Cretaceous Sediments from the P-Well in the Seme Field, Dahomey Basin, Benin Republic: Biostratigraphic Study and Hydrocarbon Potential Assessment

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ABSTRACT

The ditch cuttings of shale and sandstones sediments penetrated by the offshore P-well in the Seme Field, Dahomey Basin Southern Benin Republic were studied to establish the biostratigraphy and hydrocarbon potential .The total depth of the well is approximately 2257m. A total of twenty (20) samples of shale and six (6) sandstone samples were selected and used for this study. Forty one (41) species of planktic foraminifera and eighty eight (88) species of benthic foraminifera were recovered from the residue. Planktonic foraminifera species identified include Dicarinella concavata, Globigerina linerpata, Globotruncana aegyptica, Hedbergella delrioensis, Heterohelix moremani, Heterohelix striata, Rugoglobigerina rugosa macrocephala and Whiteinella archeocretacea while the benthic foraminifera species include Ammobaculites bauchensis, Bulinina reussi, Eponides spp.,Nodosaria limbata and Oonlina reussi to mention few. Based on the planktonic species five biostartigraphic zones were marked: Whiteinella archeocretacea zone (Turonia), Dicarinella concavata zone (Late Coniacian), Dicarinella asymmetrica zone (Santonia), Globotruncanita calcarata (Late Campanian) and Globotruncana aegyptica zone (Late Maastrichtian). Due to the presence of presence of Ammobabulites spp, Bolivina spp, Haplophragmoides spp, Lenticulina spp and Panulina spp among many others, the paleoecology of the foraminifera ranges from the continental shelf to abyssal plain in the general area of deposition. Source rock parameters have Total Organic Carbon , Hydrogen Index, Source Potential and Tmax values ranging from 0.66-4.68wt%,174-441 mgHC/ g TOC,1.8-19.4 mgHC/g rock and 386°C-439°C.The source rocks have organic richness essentially Types II,III and II-III oil and gas prone kerogen that are generate oil and gas that are to thermally immaturity marginally.

Keywords: Dahomey, Coniacian, Turonian, Afowo, Okitipupa, Seme, Benin Republic

INTRODUCTION

The Dahomey Basin is a very extensive sedimentary basin in the Gulf of Guinea which extends from the southeastern Ghana through Togo and Benin Republic on the west side to the Okitipupa ridge/Benin Hinge line on the east side in the southern part of Nigeria. The basin evolution involved basement fragmentation, block faulting and subsidence of the Jurassic basement complex couple with wrench movements of the basement blocks. The basin consists of sedimentary formations (Cretaceous –Tertiary) that outcrop in an arcuate belt roughly parallel to the coastline.

The Dahomey Basin generally is a combination of inland / coastal / offshore basin that is located in the Gulf of Guinea. It is separated from the Niger Delta, Nigeria by a subsurface basement high referred to as the Okitipupa Ridge (Omatsola and Adegoke, 1981) and its offshore extent is poorly defined. Sediment deposition in the basin follows an east-west trend. In the Republic of Benin, the geology is fairly well known (Billman, 1976; De Klasz, 1977). In the onshore, Cretaceous strata are about 200m thick (Okosun, 1990).

In recent time, hydrocarbon exploration had started in Lagos, eastern Dahomey Basin in Nigeria and Tano Basin in Ghana which is presently producing oil. This study aimed at examining the hydrocarbon potentials of the sediments in the P-Well drilled in the Seme Field, Benin Republic within the Dahomey basin. This location is between Nigeria and Ghana. This research is to check the continuity of the source beds within the same geological interval across the basin. The data generated will allow better interpretation of the hydrocarbon potential laterally and stratigraphycally across the basin. The well is located

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in the Southern Benin in the Seme Field Figure 1.

