

PETROLEUM POTENTIAL ASSESSMENT: A CASE STUDY OF SHALLOW OFFSHORE SEDIMENT, OFF SHORE DEPOBELT, NIGER DELTA

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Abstract: *The Niger Delta, one of the World's largest Tertiary delta systems is situated in the southern part of Nigeria and it is considered one of the most prolific hydrocarbon provinces of the world and accounting for about 95% of Nigeria's total income. The increase in high demand in crude oil product, causes for exploitation and continuous search for hydrocarbon. This research focuses on using sedimentological, mineralogical and organic geochemical techniques to characterize two wells in the Niger Delta to aid exploration activities in the basin.*

A total of 108 Samples of representative ditch cuttings were collected from recently drilled wells within the Benin-Agbada Formation in OML 119, located in the shallow off-shore depobelt of the eastern Niger Delta Basin. The lithologic description of the wells revealed shale, shaley sand, sandy shale and sand at different depth intervals. The samples were subjected to petroleum generation potential analysis. Derivative values were deduce from Oil Content (SI), Oxygen Index (OI), Thermal Maturity (Tmax), Hydrogen Index (HI), Generation Potential (GP) and Production Index (PI).

These values exceeded the threshold required for siliciclastic petroleum source rocks. The HI values wells 2 and 1 ranges from and 27-139(Type III kerogen) 21-90 (Type IV Kerogen) This study show that the sediments organic matter present are capable of generating gas (gas prone).

Key Words: *The Niger Delta, sedimentological, siliciclastic, lithologic.*

1. INTRODUCTION:

The search for oil in Nigeria has led to great increase in the know ledge of the geology of the coastal sedimentary basin in the Niger Delta. The Niger Delta is one of the World's largest Tertiary delta systems and till date. it is considered one of the most prolific and economic sedimentary basin in Nigeria because of impact size petroleum accumulations discovered and produced as well as the spatial distribution of hydrocarbon resources in the province with world known recoverable hydrocarbon of over 20 billion barrels of oil and 120 trillion of gas from the basin which is at least 75 sq km sedimentary basin fill over 12km thickness in its central part. and is situated on the west African continental margin at the apex of the Gulf of Guinea, which formed the site of a triple junction during continental break-up in the Cretaceous time.

The Niger Delta is situated in the Gulf of Guinea and extends throughout the Niger Delta province as defined by Klett et al (1997). The focus on the Tertiary Niger Delta basin by various workers has gained prominence following its discovery as a petroleum laden basin in the 1950's by shell BP. Since then. Nigeria has been rated as the sixth largest oil producing country in the world with proven ultimate reserve of about thirty billion barrels of oil and two hundred and sixty trillion cubic feet of natural gas (Reijers et al. 1996)

This depobelt form one of the largest regressive deltas in the world, which covers an area of 300.000 km² (Kulke. 1995) and a sediment volume of 500.000km³ (Hospers. 1965). This study is focused on the Niger Delta Basin with the view of adopting organic geochemical methods in evaluating the mineralogical and compositional characterization of the province, to determine the clay minerals present, to study the heavy mineral present, Organic matter richness, Organic matter types, maturity of sediment and the hydrocarbon potential in the study area

Location of study area

The study field is located within the shallow offshore of the eastern depobelt of the Niger Delta basin (Figure 1) which is located in OML 119. It is 130km from Brass and 55km from Bonny.

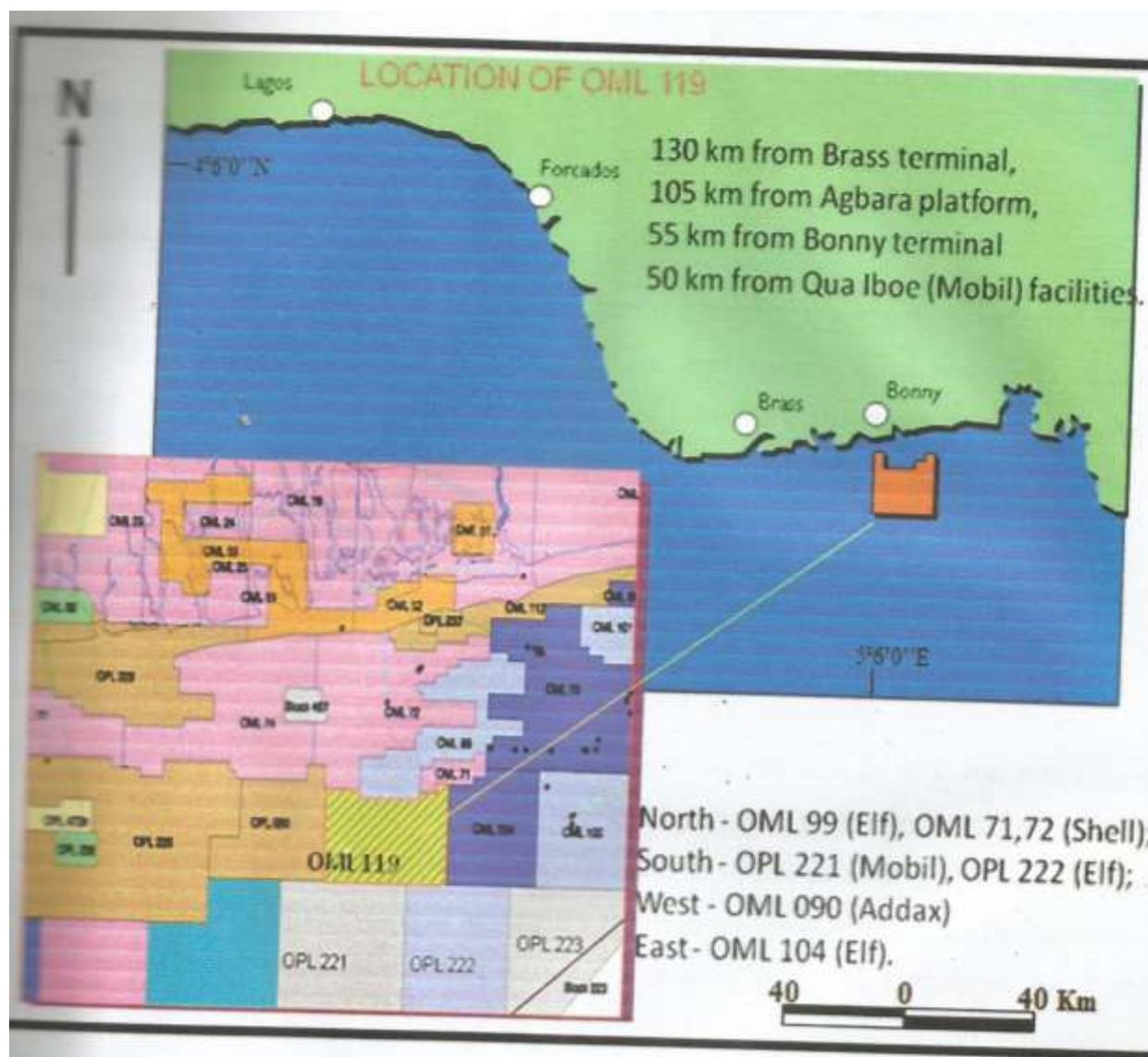


Figure 1: Geological map showing the study area/location map of OML 119

Objectives of the study investigation

The main objective of this work is to investigate the compositional characteristics of ditch cuttings from shallow off-shore wells in OML 119 field.

To carry out X-Ray Diffraction (XRD) study on the ditch cuttings for proper identification of the clay mineral composition in the sediments. To carry out Total organic carbon (Toe) and Eval Rock (rock evaluation pyrolysis) to determine the quality/type, quantity of organic matter richness of the shale samples.

2. METHODOLOGY: SAMPLING

Shallow offshore ditch cuttings samples were collected from two wells, well 1 and 2 in OML 119 field located in the eastern Niger Delta basin of Nigeria.

