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n-ALKanes Base Exploration as Potential Petroleum Source Rocks in
ILullemeden Basin (Sokoto Basin) North west Nigeria

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ABSTRACT

The aim of this work is to investigate the potential petroleum shales of Dukamaje formation in Sokoto basin for their petroleum potentials. A total of sixteen samples were obtained from different parts of the basin. The samples were subjected to sohxlet extraction to extract the bitumen. The bitumen was subjected to column chromatography and aliphatic and aromatic fractions were collected from each sample by using DCM and n-hexane as solvents. The fractions were subjected to GC/MS analyses with the application of SIM method (selected ion monitoring) which revealed the wide variety of hydrocarbons compounds including n-alkanes, hopanes, sterenes, phenanthrenes, methylphenanthrenes and triaromatic steroids. Interpretation biomarker parameters revealed that the rocks under studies are endowed with organic matter. Also biomarker correlation parameters were employed to compute the quantity of organic matter, type of organic matter, thermal maturity of the organic matter and to assess the depositional environment of the rocks samples. The biomarker parameters indicated that the source organic matter is mostly from marine environment, the depositional condition found to be anoxic reducing condition. The shales are rich in organic matter and the shales are found to be partially matured.

Keywords: petroleum shales; sohxlet extraction; n-alkanes; organic matter and column chromatography

1.0 INTRODUCTION

Rocks that produce hydrocarbons from organic matter buried within the rocks pore space are known as source rocks (Kogbe, 1980). The most common organic-rich sedimentary rocks, thought to be the source rocks for most oil and gas, is shale. Much shales are often blacks and are referred to as black shale. The black color comes primarily from its organic content (Kogbe, 1980). A black shale may have 1-3 % organic matter, where as a green or grey shale may have only about 0.5 % organic matter. Organic-rich black shale is relatively common in many areas of the world (e.g. the Kimmeridge clay shale formation of the North Sea) (Maldowan *et.al.*, 1985) of the total organic matter deposited in the earth crust, only about 2 % becomes Petroleum out of this, 2% about 0.5 % find its way into a commercially exploitable reservoir. The petroleum deposit exploit comes from tiny fraction of all the organic matter that is deposited within the earth crust. Thus petroleum

generation is a very inefficient process (Maldowan *et.al.*, 1994).

The Iullummedem Basin in North-Western Nigeria is known locally as "Sokoto Basin". (Kogbe and Dubois, 1980). It consists predominantly of a gently of undulating plain with an average elevation varying from 250 - 400 metres above sea level (Kogbe, 1980). This plain is occasionally interrupted by low mesas. A low escarpment which was named the "Dange scarp" by early workers is the most predominant feature in the basin; it is closely related to the geology. The areas to the east of this escarpment consist mainly of a gently undulating, sandy plain, which extends south-westwards to outcropping Basement complex (Brassll and Eiglington, 1993). Further to the west of this escarpment, another escarpment occurs marking the eastwards limit of a series of younger rocks with a more varied topography (Kogbe and Dubois, 1980).

Lullemeden basin is entirely cratonic basin created by tectonic epeirogenic movement within cratonic rocks. This movement is an evidence from the beginning of the palaeozoic and continued until the late cretaceous when the opening of the Gao was achieved. The movements are responsible for the SW progradation of sediment deposited within basin (Hulka *et. al.*, 1990). In addition to the escarpments, numerous outliers and remnant of the continental terminal occur as tabular hills or low hummocks over the dip slope of the Paleocene formations. The Dange scarp is no longer recognizable, while the flat topped hills made of up continental terminal deposit, has completely over stepped the younger formation in many places (Kogbe and Dubois, 1980).

The Gundumi and Illo formations have been studied; it contains fossils wood (Kogbe *et. al.*, 1982). The flora of the “Continental interclaire” in Niger Republic has been studied in detailed (Kogbe, 1982). South of the Air, in the Tegama and Demergou areas (Chudeau *et. al.*, 1994). Silicified wood has been collected from the overlain beds by the marine of upper Cenomanian deposits with *Neolobitesvibrayeanus* (Kogbe, 1982). Mayeux (2004) has described many specimens of silicified wood of the genus *Dadoxylon (Araucroxylon)* from localities throughout the sahara and observed that these trees show an araucaroid structure in their tracheid cells and may not belong to the *Araucariaceae*.