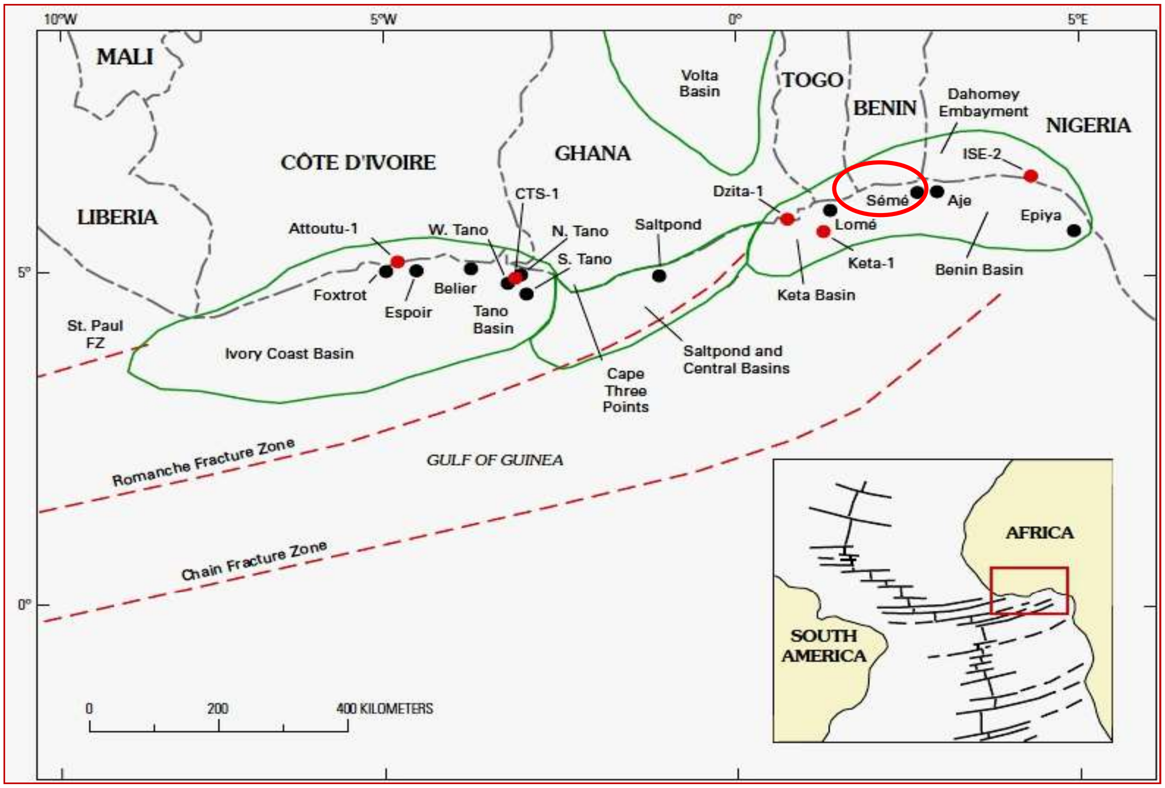

Figure 1: Regional map of Dahomey Basin showing Ghana, Togo and Benin Republic, the red ring portion is the location of the P-well (modified after Brownfield and Charpentier 2006).

The stratigraphic setting of the Dahomey Basin has been described in detail in the works of Adegoke, 1969; Ogbe, 1970; Kogbe, 1974; Billman, 1976; Omatsola and Adegoke, 1981; Ako *et al.,* 1980; Okosun, 1990; Idowu *et al.,* 1993; Adekeye, 2005 and Adekeye *et al.,* 2006. These authors reported five lithostratigraphic formations covering the Cretaceous to Tertiary ages. The formation from the oldest to the youngest include: Abeokuta Group comprises Ise, Afowo and Araromi formations (Cretaceous), Ewekoro Formation (Paleocene), Akinbo Formation (Late Paleocene-Early Eocene), Oshosun Formation (Eocene) and Ilaro Formation (Middle-Late Eocene). Figure 2 shows the regional stratigraphic chart of the basin which establish the above formations mentioned.

MATERIAL AND LABORATORY PROCEDURES

The ditch cutting samples were collected from a carefully logged P-well drilled by an indigenous oil company in Nigeria in the Seme field Benin Republic. The well has a basal whitish sandstone of about 250m thick which is overlain by dark grey poorly laminated sandy shale of about 25m and in turn overlain by grey to light grey shale of over 1900m thick (Figure 3).

Twenty shale samples were selected and subjected to Rock Eval Pyrolysis at the Weatherford Laboratories, Texas, United States of America. Standard procedure of Rock Eval Pyrolysis experimentation on rock Eval II machine was carried out. The Rock Eval II pyrolysis has the ability of measuring the Total Organic Carbon (TOC) content in the pulverized samples at elevated temperature of 600°C (Espitalie *et al.,* 1977). Pyrolysis of 10-50mg of samples at 300°C for 4 minutes was followed by programmed pyrolysis at 25°C/min to 550°C in an atmosphere of helium. The parameters assessed from Rock Eval Pyrolysis include: Source Potential (SP), Genetic Potential (S1 + S2), Thermal Maturity of the organic matter (Tmax), Total Organic Carbon content (TOC), Hydrogen Indices (HI) and Productive Index (PI).

