a proxy for illite, its structure is similar to that of illite, except that illite is less in alkalies, and has less substitution of Al for Si. The weathering and alteration of K and Al rich rocks produce illite under high pH condition (Read, 1984) [8].

According to Krynine and Judd 2005[5], Plasticity has to do with the way soil material will respond to the application of external force. It is termed plastic when it deforms continuously and permanently without cracking or rupturing. Plastic deformation doesn't return to its original state even after the force has been removed. It is an irreversible deformation. It is the opposite of elastic deformation where materials rebound back to original or near original state after the force has been removed. Also, they stated that the Limits of Consistency (Atterberg's Limits) of sediments determines the moisture content as the sediments move from liquid - plastic – semi solid state.

5. Methodology

Both field and laboratory analyses were employed in this work.

5.1 Field Analysis

A total of 10 samples were collected at an equi-distance of 100m apart from each of other. The geo – reference of each sample point and the textural parameters of each samples are described in Table 2. The samples were then taken to the laboratory for XRD and determination of the Atterberg Limits – Liquid limit (LL), Plastic limit (PL) and Plasticity Index (PI).

5.2 Mineralogical Analysis

The samples received were crushed, and were pulverized to 100% passing through 75µm sieve, and submitted for XRD analysis. The pulverized fraction was analyzed using Rigaku Miniflex 600 XRD equipment employing Cu-Kα radiation at 2theta angle 2o – 70o. This was done to determine the mineralogy of the sediments.

5.3 Determination of Atterberg's Limits

The Consistency Limits (Atterberg's Limits) of the sediments were analyzed to determine the moisture content as the sediment pass from liquid to plastic. The experiments and calculations were carried out as outlined by ASTM D 4318[2]. The properties evaluated are the Liquid Limit, the Plastic Limit and Plasticity Index. The Liquid Limit (LL) is the moisture content that will make clay liquid; the Plastic Limit (PL) is the moisture content in which molded clay can be rolled or remolded without cracking or rupturing. The sensitivity and response of soil to changes in the moisture in the fluid or ambient humid air that comes in contact with it is the Plasticity Index. The Plasticity Index (PI) is the arithmetic difference between Liquid Limit and Plastic Limit (LL – PL). Plasticity is an irreversible deformation.

6. Presentation of Results

6.1 Sample description

10 samples were collected from ten different locations that were approximately 100 m apart. Samples are silt to clay sized sediments. Two of the samples were grey and dark grey in colour,

while others range in colour from light brown to dark brown See Table 2.

Table 2: Description of Sampled Sediments and Location.

Locations	Reference	Colour	Rock type
OB1.	N04°55'15.3'' E006°15'23.3	Dark brown	Silty clay
OB2.	N04°55'15.4'' E006°15'23.4	Brown	Clay
OB3.	N04°55'15.3'' E006°15'23.4	Brown	Silty clay
OB4.	N04°55'15.3 E006°15'23.2	Dark brown	Silty clay
OB5.	N04°55'15.3'' E006°15'23.1	Grey	Clay
OB6.	N04°55'15.3'' E006°15'22.9	Brown	Silty Clay
OB7.	N04°55'15.2'' E006°15'22.6''	Dark grey	Clay
OB8.	N04°55'15'2 E006°15'22.5''	Brown	Clay
OB9.	N04°55'15'3'' E006°15'24'5	Light brown	Clay
OB10.	N04°55'15'4'' E006°15'24.3''	Dark brown	Silty Clay

6.2 XRD Analysis

Four of the samples OB1, OB3, OB5 and OB9 were taken for whole rock X-ray diffractometer in order to determine the mineralogy of the deposits. The crystalline phases detected by XRD for the various samples are shown in the quantitative analysis results sheets, with associated diffractograms and mineralogical plots of the sediments Figures 2 -5.

6.3 Analyzed Consistency Limits (Atterberg's Limits) of the Sediments (Table 3)

Table 3: Consistency Limits (Atterberg's Limits) of Sediments.

