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Hydrocarbon Source Rock Potential of the Lacustrine Black Shale Unit, Mamfe Basin, Cameroon, West Africa

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Abstract

The potential for conventional and/or unconventional hydrocarbon exploration requires the presence of organic-rich, thermally mature rock units containing oil or gas-prone kerogen. Thick black, organic rich shale intervals are well exposed along roadside cuts and river banks at several localities in the eastern part of the Mamfe Basin. Earlier described as anoxic lake bottom deposits, these fine grained rocks constitute the probable pod of active source rock in this basin and belonging to the middle stratigraphic unit of the three that make up the basin's sedimentary fill. Samples collected from representative outcrop sections (Etoko mile 21, Bachuo Ntai, and Satom Bridge) in the study area were subjected to geochemical analytic techniques; Total Organic Carbon (TOC), Rock-Eval Pyrolysis and Vitrinite reflectance (%Ro) values were calculated. TOC data obtained range from 1.06% to 16.10% indicating good to excellent hydrocarbon generative potentials, Rock-Eval Pyrolysis data plotted along Kerogen Types I, II and III with oil and gas generative potentials. 4 out of 9 samples fall within the oil window from the calculated %Ro while temperatures corresponding to the peak of kerogen pyrolysis (Tmax) and Production Index (PI) for the 9 samples range from 398°C to 463°C indicating that the organic matter (OM) are immature to post mature. The black shale unit of this part of the basin therefore contains very high amounts of good to excellent quality of thermally matured organic matter which can produce and expel oil and gas respectively.

Keywords: Kerogen, Mamfe Basin, Rock-Eval pyrolysis, source rock, Total organic carbon (TOC), Vitrinite Reflectance (%Ro)

1. Introduction

With records showing a recent steady decline in the country's oil production from current producing permits within the marine coastal sedimentary basins and in an effort to boost this very important sector of her economy, the government of Cameroon recently accorded hydrocarbon exploration permits for prospection activities to begin in new areas. Two areas concern in this bid include, the Mamfe Basin in the south west, the Garoua and the adjoining Koum Basins respectively in the north of the country (Figure 1).

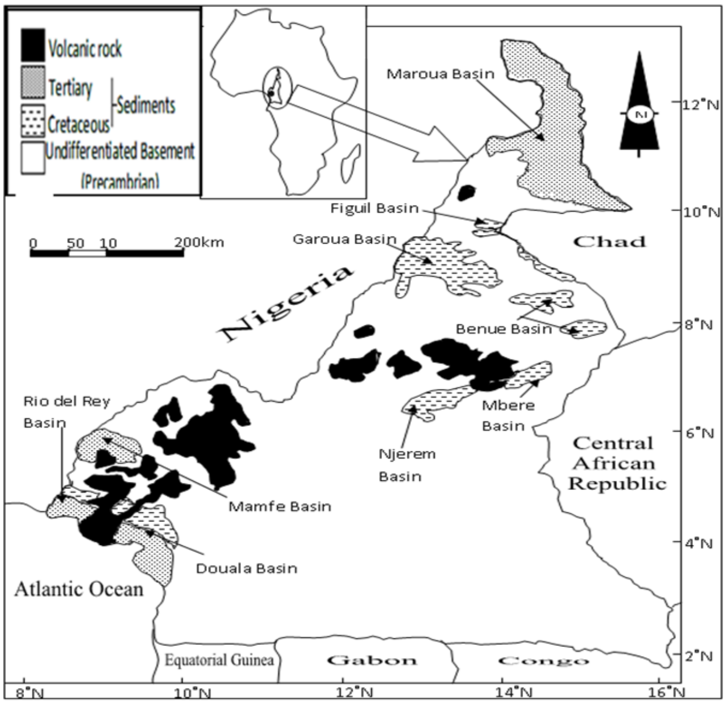

Figure 1. Map of Cameroon showing the Mamfe and Garoua Basins among other sedimentary basins, note the two only currently producing Atlantic coastal basins: Douala/Kribi-Campo and Rio del Rey

Cameroon's oil and gas is currently produced from offshore fields of the two coastal sedimentary basins; the Douala/Kribi-Campo and the Rio del Rey (Figure 1), in which geological investigations have been more advanced. On the contrary, the geology of the hinterland basins has hitherto been relegated to the background but is gaining pace especially in the Mamfe Basin, following the recent discovery of exploitable mineral deposits like lead, zinc, rutile and sapphire Lapplaine and Soba (1967), Du Mort (1968), Ndougsa-Mbarga, Manguelle-Dicoum, Campos-Enriquez and Atangana (2004) , Kanouo (2008), Kanouo te al. (2012), Nguimbous-Kouoh, Takougam, Nouayou, Tabod and Manguelle-Dicoum (2012) and now, its eminent petroleum prospectivity has attracted this work and others.

The Mamfe Basin (Du Mort, 1968) is a low altitude region located in the Manyu Division of the South West Region and lies between latitude 5°30 and 6 °00' and longitude 8°45 and 10°00. It is oriented in a NE-SW trending direction, measuring 130km in length and a widest part is about 60 km and covering a total surface area of 2400 km^2 The basin stretches across the Cameroon-Nigerian boundary to join the Benue Trough in the west and is bordered by the Obudu and Oban Massifs, respectively in the north and south (Figure 2), while in the east, it narrows and disappears under the Bamenda Highlands which forms part of the Cameroon Volcanic Line (CVL).

