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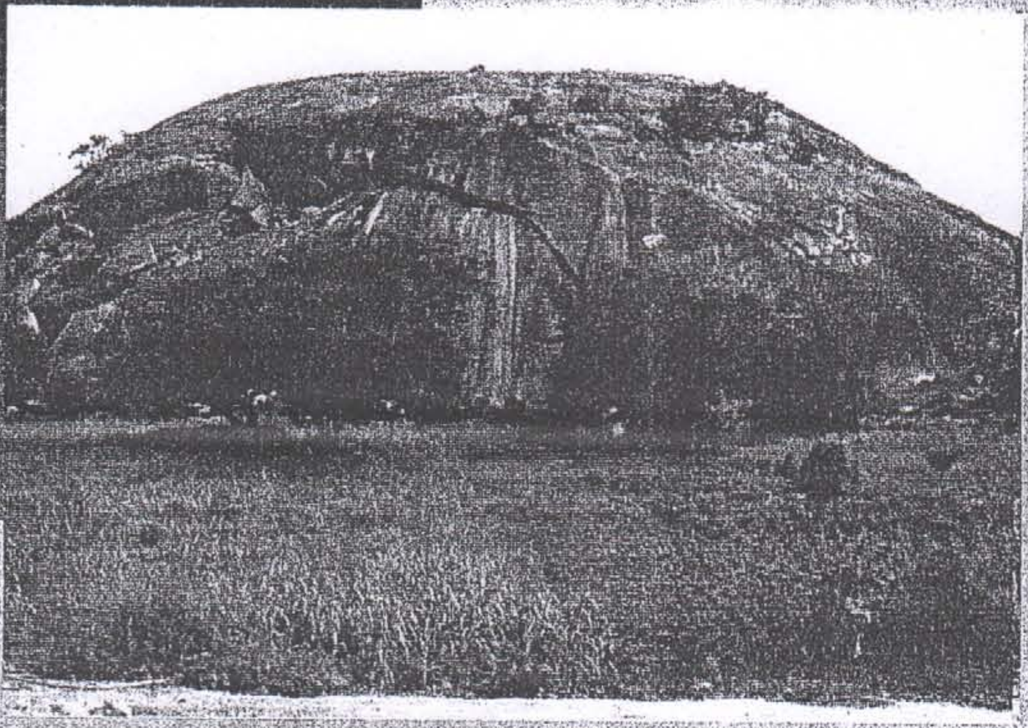

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TABLE OF CONTENTS

VARIATION IN THE PHYSICOCHEMICAL AND RHEOLOGICAL PROPERTIES OF CLAYS FROM KANJE AND DOKA TOFA AREAS, NORTHCENTRAL NIGERIA AND IMPLICATIONS FOR USE AS DRILLING MUD

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ABSTRACT

The physico-chemical and rheological properties of clays derived from the weathering of basalts around Kanje, Nasarawa State and Doka Tofa, Plateau state, North Central Nigeria were studied.

Fifty-one samples were collected from pits dug to a maximum depth of 5m. The following chemical and rheological parameters were determined in the laboratory: basic cations present, cation exchange capacity, pH, Specific Gravity, plastic viscosity, apparent viscosity , yield point, filtration, liquid and plastic limits.

The samples have a predominance of calcium over sodium as the basic cations and showed tremendous improvement in the rheological properties after treatment with sodium carbonate. The filtration properties were tested to be good. 62% of the samples from Kanje were found suitable for the drilling of water wells, 14% would need further improvement with viscosifiers while only one sample was found to be outrightly useful as drilling mud. 53% of the samples from Doka Tofa were found useful for drilling oil and water wells while the remaining 47% could be useful for drilling water wells.

1.0. GENERAL INTRODUCTION

The increasing importation of bentonite in drilling for oil, gas, mineral exploration and water in Nigeria has been a source of foreign exchange loss. The quest for locally available materials is imperative in order to meet the local content contribution to the industry and also conserve our foregn exchange.

The functions of a drilling mud include: transportation of rock cuttings to the surface, lubricating of drilling bit, application of hydrostatic pressure in the well bore, ensuring well safety and minimising fluid loss across permeable formations by forming a filter cake on the walls of the well. (Gray and Darley, 1980). No single drilling fluid can fulfill all of these functions perfectly except, if it is mixed with an additive in a manner to create the optimum physical and chemical characteristics essential for downhole conditions. Bentonite is one of the major additives which can give the proper rheological and filtration control properties. Some attempts were made earlier to assess the suitability of Nigerian black cotton soils as drilling mud. (Omole et al, 1989, Eyisi et al,1996, Oyedeji et al, 2006). The purpose of this paper is to examine the suitability of the clays derived from basalts in the northcentral parts of Nigeria.

1.1 Location

Kanje lies in the northern part of Nasarawa State within latitudes 08° 10' 00"N -08° 17' 00"N and longitudes 009° 00' 00"E - 009° 10' 00"E on 1:100,000 Sheet 232 Akiri covering about 75km^2 while Doka Tofa lies within latitudes 09° 00' 00"N and 09° 04' 00"N longitudes 009° 21' 00"E and 009°23' 00"E on 1: 100,000 Sheet 190 Pankshin with an area extent of 26 sq. kilometers.

2.0 GEOLOGICAL SETTING OF STUDY AREAS

Kanje-Abuni falls within the Middle Benue Trough, and is underlain by sandstone, shale and basalt. (Fig.1)

The sandstone varies from medium to coarse-grained in texture, exhibits joint systems and dips 26°E . The shale is light-grey to dark-grey in colour, fissile in places and intercalated with thin bands of sandstone. The basalt is light-green to dark-green and fine-grained in texture. It outcrops as a cone around the Azara junction at Kanje and as scattered boulders, which were thought to be remnant of basaltic flows between Kanje and Abuni.

The Doka Tofa area is underlain by Pre-Cambrian migmatite gneisses, Jurassic alkaline Younger Granites and Tertiary volcanics. (See fig. 3.) The migmatite gneisses occur as lowlying weathered outcrops. The Younger Granites occur towards the northeastern portion of the area (the Sara-Fier complex) as an intrusion into the basement complex rocks.

The volcanics constitute the youngest rocks, occuring as scattered boulders. They are dark, fine-grained, lateritised and vessicular. Part of the lithological constituent in this area is volcanic ash possibly erupted during the Tertiary. The ash is suspected to be responsible for the formation of bentonitic clay in the area.