SAMPLE LOCATION AND ROCK TYPE	LIQUID LIMIT (LL)	PLASTIC LIMIT (PL)	PLASTICITY INDEX (PI) (LL – PI)
Location 1 Silty Clay	35.44	-	NP
Location 2 Clay	37.3	20.4	16.9
Location 3 Silty Clay	34.73	-	NP
Location 4	32.7	-	NP

Silty Clay			
Location 5 Clay	39.8	28.6	11.2
Location 6 Silty Clay	46.9	-	NP
Location 7 Clay	47.93	24.7	23.23
Location 8 Clay	57.6	26	31.6
Location 9 Clay	57.6	29.2	28.1
Location 10 Silty Clay	34.23	-	NP

NP = Not plastic

Qualitative Analysis Results

Phase name	Formula	Figure of merit	Phase reg. detail	Space Group	DB Card Number
Quartz, syn	Si O2	0.912	S/M(PDF-4 Minerals 2024)	154 : P3221	01-085-0865
Orthoclase	Al2 O3 · K2 O ·6 Si O2	3.194	Import(PDF-4 Minerals 2024)	12 : C12/m1	00-002-0534
Muscovite	K Al2 (Si3 Al) O10 (O H , F)2	2.920	Import(PDF-4 Minerals 2024)	15 : C12/c1	00-002-0467
Albite	Na Al Si3 O8	1.702	Import(PDF-4 Minerals 2024)	2 : C-1	00-001-0739

Phase Data View

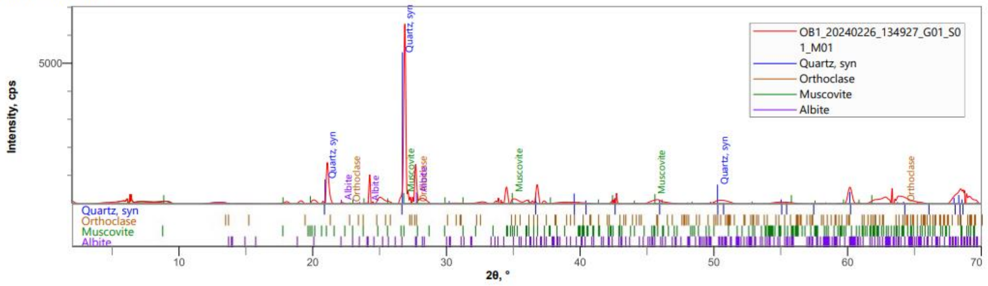

Figure 2a: Qualitative result sheet and difractogram for OB1

Plot of results

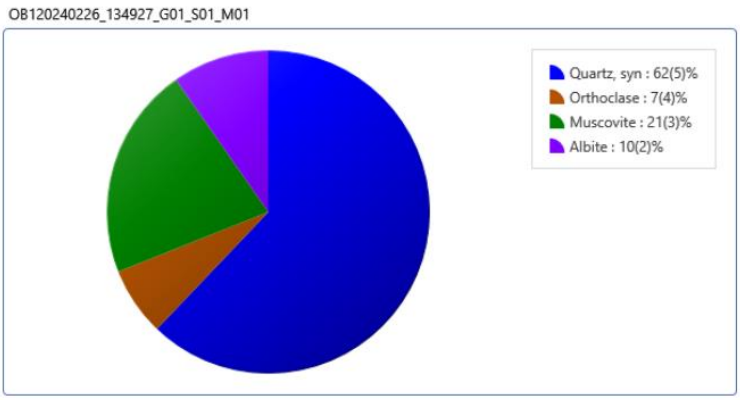

Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Quartz, syn	Orthoclase	Muscovite	Albite
OB1_20240226_134927_G01_S01_M01	0	62(5)	7(4)	21(3)	10(2)

Figure 2b: Mineralogical plot of OB1

Phase name	Formula	Figure of merit	Phase reg. detail	Space Group	DB Card Number
Quartz, syn	Si O2	0.634	S/M(PDF-4 Minerals 2024)	154 : P3221	00-046-1045
Orthoclase	Al2 O3 · K2 O ·6 Si O2	2.046	Import(PDF-4 Minerals 2024)	12 : C12/m1	00-002-0534
Muscovite	K Al2 (Si3 Al) O10 (O H , F)2	3.159	Import(PDF-4 Minerals 2024)	15 : C12/c1	00-002-0467
Albite	Na Al Si3 O8	1.874	Import(PDF-4 Minerals 2024)	2 : C-1	00-001-0739