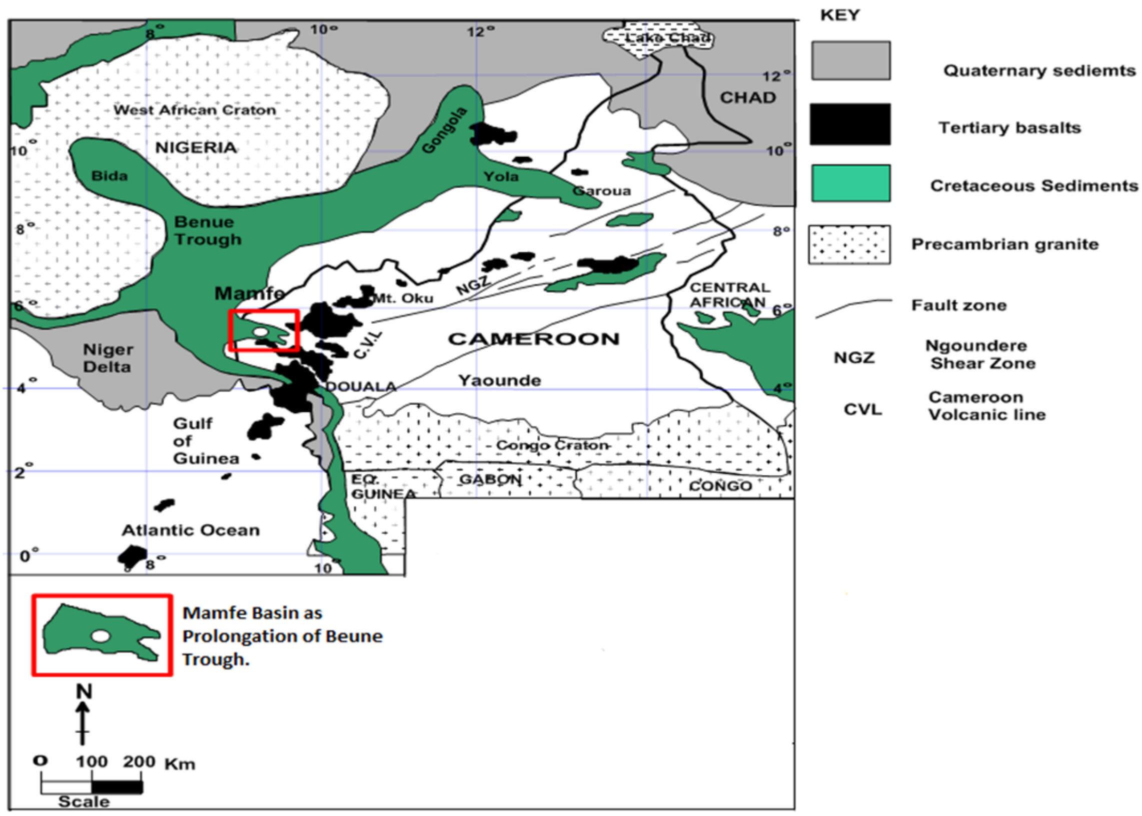

Figure 2. A regional geologic map of the central part of the Gulf of Guinea showing location of the Mamfe Basin among other geologic structures; the Benue Trough and the CVL

Preliminary geological studies; Wilson (1928), Le Fur (1965), Dumort (1968), Hell, Ngako, Bea, Olinga, and Eyong (2000), Eyong, (2001), Eyong (2003), Eyong, Wignall, Fantong, Best and Hell (2013), and geophysical surveys; Fairhead and Okereke (1987), Benkhelil (1989), Kangkolo and Ojo, 1995, Manguelle-Dicoum, Nouayou, Tabod, and Kwende-Mbanwi (1999), Fairhead, Okereke, and Nnange (2004), Ndougsa-Mbarga, et al. (2007), Abolo (2008), kangkolo (2008), Kanouo (2008), Tabod, Tokam-Kamga, Manguelle-Dicoum, Nouayou and Nguiya (2008), Kanouo et al., 2012, Nguimbous-Kouoh et al., 2012, have indicated that predominantly thickly folded and fractured fluviatile to deltaic cross stratified conglomeratic sandstones, intercalated by thick beds of black organic rich lacustrine carbonaceous rocks and thin beds of carbonates and evaporites make up the Mamfe Basin sedimentary fill. Hydrocarbon prospectivity in the Mamfe Basin like any other basin must rely essentially on the presence of oil and/or gas-prone rock units which should have generated and expelled hydrocarbons. Other nearby basins, like the continental fluvio-lacustrine Chad Basin, is presently a prolific hydrocarbon producer while the adjoining Benue Trough of Nigeria to which the Mamfe Basin is genetically linked, is also known to be prospective. The current government action is therefore expected to awaken more studies in the basin especially geared toward hydrocarbon exploration.

The present work is aimed at contributing to the hydrocarbon exploration activities that have been initiated by the National Hydrocarbon Co-operation on behave of the government. This consist of mapping and collecting samples from the sedimentary sequences that are exposing the black organic rich rock strata in the eastern half of the Mamfe Basin, and subject the selected samples to geochemical analytical techniques so as to assess (I), how rich the rocks are in organic matter content from Total organic carbon content (TOC) analysis, (II), the quality or type of organic matter (kerogen) from which either oil or gas or both could have been produced (Rock Eval Pyrolysis) and (III), Vitrinite reflectance (%Ro) values and burial temperatures (Tmax) calculated, all of which will assist in the assessment of these rocks for their potentials to generate and expel the oil and/or gas expected to be found in the Mamfe Basin. The fine grained rock sequences from which samples were obtained and used in this work belong to the Late Cenomanian-Turonian middle unit of the three that make up this basinal fill. They are said to have been deposited in an anoxic deep lake bottom environment Njoh, Nforsi, Datcheu (2015).