1.2 Geology of the Nigerian Sector of the Basin

In north-western, the sediments of the Lullemeden Basin were accumulated during three main phases of deposition, namely; Continental Mesozoic and tertiary phases (the first and the last), with an intervening marine Maastrichian to Paleocene phase (the second). Overlying the pre-Cambrian Basement uncomfortably, the Illo and Gundumi Formations, made up of grits and clays, form parts of the “Continental Interclaire” of West Africa. They are overlain uncomformably by the Rima Group, consisting of mudstones (Talako and Wurno Formations), separated by the fossiliferous, shelly Dukamaje Formation. The Paleocene Dange and Gamba Formations (main shales) are separated by the calcareous Kalanbaina Formation. The

Geological works in Sokoto Basin date back to the late 1800s, but most of the published materials relate to the general geologic observation or descriptions of the fossils localities (Kogbe and Dubois, 1980), published the results of this pioneering study of the geology and geography of the northern Nigeria, including the Sokoto Basin. Their observation and description are still valid till today. However the regional upheaval resulting in folding and fracturing the cretaceous rocks which they dated as Eocene is now known to have occurred at the end of the Paleocene. The subsequent period of the intense erosion took place during Eocene. D.H Parker of the geological survey of Nigeria marked the geology of a large segment of the Sokoto province (Debois, 1979).

1.1 Literature Review

Saturated and aromatic hydrocarbon fractions from the column chromatographic fractionation of the extract will be analyzed by GC/MS at selected ion monitoring modes for identification and quantification of compounds respectively with internal standard. The GC linked to MS is used for analysis. The GC oven will be programmed from 300°C (held for 5min) and raised at 70 °C/min to 3000°C where it will be held for 30 min (Kogbe, 1980). MS will be set at the mass spectra of 50-550 m/z; compound will be identified from their respective of mass spectra in comparison with published mass spectra and mass chromatograms (Brassll and Eiglington, 1993).

overlying continental Gwandu formation (Continental Terminal) is of Tertiary age. These sediments dip gently and thicken gradually towards the northwest, with a maximum thickness of over 1200 m near the frontier with Niger Republic (Debois, 1979).

The correlation based on lithology, sedimentary structures, and fossil content, although apart from silicified wood, the formation is fossiliferous or barren. The pisolic and nodular clay members of Illo formation extend in to the northern area of Republic of Benin, where they have been wrongly designated as the lower part of “Gres du Niger”. These sediments lie in the “basin du kandi” in

Republic of Benin. Both the Illo and Gundumi Formation are believed to belong to a thick accumulation of continental deposit in Niger, known as “continental interclair”. Correlation is based mainly on the occurrence of silicified wood similar to that found within the Illo and Gundumi formations, and referred to as *Dadoxylon* (Debois, 1979).

Correlation has also been made with the Bima sandstone of north-eastern Nigeria, based on structure and contacts with the basement. An outstanding characteristic in the Bima sandstone is current bedding, which is also a widespread feature

1.3 Normal Alkanes Characteristics

The distribution of *n*-alkanes in crude oils can be used to indicate the organic matter source (Duan and Moldowan, 2001). For example, the abundance in the *n*-C₁₅ to *n*-C₂₀ suggests that is marine organic matters with contribution to the biomass from algae and plankton (Peters and Moldowan, 1993). Oil samples characterized by uniformity in *n*-alkanes distribution patterns suggest that they are related and have undergone similar histories with no signs of biodegradation (Ficken *et al.*, 2000) and (Duan and Ma, 2001).

n-Alkanes are widely distributed in various plants and other organisms and are probably the most exploited class of biomarkers. High proportions of long chain C₂₇-C₃₁ members relative to the total *n*-alkanes especially, *n*-C₂₇ and *n*-C₂₉ are typical of terrestrial higher plants, where they occur as main components of plant waxes i.e. leafcuticles, spores, pollens, and resins, (Wang *et al.*, 2006).