Phase Data View

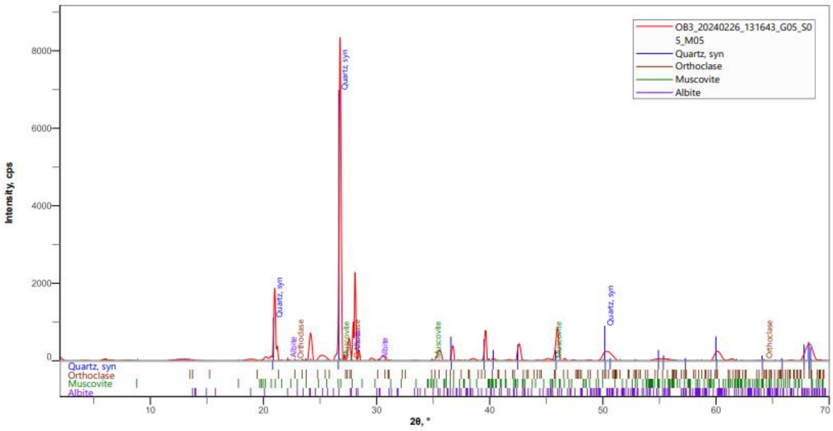

Figure 3a: Qualitative result sheet and difractogram for OB3

Plot of results

OB320240226_131643_G05_S05_M05

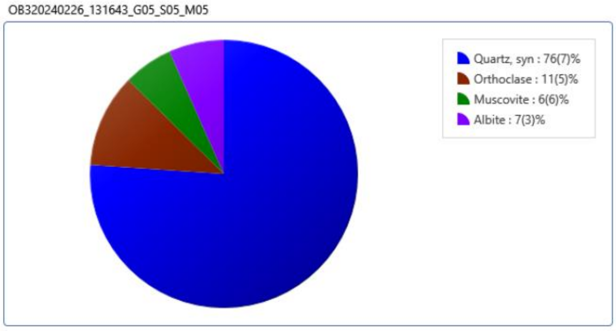

Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Quartz, syn	Orthoclase	Muscovite	Albite
OB3_20240226_131643_G05_S05_M05	0	76(7)	11(5)	6(6)	7(3)

Figure 3b: Mineralogical plot of OB3

Phase name	Formula	Figure of merit	Phase reg. detail	Space Group	DB Card Number
Quartz	Si O2	2.835	Import(PDF-4 Minerals 2024)	152 : P3121	00-003-0444
Albite	Na Al Si3 O8	3.093	Import(PDF-4 Minerals 2024)	2 : P-1	00-003-0451
Muscovite	K Al2 (Si3 Al) O10 (O H , F)2	3.049	Import(PDF-4 Minerals 2024)	15 : C12/c1	00-002-0467
Orthoclase	Al2 O3 · K2 O ·6 Si O2	3.337	Import(PDF-4 Minerals 2024)	12 : C12/m1	00-002-0534