2. Geology Of The Mamfe Basin

2.1 Tectonic Setting

The Mamfe sedimentary basin is a rift basin that was initiated by the response of the Precambrian basement of this region to the break-up of Gondwana and subsequent separation of South American from the African continental plate (Cratchley and Jones, 1965, Olade, 1975, Benkhelil, 1989, Ndougsa et al., 2004, Nguimbous-Kouoh et al., 2012). Like other rift basins of this sub-region, the Mamfe Basin is part of the West Central African Rift System (WCARS) that is intimately associated with the opening of the South Atlantic Ocean and the formation of the Gulf of Guinea (Petters, 1978; Fairhead and Green, 1989, Eyong, 2013). During its formation, this basin appeared as a bifurcation or an eastern tectonic arm that extended eastward from the south-eastern portion of the Benue Trough into the south-western part of Cameroon (Figure 2). It should be noted that, like the Mamfe Basin in the south-east, a second arm also extended eastward into Cameroon, but from the north-western portion of the Benue Trough, known as the Garoua Basin.

The Mamfe Basin evolved through several tectonic stages and can be summarized (Table 1) as follows:

Table 1. Stages of tectonic evolution in the Mamfe Basin (Modified from Abolo, 2008)

	Phase	Event	Age
1	Eo-rift	characterized by the initial rifting and possible deposition of the first alluvial fan conglomerates	Barriasian-Pre Barremian
2	Syn-rift and subsidence	rifting and alluvial fan conglomerates deposition continued together with fluvial sandstones and lacustrine shales	Barremian-Early Albian and Late Albian-Cenomanian
3	Post-rift-1	folding, faulting and erosion in responds to the Abakaliki tectonic event in Nigeria.	Santonian-Early Campanian
4	Post-rift-2	all other events that occurred during the latest Cretaceous and beyond; continued erosion, magmatization and possibly uplift.	Late Cretaceous and beyond

It is implied from this table that even after the initial rifting events, the basin continued to sag and deepens as more sediments were deposited. Deposition might have ended during the Cenomanian-Turonian, but later tectonic events in the neighboring Benue Trough of Nigeria (Freeth, 1990) further superimposed the folding and faulting that characterized both the sedimentary and basement rocks of the Mamfe Basin.

Gravity anomalies data (Ndougsa-Mbarga et al., 2007) indicate that the basin has a complex structure. It is made up of three sub-basins; a west, middle and east sub-basins respectively separated by structural highs and that this basin generally shallows to the east. The basin is underlain and fringed by reactivated, fault-bounded granito-gneissic rocks of the Pan-African Mobile Belt (550 ± 100 Ma) and are both intruded by Tertiary anorogenic and effusive basic intermediate rocks such as syenites, diorites, trachytes and basalts that belong to the CVL (Njonfang and Moreau,1996 and Eyong et al., 2013). Wilson (1928,; Le Fur (1965), Dumort (1968) and Eyong et al.. (2013) noted foliated augen gneisses which occur in association with N–S tectonized leptynite bands in Bokwa and Kendem Villages to the east, a mylonitic zone that outcrops at Ekonemann-Awa to the SW region of the basin and migmatites found at the fringes of syn-tectonic granite intrusions of Pan-African age.

2.2 Stratigraphic Framework

The lithostratigraphic framework of the Mamfe Basin was initiated by the early authors; Wilson (1928), Le Fur (1965), Dumort (1968) and Petters (1978). Further and most recent publications are marked by gross inconsistencies in the manner in which each author sub-divides and present the framework of the sedimentary deposits of this basin. Le Fur (1965) had earlier recognized and sub-divided these rocks into five units (Series) which were identified as C1 to C5 respectively from base to top. IRGM/DYU1 (2000) recognized only three units (unspecified) that were later on supported by Abolo, 2008, who packaged the entire 4000m thick sedimentary infill of the Mamfe Basin into a single formation made up of three members. Eyong et al. (2013) on the other hand sub-divided these same rocks into five formations some which were further sub-divided into several members. Bassey et al. (2013) further compounded the controversies by recognizing only two members from a lone Mamfe Formation.

However, preliminary outcomes of current research aimed at appropriately correcting the framework of the Mamfe Basin are pointing to three fundamental stratigraphic units (formations) for this basin. Until these findings are published, it is generally agreed by many that the rocks of this basin can best be sub-divided into three units (formations or members); a lower alluvial fan conglomerate to a fluvial channel cross bedded conglomeratic sandstone, a middle predominantly repeated sequences of alternating black shales, limestones sandstone and evaporates (lacustrine) and another fluvial sandstone unit at the top of the basin (Figure 3).

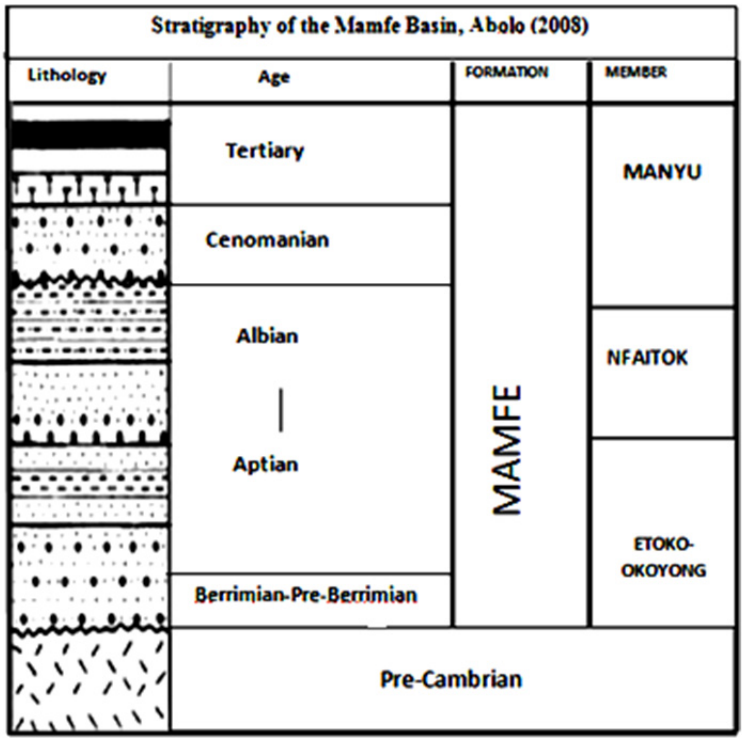

Figure 3. Stratigraphy of Mamfe Basin (Abolo 2008) showing three members of the lone Mamfe Formation lying on the Pre-Cambrian basement rocks

These sediments have been intruded by igneous rocks, folded and faulted by post depositional tectonic events.