1.4 Vital Rocks Properties

Petroleum is generated within small voids, or pore spaces, of a source rock. Many rocks have pore spaces within them. Sandstone comprises grains of predominantly quartz, chemically cemented together with minerals that accumulate where the grains touch (Espitalie *et al.*, 1980). The mineral cement holding these grains together may be very strong and the rock is then described as being highly or well consolidated. However, in some cases this bonding is not very strong and such a rock would be described as poorly consolidated or unconsolidated (Ocampo *et al.*, 1992).

in the Illo and Gundumi formations. In addition where ever there is lower contact could be observed, The BIMA sandstone rest directly on the basement (Maioli *et al.*, 2011). The same observation is true for the Illo NAD Gundumi formations which are underlain by the basal conglomerates that become hardened towards the contact with the basement. It has also been suggested that Bima sandstone was deposited by fluvial current flowing from the north-west, repeatedly interrupted by minor disturbances, a fact confirmed by the direction of cross-beds in the area (Maioli *et al.*, 2011).

The short chain *n*-alkanes with odd-to-even predominance in the medium molecular weight region (C₁₁-C₁₇) maximizing at *n*-C₁₆ are predominantly found in algae and microorganisms (Peters *et al.*, 1993).

The ratio of odd/even carbon numbered *n*-alkanes has been in use over a long period in estimating the thermal maturity of fossil fuel (Wang *et al.*, 2006). These ratios can be expressed as a carbon preference index (CPI) and improved odd-to-even predominance (OEP) (Clementz, 1979). The CPI and OEP values above or below 1.0 indicate low thermal maturity. Values of 1.0 suggest, but do not prove, that an oil or rock extract is thermally mature. The CPI or OEP values below 1.0 are unusual and typically low maturity oils or bitumen from carbonate or hypersaline environments (Peters *et al.*, 2005). Organic matter inputs do affect these ratios and therefore are mostly applied with caution.

1.5 Source Rock and Hydrocarbon Generation

Millions of years ago, plant and animal remains could sometimes accumulate and become buried by deposited material. Often this was in slow moving or stationary water environments such as swamps, lakes, coastal regions, and shallow seas.

As these organic remains and other non-organic particles (clay minerals, fine sands, and silts) sank to the bottom, thick beds of sediment built up over a long period of time (thousands to millions of years) (Ocampo *et al.*, 1992). As the organic-laden sediments became buried deeper by more

silted sediments and by movement of the earth's crust, they were subjected to increasing temperatures and pressures. The sediments, under diagenesis, became sedimentary rocks about 99 % of all hydrocarbon deposits are found in sedimentary rocks. Within the tiny pore spaces of the rock, the organic matter also underwent chemical transformation (Ocampo *et. al.*, 1992).

Under certain conditions, oil is generated from organic remains. The most important factor is temperature; oil generation starts at 50 °C, conversion to oil peaks at 90 °C and stops at 175 °C. This range of temperature, 50° to 175°, is known as the oil window. As higher temperatures generate oil more quickly, younger sediments must have been exposed to higher temperatures to create significant quantities of oil. However, even at higher temperatures, oil generation still takes millions of years (Ocampo, *et. al.*, 1992).

Below and above the oil window, decay of the organic remains will generate gas. Below 50 °C, biogenic gas (generated by microbes) or swamp gas will result. Above 175°, thermal gas will result. Temperatures at the lower end of the oil window will generate heavy oils, with increasing temperatures generating lighter (and more valuable) hydrocarbons. If the temperature of the rock becomes too high (above 260 °C) then the organic material (and therefore the oil generating potential) is destroyed (Ocampo *et. al.*, 1992).

Petroleum comprises carbon (83 %) and hydrogen (13 %), and some-times small amounts of sulfur (2 %), nitrogen (0.5 %), and oxygen (0.5 %). Hydrocarbons (composed of carbon and hydrogen

1.6 Research Problem

Recently there has been a growing debate on the petroleum potentials of the Nigerian inland Basins. One of which is the Sokoto Basin. Works on the petroleum potential of the Basin have been mainly geological. However, a deeper look into the potential source rocks for e.g. Using molecular biomarkers has not been done.

