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AN EVALUATION OF THE HYDROCARBON POTENTIALS OF THE GBOKO FORMATION, MIDDLE BENUE TROUGH, NIGERIA

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ABSTRACT

A total of seventeen (17) rock samples from the Albian Gboko Formation were collected from the quarry of Benue Cement Company for organic geochemical analysis, in order to evaluate its hydrocarbon potential . Total Organic Carbon (TOC) values for the samples ranges from 0.11-0.5wt%. The rock-eval data recorded $S_{2,}$ hydrogen index (HI), Oxygen index (OI), $T_{max,}$ and production index (PI) of 0.04-0.11, 25-54, 50-400, 310-461^{0}C, and 0.4-0.6, respectively. These implies that the samples has a fair to poor source rock quality with a type IV kerogen. Optical methods (R_0, TAI & VKF) conducted on three selected samples of shales reveal vitrinite reflectance (R_0) of 0.77%, 1.11% and 1.54%, while thermal alteration index (TAI) recorded 2.7, 3.3 and 3.7. Kerogen fluorescence indicated weak to non fluorescence. These results infer that the sediments had evolved from oil to gas window due to severe thermal effects . This indicates their potential to generate hydrocarbon gas

KEYWORDS: Gboko Formation, Middle Benue Trough, Kerogen, Source Rock Quality, Thermal Maturity

INTRODUCTION:

The Benue Trough of Nigeria is a NE-SW trending linear structure which is intimately related to the development of the Benue Rift (Wright 1981).The Benue Rift was installed as the failed arm of a trilete fracture (rift) system, during the break up of the Gondwana supercontinent and the opening up of the southern Atlantic and Indian Oceans in the Jurassic (Burk et al,1972; Olade,1975 ;Benkhelil,1982; Horque and Nwajide '1989,) It is filled with thick accumulation of sediments deposited under rapidly changing conditions with ages ranging from Albian to Maastrichtian.

The Benue Trough consist of two parallel rifts separated by an axial ridge which represents an area of possible uplift or basic intrusion at depth of 2km or less (Ajakaiye, 1981). The southern limit of the Benue trough is the northern boundary of the Niger Delta, while the northern limit is the southern boundary of the Chad basin. The Trough contains up to 6,000m of Cretaceous-Tertiary sediments of which those predating the mid Santonian have been compressionally deformed, faulted and uplifted in several places.

Different investigations have also been carried out on the hydrocarbon prospectivity of the Benue trough by Petters and Ekweozor (1982), Nwanchukwu (1985), Obaje (2004) and Obaje et al (1999). All these studies revealed that aquatic organic matter is deposited over terrestrial organic matter in a vertical sequence (Barker 1982). On burial, the aquatic organic matter generates oil, while the terrestrial organic matter generated gas and waxy crude. (Avbobo and Ayoola, 1981). Nwachukwu (1985) used different geothermal gradients to show that sediments mature earlier at higher geothermal gradients.Thus,within the range of geothermal gradients investigated, the Asu – River Group started oil generation between Cenomanian and Campanian time. By Santonian to Maastrichtian time, generation was completed (Nwanchukwu,1985; Obaje, 2004; Abubakar, 2017). The present study is centered on the Albian Gboko Formation which belongs to the Asu Rriver Group in the Middle Benue Trough (Fig 1) The objectives of the present work are to assess the source rock quality of the Albian sediments and to determine the hydrocarbon potential.

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OUTLINE STRATIGRAPHY OF THE MIDDLE BENUE TROUGH

The Benue Trough is arbitrarily subdivided into lower, middle and upper portion. Although, no concrete line of subdivision can be drawn to demarcate the individual portions, but major localities (towns/settlements) that constitute the depocentres of the different portions are well documented.

The basal and oldest Asu- River Group is of Albian age comprising the Gboko Formation, Uomba Formation and Arufu Limestone. The Gboko Formation, located to the North-West of Gboko consists of thick, fissile and carbonaceous shale and contain thin beds and lenses of limestone underlying a thick series of siltstones intercalated with thin beds of sandstones (Farrington 1952).According to Reyment(1965),the Gboko Formation was deposited during the first transgressive phase of the Late Albian. Reyment (1965) gave the type locality of the Uomba Formation as the Uomba River, Benue province and described the Uomba Formation as consisting of mainly sandstones, shales and sandy shales. It is thought to have been laid down about the same time as the Gboko Formation under parallic and marine conditions. The Arufu Limestone is located east of Makurdi in the Benue Trough and was also deposited at the same time under the same condition as those of Gboko Formation (parallic marine).

The Asu – River Group is overlain by the Kean-Awe Formation. Dessauvagie (1974) described the Keana Formation as coarse grained, feldspathic, micaceous sandstones with siltstones and tentatively dated the Keana Sandstone as Albian to Cenomania.The stratigraphic unit was laid down as a delta complex during the regression of the Albian cenomanian seas down the Benue Trough.The Awe Formation ranges from late Albian to early Cenomanian and consists of flaggy medium to coarse grained sandstones intercalated with carbonaceous shales. It was deposited under transitional marine to fluviatile condition (Nwajide, 1990 Obaje, 2009).

The Eze Aku Formation which overlies the Keana – Awe Formation consists of calcareous shale, micaceous fine to medium grained sandstones and occasional limestone. It appears to have been laid down in a shallow marine coastal setting, the Formation is thought to range in age from Cenomanian to early Turonian (Obaje, 2009)

The deposition of Awgu Formation marks the end of marine sedimentation in the Benue Trough. The Formation is made up of bluish grey to dark – black carbonaceous shales, calcareous shale, shaly limestones, siltsones and coal seams. According to Murat (1972), the Awgu Formation was deposited during Coniacian -early Santonian regression.

The last youngest lithostratigraphic unit in the Middle Benue Trough is the Lafia Formation,which was deposited under continental conditions (fluviatile) in the Maastrichtian and lies unconformably on the Awgu Formation. It is lithologically characterized by ferruginized sandstones, red loose sands, flaggy mudstones, clay and clay stones (Obaje et l,1999).(Fig 2)

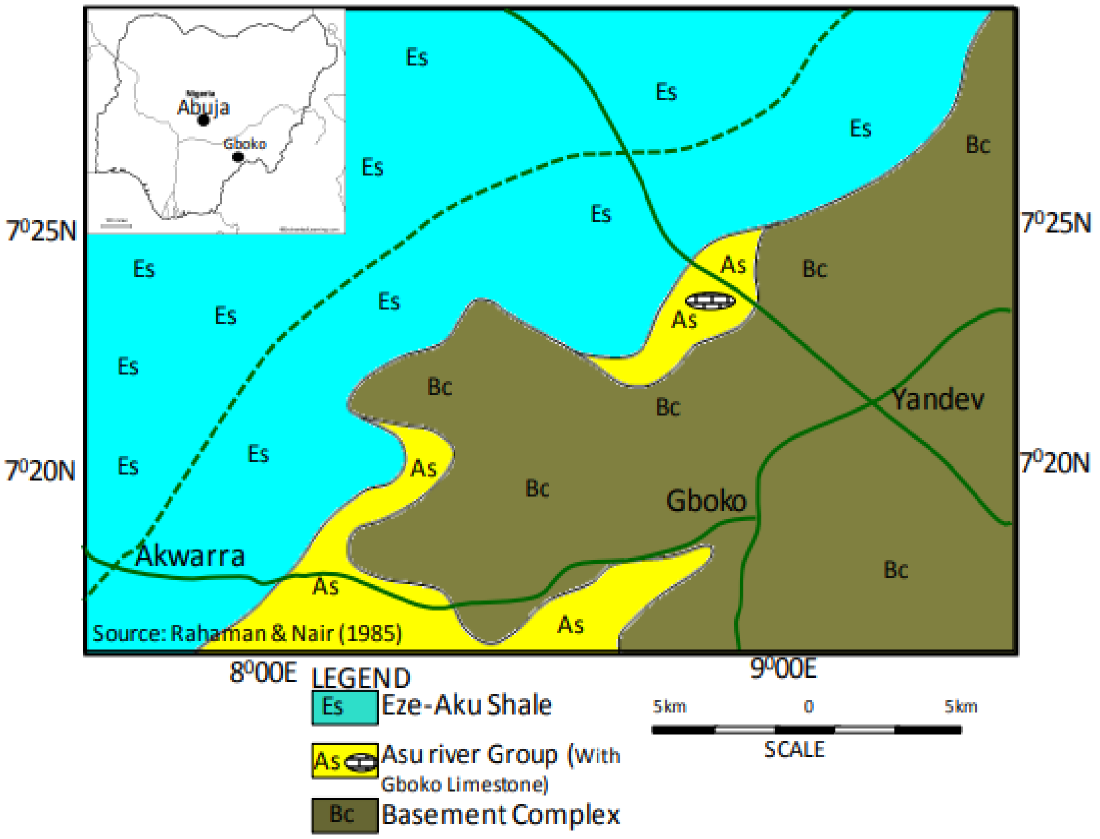


Fig 1: Geological map of Gboko area showing Gboko Formation outcrop North West of Yandev(After Rahman and Nair,1985)

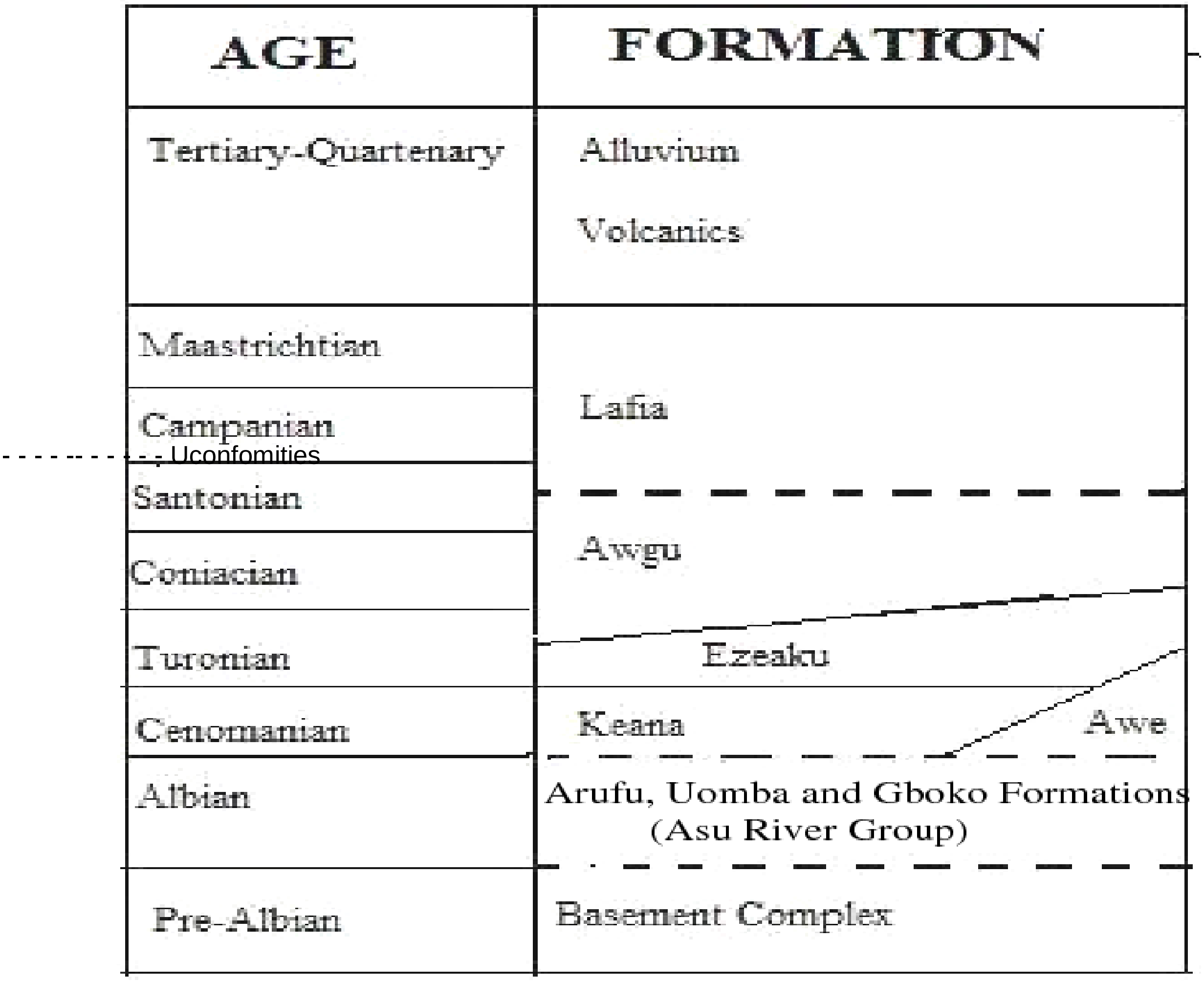


Fig 2: Stratigraphy of the Middle Benue Trough (After N.O.Patrick, 2013)

METHODOLOGY

To achieve the objective of this research,both field and labotory investigations were carried out.Three different sections of the quarry of the Benue Cement Company were logged and a total of seventeen(17) representative rock samples of shales and limestones were collected. The following organic geochemical analyses were carried out:

1. All seventeen(17) rock samples were subjected to Total Organic Carbon(TOC) analysis based on the Rock Eval Method.
2. Rock-Eval pyrolysis was conducted on all seventeen (17) samples for a determination of the hydrocarbon generative potential of organic matter content. Geochemical parameters determined include the hydrocarbon yield from cracking of kerogen(S_2), the temperature at which the maximum release of hydrocarbons from cracking of kerogen occurs during pyrolysis (Tmax),Production Index(PI), Hydrocarbon Index (HI) and Oxygen Index(OI)
3. Thermal maturity analyses: Vitrinite Reflectance (%R),Thermal Alteration Index(TAI) and Visual Kerogen was carried out on three selected samples of shales with the highest TOC.