Phase Data View

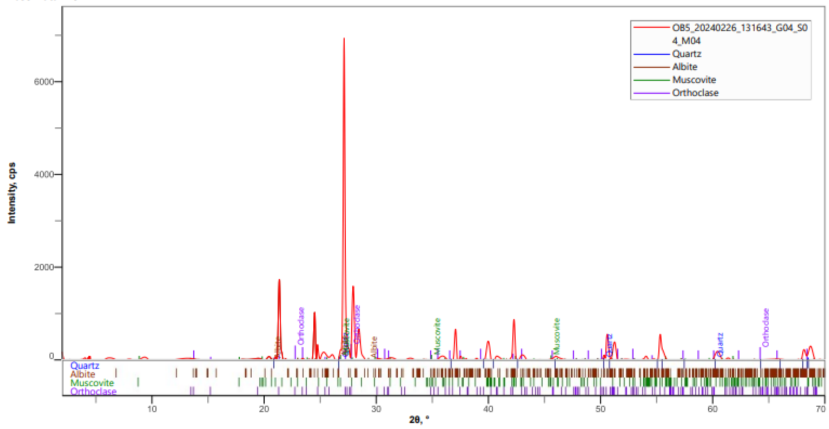

Figure 4a: Qualitative result sheet and difractogram for OB5

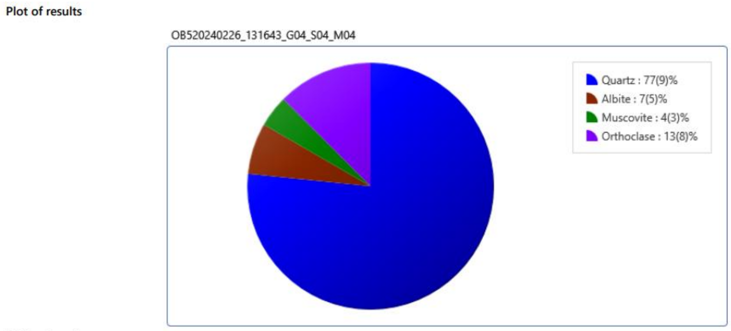

Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Quartz	Albite	Muscovite	Orthoclase
OB5_20240226_131643_G04_S04_M04	0	77(9)	7(5)	4(3)	13(8)

Figure 4b: Mineralogical plot of OB5

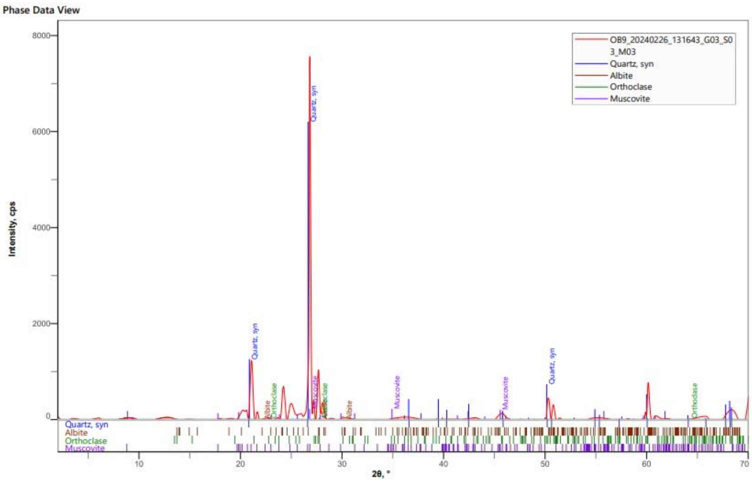

Figure 5a: Qualitative result sheet and difractogram for OB9

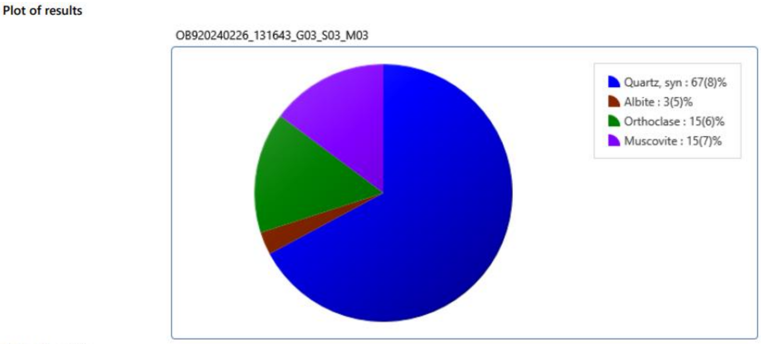

Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Quartz, syn	Albite	Orthoclase	Muscovite
OB9_20240226_131643_G03_S03_M03	0	67(8)	3(5)	15(6)	15(7)

Figure 5b: Mineralogical plot of OB9

7. Discussion

7.1 Mineralogical Composition

The sediments were observed to be very fine grain silt and clay that will stain the hands. They are not fissile, but are mudstone to clays. Their mineralogical composition as shown by the bulk analysis is presented in Table 4 below.

Table 4: Mineral Composition of Selected Samples from Obogoro Community.