1.7 Aim and Objectives

only) make up over 90 % of most crude oils. Materials that have spaces within them, like a sponge, are described as porous, the extent of this porosity is measured as the fraction of the total rock volume occupied by the pore spaces. Porosity is expressed as a percentage; if 20 % of the total volume of a rock was made up of pore spaces, the porosity would be 20 %. Rock porosity is very important, for without porosity, oil cannot be generated, cannot migrate, and cannot accumulate in a reservoir (Ocampo *et. al.*, 1992).

Within a porous rock, it is possible for the pore spaces to be connected. Fluids (gas, oil, or water) can flow between the pores, moving through the rock. However, there are also rocks that are porous where the rock spaces are not connected. Fluid in the pore spaces cannot move through the rock. The ability of a rock to allow fluid to flow through it is called permeability. A rock can be porous but impermeable (cement is an example of a porous, impermeable solid), but a permeable rock must have porosity (pore spaces that can be connected must exist). Permeability is important, for without it oil generated in the source rock cannot migrate to reservoir and cannot be exploited (Ocampo *et. al.*, 1992).

Shale has tiny pores that are connected by tiny passages. It takes a long time for the water and the oil produced within the shale source rock to be squeezed out by pressure. The actual mechanism by which the oil leaves the source rock is uncertain, but it is thought that the oil is initially in solution in the water under the high pressures that exist in the source rocks (Peters and Moldowan, 1993).

The aim of this research is to investigate the hydrocarbon potentials of the potential source rocks in Sokoto Basin.

The specific objectives of this research are as follows:

1. Determination of the quantity of organic matter in the shale samples.
2. Determination of the types of organic matter in the shale samples.
3. Determination of the thermal maturity of organic matter in the shale samples.

4. Assessment of the depositional environment of the rocks.

1.8 Scope and Limitation

The research covered some parts of the Sokoto Basin where samples were obtained. This research is limited to achieve the stated objectives using biomarkers only. Rock-Eval pyrolysis will not be employed.

2.1 Materials

The instruments and chemicals used for this experiment are listed below;

2.1.1 Apparatus

Table 2.1 Instrument Used for the Experiments.

Instruments	Models	Manufacturers
Weighing balance	Adventurer TM. OHAUS	OHAUS CHINA
Hot plate	Gerhardf Karlkolb, Germany	Agilent 5973 MSD
GC/MS	Agilent 6890 GC linked	Agilent Technology USA

Table 2.1: Instrument Used for the Experiments

Mass/Charge (m/z) ratio	Compound type	Fraction
85	n-alkanes ($\geq C_{15}$)	Saturates
178	Phenanthrenes	Aromatics
192	Methyl Phenanthrenes	Aromatics
191	Hopanes	Saturates
218	Steranes	Saturates
231	Triaromatic steriods	Saturates

Table 2.2: m/z Ions of Different Aliphatic and Aromatic Hydrocarbons Identified

2.0 METHODS

2.2 Sample Collection

Samples used for this study were collected from four different boreholes within Sokoto Basin. Four samples were collected from each borehole at the same depth intervals. The first set of samples were collected from the borehole opposite to the Energy Research Centre, Usmanu Danfodiyo University, Sokoto (Latitude:13° 1N, Longitude: 5° 13'E).

These were labeled; ERC.A, ERC.B, ERC.C, and ERC.D respectively.

The second set of samples were obtained from a borehole at Asma'u Girls Islamic Collage Runjin Sambo Sokoto (Latitude:13 °3'23.4"N, Longitude:5°12' 5.4"E) and were labeled; AGIC.A, AGIC.B, AGIC.C and AGIC.D respectively.

The third set of samples were obtained from the borehole also at Runjin Sambo behind Juma'at mosque Sokoto at the same latitude and longitude with the above one and labeled; RSBJM.A, RSBJM.B, RSBJM.C and RSBJM.D respectively. The fourth set of samples were obtained from the borehole at Mabera Salame (Longitude; 12°75"N, Latitude:5° 14E) and were labeled; MBSLM.A, MBRSL.B, MBRSL.C and MBRSL.D respectively. All the samples were collected at the same depth intervals of about 20 m. The Samples were obtained with the help of the Rural Water Supply Sanitation Agency, Daura, Katsina State (RUWASSA), K.K. Company Sokoto State and Sokoto State Water Board.

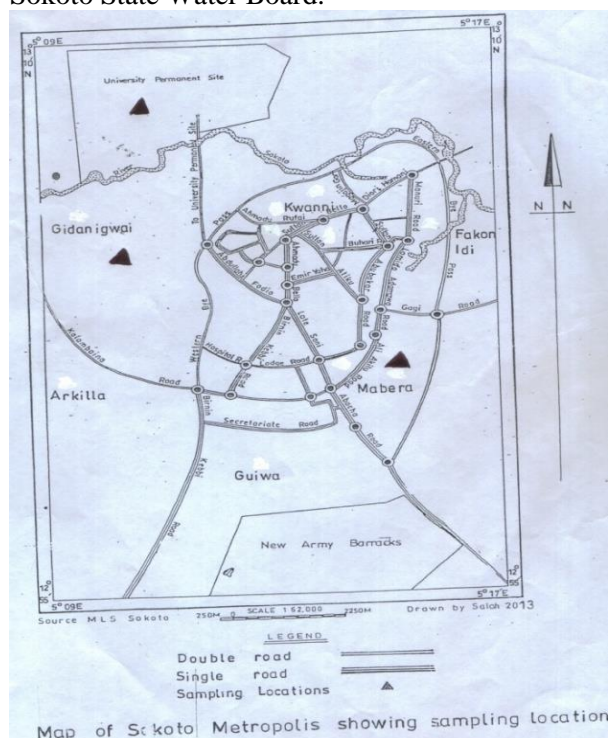


Figure 2.1: Map of Sokoto Metropolis Showing Sampling Locations.

2.3 Biomarker Analysis

The principle requirements in biomarker analysis are identification and quantification of individual compounds or families of components. To facilitate these objectives, biomarker need to be liberated or extracted from the sediment, rocks matrix or petroleum and subsequently, the complex mixture obtained needs to be simplified to a sufficient degree that individual constituents can be characterized (Brassel and Eglinton, 1993). The biomarkers used for this analysis are as follows: n-alkanes, hopanes, stranes, phenantrenes, methyl-phenantrenes, and triaromatic steroids.

2.3.1 Soxhlet Extraction

The biomarkers extraction was done using Soxhlet extractor. 70 g of the samples was placed into an extraction Thimble. The solvents used for the extraction are Dichloromethane and Methanol (93 % and 7% respectively). Each sample was extracted for 24 hrs. Rotary evaporator was used for the evaporation of the solvent to very minute quantity. Column Chromatography was done for the recovery of aliphatic and aromatic hydrocarbons.

2.3.2 Column Chromatography

5.00 cm³ beaker was properly washed and rinsed with the solvent (Methanol). After drying, 50.0 mg of the extract was loaded on the alumina and then mixed until it was uniformly distributed in the alumina. The column was rinsed with n-hexane and

small piece of cotton wool was inserted. 10.00 g of silica gel was wetted with n-hexane and packed into the column as a stationary phase. 1.00 cm³ thick layer of alumina was added on the alumina then the sample was then covered with another 1.00 cm³ layer of alumina. Saturated hydrocarbons were eluted by using n-hexane while aromatic hydrocarbons were eluted using mixture of n-hexane DCM (70:30 cm³).

2.3.3 GC/MS Analysis

Saturated and aromatic hydrocarbon fractions from the column chromatographic fractionation of the rocks bitumen were analyzed by GC/MS at selected ion monitoring mode. The GC oven was programmed from 50⁰C (held for 5 min.) and raised at 7⁰C/min to 300⁰C where it will be held for 30min. Compound were identified from their retention times in comparison to published mass Chromatograms (Peters *et.al.* 2005).