Age			Formations
CENOZOIC			Volcanics
MESOZOIC	CRETACEOUS	Maastrichtian	Lafia Formation
		Santonian-Campanian	Volcanics
		Coniacian	Awgu Formation
		Late Turonian Early Turonian	?
		Late Cenomanian	Ezeaku/Keana Formation
		Early Cenomanian	Awe Formation
		Mid-Late Albian	Asu River Group
Pre Cambrian		Basement Complex Meta Sediments	Migmatite-Gneiss –Schist Complex Older Granite Series

Table 1 Stratigraphy of the Middle Benue trough (After Offodile, 1976)

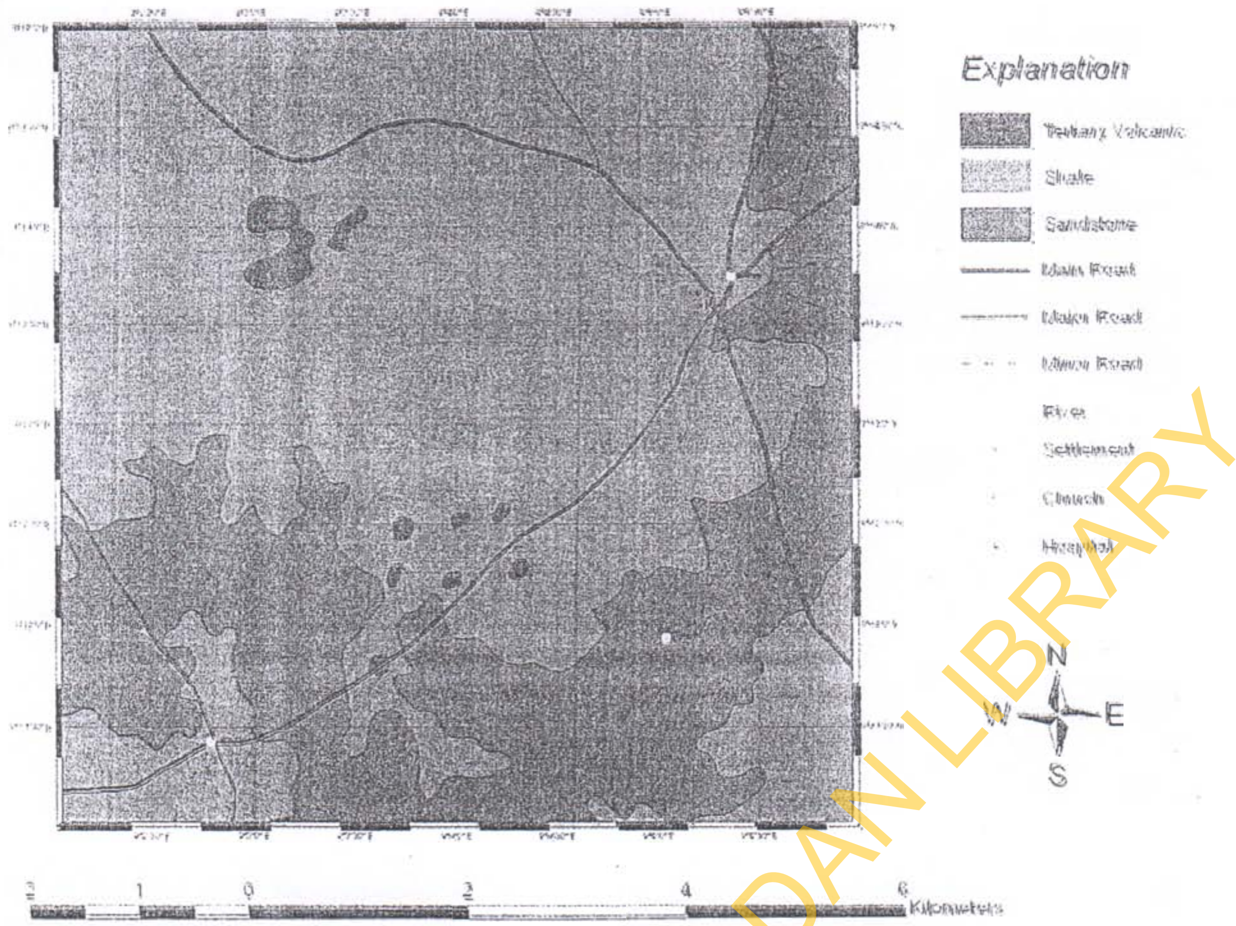

Fig. 1 Geological map of Kanje/Abuni , Nasarawa State

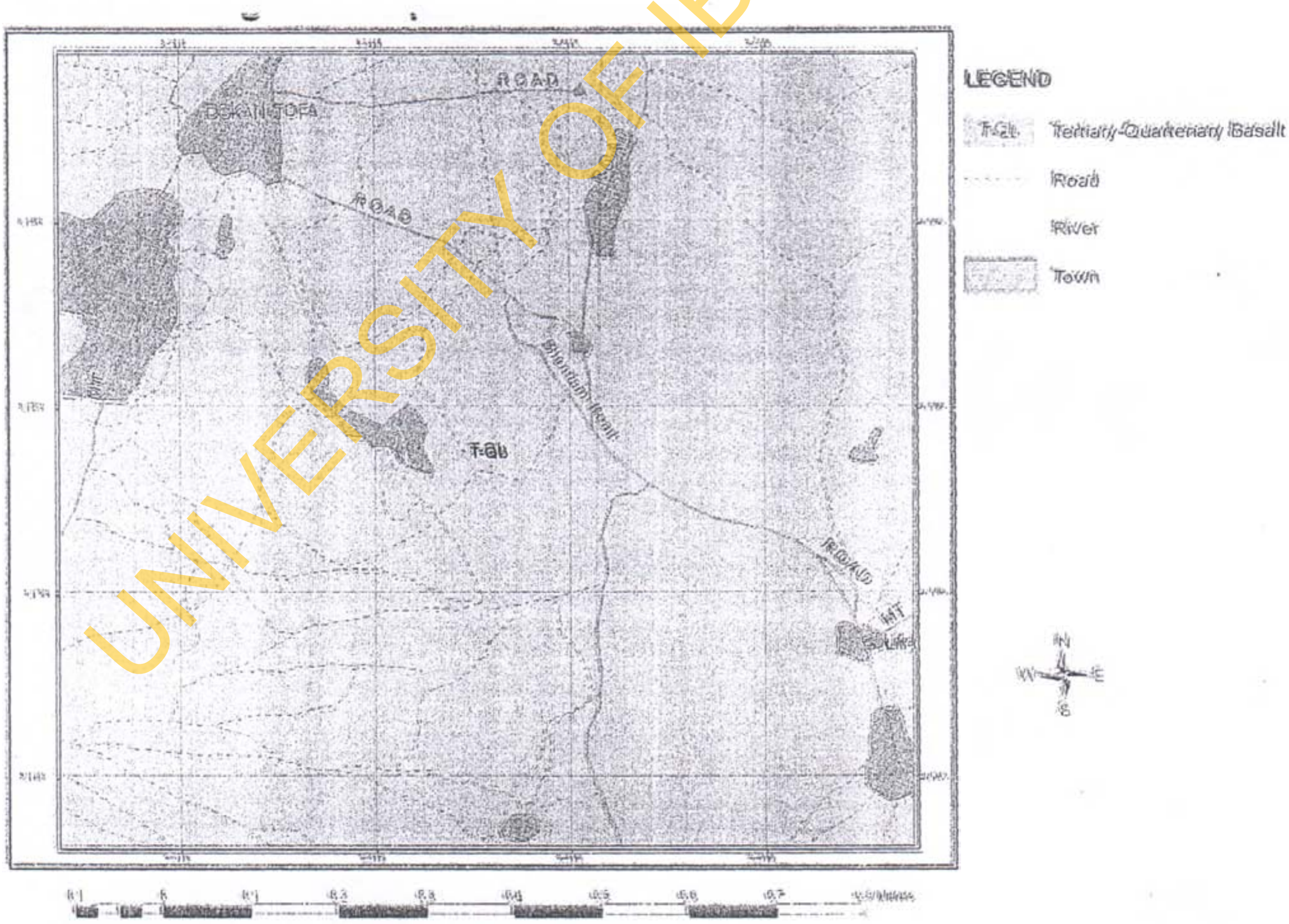

Fig. 2 Geological map of Doka Tofa area

3.0 MATERIALS AND METHODS

3.1 Fieldwork

Clay samples were collected from hand-dug pits. In pits with homogeneous profiles, only one sample each was collected. However, more than one sample was collected from pits with more than one horizon. The pits were sited at 100m interval in areas underlain by basalts.

3.2 Laboratory Analyses

51 samples in all were collected and processed for various laboratory analyses. The samples were tested for the physical and chemical parameters and the rheological properties. The Major element oxides were determined using the ICP-MS technique at the ALS laboratories, Canada. Rheological and filtration properties of each sample were tested under six different conditions (i.e. 35g/350 ml, 40g/350ml and 45g/350ml clay concentration all in their natural state, and 35g/350ml, 40g/350ml and 45g/350ml clay concentration each beneficiated with 7% Na_2CO_3. All rheology experiments were run on a direct-indicating viscometer powered by a two-speed synchronous motor to determine the shear stress at 100, 200, 300, and 600 rpm at the Petroleum Engineering department, University of Ibadan.. Mud is contained in the annular space between two cylinders. The outer cylinder is driven at a constant rotational velocity. The rotation of the rotor sleeve in the mud produces a torque on the inner cylinder, or bob. A torsion spring restrains the movement of the bob, and an attached dial indicates its displacement. The filtration properties were determined with pressure of 100 psi from nitrogen cylinder discharged on the cell of filtration set-up machine. The amount of filtrate discharged in 30 minutes is measured, as is the thickness of the filter cake to the nearest 1mm after washing off excess mud with a gentle stream of water.

4.0 RESULTS OF CHEMICAL ANALYSES

Chemical Analytical results are shown in the Tables 2,3,4,5,6,7,8; Figs 3&4, depict the graphical relationship for the Ca:Mg:Na ratios.

Table 2. Distribution of oxides of major elements in the Kanje-Abuni samples

	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	OA-GRA05	TOT-ICP06
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3	TiO_2	MnO	P_2O_5	SrO	BaO	LOI	TOTAL
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
BT/NS/KJ/002	43.1	14.55	13.3	3.27	5.23	1.84	0.56	0.03	3.41	0.15	0.75	0.08	0.09	13.45	99.8
BT/NS/KJ/003	42.6	16.55	13.25	0.62	1.5	0.14	0.5	0.04	4.72	0.22	0.09	0.01	0.05	18.4	98.7
BT/NS/KJ/005	53.8	14.1	10.8	0.75	1.28	0.58	1.6	0.03	4.44	0.22	0.15	0.01	0.07	12.3	100
BT/NS/KJ/006	53.3	14.65	9.79	0.73	1.24	0.49	1.43	0.03	3.95	0.24	0.11	0.01	0.07	12.9	98.9
BT/NS/KJ/007	47.6	16	12	0.55	0.98	0.3	1.18	0.03	4.77	0.18	0.14	0.01	0.06	14.1	97.6
BT/NS/KJ/008	53.4	16.15	10.75	0.41	1.11	0.42	2.08	0.02	2.98	0.15	0.13	0.01	0.07	11.1	98.8
BT/NS/KJ/009	62.9	13.3	8.23	0.28	0.52	0.39	1.5	0.02	3.58	0.1	0.09	0.01	0.05	7.89	98.9
BT/NS/KJ/010	53	16.2	8.95	0.64	0.94	0.66	1.46	0.03	3.7	0.08	0.17	0.02	0.05	11.8	97.7
BT/NS/KJ/011	52.4	15.3	10.65	0.61	1.01	0.57	1.54	0.03	4.36	0.15	0.17	0.02	0.07	12.65	99.5
BT/NS/KJ/014	50.2	18.45	13.1	0.24	0.54	0.12	1.1	0.03	4.32	0.22	0.08	0.01	0.06	11.55	100
BT/NS/KJ/018	53.6	16.15	8.51	0.4	1.14	0.42	1.96	0.02	3.39	0.11	0.1	0.01	0.07	12.2	98.1
BT/NS/KJ/019	51.9	15.3	11.8	0.45	1.05	0.37	1.56	0.03	3.81	0.22	0.08	0.01	0.06	11.65	98.3
BT/NS/KJ/020	55	13.2	7.98	0.64	0.84	2.05	1.44	0.01	1.03	0.06	0.03	0.01	0.05	11.45	99.8
BT/NS/KJ/025	57.9	18.85	6.26	0.47	0.84	1.57	1.74	0.01	1.07	0.15	0.03	0.01	0.07	10.6	99.6
BT/NS/KJ/026	59.8	17.9	6.16	0.31	0.79	1.13	1.44	0.01	1.14	0.07	0.01	0.01	0.05	11	99.8
BT/NS/KJ/030	49.4	15.95	12.65	0.53	1.16	0.33	1.66	0.04	4.16	0.07	0.08	0.01	0.06	13.95	100
BT/NS/KJ/031A	55.8	12.8	8.35	0.61	1.31	0.17	1.71	0.02	2.54	0.34	0.02	0.01	0.13	14.3	98.1
BT/NS/KJ/031B	57.5	12.35	8.44	0.6	1.29	0.2	1.65	0.03	2.67	0.08	0.02	0.01	0.07	13.6	98.5
BT/NS/KJ/032	53.2	12.95	12.2	0.92	1.32	0.39	1.33	0.03	3.7	0.33	0.14	0.02	0.13	13.5	100
BT/NS/KJ/033	51.9	13.35	12.2	0.87	1.26	0.45	1.22	0.04	4.35	0.12	0.17	0.02	0.06	13.95	100
BT/NS/KJ/034	59.3	14.2	7.94	0.43	0.94	0.2	2.08	0.02	2.11	0.2	0.01	<0.01	0.1	12.1	99.6
MEAN	53.22	15.44	10.16	0.68	1.25	0.61	1.46	0.03	3.34	1.64	0.12	0.02	0.07	12.59	

Oxide	n	Minimum	Maximum	Mean	Std. Deviation
CaO	21	0.24	3.27	0.6824	0.61939
MgO	21	0.52	5.23	1.2519	0.94608
NaO	21	0.12	2.05	0.6090	0.55747
KO	21	0.50	2.08	1.4638	0.40552

Table 3 Calcium:Magnesium:Sodium ratio in the Kanje-Abuni samples

Oxides (%)	Wyoming Montmorillonite	Califonia Montmorillonite	Wyoming Bentonite	Ein Al Bayda (Jordan)	Nasarawa Kanje and Abuni
SiO_2	62.9	52.4	66.12	51.59	53.22
TiO_2	0.16	0.33	-	1.59	3.34
Fe_2O_3	3.97	1.76	2.46	9.19	10.16
Al_2O_3	19.3	15.0	17.01	16.70	15.44
MnO	0.01	0.16	-	0.05	1.64
MgO	2.80	6.68	1.51	4.30	1.25
CaO	1.80	0.81	1.37	0.46	0.68
Na_2O	1.54	1.21	2.02	0.93	0.61
K_2O	0.56	0.33	0.54	2.46	1.46
LOI	5.1	19.5	7.3	12.40	12.59

Table 4 Comparative analysis of Kanje-Abuni samples with samples from other countries

	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	ME-ICP06	OA-GRA05	TOT-ICP06
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3	TiO_2	MnO	P_2O_5	SrO	BaO	LOI	TOTAL
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
BT/PL/DT/037A	62.9	12.3	6.15	0.53	0.61	0.09	0.78	0.03	2.19	0.06	0.01	0.01	0.04	12.5	98.2
BT/PL/DT/037B	54.5	16.2	7.26	0.58	1.18	0.16	0.78	0.03	2.07	0.07	0.03	0.01	0.04	15.15	98.1
BT/PL/DT/038	50.7	18.65	9.51	0.46	0.53	0.1	0.6	0.03	2.37	0.2	0.01	<0.01	0.06	15.35	98.6
BT/PL/DT/042	55.9	15.35	7.2	0.84	0.94	0.21	0.81	0.02	2.54	0.11	0.04	0.01	0.05	14.2	98.2
BT/PL/DT/046A	54	17.4	7.58	0.55	0.97	0.4	1.37	0.01	1.83	0.09	0.02	0.01	0.07	13.75	98.1
BT/PL/DT/046B	61.8	15.65	4.22	0.65	0.68	1.1	4.21	0.03	0.7	0.04	0.01	0.03	0.18	8.88	98.2
BT/PL/DT/047	49.6	17.15	8.82	1.14	1.3	0.3	0.61	0.03	2.02	0.09	0.05	0.01	0.04	17.5	98.7
BT/PL/DT/048	55.8	15.2	7.31	0.59	1.29	0.31	0.77	0.03	2.28	0.08	0.02	0.01	0.04	14.4	98.1
BT/PL/DT/049	64.6	11.65	6.43	0.49	0.61	0.1	0.78	0.03	2.21	0.05	0.01	0.01	0.04	12.1	99.1
BT/PL/DT/050	63.7	11.9	6.26	0.6	0.62	0.09	0.79	0.03	2.15	0.06	<0.01	0.01	0.04	11.9	98.2
BT/PL/DT/051	58.1	13.6	7.96	0.91	0.99	0.26	0.88	0.03	2.32	0.12	0.03	0.01	0.05	13.4	98.7
BT/PL/DT/054	61.2	13.75	6.67	0.5	0.7	0.2	0.91	0.03	2.87	0.08	0.01	0.01	0.04	12.75	99.7
BT/PL/DT/057	54.4	15.45	7.69	0.62	0.9	0.14	0.69	0.03	2.57	0.08	0.02	0.01	0.04	15.6	98.2
BT/PL/DT/058A	57.9	14.65	7.61	0.54	0.75	0.15	0.78	0.03	2.55	0.07	0.03	0.01	0.04	15.35	100.5
BT/PL/DT/058B	52.1	15.95	7.95	0.8	1.41	0.26	0.68	0.03	2.14	0.13	0.03	0.01	0.05	17.2	98.7
BT/PL/DT/059	56.2	15.15	7.58	0.38	1.71	0.34	0.77	0.03	2.16	0.17	0.01	<0.01	0.05	15.55	100
BT/PL/DT/060	51.2	15.6	7.82	1.07	1.9	0.38	0.65	0.03	1.82	0.14	0.05	0.01	0.05	17.45	98.2
BT/PL/DT/061A	56.4	14.55	7.59	0.68	1.41	0.16	0.74	0.03	2.03	0.13	0.01	0.01	0.05	16.2	100
BT/PL/DT/061B	50.7	14.6	7.26	2.93	2.35	0.2	0.68	0.03	1.77	0.09	0.02	0.01	0.04	18.35	99
BT/PL/DT/062	57.2	14.7	7.39	0.8	1.66	0.3	0.82	0.03	2.02	0.11	0.01	0.01	0.05	14.8	99.9
MEAN	56.45	14.97	7.31	0.78	1.13	0.26	0.96	0.03	2.13	0.1	0.02	0.01	0.05	14.69	98.82

Table 5. Distribution of oxides of major elements in Doka Tofa samples

The SiO_2 for the samples from Kanje, though lower than the values for the Wyoming bentonite and the Wyoming montmorillonite, compares favourably with samples from Jordan and the Californian montmorillonite. The values for TiO_2 and Al_2O_3, MnO, MgO, CaO, Na_2O and K_2O fall within the same range with values for the Jordanian sample but closer to the Wyoming montmorillonite. The samples from Doka Tofa (See Tables 4 and 6) have SiO_2 values higher than samples from Jordan and the Californian montmorillonite but a bit lower than the Wyoming montmorillonite and Wyoming bentonite. The TiO_2, Fe_2O_3, and Al_2O_3 values of Kanje and Abuni samples compare favourably with the reference samples from Wyoming, California and Jordan.

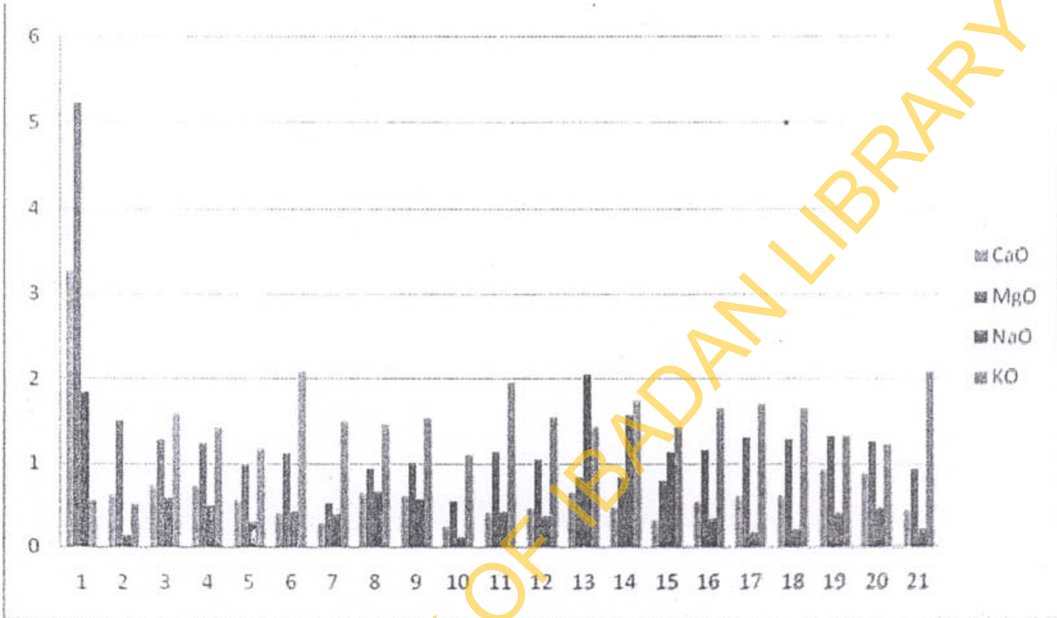

Fig. 3 Bar chart for Ca:Mg: Na ratio for Kanje and Abuni samples

Oxides (%)	Wyoming Montmorillonite	Califonia Montmorillonite	Wyoming Bentonite	Ein Al Bayda (Jordan)	(Kanje)
SiO_2	62.9	52.4	66.12	51.59	56.45
TiO_2	0.16	0.33	-	1.59	2.13
Fe_2O_3	3.97	1.76	2.46	9.19	7.31
Al_2O_3	19.3	15.0	17.01	16.70	14.97
MnO	0.01	0.16	-	0.05	0.1
MgO	2.80	6.68	1.51	4.30	1.13
CaO	1.80	0.81	1.37	0.46	0.78
Na_2O	1.54	1.21	2.02	0.93	0.26
K_2O	0.56	0.33	0.54	2.46	0.96
LOI	5.1	19.5	7.3	12.40	14.69

Table 6 Comparative analyses chart of major elements for samples from Doka Tofa area with other countries

Wt %	n	Range	Minimum	Maximum	Mean	Std. Deviation
CaO	20	2.55	0.38	2.93	0.7830	0.54368
MgO	20	1.82	0.53	2.35	1.1255	0.49942
Na_2O	20	1.01	0.09	1.10	0.2625	0.21966
K_2O	20	3.61	0.60	4.21	0.9550	0.78264
	20					

Table 7 Descriptive Statistics for samples from Doka Tofa

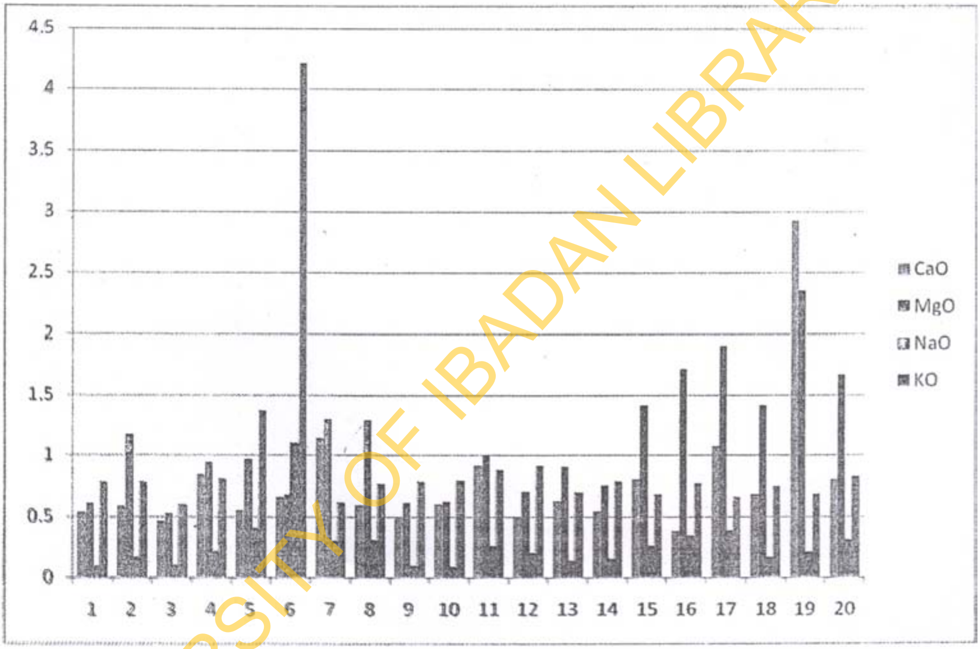

Fig. 4. Bar chart for Ca:Mg:Na:K for samples from Doka Tofa

4.1 X-ray Diffraction Results

The results of X-ray diffraction are in Table 8 and the diffractograms of Sample DT 047 from Doka Tofa are in Figs. 5,6 and 7. The results show that this typical sample from Doka tofa has an average of 70% Smectite, low in Illite, Mica and Kaolinite. The type of Smectite present will affect the swelling potential

Sample ID	DT 047	DT 060
Whole Rock Mineralogy (Weight Percent)		
Quartz	19	16
K-Feldspar	6	4
Calcite	0	0
Pyrite	0	0
Gypsum	0	0
Total Phyllosilicates	75	80
TOTAL	100	100
Phyllosilicate Mineralogy (Relative Abundance)		
Palygorskite	0	0
Smectite	80	90
R0 M-L I/S (40%S)*	0	0
R1 M-L I/S (30%S)**	0	0
Illite&Mica	8	3
Kaolinite	4	6
Chlorite	8	1
TOTAL	100	100
Summary Mineralogy (Weight Percent)		
Quartz	19	16
K-Feldspar	6	4
Calcite	0	0
Pyrite	0	0
Gypsum	0	0
Palygorskite	0	0
Smectite	60	72
R0 M-L I/S (40%S)*	0	0
R1 M-L I/S (30%S)**	0	0
Illite&Mica	6	2
Kaolinite	3	5
Chlorite	6	1
TOTAL	100	100

*RO M-LI/S 40S - Randomly Oriented Mixed-Layer Illite/Smectite with 40% Smectite Layers
**RI M-LI/S 30S - Randomly Oriented Mixed-Layer Illite/Smectite with 30% Smectite Layers

Table 8.Summary of the mineralogy of two samples from Doka Tofa from X -ray diffraction results

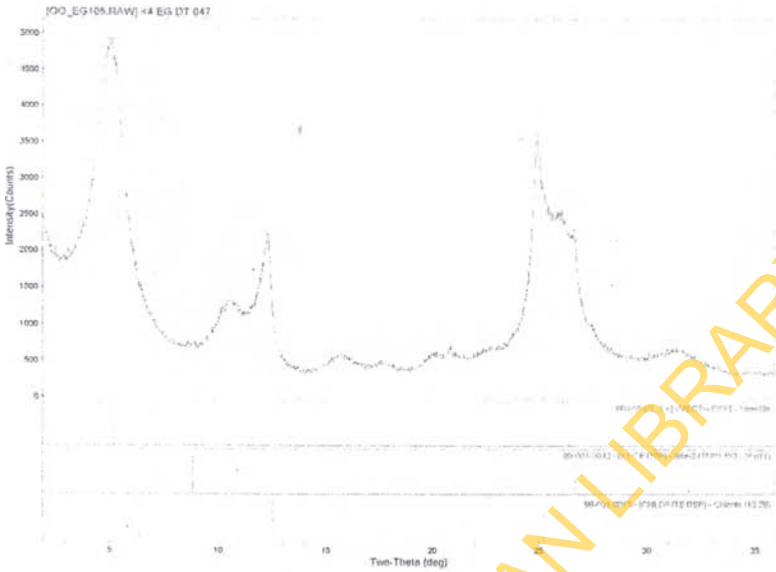

Fig. 5 X-ray diffractogram for sample DT 047 (Raw sample)

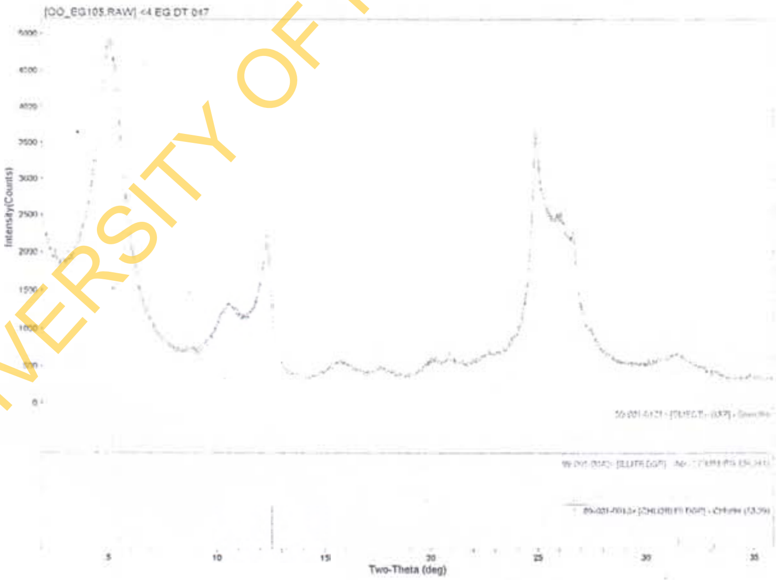

Fig 6. X-ray diffractogram for Sample DT 047 (powder run)

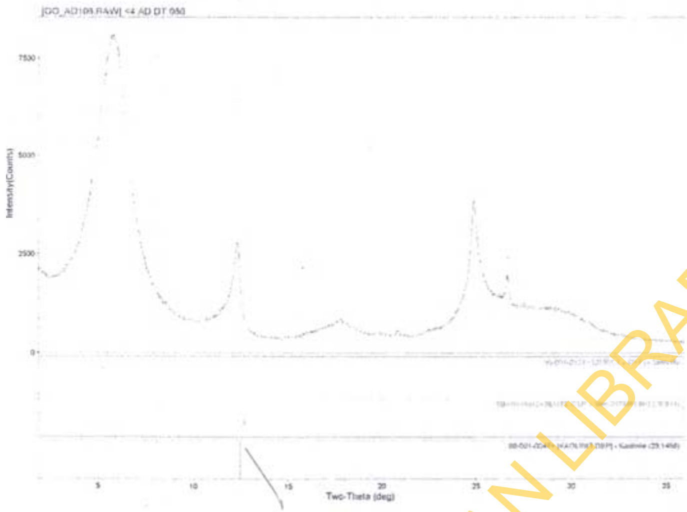

Fig. 7 X-ray diffractogram for sample DT 047 (glycolated)

Cation Exchange Capacity

S/No.	Sample No.	Exchangeable Cations meq/100g (AMAS method)					CEC	Surface Area
		pH	Ca^{2+}	Mg^{2+}	Ca^{2+}	K^{+}	MBA Method	m^2/g clay
1.	BT/PL/DT/037B	8.26	17.98	26.00	3.53	0.63	53.02	307.20
2.	BT/PL/DT/038	7.60	9.40	11.89	1.69	0.85	26.67	144.10
3.	BT/PL/DT/046A	8.69	8.58	9.28	6.03	1.36	28.62	150.40
4.	BT/PL/DT/047	8.40	35.98	24.40	3.96	0.67	68.37	406.90
5.	BT/PL/DT/054	8.12	14.23	16.55	2.01	1.24	32.42	177.70
6.	BT/PL/DT/058A	7.59	9.53	20.16	1.79	0.77	33.89	191.10
7.	BT/PL/DT/058B	8.39	17.68	22.97	4.07	1.38	49.97	289.50
8.	BT/PL/DT/060	9.14	46.20	55.02	6.84	0.92	98.08	568.30
9.	BT/PL/DT/061B	8.71	37.05	4.55	5.37	0.96	73.86	433.70

Table 8a CEC, Surface area for samples from Doka Tofa

S/No.	Sample	Exchangeable Cation (meq/100g) (AMAS Method)					CEC(meq/100g clay) MBA method	Surface Area m^2
1.	BT/NS/KJ/003	7.92	9.55	21.38	1.52	0.82	36.68	210.10
2.	BT/NS/KJ/006	7.94	5.98	9.28	1.63	0.88	19.79	103.80
3.	BT/NS/KJ/010	7.92	8.33	7.43	1.46	1.12	19.18	97.60
4.	BT/NS/KJ/014	6.48	5.45	4.45	3.55	1.04	16.33	75.40
5.	BT/NS/KJ/018	7.30	7.23	9.87	2.61	1.15	22.93	109.50
6.	BT/NS/KJ/020	7.27	10.08	7.27	1.29	0.52	21.54	104.60

Table 8b. CEC, Surface area for samples from Kanje-Abuni

The clays have low to high CEC values. High CEC values may be due to the presence of zeolites. The CEC values show that the clays have a capability to exchange Calcium with Sodium to produce a Sodium bentonite product. High values of Specific surface area implies that the samples have high adsorption capabilities and good cation exchange capacities.

4.2. RHEOLOGICAL PROPERTIES

The following are the parameters calculated from the experimental data

Plastic Viscosity (PV): $PV = \theta_{600} - \theta_{300}$ in (cp)

Apparent Viscosity (AV): $AP = \frac{\theta_{600}}{2}$ in (cp)

Yield Point (YP): $YP = \theta_{300}$ - PV

The results (Table 9, 10, 11, 12) obtained at natural state of the samples have revealed that they could not be used at that state because of their low flocculation due to calcium dominance in those samples. Meanwhile the addition of 7% of sodium carbonate to each concentration has shown appreciable increment in the dial reading on the viscometer which occurred as a result of sodium replacing the dominant calcium ion. In addition, increase in clay concentration from 35g to 45g also contributed to better performance of the clays.

S/No	Dial reading at 600_{RPM}	Name of Sample	Total No	Percentage (%)	Remarks
1	0 – 5	NS/KJ (007, 011, 014, 025)	4	19	Failed
2	6 – 15	NS/KJ (002, 005, 006, 008, 009, 010, 018, 019, 020, 026) NS/AB (030, 033, 034)	13	62	Could be used for water bore hole
3	16 – 29	NS/KJ 003 NS/AB 031A, 032	3	14	Needs further improvement either by increasing mass concentration or by adding viscosifier or both
4	30 >	NSAB 031B	1	5	Useful for all sort of drilling

Table 9 Summary of the rheological properties of samples from Kanje-Abuni areas.

Mass (g)	State	600 (rpm)	300 (rpm)	200 (rpm)	100 (rpm)	Gel Strength	AV (cp)	PV	YP ($lb/100ft^2$)	FL (ml)	FCT (mm)
35	Without Na_2CO_3	4	3	2	1	00/00	2	1	2	-	-
35	With Na_2CO_3	5	3	2	1	00/00	2.5	2	1	-	-
40	Without Na_2CO_3	4	3	2	1	00/00	2	1	2	-	-
40	With Na_2CO_3	5	3	2	1	00/00	2.5	2	1	-	-
45	Without Na_2CO_3	4	3	2	1	00/00	2	1	2	-	-
45	With Na_2CO_3	6	3.5	2.5	1.5	01/01	3	2.5	1	-	-

Table 10 Rheological properties of a typical sample from Kanje(Sample NS.KJ.002)

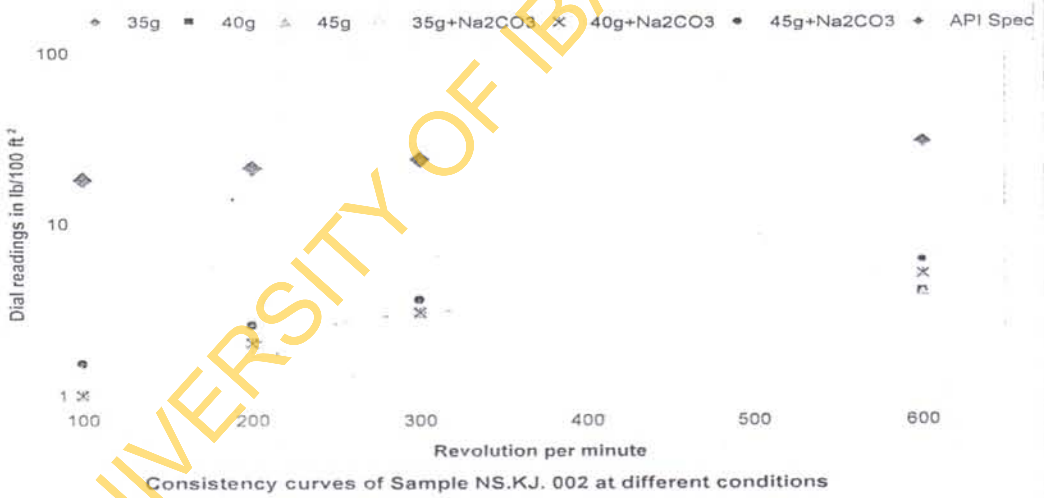

Fig. 8. Consistency curves for a sample from Kanje NS KJ 02

The results of sample **NS.KJ. 002 (Fig.5)** did not meet up with API specifications under the conditions above meanwhile it could be considered for drilling water bore hole

S/No	Dial reading at 600_{RPM}	Name of Sample	Total No	Percentage of total samples (%)	Remarks
1	0 – 5	-	0	0	Failed
2	6 – 15	PL/DT (037A, 038, 046A, 046B, 050, 051, 057, 058A, 059)	10	47	Could be used for water bore hole
3	16 – 29	PL/DT (042, 048, 049, 054, 062)	5	24	Needs further improvement either by increasing mass concentration or by adding viscosifier or both
4	30 >	PL/DT (037B, 047, 058B, 060, 061A, 061B)	6	29	Useful for all sort of drilling

Table 11 Summary of the rheological properties of clay samples from Doka Tofa

Mass (g)	State	600 (rpm)	300 (rpm)	200 (rpm)	100 (rpm)	Gel Strength	AV (cp)	PV	YP (lb/100ft^2)	FL (ml)	FCT (mm)
35	Without Na_2CO_3	2.5	1.5	0.5	0	00/00	1.25	1	0.5	-	-
35	With Na_2CO_3	9	5.5	4.5	2.5	01/02	4.5	3.5	2	-	-
40	Without Na_2CO_3	3	2	1	0	00/00	1.5	1	1	-	-
40	With Na_2CO_3	10	7	5	3	01/02	5	3	4	-	-
45	Without Na_2CO_3	3	2	1	0	00/00	1.5	1	1	-	-
45	With Na_2CO_3	11	7.5	5.5	4	02/02	5.5	3.5	4	-	-

Table 12 Summary of rheological properties of one sample from Doka Tofa PL DT 037A

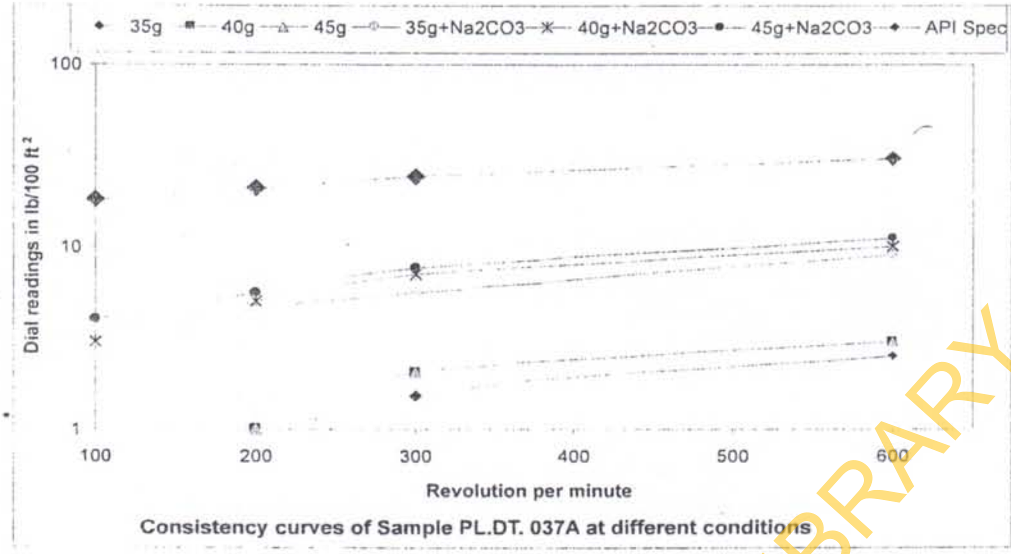

Fig. 9 Consistency curves of a sample (PL.DT.037A) from Doka Tofa at different conditions

The results of sample PL.DT. 037A did not meet up with API specifications under the conditions above meanwhile it could be considered for drilling water bore hole.

5.0 ENGINEERING PROPERTIES

As indicated in Tables 13 and 14,
The samples from Kanje have %fines (clay and silt-size) fraction ranging from 39%-70%. Fine sand ranged between 30-57%. The samples have medium to high plasticity. The plasticity of the samples ranged between 13 and 41.4 while those from Abuni ranged between 11.5 and 32.2. The low values for the Abuni samples may be due to the sandy nature of the terrain. The Doka Tofa samples also have % fines ranging between 35-70% and fine sand ranging between 30-64% medium to high plasticity.

Activity values were calculated using the formula Activity=Plasticity Index/Clay fraction
Two samples from Doka Tofa, Plateau state have activity values greater than 4 suggesting that the dominant clay mineral is montmorillonite. The remaining samples have activity values ranging between 1 and 4 showing that they have medium swelling potential.

Sample No	% Clay	% Silt	% Fine Sand	% Medium Sand	% Coarse Sand
BT/NS/KJ/002	21.5	41.5	37	-	-
BT/NS/KJ/003	20.5	39.0	40.5	-	-
BT/NS/KJ/005	15.0	30.0	55.0	-	-
BT/NS/KJ/006	18.0	25.0	57.0	-	-
BT/NS/KJ/007	25.0	39.0	36.0	-	-
BT/NS/KJ/008	16.5	26.5	57.0	-	-
BT/NS/KJ/009	23.0	40.0	37.0	-	-
BT/NS/KJ/1010	14.0	34.0	52.0	-	-
BT/NS/KJ/011	19.0	35.0	46.0	-	-
BT/NS/KJ/014	18.0	28.0	54.0	-	-
BT/NS/KJ/025	19.5	26	54.5	-	-
BT/NS/KJ/026	16.0	34.5	49.5	-	-
BT/NS/AB/030	34.0	35.0	31.0	-	-
BT/NS/AB/031A	07.0	38.0	55.0	-	-
BT/NS/AB/031B	24.0	34.0	42.0	-	-
BT/NS/AB/032	20.0	37.0	43.0		
BT/NS/AB/033	10.0	19.0	57.0	12.0	2.0
BT/NS/AB/034	20.0	40	40.0	-	-

BT/PL/DT/037A	17.5	48.0	34.5	-	-
BT/PL/DT/037B	20	28.0	52.0		
BT/PL/DT/038	20	45.0	35.0	-	-
BT/PL/DT/042	20	41.0	39.0	-	-
BT/PL/DT/046A	16.5	32.0	51.5	-	-
BT/PL/DT/04B	28.0	42.0	30.0		
BT/PL/DT/047	11.0	29.0	60.0	-	-
BT/PL/DT/048	21.0	44.0	35.0	-	-
BT/PL/DT/049	25.5	34.5	40	-	-
BT/PL/DT/050	8.5	27.0	64.0	-	-
BT/PL/DT/051	17.5	27.5	55.0		
BT/PL/DT/054	05.0	34.0	61.0	-	-
BT/PL/DT/057	18.0	44.0	38.0	-	-
BT/PL/DT/058A	17.0	32.0	51.0		
BT/PL/DT/059	16.0	21.0	63.0	-	-
BT/PL/DT/060	11.0	28.5	60.5	-	-
BT/PL/DT/061A	20.0	45.5	35.5	-	-
BT/PL/DT/061B	27.0	38.0	35.0	-	-
BT/PL/DT/062	22.0	35.0	43.0	-	-

Table 13 Table of Particle size distribution of samples from both study areas.

Sample No	Liquid Limit (%)	Plastic limit (%)	Plasticity Index	Casagrande Chart classification
BT/NS/KJ/002	41.3	28.3	13.0	Medium plasticity
BT/NS/KJ/003	45.1	23.6	21.5	Medium plasticity
BT/NS/KJ/005	48.2	17.1	37.1	Medium plasticity
BT/NS/KJ/006	67.2	25.8	41.4	High plasticity
BT/NS/KJ/007	45.8	17.0	28.8	Medium plasticity
BT/NS/KJ/008	47.4	18.9	26.5	Medium plasticity
BT/NS/KJ/009	49.1	19.2	29.9	Medium plasticity
BT/NS/KJ/010	52.0	26.9	25.1	High plasticity
BT/NS/KJ/011	55.3	23.4	31.9	High plasticity
BT/NS/KJ/014	50.1	23.2	26.9	High plasticity
BT/NS/KJ/018	58.2	31.3	26.9	High plasticity
BT/NS/KJ/019	48.0	17.9	30.1	Medium plasticity
BT/NS/KJ/020	40.3	19.7	20.6	Medium plasticity
BT/NS/KJ/025	64.2	26.4	37.8	High plasticity
BT/NS/KJ/026	50.4	18.9	31.5	High plasticity
BT/NS/AB/030	38.5	27.0	11.5	Medium plasticity
BT/NS/AB/031A	42.0	18.4	23.6	Medium plasticity
BT/NS/AB/031B	55.9	23.7	32.2	High plasticity
	46.4	18.2	28.2	Medium plasticity

BT/PL/DT/037A BT/PL/DT/037B	46.4 66.8	18.2 34.1	28.2 32.7	Medium plasticity High Plasticity
BT/PL/DT/038	44.2	17.9	26.3	Medium plasticity
BT/PL/DT/046A BT/PL/DT/046B	31.0 64.0	23.2 25.6	17.8 38.4	Medium plasticity High plasticity
BT/PL/DT/047	62.0	21.1	40.9	High plasticity
BT/PL/DT/048	61.0	22.2	38.8	Medium plasticity
BT/PL/DT/049	44.1	18.4	25.8	Medium plasticity
BT/PL/DT/050	62.4	24.7	37.7	High plasticity
BT/PL/DT/050	50.3	18.9	31.4	High plasticity
BT/PL/DT/051	65.1	26.4	38.7	High plasticity
BT/PL/DT/054	61.0	23.7	37.3	High Plasticity
BT/PL/DT/057	64.3	24.6	39.7	High Plasticity
BT/PL/DT/058A BT/PL/DT/058B	46.0 72.3	17.3 36.0	28.7 36.3	Medium Plasticity High Plasticity
BT/PL/DT/059	70.2	26.2	44.0	High Plasticity
BT/PL/DT/060	64.0	29.1	34.9	High Plasticity
BT/PL/DT/061A BT/PL/DT/061b	68.5 43.0	33.7 26.0	34.8 17.0	High Plasticity Medium Plasticity

6.0 CONCLUSION

The clay samples derived from the weathering of basalts in the north-central part of Nigeria have good rheological, chemical and engineering properties. The rheological properties also showed good improvement after treatment with sodium carbonate. Performance can also be enhanced if viscosifier is added. They were found to be adequate for the drilling of water wells.

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