3. Materials and Matrials

Out of the many outcrop sequences encountered during the field phase of this study, three representatives sections were chosen, lithologically described and sampled. 9 samples were thereafter selected, 3 from each section and subjected to the geochemical analyses.

Organic geochemical analyses performed include total organic carbon (TOC) and Rock-Eval pyrolysis (RE) were carried out in the laboratory of GEOMARK RESEARCH LTD, Huston USA. The TOC of the samples was analyzed using the LECO CR-412 Carbon analyzer. O.35g of each sample was dried, ground and homogenized and after treatment with acid to remove any inorganic carbon from carbonates, the sample was placed in an auto sampler sack before loading into the instrument. Each sample is then combusted in the presence of excess oxygen, allowing carbon dioxide to form from the free organic carbon in the rock. The amount of carbon dioxide is directly proportional to the amount of organic carbon or the TOC of the rock. The values in wt% were considered as the hydrocarbon generative potential of each rock sample analyzed.

The Rock-Eval pyrolysis technique used in this study is based on the method described by Espitalie., Laporte., Madec, Marquis, Leplat and Paulet (1977) Espitalie, Deroo and Marquis (1985 & 1986), Peters (1986), and Riedeger (1991). The pyrolysis method consists of a programmed temperature heating in a pyrolysis oven in an inert atmosphere (helium) of small samples weighed each at 100 mg. Each sample is heated at a rate of 25°C/min between 300° and 600°C to yield the amount of volatile hydrocarbons present in the sediment (S_1), the amount of hydrocarbons released during pyrolysis (S_2), and the amount of CO_2 released during heating to 390°C (S_3). These values were then combined with TOC values to provide the information that was used to calculate the hydrogen index (HI = 100 x S_2/TOC in milligrams hydrocarbon per gram of TOC) and the oxygen index (OI = 100 x S_3/TOC in milligrams CO_2 per gram of TOC). The temperature of maximum hydrocarbon release during pyrolysis (T_{max}) was also obtained for the organic matter thermal maturity. Values for Vitrinite Reflectance (%Ro) were calculated using the mathematical formula; %Ro = 0.0180xTmax-7.16 after Jarvie (1991).

4. **Results and Interpretations**

4.1 Lithology

The three sections selected to characterize the study area include; the Satom Bridge (ST), Bachuo Ntai (SB) and Etoko mile 21 (SE) outcrops respectively from west to east. The Satom Bridge outcrop occurs along the right bank (facing upstream) of River Manyu near Mamfe Town with coordinates, N 05^0 45΄ 56.4”, E $009^0$18’37.1”and elevation of 55m above msl. It extends continuously from downstream to below the bridge and for over 2km upstream to include the John Holt beach upstream. At the bridge, 9m of sediments are exposed comprising black organic rich shale frequently alternating by thin to moderately thick limestone beds. Very black shales, sometimes lignite, predominates the lower section of this outcrop. Thin limestone beds occur frequently within this lower shale section but they become dominant at the upper part where the shale and limestone are almost equally inter-bedded. Shale laminations are also observed within the almost pure limestone beds. The shale beds from which the samples analyzed were collected present visible dispersed particles of organic matter (Figure.4).

A typical fining upward sequence of sediments is exposed near Bachuo Ntai village along the steep slope of a hillside behind this village. The lower part of this section comprises considerable thick black shale beds alternating with limestones while the top part is capped by silty to conglomeratic poorly to moderately sorted sandstone beds.