2.3.4 Formulae for the Computation of Biomarker Parameters

Biomarker parameters used as indicators of the source environment or the thermal maturity of source rock and or soil. These paramters were calculated using some mathematical formulae (Bray and Evans, 1961; Moldowan *et.al.*, 1994; Ficken, 2000).

n- Alkanes Formulae

- CPI=[2(C₂₃+C₂₅+C₂₇+C₂₉)/[C₂₂+2(C₂₄+C₂₆+C₂₈)+C₃₀]I
- OEP=(C₂₁+6C₂₃+C₂₅)/4(C₂₂+C₂₄).....II
- Dew=Σ(C₂₁-C₃₁)/Σ(C₁₅-C₂₀).....III
- Pr/Ph=n-C₁₇/n-C₁₈.....IV
- Paq=(C₂₃+C₂₅)/(C₂₃+C₂₅+C₂₉+ C₃₁)..... V

Table 2.3 n-alkanes Identified by GC/MS

Carbon No.	Name	Molecular Formula
C15	n- Pentadecane	C15H32
C16	n- Hexadecane	C16H34
C17	n- Heptadecane	C17H36
C18	n- Octadecane	C18H38
C19	n- Nonadecane	C19H40
C19 (Pr.)	2, 6, 10,14- tetramethyl pentadecane	C19H40
C20	n- Icosane	C20H42
C21	n- Henicosane	C21H44
C22	n- Docosane	C22H46

C23	n- Tricosane	C23H48
C24	n- Tetracosane	C24H50
C25	n- Pentacosane	C25H52
C26	n- Hexacosane	C26H54
C27	n- Heptacosane	C27H56
C28	n- Octacosane	C28H58
C29	n- Nonacosane	C29H60
C30	n- Triacontane	C30H62
C31	n- Hentriacontane	C31H64
C32	n- Dotriacontane	C32H66

3.0 RESULT

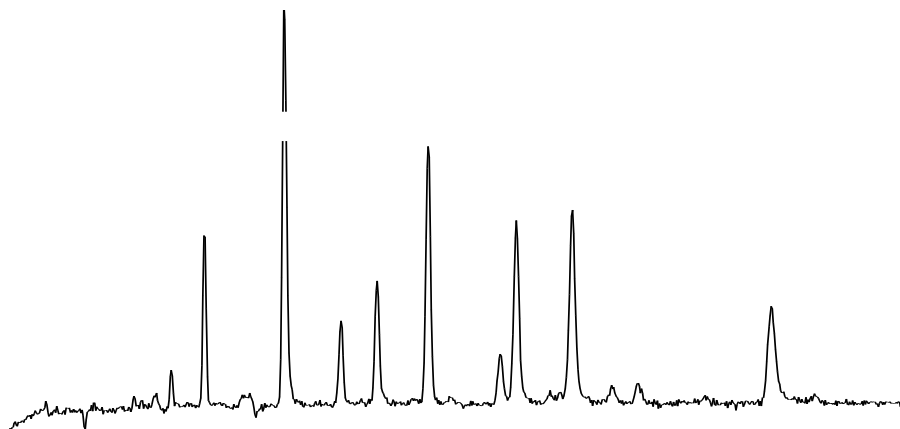
3.1. The results of the analyses obtained from this research are presented in this chapter.

Table 3.1 shows the quantity of the bitumen in all the samples which indicated that the percentage yield of all wells is >1

Table 3.1: Weight of the shale's Used for the Extraction and Weight of Extract obtained

Table 3.1: Weight of the shale's Used for the Extraction and Weight of Extract obtained

Sample	Depth(m)	Weight of extract(g)	%extract
ERC A	40	1.12	1.74
ERC B	60	1.16	1.66
ERC C	80	1.15	1.64
ERC D	100	1.16	1.66
MIN±SD	70±26	1.15±0.23	1.68±0.04
AGIC A	35	1.01	1.44
AGIC B	55	1.11	1.57
AGIC C	75	1.14	1.63
AGIC D	95	1.21	1.73
MIN±SD	65±26	1.12±0.08	1.59±0.12
MBRSL A	45	0.76	1.09
MBRSL B	65	0.81	1.14
MBRSL C	85	0.91	1.3
MBRSL D	105	0.93	1.33
MIN±SD	75±26	0.85±0.08	1.22±0.11
RSBJM A	35	0.88	1.26
RSBJM B	55	0.89	1.25
RSBJM C	75	0.93	1.33
RSBJM D	95.00	0.39	2.00
MIN±SD	65±26	1.02±0.26	1.46±0.36

Figure 3.1: Representative m/z 85 mass chromatograms Showing Distribution of n-AlkanesKey: a, b, c, d, e, f, and g are C₁₅, C₁₆, C₁₉, C₂₃, and C₂₇ n-alkanes respectively**Table 3.2: Result of n-Alkanes Biomarker Parameters**

	CPI	OEP	Pr/ Ph	DEW	Paq
ERC A	0.82	0.80	0.39	1.70	1.00
ERC B	0.80	0.19	0.33	0.61	1.08
ERC C	ND	ND	ND	ND	ND
ERC D	0.74	0.94	0.83	0.35	1.00
MIN±SD	0.79±0.04	0.64±0.30	0.52±0.30	0.89±0.06	1.00±0.02
AGIC A	0.41	0.61	0.06	1.68	1.00
AGIC B	0.41	0.61	0.06	1.68	1.00
AGIC C	1.41	1.02	1.05	2.77	0.36
AGIC D	2.31	1.15	1.63	2.36	0.52
MIN±SD	0.91±0.40	0.85±0.20	0.70±0.06	2.12±0.50	0.72±0.30
MBRSL A	1.41	0.83	1.14	1.78	0.58
MBRSL B	2.31	0.83	0.69	1.78	0.58
MBRSL C	1.30	0.53	3.31	1.22	0.67
MBRSL D	1.32	0.83	0.69	1.78	0.58
MIN±SD	2.09±0.10	0.76±0.10	1.46±0.60	1.64±0.20	0.60±0.02
RSBJM A	1.14	1.00	3.62	0.80	0.67
RSBJM B	ND	ND	ND	ND	ND
RSBJM C	1.14	0.88	0.36	2.00	1.00
RSBJM D	ND	ND	ND	ND	ND
MIN±SD	1.14±0.02	1.94±0.01	1.99±0.30	1.40±0.10	0.84±0.20

4.0 DISCUSSION

The results obtained from the GC/MS analyses of the rocks samples were used to ascertain the

source organic matter, depositional environment, depositional condition and thermal maturity of the organic matter. Results obtained from these analyses were presented in table 3.1 (weight of the source rock and percentage organic matter). Table 3.2 (result of n-alkanes biomarker parameters), Figure 2.1 (Map of Sokoto Metropolis Showing the Sampling Locations), Figure 3.1 (Representative m/z 85 Mass Chromatograms Showing Distribution of n-Alkanes). The GC/MS analyses were conducted for both aliphatic and aromatic fractions through Selected Ions Monitoring (SIM) GC/MS method of analysis which revealed the presence of many hydrocarbon compounds known to be present in petroleum. The compound included to be n-alkanes (m/z 85).

The distribution of n-alkanes in crude oils, source rocks, shales and coals can be used to indicate the organic matter source (Duan, 2011). For example, the increase in the n-C₁₅ to n-C₂₀ suggests marine organic matters with contribution to the biomass from algae and plankton (Peters and Moldowan, 1993). Rocks samples characterized by uniformity in n-alkanes distribution patterns suggest that they are related and have undergone similar histories with no signs of biodegradation (Ficken *et. al.*, 2000; Duan and Ma, 2001). Since all the samples analyzed show abundance of n-alkanes from C₁₅ to C₂₀, the source organic matter is from marine organic matter with contribution to the biomass from algae and plankton. This can also be assessed by carbon preference index (CPI) which is the ratio obtained by dividing the sum of the odd carbon-numbered n-alkenes to the sum of the even carbon numbered n-alkanes.

However, CPI is affected by both source and maturity of crude oils (Tissot and Welte, 1984). CPI of about 1.00 generally shows no even or odd carbon preference and indicates marine organic matter. Also, it can be used in source identification. The degree of waxiness can be expressed by the $\Sigma C_{21}-C_{31}/\Sigma C_{15}-C_{20}$ ratios. The rocks characterized by high abundance of n-C₁₅ to n-C₂₀ n-alkanes in the saturate fractions reflect low wax (Moldowan *et. al.*, 1994).

The degree of waxiness <1 reveals low waxy nature and suggests marine organic sources (Peters and Moldowan, 1993) of higher plants deposited under reducing conditions. This means that, the well from ERC with DEW value 0.89 ± 0.06 indicates the low degree of waxiness and they are from marine organic source whereas wells from AGIC, MBRSL and RSBJM with DEW values 1.90 ± 0.10 , 1.64 ± 0.20 and 2.12 ± 0.05 show higher DEW contained. Both pristine (2,6,10,14- tetramethylpentadecane) and phytane (2,6,10,14- tetramethyl hexadecane) are derived from the phytol side chain of chlorophyll, either under reducing conditions (phytane) or oxidizing conditions (pristane).

Alkane proxy (Paq) is another parameter used for the assessment of the origin of organic matter (Ficken *et. al.*, 2000), Paq values of 0.01-0.23 are from terrestrial plant wax and 0.48-0.94 are of floating species of macrophyte. The values obtained are 1.00, 0.79, 0.60 and 0.84 respectively which are greater than 0.48 and this shows that they are from floating species of macrophyte.

Also terrigenous versus aquatic ratio (TAR) n-alkane ratio is another parameter for vital source organic matter (Ficken *et. al.*, 2000). The value from 3.30-4.00 are from marine algae organic matter. The obtained values are less than 4.00 which indicates marine algae organic matter origin (Faramawy *et. al.*, 2010)

The depositional environment can also be determined by the use of alkanes proxy (Paq.) parameter (Ficken *et. al.*, 2000). The values ranging from 1-2 indicate aquatic depositional environment reducing condition (Anoxic condition). The values obtained from these analyses range from 0.60 ± 0.30 - 1.00 ± 0.02 which indicate aquatic depositional environment, reducing condition (Anoxic condition).

Depositional environment can also be assessed by the values of odd-even predominance (OEP) obtained (Hunt, 1996) and this reveals that value <1 are aquatic depositional environment, reducing condition (Anoxic condition). The values obtained from these analyses range 0.60 ± 0.30 , 0.76 ± 0.01 and 0.85 ± 0.25 for well ERC, MBSL and

respectively, and 1.94 ± 0.03 for well RSBJM which indicates aquatic depositional environment.

CPI is another important biomarker parameter which indicated depositional environment and depositional condition of the organic matter i.e. lacustrine depositional environment (Hunt, 1996). The values obtained from this analysis range from 0.97-2.09 which indicated lacustrine depositional environment.

5.0 CONCLUSION

The Geochemical investigations conducted on the rocks samples obtained from Sokoto basin has revealed the presence of different biomarkers, such as n-alkanes, phenantrenes, hopanes, sterenes, and triaromatic steroids. The biomarker parameters calculated indicated that the percentage bitumen extract obtained from the shale samples revealed that the shales are rich in organic matter and the source organic matter of the shales are from marine organic sources and are deposited under reducing condition (Anoxic condition) and finally the biomarker parameters calculated indicated that the shales in Dukamaje formation are thermally immature.

RECOMMENDATIONS

By considering the results obtained from the geochemical analyses of the sample investigated. The following recommendations are put forward:

- i. More work should be done on geochemical analyses in other formations of the Sokoto basin.
- ii. Geochemical analyses should be carried out from other part of the basin which has not been covered in this research, particularly by the use of Rock-Eval pyrolysis, Total organic carbon (TOC) and other biomarker parameters such as porphyrins, adamantane e.t.c.

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