All samples were prepared according to standard organic geochemical samples preparation methods e.g Espitalie et al. 1977, Techmuller, 1982 ;Waples and Machitara, 1991; Obaje 1994.

REULTS AND DISCUSSION: The sections of the quarry sampled and stratigraphic log are presented in Figures 3(a,b and c) and Figure 4

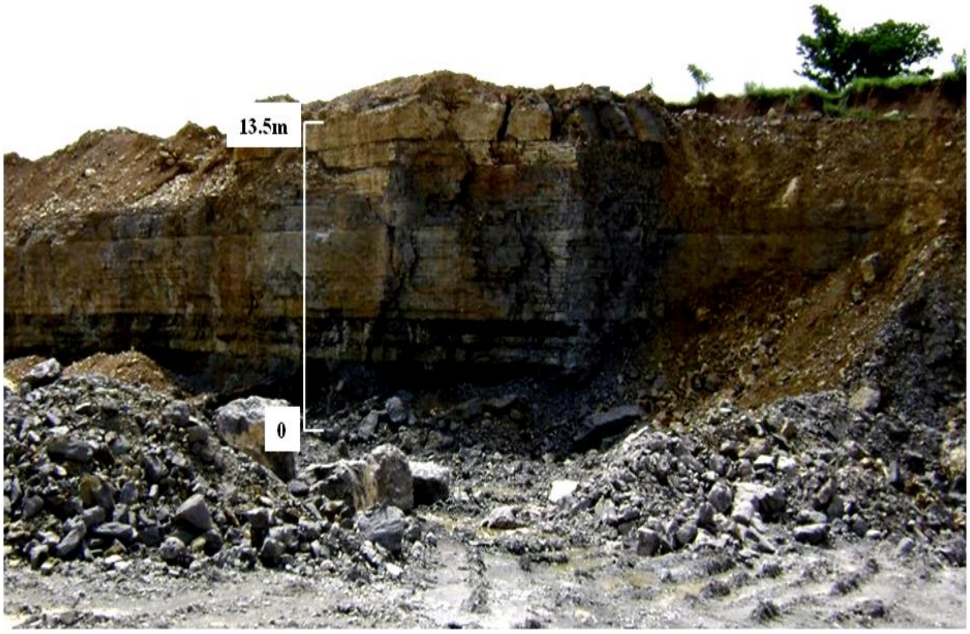
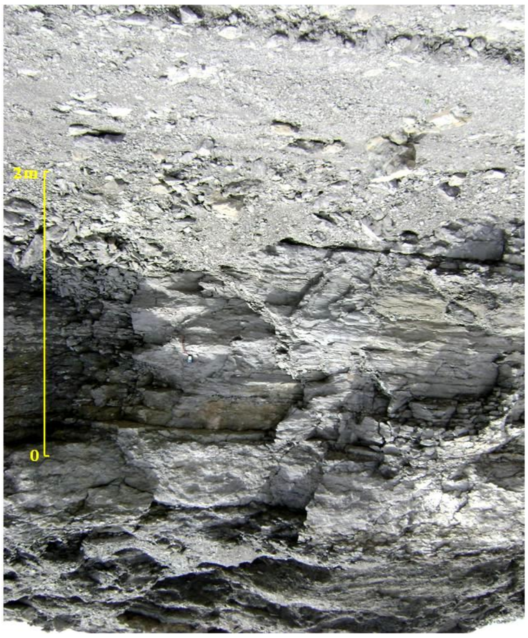


Fig 3a:Sampled section A:Interbedded limstones and shales



Section B:Indurated shales and limestones

Fig 3c: Sampled section C: Interbedded limestones and shales with heavily laterised upper unit.

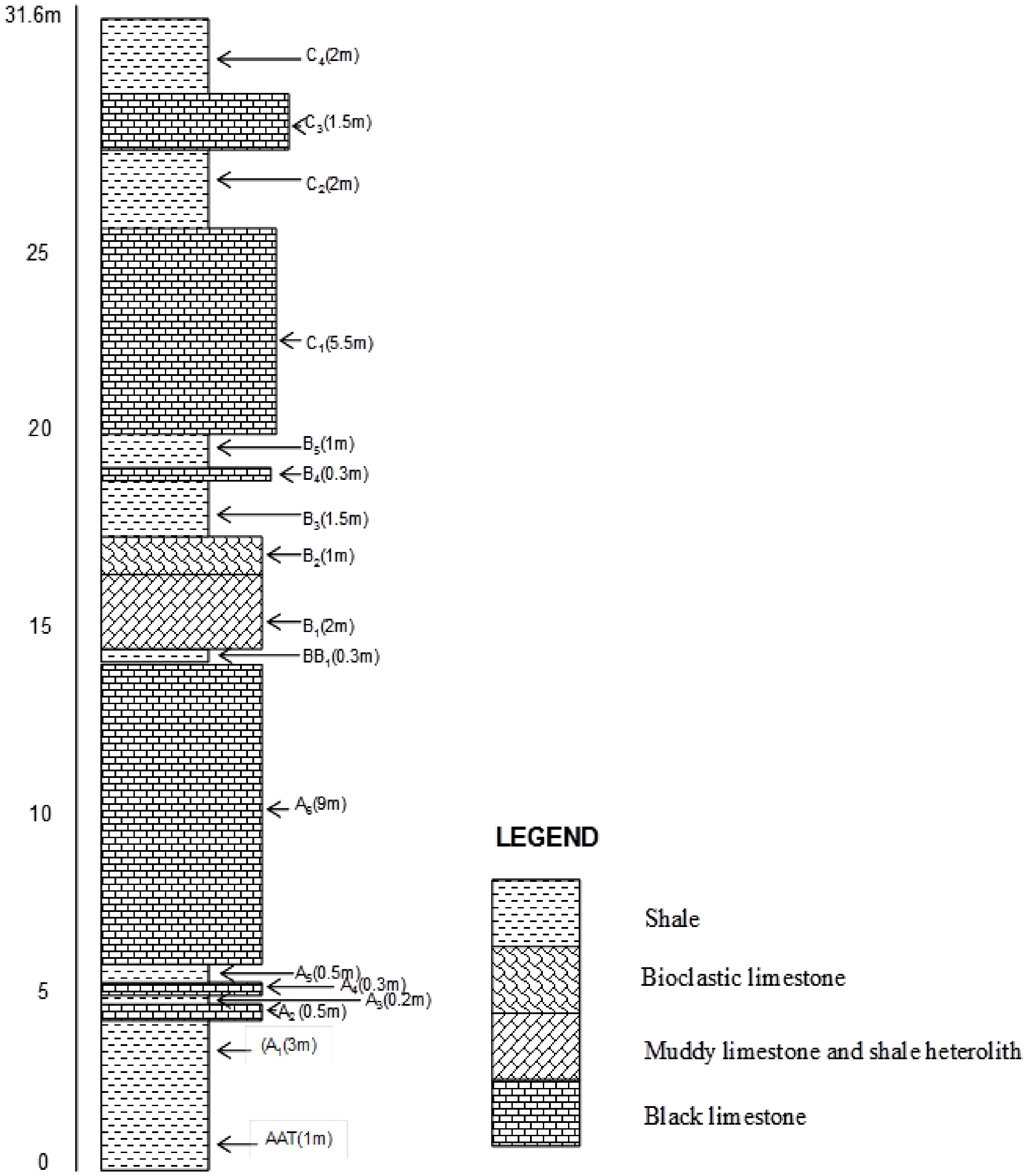


Fig.4: Stratigrahic log of sampled sections of the B CC Quarry

Table 1: TOC and Rock Eval results

Sample	LITHOLOGY	TOC Wt%	S_1 mgHC/g	S_2 Mg HC/g	S_3 MgH C/g	T_{max} (^{o}C)	HI MgHC/g TOC	OI mgCO$_2$/ g TOC	S_2/S_3	S_1/Toc	PI
C_4	Shale	0.51	0.08	0.04	0.05	461	8	10	1	15	0.66
C_3	Limestone	0.07	0.01	0.00	0.11	-1 *	0	151	0	13	1.00
C_2	Shale	0.31	0.11	0.07	0.15	353 *	23	49	0	53	1.61
C_1	Limestone	0.14	0.03	0.03	0.13	310 *	21	93	0	22	0.50
B_5	Shale	0.06	0.02	0.01	0.13	-1 *	17	220	0	32	0.66
B_4	Limestone	0.11	0.03	0.02	0.35	-1 *	18	315	0	28	0.61
B_3	Shale	0.24	0.05	0.04	0.38	422	17	158	0	21	0.56
B_2	Limestone	0.20	0.10	0.07	0.47	340 *	34	232	0	48	0.58
B_1	Limestone	0.13	0.06	0.03	1.17	- 1 *	22	873	0	47	0.68
BB_1	Shale	0.18	0.07	0.04	0.56	- 1 *	22	308	0	37	0.63
A_6	Limestone	0.06	0.02	0.01	0.28	- 1 *	18	491	0	36	0.67
A_5	Shale	0.27	0.06	0.08	0.29	412	30	107	0	22	0.42
A_4	Limestone	0.09	0.04	0.02	0.29	349 *	22	319	0	43	0.66
A_3	Shale	0.24	0.05	0.10	0.04	437	42	17	3	21	0.34
A_2	Limestone	0.10	0.04	0.03	0.04	449	31	41	1	40	0.56
A_1	Shale	0.24	0.08	0.11	0.17	439	46	71	1	33	0.42
AA_1	Shale	0.20	0.08	0.11	0.17	407	54	83	1	39	0.42

* Unreliable T_{max} due to poor S_2 Peak
-1 means Not measured or meaningless

(A) TOC: This is the quantity of organic matter expressed as total organic carbon (TOC) in weight percent (wt%). The minimum TOC for oil generation in shale source rock is 0.5, while that of carbonates is 0.175wt% (Law,1999). A close observation of the TOC in Table 2 shows that only one of the shale sample (C4) has the required minimum threshold, and could therefore be classified as good in hydrocarbon generation, while all other shale samples could be regarded as poor source rocks. The limestone samples with TOC values ranging from 0.10-0.20 are fair to good source rocks since some possessed values above the threshold for carbonates (0.175wt.%).

(B) Rock Eval pyrolysis: is used to determine values of organic geochemical parameters used to evaluate hydrocarbon potential of a source rock.. The basic parameters obtained are S_1, S_2, S_3, Tmax, production index (P1) Hydrogen Index (HI) and Oxygen Index (OI) (Tissot and Welte, 1984). S_1 is the amount of free hydrocarbon (gas and oil) in the sample (in mg of hydrocarbon per g of rock), S_2 represents the amount of hydrocarbon generated through thermal cracking of non-volatile organic matter. S_2 is an indication of the quantity of hydrocarbon that the rock has the potential of producing if burial and maturation continues. It is a more useful and realistic measure of source potential, unlike the TOC that only measures the carbon skeleton of organic matter and is blind to the presence or absence of associated hydrogen. S_3 is the amount of CO_2 (in mg CO_2 per g of rock) produced during pyrolysis of kerogen. S_3 is an indication of the amount of oxygen in the kerogen. Tmax represents the temperature at which the maximum replease of hydrocarbon from cracking of kerogen occurs during pyrolysis (top of S_2 peak) Tmax is an indication of the stage of maturation of the organic matter. The production index (PI) is used to characterize the evolution level of the organic matter. It can be used in conjunction with Tmax to determine the maturation state of rock samples. The Hydrogen index (HI) is a parameter used to characterize the origin of the organic matter, while the oxygen index is a parameter that correlates with the atomic ratio of O to C (oxygen to carbon). The hydrocarbon potential of the rock samples would be discussed in terms of the quantity of the organic matter, the quality of the organic matter and the maturation state (stage) of the organic matter in the rock samples.

i) The quantity of the organic matter: The source potential parameter used here is the S_2 of the rock eval data. According to Peters and Cassa (1994), S_2 values that are <2.5mgHC/g are classified as poor source rocks, those that have values from 2.5 – 10mgHC/g are classified as fair to good source rocks and those> 10mgHC/g are very good source rocks. From Table 1, both shale and limestone samples have values < 2, which implies organic depletion in the sediments, suggesting poor preservation or severe thermal conditions conditions (Hunt,1996)

ii) The quality of the organic matter: The quality of the organic matter is expressed in terms of the kerogen type. This was achieved by a plot between the hydrogen index (HI) and the oxygen inde x (OI) . Based on the modified Van Krevalen Diagram, almost all the data points plotted around the type IV maturation part. The kerogen content of the rock samples is therefore classified as type IV inert kerogen (Fig.5).

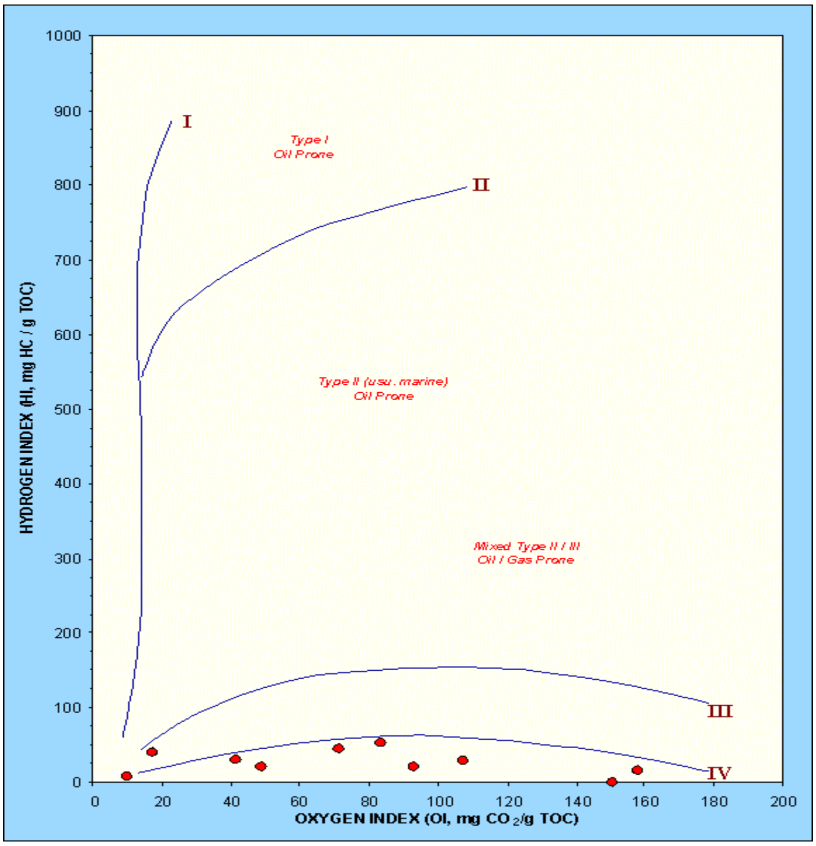


Fig 5:Kerogen type in sediments of Gboko Formation

Peters (1986) defined the following HI benchmark intervals: Gas source:HI= 50 – 150mgHC/g TOC, oil sources: HI = 150 – 300mg HC/g TOC, inert= < 50. HI of the values of the samples ranges between 0-54,with an average of 25, which also suggest a hydrogen depleted type IV inert Kerogen. The hydrogen content in kerogen is a measure of source rock quality; type I is an oil prone kerogen with abundant hydrogen,type II is an oil and gas prone with moderate hydrogen,type III is gas prone with small amount of hydrogen and type IV is an inert or dead kerogen with very little or negligible quantity of hydrogen.The unusually high Oxygen Index in most of the rock samples could be associated with the thermal break down of carbonates during diagenesis (Kartz,1993)

iii. The maturation stage of organic matter: the rock eval parameters applied here are the Tmax and the production index (PI). A total of ten samples have values that are either meaningless or unreliable Tmax due to very low S_2 peak, deduction was therefore made on the other seven samples with reliable data points. Tmax values corresponding to different stages of maturation are 400^0C-430^0C (immature), 430^0C-450^0C (mature- oil window) and > 450^0C (post mature- gas window) (Law,1999;Mode et al 2021)

Table 2: Tmax maturation table of rock samples

Samples	Tmax (^{0}c)	Maturation stage
C4	461	post mature
BBi	422	immature
A5	412	immature
A3	437	mature (oil window)
A2	449	
A1	439	
AA1	407	immature

A close observation of Table 2 shows that the samples are distributed between the immature, mature (oil window) and the post mature stages,with majority falling within the mature and post mature zones. Peters (1986) reported variation in Tmax due to differences in the types of organic matter contained in rocks,It is therefore possible that the original organic matter in the sediments was derived from both terrestrial and non- terrestrial sources, as the organic matter evolved through the different stages of oil and gas generation leaving behind a residual type IV Kerogen (Hunt,1986;,Magoon,1994; Law,1999)

The flatness of the S_2 peak of the samples is possibly due to advanced maturity occasioned by extreme heat, as evidenced by a sample with a post mature Tmax imprint.

Production Index: The last rock eval parameter used to determine the maturation stage of the sample is the production index (PI). The beginning of significant oil generation is around a PI of 0.1 and ends around 0.4 (Hunt, 1986; Tissot and Welt,1984). From Table 1, four samples namely A3 = 0.34, AA, = 0.42, A1 = 042 and A5 = 042 are within the oil window. All other samples have proceeded from the condensate to the dry gas zone, and this is also consistent with Tmax results of the samples. It is observed that samples with meaningless and unreliable Tmax possessed PI values with a post mature imprint, implying elevated level of thermal evolution of the organic matter.

(C.) Advance Thermal Maturity Indicators: Three selected samples of shales (A1, B3 and C4) with the highest TOC from each of the three section of the quarry were simultaneously subjected to Vitrinite Rreflectance (%VR), Thermal AlternationIindex (TAI) and Visual Kerogen Fluorescence (VKF), and result obtained is shown in Tables 3 and 4

Table 3: integrated interpretation of % R, TAI and VK Fluorescence

Sample	Pollen/spores				Amorphous				VR % R	TAI	Flourescence	Maturation stage
	G	Y	O	B	G	Y	O	B				
C_4	0	0	0	0	0	0	0	0	1.54	3. 7	Non-fluorescence	Dry-gas window
B_3	0	0	0	0	0	0	0	0	1.11	3.3	Non-fluorescence	End of oil window/Early condensate window.
A_1			2	1	0	0	0	0	0.77	2.7`	Weak fluorescence	Beginning of oil window.

G-Green; Y- yellow; O-Orange; B-Brown

Table 4: Percentage source material of kerogen

Samples	% Sources material		% kerogen composition			
	Amorphous debris	Herbaceous plant debris	Recycled / oxidized vitrinite	Inertinite	solid bitumen	Amorphous kerogen
C4	45	49	2	1	1	50
B3	61	4	1	1		95
A1	74	6	1	1		93

(i) Vitrinite Reflectance: The reflectance of light on polished surface of vitrinite increases with greater maturity because of change in molecular structure of macerals. The following are the empirical definition of integrated R_o(reflectivity) and TAI numbers representing the limits of oil and gas generation (Hunt,1996)

% R_0	TAI	
0.2% - 0.60%	2+	Immaturity
0.60% - 1.10%	2-3	Oil windows maturity
1.10% - 1.40%	3+3	Condensate/ wet gas window
1.40 – 3.0 or 4%	3.7- 4	Dry gas window

The data in Table 3 reveals that the samples vary from the oil to the dry gas window.Which indicates that oil and gas was generated by the Albian sediments of the middle Benue Trough.

ii. Thermal Alternation index (TAI): Staplin (1969) developed the thermal alteration index (TAI) as a relatively simple and rapid technique for evaluating kerogen maturation in well cuttings directly from its changes in colour. From the integrated R_o and TAI interpretation scale above, the samples again displayed results that are consistent with vitrinite reflectance values, which is a variation from oil to the dry gas window.

iii.. Visual Kerogen Fluorescence (VK): Fluorescence is the property of exciting light. Fluorescence microscopy is used to differentiate source rocks from non-source rocks and to differentiate the level of maturation from fluorescence colour. It has also been noticed that amorphous kerogen is potentially oil generating only if it fluoresces. The changes in fluorescence colours of the component of kerogen and coal when going from immature to mature and post mature stages of oil generation were described by Van Gijzel (1979). Fresh pollen and spores have fluorescence colour ranging from blue to red, depending on the type of species.

Fluorescence microscopy also include the form (structured or amorphous) and origin of kerogen. Structured kerogens include woody, herbaceous vitrnite and inertite. Visual kerogen estimates are usually presented in terms of the percentage of each type of kerogen in sample.Visual kerogen results of the three shale samples presented in table 3 reveals non fluorescence (indicated as 0) in the pollen and spores of samples B3 and C_4,

but playnomorph fluorescence is visible in A1(indicated as 2 and 1) as orange colour (Table 3) . This is an indication of oil window maturity to the lower limit of dry gas window (post mature)

In fluorescence microscopy,It is the oil generative type of amorphous kerogen that fluoresces, while the non generating type does not flouresce (,Petters and Ekweozor,1982; Katz(1993 and Hunt,1996). Therefore, the non fluorescing amorphous material from the result in Table 3 may have been exhausted through oil and gas generation as the kerogen matures at higher temperatures

The percentage composition of source materials in the kerogen (table 4) indicates a mixture of both amorphous and terrestrial organic matter in the C_4 sample, while amorphous kerogen is more abundant than terrestrial kerogen in B_3 and A_1 Samples, re-affirming the possible mixture of both type II (amorphous) and type III (terrestrial) kerogen in the original organic material.

An intergrated interpretation of the thermal maturity data revealed that the organic matter content of the sediments have matured from the oil window through the condensate to the dry gas window,making the Gboko Formation a gas prone deposit It is therefore possible that the extreme heat generated by the Santonian thermotectonic event resulted in the cracking of generated liquid hydrocarbon to gas via the different stages of thermal alteration of organic matter(Petters and Ekweozor,1982;Nwachukwu,1985;Obaje et al,1999 ;Abubakar,2014)

CONCLUSION

The hydrocarbon potential of the the sediments of Gboko Formation was evaluated with basic screening methods of organic geochemistry. TOC and Rock Eval pyrolysis results revealed an organic lean type IV residual Kerogen in which organic matter has been spent. Results of Thermal maturity indicatocators like Vitrinite Reflectance (%VR), Thermal Alteration Index (TAI) and Visual Kerogen Flourescence (VKF) conducted on three selected shale samples indicates a mixture of both amorphous and herbaceous organic matter which may have produced both oil and gas on advanced maturation.The evolution of the organic matter from oil to the dry gas window suggests that the Gboko Formation is within the gas generating stage.

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