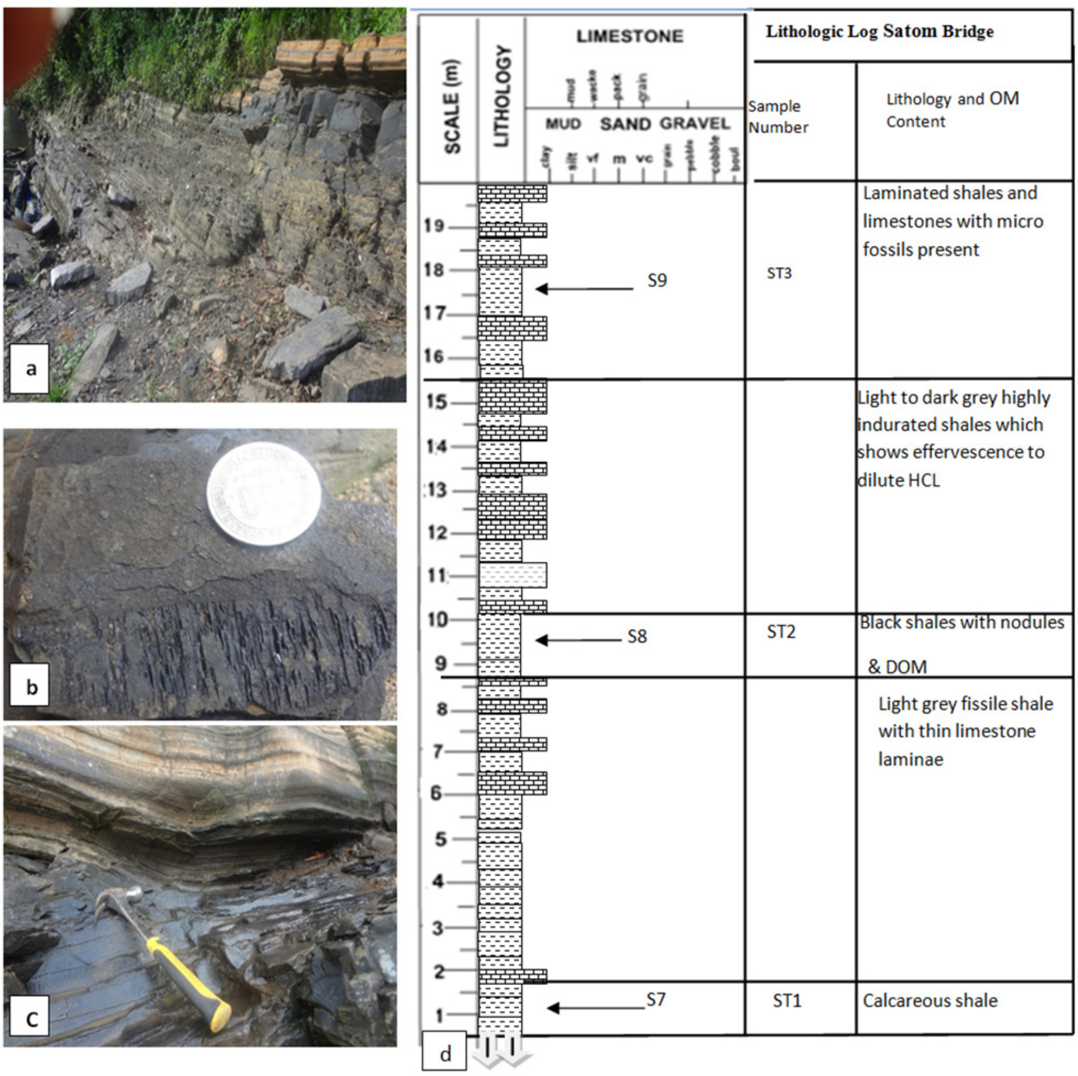

Figure 4. Part of the Satom Bridge outcrop; a) the lower part showing black shale and limestone, b) a lignitic layer and c) a limestone overlying a shale bed but note thin shale beds within the limestone

At Etoko mile 21, a sequence of black shale beds alternating with sandstones and thin limestone beds is exposed at a roadside cut about a km away from Etoko village on the road to Nchemba. Occurring on both sides of the road, this outcrop extends for about 700m and 10m high at the sample point. The shale beds like those observed at the ST location, show particles of organic materials and some are lignitic and nodular.

4.2 Organic Geochemistry

The results of the total organic matter content (TOC) and Rock-Eval Pyrolysis (RE) for the studied samples are presented on Table 2.

Table 2. Results of TOC/Rock-Eval Pyrolysis for the three outcrop samples from the study area.

Project/Sample ID	**Rock ID**	**Upper/Median Depth (m)**	**% Carbonate**	**LECO TOC** Wt%	**Rock Eval-2 S1** (mg HC/g)	**Rock Eval-2 S2** (mg HC/g)	**Rock Eval-2 S3** (mg $C0_2$/g)	**Rock Eval-2 Tmax** (‘C)
RBUE-150301-001	SB1	1.00	23.84	1.15	0.17	0.05	0.20	0(398)
RBUE-150301-002	SB2	2.00	24.26	1.06	**0.08**	**0.01**	0.15	0(398)
RBUE-150301-003	SB3	3.00	20.08	1.13	0.64	0.70	0.40	428
RBUE-150301-004	SE1	4.00	8.03	1.64	0.19	0.91	**0.09**	463
RBUE-150301-005	SE2	5.00	20.15	1.57	0.18	0.07	0.14	0(398)
RBUE-150301-006	SE3	6.00	22.28	1.50	0.17	0.11	0.20	0(398)
RBUE-150301-007	ST1	7.00	58.16	3.87	1.24	15.02	0.46	446
RBUE-150301-008	ST2	8.00	45.24	**16.10**	**11.27**	**73.97**	1.14	442
RBUE-150301-009	ST3	9.00	46.07	3.21	0.60	8.06	0.60	439

4.2.1 Total Organic Carbon (TOC)

TOC which represent the total amount of organic matter both kerogen and bitumen (expressed as a percentage by weight), present in a petroleum source rock, is the determining factor of the ability of that rock to generate hydrocarbon (Petters and Cassa, 1994 and Hunt, 1996). The higher the TOC value, the better the potential for hydrocarbon generation. These authors have classified source rocks based on TOC as follows: source rocks with wt% TOC values between 0.00-0.5 wt% are said to have poor generative potentials or are simply classified as poor, those with TOC range between 0.5 and 1.0wt% are fair, 1.0 and 2wt% are considered as good and a range of 2-3wt% and considered to be very good. The perfect hydrocarbon source rocks with excellent generative potentials, are those with TOC values >5wt%.

The analyses carried out in this work revealed that TOC (wt%) of the samples from Bachuo Ntai (SB) section ranges from 1.06 to 1.15, Etoko mile 21 (SE) section ranges from 1.50 to 1.64 while it ranges from 3.21 up to 16.10. Overall TOC for the study area ranges between 1.06 and 16.10wt%. Therefore, all the sedimentary sections from which samples were collected and analyzed from both Etoko and Bachuo Ntai are good potential hydrocarbon source rocks, samples ST1 and ST3 from Satom bridge are very good while sample ST2 represents an excellent hydrocarbon source rock (Table 2).

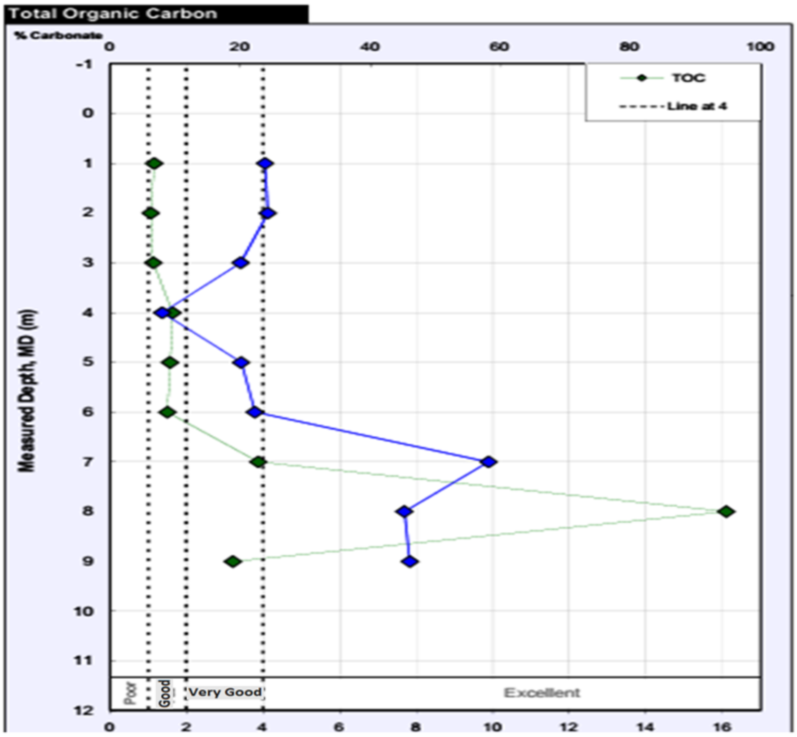

Figure 5. Diagram showing good to excellent wt% TOC values of 9 samples analyzed

However, Tissot, Durand and Espitalie. (1974), Demaison and Shibaoka (1975) and Dow (1977) noted that the measurement of organic carbon in sediments alone is insufficient to identify potential oil source beds. This is because transported terrestrial organic matter, oxidized aquatic organic matter, and reworked organic matter from a previous sedimentary cycle can create levels of organic carbon in sediments up to about 4%. Yet this organic matter is hydrogen poor, gas-prone, and without significant oil generating.

4.2.2 Kerogen Type Or Quality of Organic Matter

The Rock-Eval Pyrolysis technique provides data on the quantity, type, and thermal maturity of the associated organic matter. The data obtained from this technique are presented above (Table 2). These values were compared with TOC values to provide the necessary information from which the Hydrogen Index (HI) and Oxygen Index (OI) can be calculated (Table 3 and 4). It is however necessary also to understand that the amount of organic hydrogen is essentially controlled by the nature (type or quality) of the organic matter present in the sediment. Thus, the 4 types of kerogen reflect the relative content of organic hydrogen and the distinct biological source materials.

From the table above (Table 2), plotting the HI versus the OI of each sample analyzed in this work on the modified Van Krevelen diagram, the hydrocarbon content of the samples plot along Kerogen Type I, II and III as shown on the Figure 6.

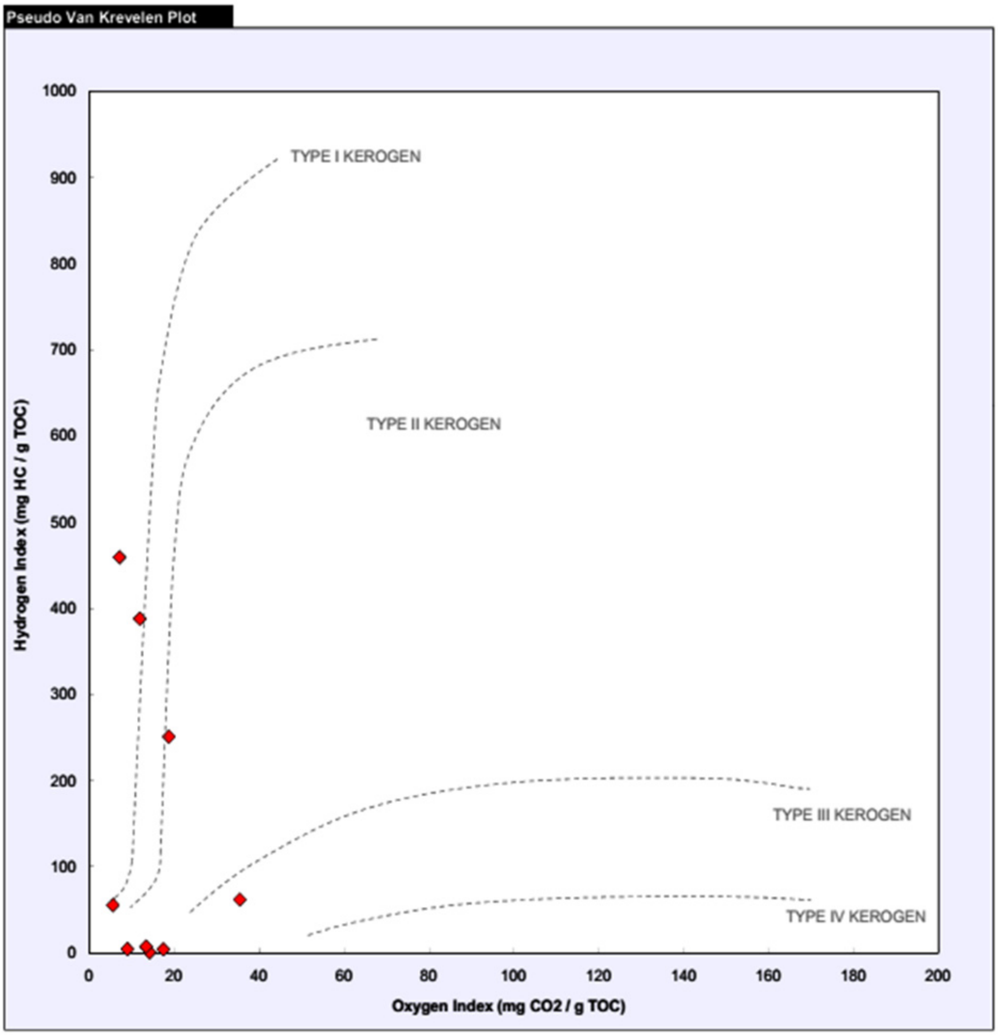

Figure 6. Modified Pseudo Van Krevelen Plot of HI/OI for different kerogen types in the samples determined by Rock Eval Pyrolysis

The Rock Eval Pyrolysis enables the prediction of hydrocarbon type that could be generated from useful parameters measured like Hydrogen Index (HI) and S2/S3 concentrations (mg HC/g). According to Peters (1986), Peters & Cassa (1994), Hunt (1996) and Dahl et al. (2004), the ratio S2/S3 is proportional to the amount of hydrogen in the source rock and is an indicator of the oil and gas generative potential. The resultant Hydrogen index and S2/S3 ratios obtained from the Rock Eval analysis of the samples is presented Table 3. HI results of six rock samples indicates that shales at Batcho Ntai locality are likely to produce only gas, two samples from Satom show oil with one sample from Satom showing gas and oil. On the hand, S2/S3 concentrations of five samples indicate gas prone (Etoko and Bachuo Ntai) and all S2/S3 concentrations in Satom locality show oil.

4.2.3 Thermal Maturation

Tmax, Vitrinite Reflectance (%Ro) and Production index (PI) are valuable Rock Eval estimates combined to determine the thermal maturity of organic matter in rock samples. Ranges for hydrocarbon source rock evaluation parameters for Rock-Eval/TOC Pyrolysis data as modified from Peters (1986) are summarized as follows; Production Index (PI) also known as transformation ratio, which is the proportion of the hydrocarbon already generated during (S1) and that generated at (S2) mathematically represented as [S1/(S1+S2)] and is related to the type and thermal maturation of organic matter (Tissot and Welte, 1984). According to Hunt (1996), PI values of 0.1, indicates the beginning of a considerable amount of oil generation and 0.4 indicates termination of oil generation and initiation of gas generation. Calculated from (Table 4)

Table 3. Source rock type based on HI and S2/S3 ratios; after Peters (1986)

<table>
<tr><th>Rock ID</th><th>Hydrogen Index (S2×100/TOC)</th><th>Source rock type</th><th>S2/S3 Conc. (mg HC/mg C0₂)</th><th>Source rock type</th></tr>
<tr><td>SB1</td><td>4</td><td rowspan="6">GAS</td><td>0</td><td rowspan="3">GAS</td></tr>
<tr><td>SB2</td><td>1</td><td>0</td></tr>
<tr><td>SB3</td><td>62</td><td>2</td></tr>
<tr><td>SE1</td><td>55</td><td>10</td><td>OIL</td></tr>
<tr><td>SE2</td><td>4</td><td>1</td><td rowspan="2">GAS</td></tr>
<tr><td>SE3</td><td>7</td><td>1</td></tr>
<tr><td>ST1</td><td>388</td><td rowspan="2">OIL</td><td>33</td><td rowspan="3">OIL</td></tr>
<tr><td>ST2</td><td>459</td><td>65</td></tr>
<tr><td>ST3</td><td>251</td><td>GAS & OIL</td><td>13</td></tr>
</table>

Table 4. Maturity and Production Index testing data from the shale facies samples in the study area

Project/ Sample ID	**Rock ID**	**Calculated %Ro** (ReTmax)	**Hydrogen Index** (S2×100/TOC)	**Oxygen Index** (S3×100/TOC)	**S2/S3 Conc.** (mg HC/mg $C0_2$)	**S1/TOC Norm. Oil Content**	**Production Index** (S1/S1+S2)
RBUE-150301-001	SB1	0.00	4	17	0	15	0.77
RBUE-150301-002	SB2	0.00	1	14	0	8	0.89
RBUE-150301-003	SB3	0.54	62	**35**	2	57	0.48
RBUE-150301-004	SE1	1.17	55	5	10	12	0.17
RBUE-150301-005	SE2	0.00	4	9	1	11	0.72
RBUE-150301-006	SE3	0.00	7	13	1	11	0.61
RBUE-150301-007	ST1	0.87	**388**	12	33	32	0.08
RBUE-150301-008	ST2	0.80	**459**	7	**65**	**70**	0.13
RBUE-150301-009	ST3	0.74	**251**	19	13	19	0.07

above and compared with this range, the PI for the 9 samples analyzed in this study indicate both oil and gas generative capacities.

The parameters for describing the levels of thermal maturity using T(max) and %Ro ranges are represented on Table 5. Plotting the PI against the T(max) for the 9 samples analyzed in this work according to Peters (1986) as shown on Figure 7, and a majority plotted within the dry gas prone zone with two plots in the type II oil prone zone and one in mixed type II/III (oil/gas prone).Three samples which plotted in the oil zone (mature zone) are all from the Satom Bridge.

Table 5. Ranges for T (max) and %Ro for describing thermal maturity of source rocks.

<table>
<tr><td colspan="2" rowspan="2">Stage of Thermal Maturation of oil</td><td colspan="2">Maturation</td></tr>
<tr><td>Vitrinite Reflectance</td><td>Tmax</td></tr>
<tr><td colspan="2">Immature</td><td>0.2-0.5</td><td><435</td></tr>
<tr><td rowspan="3">Mature</td><td>Early</td><td>0.5-0.65</td><td>435-445</td></tr>
<tr><td>Peak</td><td>0.65-0.9</td><td>445-450</td></tr>
<tr><td>Late</td><td>0.9-1.35</td><td>450-470</td></tr>
<tr><td colspan="2">Post-mature</td><td>>1.35</td><td>>470</td></tr>
</table>

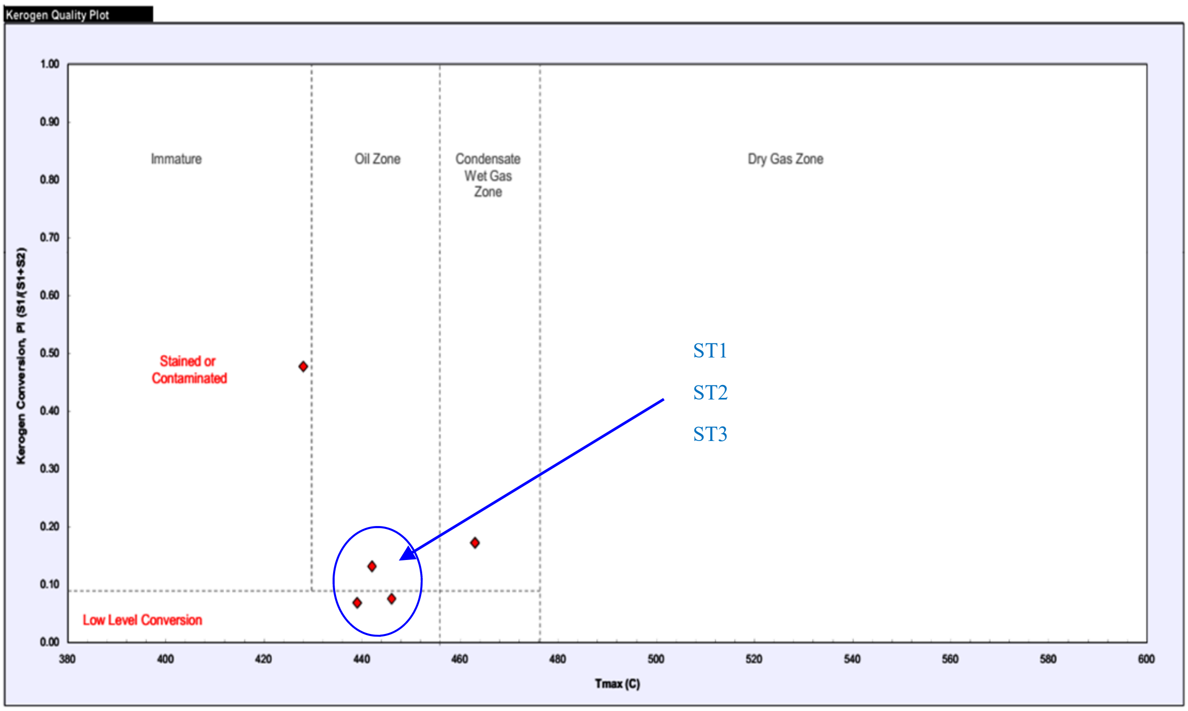

Figure 7. Maturity plot of Tmax versus PI modified from Peters (1986)

Values for Vitrinite Reflectance (%Ro) were calculated using the mathematical formula; %Ro = 0.0180xTmax-7.16 after Jarvie et al., 2001. The values obtained are expressed on the table below (Table 6) as adapted from Peters (1986).

Table 6**.** Calculated Vitrinite Reflectance of samples and levels of maturity; adapted from (Peters, 1986).

Rock ID	**Calculated %Ro** (ReTmax)	**Source rock maturation**
SB3	0.54	**IMMATURE**
		---0.6 Top of Oil Window---
ST3	**0.74**	
ST2	**0.80**	**MATURE**
ST1	**0.87**	----1.4Bottom of oil window---
SE1	**1.17**	**GAS PRONE**

From this table, all the 3 samples collected from Satom bridge and one sample from Etoko locality indicate mature source rocks at the top of oil window. One sample from Bachuo Ntai indicate an immature source rock while the calculate %Ro values for the rest of the samples were insignificant.

5. Discussion and Conclusion

The sedimentary make-up of this basin have been described as deposits of a fluvio-lacustrine setting (Ajonina and Bassey, 1997; Hell et al., 2000; Eyong, 2001, 2003, 2013; Abolo, 2006; Bassey et al., 2013; Njoh et al., 2015). Although a generally accepted lithostratigraphic framework for the basin is still being constructed, a three units sub-division of the sedimentary fill is certain and include: a lower alluvial fans to fluvial basal conglomerate and conglomeratic sandstone, a middle alternating (cyclic) aqueous to anoxic deep lake bottom black shale and limestone unit and an upper fluvial to transitional deltaic nearshore conglomeratic sandstone unit. The characteristics of these sediments generally conform with those used to identify ancient lacustrine sediments elsewhere; a combination of low energy aqueous deposits with no marine fossils, cyclic sedimentation and the presence of evaporates (Selley, 1985).

The outcrop sections from which the samples used in this study were collected belong to the middle unit of this basin. Njoh et al. (2015) have assigned to it a Mid to Late Cenomanian age based on its palynomorphs content. The very black colour of the shale, its high TOC content and organic matter quality support the obvious periodic supply of huge amounts of organic matter with fine sediments into a deep bottom lake with low oxygen concentration and preservation was as its best.

Studies have shown that there are many ancient lakes that contain organic-rich shale strata in their central parts that have generated and expel petroleum which is now trapped in sands around the old lake shoreline.

Geochemical analyses of the sediments of this unit in the Mamfe Basin reveal that they contained very high amounts of preserved organic matter that is good to excellent quality (Kerogen type I, II and III) that can generate both oil and gas. This excellent quality is most especially noted at the Satom bridge and Etoko mile 21 outcrops. The PI, T(max) and %Ro all indicated that the very oil-prone sediments are thermally very mature and so fall within the oil-window. The present petroleum geochemical data obtained has helped not only in assessing the source rock quality of these sediments but also and most importantly, helped in the identification of the stratigraphic unit which constitutes the source rock of this basin.

We can conclude here that, of the three lithostratigraphic units that make up the Mamfe Basin, the middle unit which is composed of repeated (cyclic) alternation of black organic rich shale, limestone and sandstone that were deposited in a deep anoxic lake bottom environment constitutes the probable pod of active source rock in this basin. The hydrocarbon accumulations currently being prospected for in the basin, if found, would have been generated and expelled from this unit. It is recommended that similar studies be extended to the more centrally portion of the basin in which this unit extends.

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