SAMPLE POINTS	QUARTZ	ORTHOCLASE (K – FELDSPARS)	ALBITE (NA – PLAGIOCLASE)	MUSCOVTE
OB1	62(5)%	7(4)%	21(3)%	10(2)%
OB3	76(7)%	11(5)%	6(6)%	7(3)%
OB5	77(9)%	13(8)%	4(3)%	7(5)%
OB9	67(8)%	15(6)%	15(6)%	3(5)%
AVERAGE	70.5%	11.5%	11.5%	6.75%

Clay minerals are secondary minerals which are generally the products of alteration of pre-existing rocks. The degree of weathering, erosion, transportation, environment of deposition and mineralogy of source rock determine the type of clay minerals that will be formed. Besides clay minerals, other non-clay minerals form within the size range depending on their stability and the geochemistry of the environment of deposition occur alongside. Four primary minerals occur in the sediments analyzed. They are quartz, orthoclase (K-feldspars), albite (Na plagioclase) and muscovite (white mica). The oxide quartz and the group of silicates are the most important group of rock forming minerals (Read, 1984) [8].

Quartz is very ubiquitous in acid igneous rocks. In the analyzed samples, its composition range from 62% to 77%, with an average of 70%. Quartz is a very stable mineral, with little or no disintegration during weathering and transportation of detrital sediments. As a result the end product of weathering of source rock with high percentage of quartz is usually enriched in quartz, while, the less stable minerals would have disintegrated physically and chemically to form new secondary minerals.

Feldspars are silicates that are very important group of the rock forming minerals. Igneous rocks are dominantly made up of them. We have the alkali feldspars and the plagioclase feldspars. Orthoclase [K (AlSiO3O8)] is an alkali feldspar that is a potassium aluminum silicate. It is an important component of acid igneous rocks. Some metamorphic rocks also contain orthoclase. It occurs in sandstone when the alteration and sorting of weathered granitic rock is incomplete (Read, 1984) [8]. Its composition ranges from 7% to 15%, with an average of 11.5% in the analyzed samples. Albite Na (AlSiO3O8), is another major constituent of the samples. It is plagioclase feldspar. Its proportion ranges from 4% to 21%, also, with an average of 11.5%. Albite is plagioclase feldspar which originally occurs in acid and intermediate igneous rocks. Feldspars are very dominant components of igneous rocks, but because of their instability, they disintegrate and weather into secondary minerals very fast. This gives credence to the low percentage of their proportion in the sampled sediment.

Muscovite is a silicate of aluminum and potassium; it also consists of hydroxyl and fluorine. Its origin is majorly acid igneous rock like granite and pegmatite. It is also a component of some intermediate igneous rocks, metamorphic rocks and less commonly a detrital component of immature sedimentary rocks (Perkins and Henke 2007). The proportion in the analyzed sample is 3% to 10%, with an average of 6.75%. Using the weathering index, muscovite is a stable mineral, more stable than the ferromagnesian mineral and calcium and sodic feldspars. This makes muscovite more widespread than many ferromagnesian minerals in detrital deposits. The presence and enrichment in muscovite indicates long time/intensity and distance of weathering to have eliminated other ferromagnesian and unstable minerals that may have been found in the source rocks.

The prominent occurrence of these primary minerals in the fine grained samples indicates a weathering process that is not complete.

The observed mineral suite is indicative of an acid igneous rock source. Considering the depositional environment which is the Niger Delta basin, an acid igneous rock source is not in close proximity. Therefore, sediments would have been weathered and transported from parts of the Nigerian Basement Complex consisting of acid igneous rocks down through the river channels to the Niger Delta Basin where they are deposited. Coarser materials are deposited within channels, while finer sediments like silt and clay are deposited in the associated floodplains. Most parts of the Niger Delta Basin, especially the lower reaches of rivers and coastal environments flood during the wet/rainy seasons. Obogoro community is one of those communities in the lower reaches of River Nun affected annually by these floods. It has a network of tributaries of River Nun around it (Figure 1).

7.2 Consistency Limits (Atterberg's Limits) of Sediments

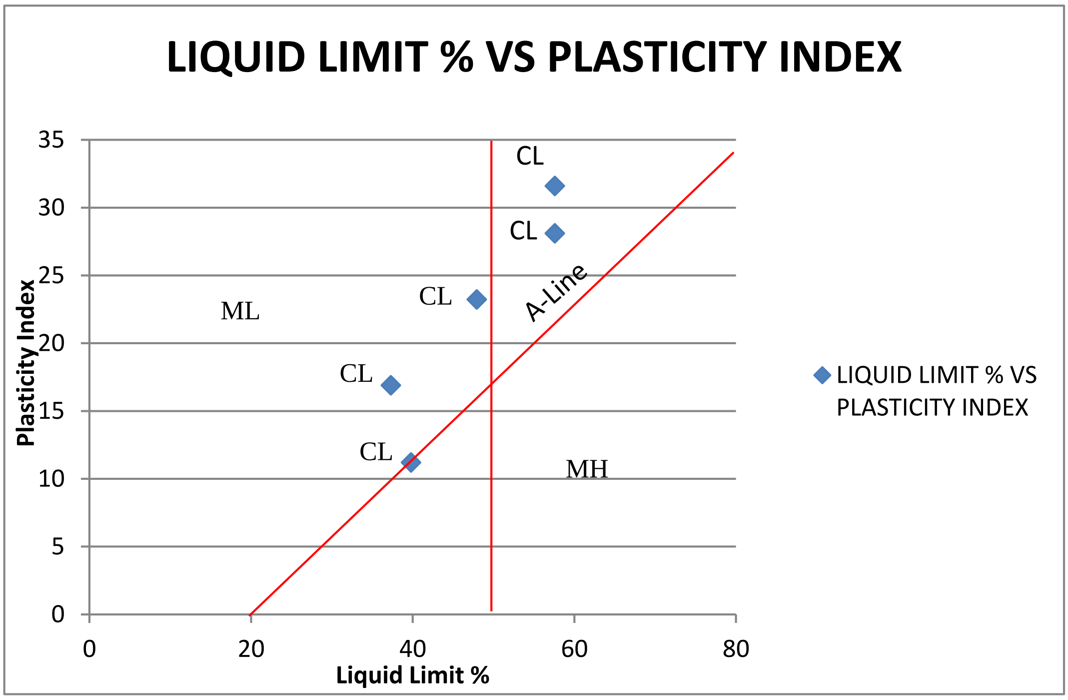

Figure 6: Plasticity Chart (After ASTM D2487 - 11)

Table 3 shows the Liquid Limit for all the samples and Plastic Limit for samples that didn't rupture while the experiments were carried out. The Liquid Limits of samples range from 32.7.0% to 57.6%, the Plastic Limit ranges from 20.4% to 29.2% and the Plasticity Index ranges from 11.2 to 31.6. According to (ASTM D2487 - 11)[3], the sediments are interpreted to range from clay low in plasticity to silt and mud that are plastic. Some of the samples: OB1, OB3, OB4, OB6 and OB10 didn't go through the Plastic limit test because they were cracking or rupturing, indicating that they are not plastic (NP).

Figure 6 is the Plasticity chart, a plot of the Plasticity Index and Liquid Limit of the sediments, most of the sediments fall above the A-line, with one on the line, this imply that they are clay. According to (ASTM D2487 - 11) [3], Fine grained materials that fall above the A-Line, with a Plasticity Index greater than 4 is classified as inorganic clay. They also fall below the 50% Liquid Limit separator and divide. Soils that fall below the 50% divide are low plasticity fine grain, and are indicated as ML, whereas, those above 50% are high plasticity fine grained soils and are indicated as MH (ASTM D2487 - 11) [3].

8. Conclusion

The fine grained deposit from Obogoro community, Bayelsa state, Nigeria was analyzed to determine the mineralogy, source rock, and engineering properties of the deposit. It was observed from the whole rock analysis using XRD, that the deposit contains prominently primary minerals: quartz, with an average of 70.5%, orthoclase and albite, both with an average of 11.5% and muscovite with an average of 6.75%. The traditional clay minerals which are secondary minerals were not observed. From the mineralogical analysis, it is inferred that the reason for the above mineralogical composition is incomplete weathering that may have resulted from environmental cum climatic conditions and mineral stability.

The Consistency Limits (Atterberg's Limits) derived from the engineering test show the sediments have Liquid Limits that range from 32.7.0% to 57.6%, the Plastic Limit ranges from 20.4% to 29.2% and the Plasticity Index ranges from 11.2 to 31.6. These results classify the sediment into a range of clay with low plasticity to silt and mud with plasticity (ASTM D2487 - 11)[3].

The plot of Liquid Limit versus Plasticity Index shows the sediments to be clay with low plasticity, because they fall above the A-line (CL) and the 50% divide (ML) respectively.

Therefore, the fine grained deposits that occur in Obogoro Community are inferred to be silt and muddy clays with low plasticity.

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