A total of one hundred and eight (108) samples were collected for both wells with well I having 42 samples and 66 samples from well 2. The collected samples were composited at an interval of 50m (fifty metres) each and stored in a calico bag and labelled for easy identification and for further petrography and geochemical analysis in the various laboratories.

Petrography and chemical (organic geochemical) analysis description

Representative shale and sandstone samples were obtained from various depths and two locations which were subjected to sedimentological, mineralogical and organic geochemical analyses. Seven (7) sandstones samples were used for grain size analysis and seven (7) samples for heavy mineral analysis, five (5) shale samples for X-ray diffraction (XRD) analysis and eleven (11) representative shale samples from both wells were used for total organic carbon (TOC) and rock Evaluation pyrolysis (rock-eval) which were used to carried out this research.

Table 1: The Depth of Collection for various samples analyzed

S/No.	XRD samples	Grains	Heavy Minerals	TOC	Rock Eval
1	2105-2155	1855-1905	1855-1905	1705-1755	1705-1755
2	3555-3605	1905-1955	1905-1955	2055-2105	2055-2105
3	880-930	2755-2805	2755-2805	2555-2655	2555-2655
4	2680-2730	1580-1630	1580-1630	2955-3005	2955-3005
5	3480-3530	2480-2530	2480-2530	3505-3555	3505-3555
6		2630-2680	2630-2680	530-580	530-580
7		3430-3480	3430-3480	1080-1130	1080-1130
8				1380-1430	1380-1430
9				2130-2180	2130-2180
10				2880-2930	2880-2930
11				3680-3730	3680-3730

ANALYTICAL TECHNIQUE FOR X-RAY DIFFRACTION ANALYSIS (XRD).

A predetermined amount of sample is hand grind and then mixed with acetone to produce thin slurry. The instrument used is the Siemens D500 Diffractometer using MDI Data Scan and JADE 8 softwares. The mixture is applied onto a glass slide which is scanned for the determination by XRD. The results are reported in semi-quantitative levels of trace to abundant

X-ray diffraction (XRD) studies can be done on sediment, Soil, Rock and Drill core. X- ray diffraction technique is a method used in the study of crystalline materials. It relates to identifying the minerals present in the sample. Each crystalline substance has its unique atomic and molecular structures, which diffract the x-ray in a definite pattern. The recognition of a pattern establishes precisely the diffracting substance.

The x-ray diffraction analysis is based on passing x-ray beam through a clay sample. The x-ray identifies the structural layer, which is dependent on the d-spacing of the clay mineral. The d- spacing is the exact spacing of the stacking of the crystal lattices, which indicates the arrangement of the atoms in a mineral. The expansion by polar molecules and the collapse of expanded units with heat can be recognized by x-ray diffraction methods. The x-ray on passing through the sample gives peaks that are typical of each type of the minerals that are contained in the sample. The x-ray beams are diffracted along a group of planes and the way they are diffracted is characteristics of the arrangement of the atoms within the mineral. This XRD method is fast and non destructive. This XRD analysis was carried out in the ACME Laboratory in Canada and the above method is applicable to the ACME Laboratories.

CHEMICAL ANALYSES (ORGANIC GEOCHEMICAL ANALYSIS)

Analytical technique for total organic carbon (Toc) content: The analytical procedure used in estimating the TOC is the LECO method. The quantity of organic matter of sediments is usually expressed in as TOC (that is weight % of organic carbon relative to weight of acid leached rock). Although the generally accepted minimum concentration of organic carbon necessary for petroleum generation and expulsion to take place is 0.5wt.% for siliciclastic rocks and 0.3 wt % for carbonate rocks (Tissot and welte. 1984), North (1985), proven source rocks contain much more organic matter.

In fact, whatever the nature of the organic matter, original carbon content lower than 0.5wt % is not likely to produce sufficient amounts of liquid petroleum with respect to the adsorption properties of the source rocks and the necessary pressure build up for the expulsion of oil Tissot and Welte (1984).

However, in the deeper part of the sedimentary basins, where maturation of organic matter has reached metagenetic stage (dry gas stage). And a residual 0.5wt % organic carbon may be evidence for an original 1.0 wt % or more.

The accumulation of sediments containing organic matter primarily occurs in aquatic environments. The amount of organic matter in sediments is controlled by several factors operating during sedimentation. These factors include, sedimentation rate, availability of substantial amount of organic matter and environmental redox condition. For sediments to contain high amount of organic matter, there must be a very high supply of organic matter which must be deposited under anoxic condition.

A high rate of sedimentation favor organic matter preservation due to rapid burial, however, a very high supply of mineral matter may cause dilution of organic matter, thus leading to sediment having relatively low TOC. Organic matter content is also related to particle size of various lithologies. In a particular environment, finer grained elastic sediments will contain higher organic matter than the associated coarser grained ones.

This is a standard procedure, which was developed by Espitalie et al. (1977) for the pyrolysis of rock samples. This was carried out to determine the quality/type, quantity and thermal maturity of the shale sample. Rock-eval pyrolysis is used for analysis of rock samples that require no demineralization and other preparation other than grinding. The sample is heated in an inert atmosphere at steadily increased temperature up to 500°C. According to Peters (1986), Rock-eval pyrolysis method determines hydrocarbon production which is monitored as a function of temperature and three main vapour pulses are identified as follows:

1st Pulse (S1 peak): refers to hydrocarbons already present in the Kerogen which are mainly steam off at a temperature of about 300°C. 2d Pulse (S2 peak): refers to hydrocarbons that are generated through thermal cracking of Kerogen at a temperature range of 300 -550°C, and 3rd Pulse (S3 peak): represents Carbon (IV) Oxide (CO₂) which have been generated from the Kerogen at the same time that hydrocarbon is generated.

However, the ratio S₂/TOC is normally referred to as Hydrogen Index (HI) which is plotted against the ratio S₃/TOC known as Oxygen Index (OI). A pseudo-Van Krevlen diagram is similar to that of H/C ratio versus O/C ratio is obtained. The samples can then be categorized as Type: I, II or III organic matter as defined by Tissot et al. (1974). The Type I and II mainly come from aquatic organic matter, and Type III comes from continental organic matter. In addition to these three types, there is residual organic matter, either oxidized in subaerial environments or during sediment transport or recycled from older sediments. This residual organic matter which is sometimes called Type IV is located below the evolution pathway. Type III in the H/C-O/C diagram and has no potential for hydrocarbon generation.

If samples are thermally mature, the Total Organic Carbon (TOC) is not entirely pyrolyzed by the Rock-Eval Pyrolysis method. TOC contents of the samples pyrolyzed were therefore determined by LECO Method. Maturation level is indicated by the transformation ratio of S₁/(S₁+S₂) as well as by the temperature maximum (T_{max}) generation peak (S₂ peak). This analytical technique is fast, cheap and simple, but it should be noted that products generated by Rock-eval Pyrolysis are not the same as those generated in nature.

3. PRESENTATION OF RESULTS

The general results for the petrography and chemical analysis shows that the lithologic description of the wells revealed shale, shaley sand, sandy shale and sand at different depth intervals, the heavy mineral results, histogram and ternary plots indicate bimodal, igneous, metamorphic and reworked sedimentary rocks provenance. The XRD result shows Quartz, kaolinite, calcite, Albite and clinocllore as mineral present in the shale samples. The TOC values for well 1 ranges from 1.22 - 5.67wt% with a mean of 3.2wt%; while well 2 ranges from 1.34- 5.18wt% with mean of 2.33wt%, these values exceed the threshold required for siliclastic petroleum source rocks. The rock eval analysis shows type III type IV kerogen type which suggest that the organic matter is immature to early transitionally mature kerogen type.

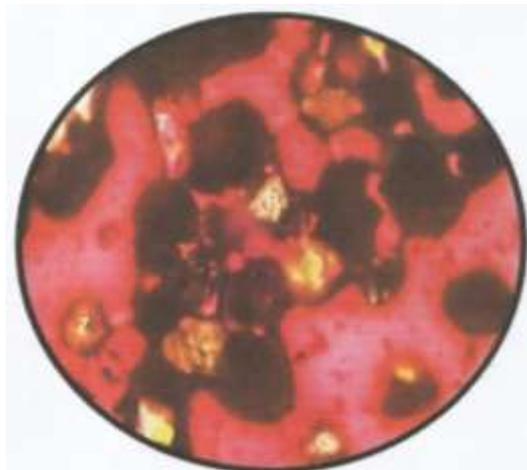


Figure 2: Photomicrograph of heavy minerals in sample 2755-2805m



Figure 3: Photomicrograph of heavy minerals in sample 1855-1905m

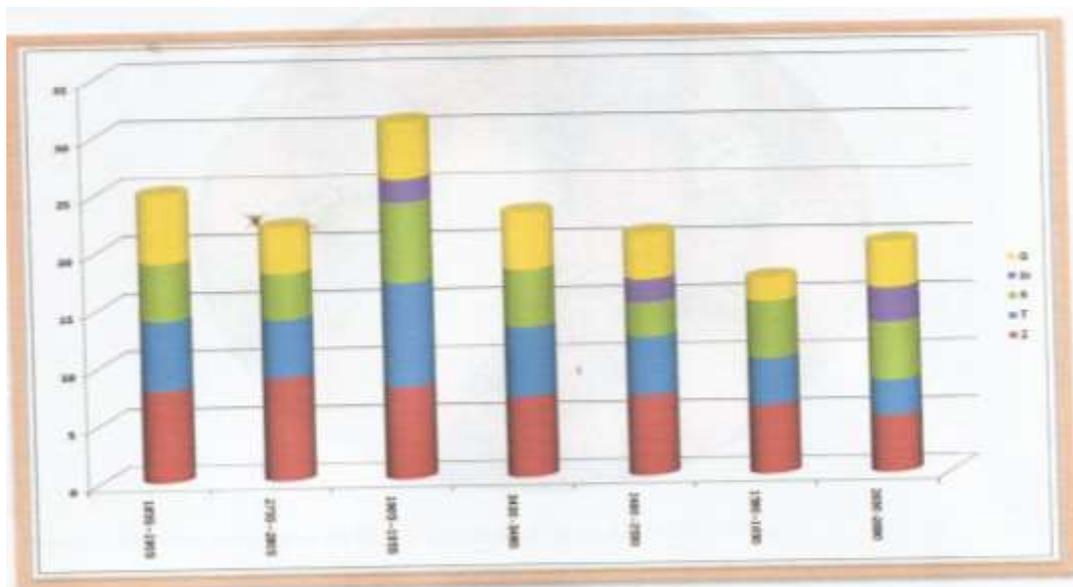


Figure 4: Heavy mineral in the study well

Table 2: X ray diffraction interpretation and percentage of mineral present

Depth (m)	Kaolinite (%)	Calcite (%)	Quartz (%)	Albite (%)	Clinochlore (%)
2105-2155	27.15	6.04	59.55	7.27	-
3555-3605	49.07	25.24	20.29	5.40	-
880-930	28.25	14.7	43.53	10.39	3.12
2680-2730	18.61	9.21	67.86	4.32	-
3480-3530	13.79	10.92	63.94	11.22	-

4. DISCUSSION OF RESULTS:

Mineralogical interpretation (XRD)

The X-ray diffraction (XRD) results reveal that non clay minerals have higher percentage especially Quartz {SiO₂}, which is predominantly significant, follow by Calcite (CaCO₃) and Albite {Na(AlSi₃O₈)} which occur in minor to traces in the shale samples. The dominant clay mineral identify in the X-ray diffraction (XRD) analysis of the study wells is Kaolinite {Al₂(Si₂O₅)(OH)₄} and also Clinochiore { Mg₄. 54Al₁₀.97 Feo.46Mno.03(Si₂.85Al₁₁ .1501 O)(OH)_g} appearing in XRD 03 which is identify as chlorite group or as a clay mineral member found in the study (well 2) shale samples.

CHEMICAL ANALYSIS (ORGANIC GEOCHEMICAL ANALYSIS) RESULTS

Organic matter concentration

Petroleum is a generative product of organic matter disseminated in the source rock. Adequate amount of organic matter, measured as percentage total organic carbon (TOC), is a necessary pre-requisite for sediment to generate oil or gas (Conford,1986); The quality of hydrocarbon generated in a given volume of source bed is linearly related to its carbon content (Welte 1972). (Jarvie 1991).

The TOC values for the cuttings collected from well 1 and well 2 show that the TOC for well 1 (range 1.22 - 5.67: average: 3.21). and well 2 (rangel.34- 5.18: average 2.33) which exceeds the threshold of TOC of 0.5% required for siliclastic petroleum source rocks (Tissot and Welte 1984) and suggests very good to excellent source rocks for well 1 and well 2 (Unomah and Ekweozor 1993).

The measurement of TOC in sediments is not sufficient to identify potential hydrocarbon source beds because transported terrestrial organic matter from previous sedimentary rock cycle can create an organic richness 4wt% and above, yet, this concentrated organic matter could be poor in hydrogen, poor in gas and without any significant petroleum generating potential Demaison and Moore (1990).

On the basis of average total organic carbon (TOC) value, which shows relationship with depth, the shale of well I and 2 can be described as good to very good (3.21wt% and 2.33wt%) for both wells as shown by the TOC versus GP in (fig.30).This interpretation is consistent with those given by Akaegbobi (2000), Doust and Omatsola (1990), Nwachukwu and Chukwura (1986), Lambert- Aikhionbare and Ibe (1984) and Ekweozor and Okoye (1980).

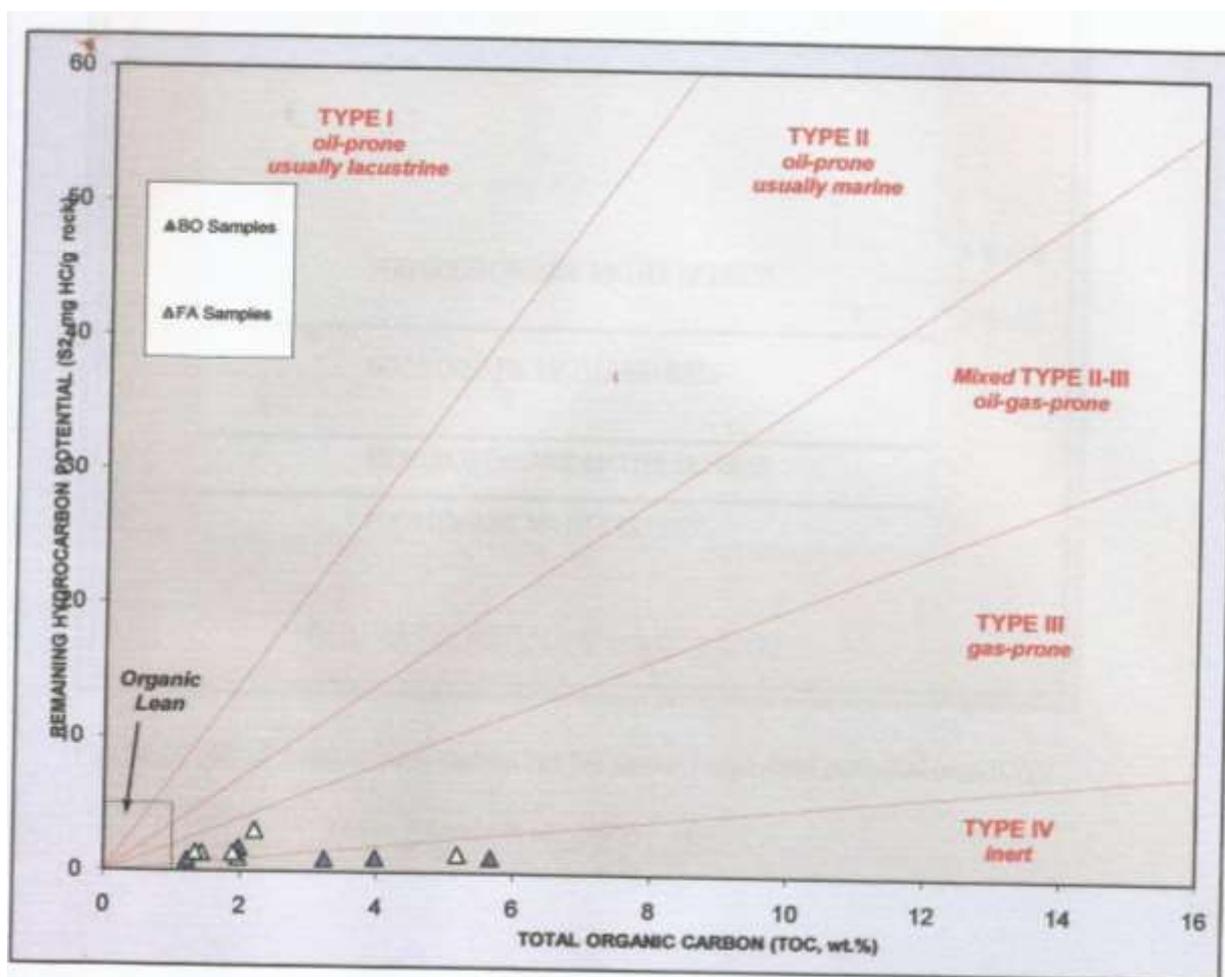


Figure 6: Plot of hydrogen carbon potential versus Total Organic Carbon

Pyrolysates and their derivatives

The values of Rock Eval parameters (s1, s2, s3 and Tmax) also known as pyrolysates and their derivatives (OP, HI, OI, and PI) are well presented in the table below while their range and average line with Akaegbobi (2000). The plot of HI versus OI gives the pseudo Van Krevelen type diagram show that both wells are of Type 111/Type 1V kerogen.

Free oil content (s1)

This provides a measure of the free oil in the samples and accounts for the material in the c7-c32 range, depending on the S1 hold time Jarvie et al, (2000), excluding heavy molecular weight resin and asphaltene fractions which are liberated during high temperatures of the s2 cycle. The s values for well 1 (range 0.07-0.23; average: 0.12) and well 2 shale (range 0.17- 5.92; average: 2.02) these can be interpreted as good for the shale of well 1 and very good for well 2 samples..

Table 3 : Range and Average values of pyrolysates and their derivatives for the study wells

Pyrolysates/Derivatives	Well 1. 5 cuttings samples		Well 2 6 cuttings samples	
	Range	Average	Range	Average
PYROLYSATES				
S1(mg/g)	0.07-0.23	0.12	0.17-5.92	2.02
S2(mg/g)	0.83-1.77	1.17	1.05-3.06	1.60
S3(mg/g)	0.48-2.49	0.94	0.75-3.60	2.15
Tmax(°c)	434-436	435.2	352-430	392.17
DERIVATION				
GP	0.90-2.00	1.286	1.22-8.98	3.61
PI	0.07-0.11	0.075	0.11-0.67	0.398
HI	21-90	47.2	27-139	82
OI	10-126	36.16	14-201	121.83
S2/S3	0.7-23	1.64	0.5-1.9	0.92

GP= Generation Potential; HI= Hydrogen Index; OI = Oxygen Index; PI = Production Index;

Source rock potential (s2)

Source rock potential (s2) is the magnitude of the pyrolysate yield obtained from cracking of kerogen. It provides a measure of the source rock organic matter to generate further hydrocarbons. The values of s2 ranges from (0.83-1.77; average: 1.17) for well 1 and (1.05-3.06; average: 1.60) for well 2, and are interpreted as poor for both wells.

Thermal maturity (Tmax)

Thermal maturity (Tmax) measured in degree Centigrade provides an indication of source rock maturity but influenced by source rock organic matter type and the presence of excess free hydrocarbons together with other factors like mineral matter content, depth of burial and age (Tissot and Welte, 1984).The values are well 1 (range 434-436; average: 435.2) and well 2 (range 352-430; average: 392.17), this can be interpreted to mean early transitionally mature for shale of well 1 and immature for well 2. This interpretation is in line with those given by Akaegbobi (1999) Nwachukwu and Chukwura (1986) and Ekweozor and Okoye (1980).

Source rock quality (hydrogen index (HI))

The HI values, otherwise known as source rock quality values are , well 1 (range 21-90; average: 47.2) and well 2 (range 27-139; average: 82). This interpretation implies that well I is Type IV and well 2 is Type III

Generation potential (GP)

Generic Potential (GP) otherwise known as potential yield or petroleum potential is the sum of s_1 and s_2 values obtained from the rock eval pyrolysis and it is measure in mg/g. The values are presented are 0.90- 2.00; average: 1.286 for well 1 and range from 1.22- 8.98; average: 3.61 for shale of well 2 respectively.

The GP for the shale of well 1 are lower than 2kgHC/ton of rock expected to be good source rock (Dymann et al 1996). While shale of well 2 are above the acceptable limit of 2kgHC/ton which is capable of generating gas. This interpretation is consistent with other interpretation deduce from source quality (HI).

Production index (PT)

The production index (P1) or Transformation Ratio (TR) measured in dimensionless unit ranges from 0.07- 0.11; average: 0.075 for well 1 and well 2 ranges from 0.11- 0.67; average: 0.39. These results can be interpreted to contained organic matter that is immature (gas) for well 1 and well 2 respectively.

S2/S3

The ratio S2/S3 was utilized by Clementz et al., (1979) as an indication of kerogen type in the absence of TOC data. This ratio reflects the ratio of hydrogen to oxygen, which is similar to HI divided by 0.1. S2/S3 values ranges from 0.7- 2.3; and average: 1.37 for well 1 and range 0.5- 1.9; average 0.92 for well 2. This can be interpreted as type III/ Type IV kerogen capable of producing gas only and regarded as gas prone.

The hydrocarbon in shale as well as other petroleum source rocks are ultimately derived from the organic matter preserved in fine grained rocks. Peters (1986) suggest that thermal maturity is equivalent to vitrinite reflectant of 0.6% (T_{max} 43 $^{\circ}C$) of rocks with HI value > 300mgHC/gTOC will produce oil; HI value ranging between 150 and 300mgHC/gTOC will produce oil and some gas; HI from 50 and 150mgHC/gTOC will produce gas and HI values < 50mgHC/gTOC are inert.

The degree of thermal evolution of sedimentary rocks organic matter from the two different sampled wells or locations, it can be deduce that from various plots such as hydrocarbon potential versus TOC reveal Type III/ Type IV but plotted out of organic lean, hC versus GP suggest good to very good organic matter richness as shown in (Fig.30), in (fig.31 and 32) HI versus T_{max} and HI versus R_o indicate Type III/ Type IV that is immature to early transitionally mature organic matter. Production index (P1) versus maturity (T_{max}) suggest that organic matter maturity ranges from immature to early mature kerogen type that is (late diagenetic to early catagenetic stages of hydrocarbon formation). These assertions are further buttress by the various geochemical plots for the two wells. TOC/ Depth indicate good to excellent, Organic matter type shows Gas. Normalized oil content ($s_1/TOC*100$) suggest low maturity or over mature source rock, maturity shows immature to early mature zone of organic matter. hydrogen index (HI) against 0.1 and HI against T_{max} index all modified from Ekweozor (2006). As a general rule, it can be said that the top of the oil window is reached when production index is approximately 0.1 and T_{max} is in the range of 435 $^{\circ}C$ - 445 $^{\circ}C$ Waples (1983).

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