The foraminifera study was carried out in the laboratory of Geology and Mineral Science department, University of Ilorin. Twenty samples selected at certain stratigraphic

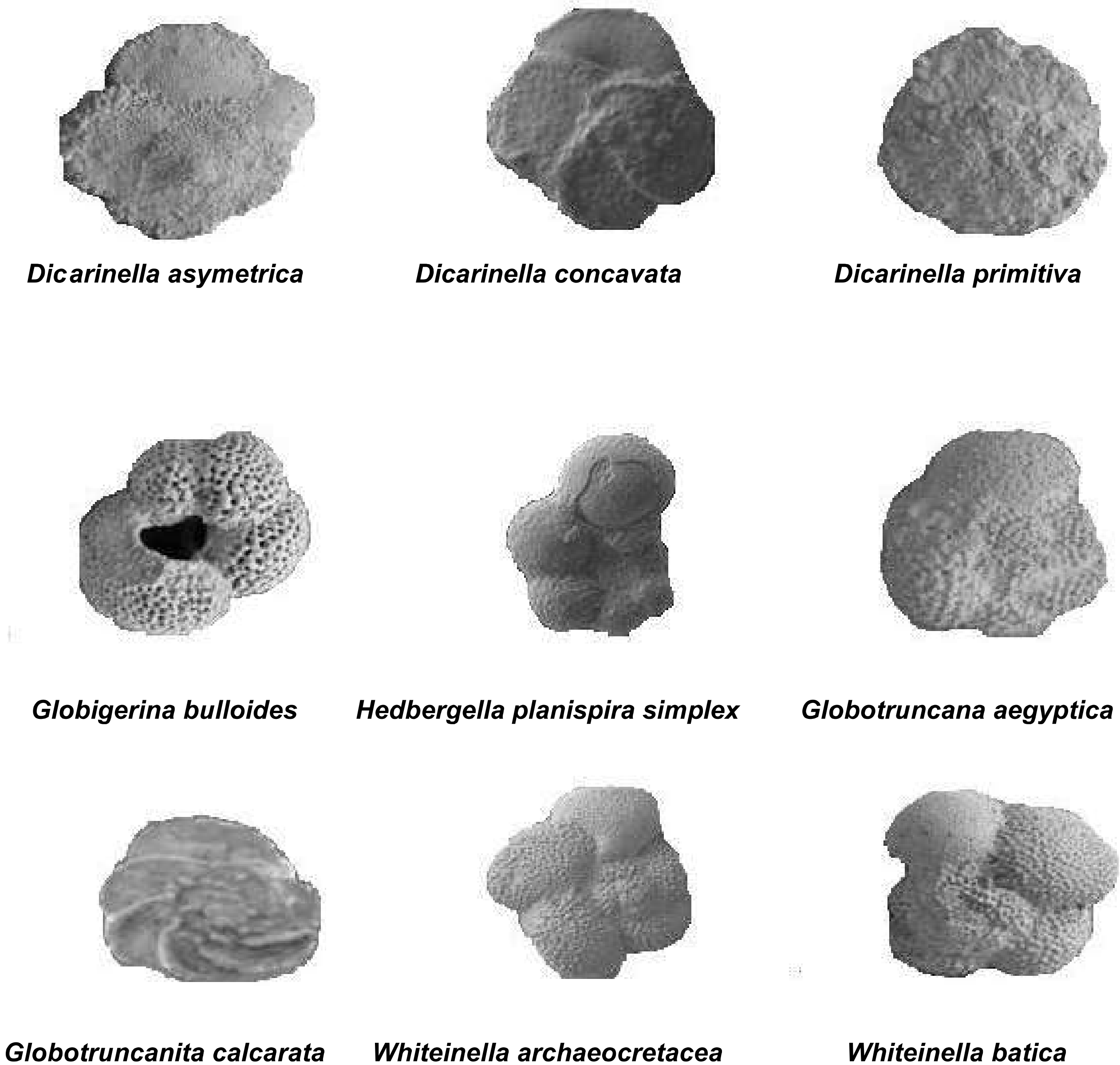

Figure 2: Some diagnostic Planktic Foraminifera species recovered from shale sediments.

horizon and subjected to digestion .The samples were soaked in hydrogen peroxide diluted with water using ratio 1:3 respectively and washed under running water using 0.063mm sieve till the water is clean. The residue was dried and distributed on a black picking tray.

Selected samples from the P-Well were used for the two analysis mentioned above. The log shows that the lithology of the well is essentially shale and sandstone

Praeglobotruncana delrioensis stephani.

Dicarinella concavata zone: *Belongs to interval zone depicting the Late Coniacian to Early Santonian age* this zone was marked by the presence of *Dicarinella concavata* in sample PEL15 at (1830m). It's defined as interval from first occurrence of *Dicarenella concavata to first occurrence of Dicarenella asymmetrical.* Other species of planktic found in this zone includes *Dicarinella primitive,*

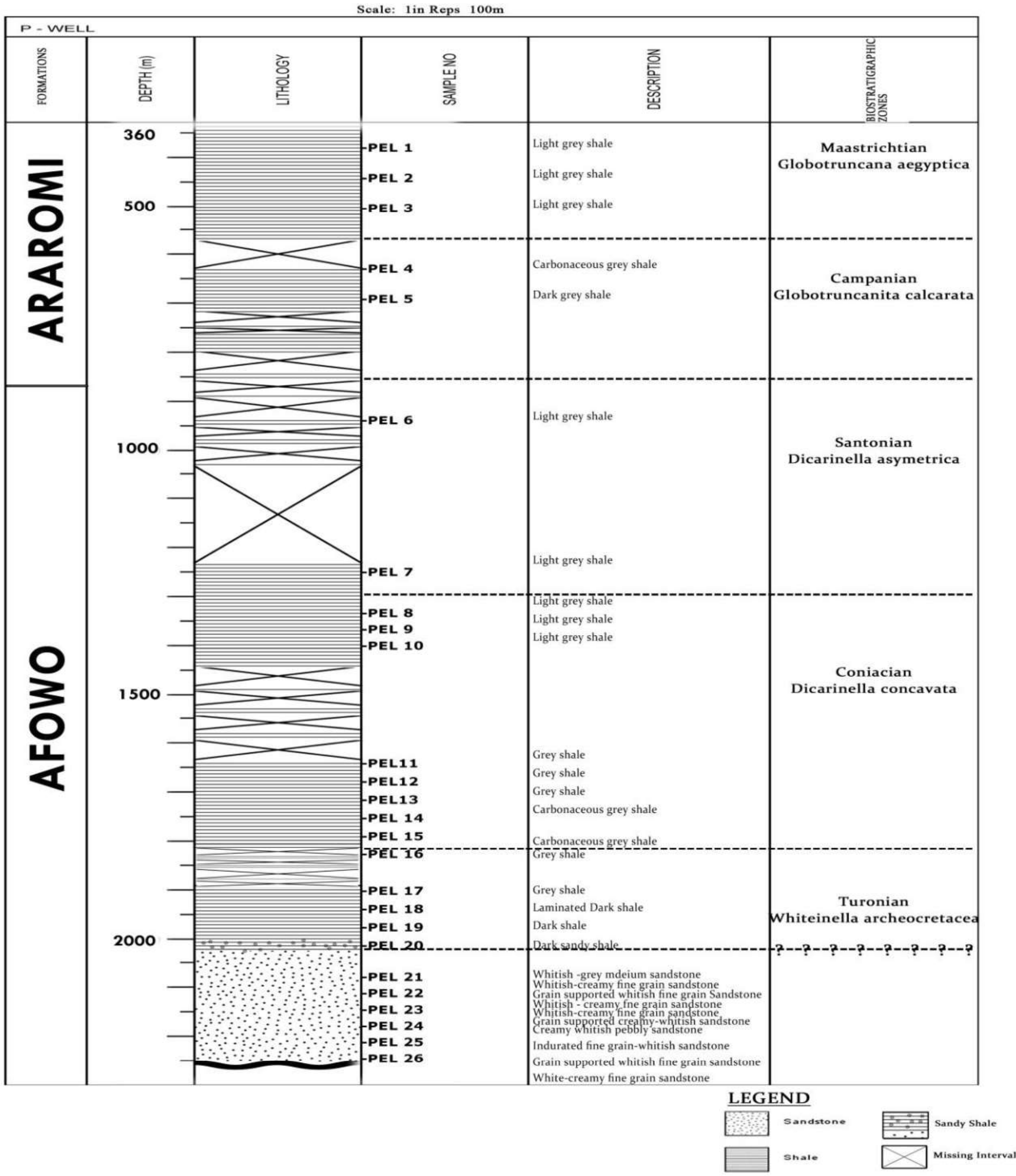

Figure 3: Shows the biostratigraphic zonations of the P-well based on the occurrence of some planktic foraminifera.

Table 1: Rock- Eval data of the shale samples from the P well Seme Field Dahomey, Basin Benin Republic.

Sample Number	Depth (m)	TOC (wt%)	S_1	S_2	S_3	T_{max} (°C)	HI (mgHC/g TOC)	OI	S_2/S_3	PI	SP (S1+S)
PEL-1	410	0.66	0.65	1.15	2.76	386	174	418	0.4	0.36	1.8
PEL-2	490	0.84	0.59	1.63	2.81	417	195	337	0.6	0.26	2.22
PEL-3	550	1.07	0.47	1.5	2.92	422	140	273	0.5	0.24	1.97
PEL-4	660	1.33	0.95	3.01	3.5	428	226	263	0.9	0.24	3.96
PEL-5	710	1.52	0.85	3.05	3.12	428	201	206	1	0.22	3.9
PEL-6	950	1.26	0.76	2.53	3.01	428	201	239	0.8	0.23	3.29
PEL-7	1290	1.15	0.42	2.57	2.91	428	223	253	0.9	0.14	2.99
PEL-8	1350	1.53	0.69	4.28	2.76	428	280	180	1.6	0.14	4.97
PEL-9	1400	1.4	1.04	4.08	3.53	427	292	253	1.2	0.2	5.12
PEL-10	1485	1.31	1.25	3.54	3.16	433	271	242	1.1	0.26	4.79
PEL-11	1660	1.11	0.81	3.08	2.72	433	278	246	1.1	0.21	3.89
PEL-12	1710	1.42	1.52	4.58	3.33	431	323	235	1.4	0.25	6.1
PEL-13	1750	1.52	1.17	5.41	2.71	433	357	179	2	0.18	6.58
PEL-14	1790	1.75	1.08	7.63	2.05	433	437	117	3.7	0.12	8.71
PEL-15	1830	1.77	1.51	7.78	1.82	432	441	103	4.3	0.16	9.29
PEL-16	1871	1.05	0.34	2.85	1.49	437	273	143	1.9	0.11	3.19
PEL-17	1925	4.45	1.07	16.53	1.06	436	372	24	15.5	0.06	17.6
PEL-18	1950	3.46	0.79	8.75	1.04	439	253	30	8.4	0.08	9.54
PEL-19	1977	3.01	0.75	6.68	1.02	436	222	34	6.5	0.1	7.43
PEL-20	2020	4.68	2.29	17.11	1.03	435	366	22	16.6	0.12	19.4

.The upper part of the well is essentially shale while the basal part is sandstone. Samples labelled PEL 1-20 are shales while PEL 21-26 are sandstones. Note, same samples were used for both foraminifera and hydrocarbon studies.

RESULTS AND DISCUSSIONS

Foraminifera Biostratigraphy

The Cretaceous sequence has been divided into ten stages and twenty eight zones (Bolli 1966) certain planktic marker species are used for the zonations. The samples of shale are very rich in planktic forms which gave clues on the age of the P-well under study, some of the planktic forms especially the marker species shown in Fig. 2 were used for biostratigraphic zonations shown in Fig. 3 .

Forty one species of planktic foraminifera was recovered from the twenty shale samples that was digested. There is high occurrence of planktic foraminifera with a total number of three hundred and thirty three of them among the numerous species found are *Contusotruncana fornicate, Dicarinella assymetrica, Dicarinella concavata, Dicarinella primitive Eoglobigerina spiralis,Globigerina spp, Globigerina bulloides, Globigerina linerpata, Globigerina pseudotriloba, Globigerina subcretacea, Globotruncana aegyptica, Globotruncanita calcarata, Guembelina globulosa, Guembelina plummerae, Guembelina reussi, Guembelina ultimatumida, Hedbergella delrioensis, Hedbergella holmdelensis, Hedbergella planispiral, Hedbergella planispira simplex, Hedbergella complex, Hedbergella sigali, Heterohelix globulosa, Heterohelix globocarinata, Heterohelix moremani, Heterohelix reussi, Heterohelix pulchra, Heterohelix striata, Hevetoglobotruncana hevetica, