

# Evaluation of Shale Properties for Chemical Wellbore Stability Study in Niger Delta

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## I. INTRODUCTION

The world oil industry has been plagued by the challenges of shale instability that arise during and after drilling. This challenge (shale instability) has been directly connected to several hole problems and indirectly linked to an enormous yearly expenditure for the industry. According to Yu et al., 2002; Zeynali, 2012, it is estimated that in terms of monetary value, the petroleum industry losses up to one billion (\$1Billion) US dollars due to the problem of instability of shale. Also the lost time due to this challenge account for over 40% of all drilling related non-productive time (Zhang et al, 2009) and these instabilities are also responsible for 10-20% of the total drilling cost. Despite the study of shale stability for several years, it is still a critical challenge in the oil industry and even in other industries, notably the mining and construction industries. A solution through this challenge is very critical to sustaining the investment made by companies in the oil industry. Such solution must include the evaluation of shale properties and directed in a manner that will drastically reduce drilling cost, completion and workover cost, and also the accompanying downtime.

It has been noted that shale makes up to 75 percent of all drilled formations worldwide and that over 90% of the instability challenges occur in shale formations (Steiger and Leung, 1992; Dzialowski et al, 1993). It is therefore an interesting proposition to study the properties of these shale formations that makes it prone to instabilities. Shales have been generally defined as sedimentary rocks with small pore radii, low permeability, medium to high clay content, and manageable porosity (Zhang, 2005). They also contain some minerals including calcite, feldspar and quartz (Osisanya, 1991). According to Manohar (1999), the distinguishing features of shale are its clays and low permeability, resulting in poor inter-connection through its characteristic narrow pore throats (pore throat diameters are within 3nm to 10nm). Shales are porous and normally saturated with formation water. Its properties are usually affected by several factors including burial depth, the amount and type of pore water, water activity, the amount and type of minerals present in them (Alizadeh, 2011; Joel, et al. 2012). These special characteristics make them likely to be affected by different phenomena including swelling, shrinkage, hydration and mechanical failure.

### • Study Objectives

This study was carried out for the evaluation of shale properties for chemical wellbore stability study. The shales were obtained from selected wells of two fields (OGN 23. and ORD 25) in the prolific Niger Delta oil province. The study objectives include

- Evaluation of shale mineralogy and clay content

- Evaluation of shale permeability
- Evaluation of shale cation exchange capacity of shale

These properties are necessary to obtain a unique profile for the selected shale that will aid in the design of drilling mud to combat the challenges of chemical wellbore instability.

## II. MATERIALS AND RESEARCH METHODOLOGY

It is believed that unfavorable interactions between shale and drilling fluids are the primary cause for wellbore instability. This interaction causes physiochemical and mechanical property alterations, making the formation wellbore to be unstable. An analysis of the intrinsic physical and chemical properties of shale can help us understand the problems and lead to better formulation of drilling fluids (Osisanya, 1991; Breeden and Shipman, 2004). In many cases, the solutions to wellbore instability problems can be developed on the basis of laboratory tests.

For the purpose of this study, 23 shale samples were collected from 9 wells, selected across two fields. The procedure employed in preparing the shales for the different experiments, and determination of their permeability, mineralogical composition, and cation exchange capacity is presented as follows.

**Table 1: Selected Wells and their depths (ORD FEILD) 4750ft – 12660ft**

S/No	Well Number	Depth (Feet)
1	2B	4750 – 4780
2	2B	6330 – 6360
3	2B	7260 – 7290
4	3A	8100 – 8130
5	3A	8680 – 9110
6	4B	10065 – 10080
7	4B	10110 – 10125
8	6A	12390 – 12405
9	6A	12570 – 12584
10	6A	12645 – 12660
11	6B	12390 – 12405
12	6B	12645 – 12660
13	6C	12645 – 12660

**Table 2: Selected details of OGN field and Wells (1525ft – 9885ft)**

S/No	Well Number	Depth (Feet)
1	1B	1525 – 1560
2	1B	3540 – 3570
3	1B	4650 – 4680
4	2B	4915 – 4930
5	2B	5575 – 5590
6	2B	5635 – 5650
7	5A	6820 – 6835
8	5A	7375 – 7390
9	2C	7870 – 7885
10	2C	9130 – 9139

• **Shale sample Preparation**

The highly sought quality results in shale characterization studies will be defeated if the confidence about shale samples preservation and preparation before running experiments are not properly handled. This is a critical aspect of shale characterization studies as it is often said that experimental results are as good as the procedure for obtaining samples and the quality of samples obtained. The procedure employed in preparing the shale samples is briefly outlined.

- Shale samples were obtained from the two fields; they were assigned identification numbers for easy identification.
- The shale were then cleaned with mineral oil to remove the drilling mud that was used in coring the shale
- They were then stored in a container filled mineral oil, the same container was monitored for leakages
- Then the shale was then prepared for the different experiments that were to be carried out, including XRD, CEC, and permeability.
- For the permeability test, the shale were mounted as cylindrical core plugs, while for the CEC and XRD test, the shales were made into powdered form for easy test and analysis.
- Thereafter experiments and test to obtain the necessary results were carried out.



**Fig. 1: Mounted Shale Plugs**

• **Shale Permeability Determination**

Shale permeability is defined as a shale formation ability to admit the passage of fluid through it. It is a function of the available and inter-connected pore spaces within the shale. It is a critical and far reaching property of shale. The ability of ions to flow through shale is controlled by the relative ion size to shale pore throat size which in turn affects the shales membrane efficiency and ion selectivity. The measurement of permeability has been shown to be correlated with membrane efficiency and ion selectivity.

The shale permeability for this study was obtained using a locally fabricated permeameter that was particularly fabricated for the purpose of this study. Each of the prepared core samples was mounted on a rubber sleeve and loaded into the core holder shown in Figure 1. The cores were then flooded with brine at a constant flow rate of 1cc/min. The pressure drops across the cores were recorded. Other necessary parameters to enable the calculation of brine permeability by Darcy’s law were also obtained. The

permeability calculated here is the effective permeability to brine.



**Fig. 2: Locally fabricated permeameter for shale permeability determination**

Darcy’s law is given by the following equation:

$$q = \frac{kA\Delta P}{\mu L}$$

(3.1)

Where

- q = Volumetric flow rate (cc/sec)
- k = Permeability (Darcy)
- A = Cross sectional area of core (cm<sup>2</sup>)
- ΔP = Pressure difference across core (psi)
- μ = Viscosity of brine (cp)
- L = Length of core (cm)

• **Shale Mineralogy Characterization**

Clays are hydrous aluminium phyllosilicates sometimes with variable amounts of iron, magnesium, aluminium, alkali metals, alkali earth metals and other cations found in or near the surface of the earth. Shales comprise clay minerals and non-clay mineral fractions, the clay fraction comprises Kaolinite Group, Smectite Group, Chlorites, Illites, Mica and Palygorskite Group whereas the non-clay mineral fractions comprise silica, feldspars, Zeolites carbonates and sulphates (Moorhouse, 1958; Grim, 1968; Martin – Vivaldi and Robertson, 1971).

X -Ray diffraction data of the shale samples of ORD and OGN fields were used in the semi-quantitative interpretation. The bulk composition of the shale samples was determined using the Table of Key Lines in X – Ray Powder Diffraction Patterns of Minerals in Clays and Associated Rocks (1997).

Twenty-three (23) shale samples from nine (9) wells across two (2) fields of the Niger Delta region were used for this study. Fourteen (13) samples were taken from different wells and depths across the ORD field and ten (10) samples similarly taken from the OGN field. The shale samples were characterized using the following methods:

- Mineralogy and Clay Content Analysis – X-Ray Diffraction
- Permeability – Fabricated Permeameter
- Cation Exchange Capacity – Methyl Blue Test

• **Chemical and Mineralogy Analysis of Shale Sample**

X-Ray Diffraction (XRD) was used to determine the crystalline structure and composition of the shale minerals by determining the angles at which the x-Ray beam is diffracted (Breedon and Shipman, 2004). The wavelength for an x-Ray is of the range of 0.01 to 100 Å (1 Å= 10<sup>-10</sup>m). Because the

spacing of atomic planes in crystalline materials is in the order of about 1 Å, this makes X-Rays a useful tool in analyzing crystalline structure and mineralogical composition of shale (Osisanya, 1991).

Shale mineralogy analysis is used to identify the type and relative amounts of minerals present in shale samples. X-Ray diffraction analysis (XRD), X-Ray Fluorescence and Fourier Transform Infra Red Spectrometry are common techniques of analysis utilized. According to studies done by Jenkins and Walker (1978), the XRD technique is the best technique for identification while infrared spectrometry is the best for quantitative determination of the minerals. However results from both techniques are highly dependent on particle size and the orientation of the minerals present in the samples. For this study, X-Ray Fluorescence analysis (XRF) and X-Ray Diffraction were used for elemental compositional analysis.

The shale samples were dried, ground to a fine powder and placed in a sample holder for analyses. The time required for the instrument to complete the X-ray fluorescence pattern is two to four minutes. X-ray fluorescence analyses were done using a very small amount of about one gram of dried solids, but 50g was submitted. An X-ray diffraction analysis requires expensive instrumentation and a knowledgeable analyst trained in the operation of the instrument and interpretation of the data. Owing to limitations of obtaining pure standards and the crystalline nature of some samples, the X-ray fluorescence data is only semi- quantitative for the mineralogical composition of the shale.



Fig. 3: X-Ray Diffractometer

• **Cation Exchange Capacity**

The cation exchange capacity (CEC) of shales is a measure of the intensity of the negative charge environment between clay platelets and hence co-ions electrical exclusion property of shales. High cation exchange capacity indicates strong electrical repulsion of anions; therefore, the cation exchange capacity should influence the shale membrane efficiency (Keijzer et al, 1999). The higher the CEC is, the more reactive the shale. Sand stone and limestone typically are non-reactive and have CEC values of less than 1 Meq/100g. Moderately reactive shale has a CEC value from 10 to 20 Meq/100g while reactive shale has a CEC value greater than 20 Meq/100g. The cation exchange capacities for the shales were conducted as follows:

- 10g of grinded shale samples were weighed out and dispersed in 350 milliliters of deionized water using a magnetic mixer for 15 minutes.
- 2 milliliters of the mixture was transferred into a 250 milliliters flask using a syringe.

- 10 milliliters of deionized water was added and the resulting mixture treated with 15 milliliters of hydrogen peroxide (to oxidize any organic matter as they too absorb methylene blue dye).
- After boiling gently for 10 minutes, the mixture was diluted to 50 milliliters with deionized water.
- The mixture was titrated against reagent grade 0.01M methylene blue solution.
- The dye was added in increments of 0.5 milliliters and drops of the solution were placed on filter paper until a purple Halo was observed around the solids.



Fig. 4: Methylene Blue Test Kit

RESULTS AND DISCUSSION

**Shale Characterisation**

The results from the XRD analysis in terms of clays and non – clays minerals and their volume by percentage in the samples from two fields- ORD and OGN in the Niger Delta region are presented as follows.

**ORD Field Shale Mineralogy**

Clay types identified in this field include Palygorskite, Nacrite, Kaolinite, Chlorite, Brookite, Lizardite, Sepiolite, montmorillonite, Chlorite-Montmorillonite and Mica-Montmorillonite. These fall into the following groups:

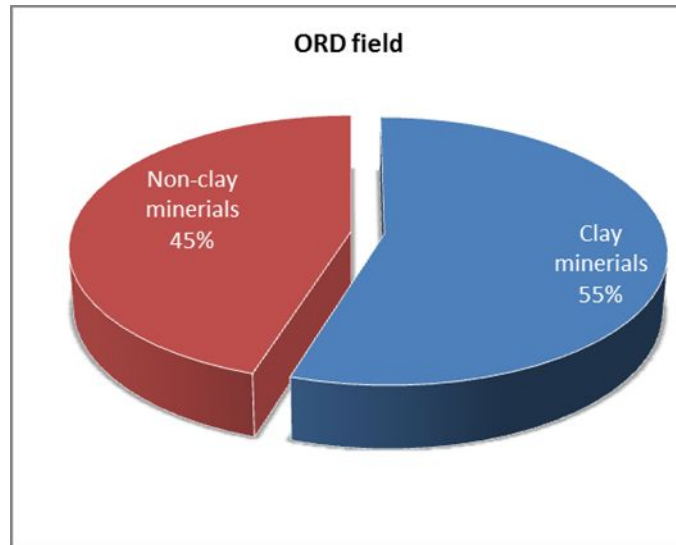
1. Kaolinite Group Comprising Kaolinite, and Nacrite.
2. Smectite Group Comprising Montmorillonite and Brookite
3. Chlorite Group – Chlorite
4. Palygorskite Group comprising Palygorskite and Sepiolite
5. Mixed – Layer Clays comprising Chlorite-Montmorillonite and Mica-Montmorillonite.

The major clay minerals in this field include Palygorskite, Nacrite and Kaolinite whereas the minor clay minerals are Chlorite, Brookite, Sepiolite, montmorillonite, Chlorite-Montmorillonite and Mica-Montmorillonite. This indicates minimal presence of swelling clays (Smectite). Table 3 shows the percentage distribution of clay and non clay minerals within the samples collected across the different depth of the selected wells in ORD field.



**Table 3: Clay and Non-Clay Mineral Composition of wells in ORD Field**

WELL #	Depth (ft)	Number of minerals	Number of clay minerals	Number of non-clay minerals	% of clay minerals	% of non-clay minerals
2B	4750 – 4780	9	3	6	61.84	38.16
2B	6330 – 6360	22	7	15	52.79	47.21
2B	7260 – 7290	11	3	8	65.46	35.54
3A	8100 – 8130	11	3	8	53.83	46.17
3A	8680 – 9110	10	3	7	63.17	36.83
4B	10065 – 10080	10	3	7	59.05	40.95
4B	10110 -10125	17	5	12	44.20	55.80
6A	12390 - 12405	12	3	9	49.55	50.45
6A	12570 - 12584	10	3	7	62.0	38.0
6A	12645 - 12660	11	2	9	58.40	41.60
6B	12390 - 12405	10	3	7	56.66	43.34
6B	12645 -12660	9	3	6	53.87	36.13
6C	12645 -12660	30	3	27	38.04	61.96



**Fig. 5: Clay and Non Clay Mineral Distribution ORD Field**

**OGN Field Shale Mineralogy**

The type of clays identified in the formations (wells) of this field include palygorskite, Nacrite, Kaolinite, Chlorite, Lizardite, Sepiolite, montmorillonite, Vermiculite and Pyrophyllite-Montmorillonite. The clays fall into the following groups:

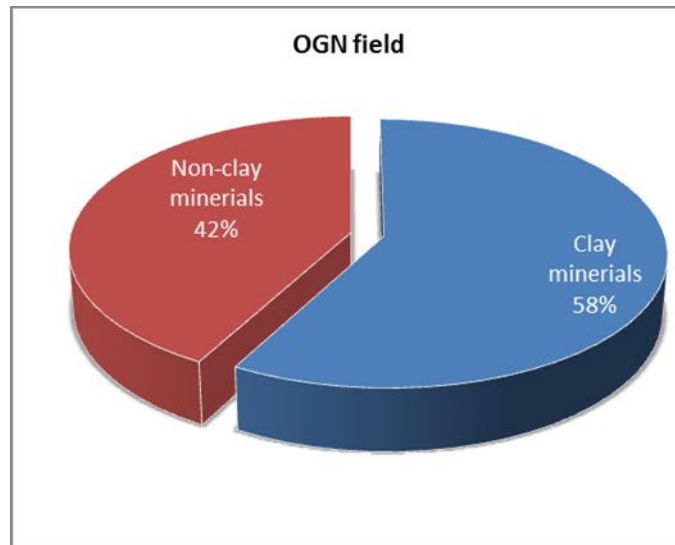
1. Kaolinite Group Comprising Kaolinite, and Nacrite.
2. Smectite Group Comprising Montmorillonite and Vermiculite.
3. Chlorite Group – Chlorite.
4. Palygorskite Group comprising Palygorskite and Sepiolite.
5. Mixed – Layer Clays - Pyrophyllite-Montmorillonite.

The major clay minerals in this well include Palygorskite, Nacrite and Kaolinite whereas the minor clay minerals are Chlorite, Sepiolite, montmorillonite, Vermiculite and Pyrophyllite-Montmorillonite. Table 4 shows the percentage distribution of clay and non clay minerals within the samples collected across the different depth of the selected wells in OGN field.

**Table 4: Clay and Non-Clay Mineral Composition of Wells in OGN Field**

WELL #	Depth (ft)	Number of minerals	Number of clay minerals	Number of non-clay minerals	% of clay minerals	% of non-clay minerals
1B	1525 – 1560	10	3	7	61.61	37.39
1B	3540 – 3570	14	3	17	48.98	51.02
1B	4650 – 4680	11	4	7	50.94	49.06
2B	4915 – 4930	12	3	9	54.49	45.41
2B	5575 – 5590	8	2	6	65.94	34.06
2B	5635 – 5650	18	4	14	56.34	43.66
2C	7870 – 7885	11	4	7	59.01	40.99
2C	9130 – 9139	10	3	7	62.05	37.95

5A	6820 – 6835	11	3	8	54.34	45.66
5A	7375 – 7390	13	3	10	54.34	45.66



**Fig. 6: Clay and Non Clay Mineral Distribution OGN Field**

In both fields, clays with potentials to swell and known as swelling clays comprise the following

1. **Smectites:** Montmorillonite, Brookite and Vermiculite.
2. **Palygorskite Group:** Palygorskite and Sepiolite
3. **Mixed Layer Clays:** Pyrophyllite-Montmorillonite, Chlorite-Montmorillonite, Sodium-Montmorillonite and Mica-Montmorillonite.

The presence of Feldspars such as K-feldspar, Plagioclase feldspar, Albite, Anatase and Fayalite indicates that the phenomenon of shale swelling (hydration) when in contact with formation water or water based mud may accelerate the formation of clays in both fields. It is noted that across the two fields, the clay minerals were about 55% while the non clay minerals were about 45% for ORD feild, while it is 58% clay minerals and 42% non clay minerals for OGN field (see Figs 5 and 6). Similarly, the clay mineral Palygorskite, a relatively less reactive shale was the most abundant across the selected wells of the two fields, followed by Nacrite and Kaolinite. The smectite group of clay minerals (montmorillonite, brookite, vermiculite) were minimal in both fields. The distributions of clay minerals across both fields are shown in Table 5.

**Table 5: Clay Mineral Distribution of tested Samples (ORD and OGN Field)**

Clay Minerals	Proportion (%)			
	ORD Field		OGN Field	
	Min	Max	Min	Max
Palygorskite	33.14	56.52	39	56
Nacrite	3.32	5.5	2.5	6.6
Kaolinite	1.5	6	1.25	5.16
Sepeolite	1.63	3.12	2.18	3.4
Na-montmorillonite	1.51	1.63	0	0
Montmorillonite	1.12	1.32	0	1.31
Chlorite	1.69	3.25	8.31	26.22
Chlorite-montmorillonite	0	1.12	0	0
Pyrophyllite-montmorillonite	0	0	0	2.2
Mica-montmorillonite	0	1.12	0	0
Brookite	0	1.12	0	0

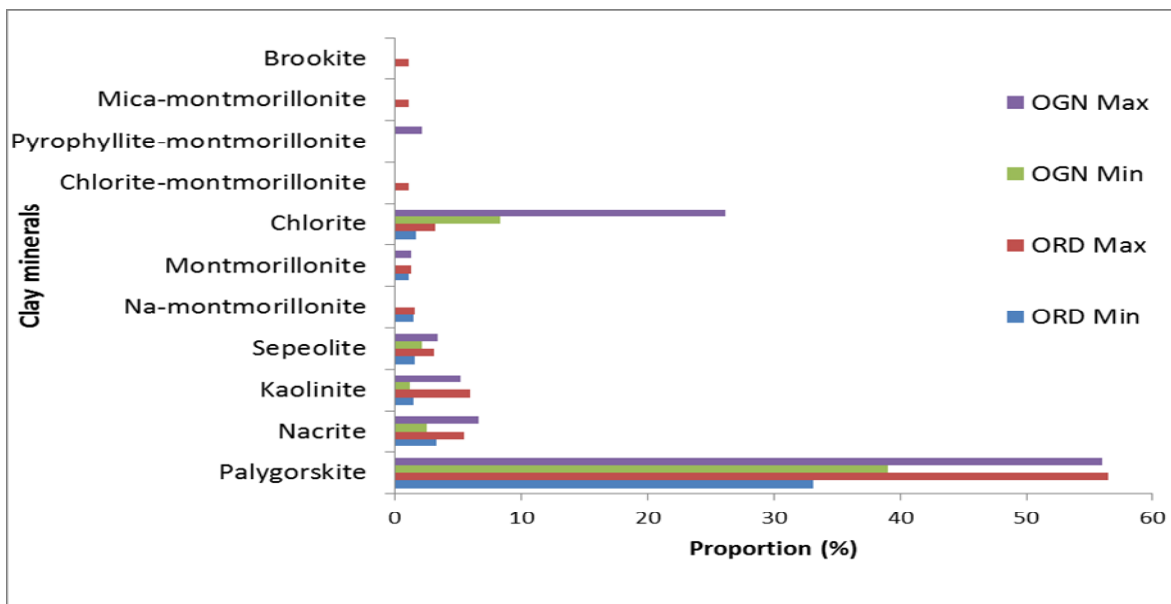


Fig. 7: Minimum and maximum clay mineral proportion in shales (OGNI AND OREDO FIELDS)

• **Shale Permeability**

The results obtained from the permeability experiment carried on the shale using the locally fabricated permeameter (Fig 2) is presented as follows. It is observed that the permeability values of the different shale samples tested were low. This is typical of shale because of its poor connectivity through narrow pore throat and agrees with other studies carried out to determine permeability of shale samples (Al Bazali, 2005; Zhang, 2005).

Table 6: Permeability of Selected Shale Samples

Core ID	Viscosity of brine (cp) @28°C	Brine concentration (ppm)	Length of Core (cm)	Area of core (cm <sup>2</sup> )	Pressure differential (psi)	Permeability (mD)
A1	4	5000	1.94	28.49	2.238	0.1536
B3	4	5000	3.8	63.36	2.238	0.1353
C5	4	5000	2.27	28.59	0.866	0.2110
A5	4	15000	2.30	31.60	2.888	0.1590
B1	4	15000	2.04	29.36	1.5	0.1752
C3	4	15000	1.95	28.59	1.625	0.1469
A3	4	25000	2.10	29.88	1.3	0.2046
B5	4	25000	2.10	29.88	1.8	0.1971
C1	4	25000	1.78	27.13	1.6	0.1552

• **Cation Exchange Capacity of Shale**

Clay minerals owe their unique structure to the substitution of ions within the octahedral and tetrahedral sheets. The substitution usually leads to the presence of excess negative charges negative on the minerals crystal surface. This excess charges needs cation from the drilling fluid to counter it and thus ensure electrical neutrality. The cation exchange capacity is a measure of the excessive negative charges on the shale surface. It ensures at a glimpse the required cations that are necessary to ensure electrical neutrality with a shale sample and by extension the formation. This is because the presence of these charged surfaces in clay minerals is known and expected to give rise to some complex electrochemical interactions that is largely responsible for the characteristic behaviour exhibited by shales leading to wellbore instability problems.

Results obtained for the cation exchange capacity of the tested shale samples are as presented in Table 4.11. The results for the cation exchange capacity can be correlated with the shale mineralogy and brine concentration for an understanding of

the principle of shale swelling when exposed to brine and water based drilling mud. It has been noted that Niger Delta shale samples are classified into low (CEC < 12) and moderate (CEC > 12) reactivity shale types with the low reactivity shale exhibiting low swelling and the high reactivity shale exhibiting medium swelling and high cutting disintegration (Akpokodje, 1994); the results obtained from the tested shale samples shows that they fall into the low reactivity shale samples with regards to their cation exchange capacity values ranging from 2.5 Meq/100g to 10.5 Meq/100g and agrees with the mentioned researcher. This is also in agreement with the mineralogy and clay mineral results that is dominated by the less reactive and low swelling palygorskite, nacrite and kaolinite. Kaolinite group of minerals are known to have low CEC partly due to the presence of impurities and broken bonds at the edges of the mineral flakes (Ekeocha, 2015).

The results also show that CEC has major significance in determining clay mineral properties and as such critical in shales ability and propensity to absorb water. This is because the movement of water and even ions to and from the shale/mud during the shale/mud interaction is usually

controlled and influenced by the cation exchange capacity. This implies a general correlation between shale CEC, water activity, its water holding capacity and its mineral composition is possible and achievable, in that the higher the reactive clays (Smectite) the higher the CEC, thus the higher the swelling capacity of the shale. This agrees with the result published by Bell, (2007).

**Table 6: CEC values for sampled shales**

CORE SAMPLE ID	CEC (Meq/100g)
2A	3.0
2B	3.5
4B	6.5
13A	2.5
13B	3
13C	2.5
13D	2.5
16A	2.5
19A	6.0
19C	9.0
22A	6.0
22B	9.5
22C	4.5
22D	10.5
23A	7.0
23B	7.5

### CONCLUSION

The importance of shale properties evaluation in the study of wellbore instability caused by the interaction between shale formation and drilling fluid cannot be overemphasized in the light of the fact that most instability issues occur in shale formations.

The shale mineralogy analysis carried out showed the dominance of clay minerals (55%) over non clay minerals (45%). Similarly the samples contained Palygorskite, Nacrite and Kaolinite as the dominant minerals with little amount of montmorillonite and mixed clays. This was observed across the selected wells of both OGN and ORD field.

Low Shale permeability was observed for the selected shale samples indicative of the samples poor pore connectivity.

The sampled shales were of low reactivity and swelling as indicated by its low cation exchange capacity values.

The higher the clay content, the more likely the shale will be reactive to swelling. Therefore, the X-ray diffraction data can be used in conjunction with other considerations like cation exchange capacity, water activity and permeability when formulating a drilling fluid for specific sections of the well. When it is known that a section of the well will have high clays present, a more inhibitive drill fluid should be considered.

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#### ACKNOWLEDGEMENT

The authors wish to acknowledge the Petroleum Technology Development Fund (PTDF) for providing funds for this research. Also we thank the World Bank Africa Centre of Excellence, Centre for Oilfield Chemical Research, University of Port Harcourt for their commitment and support.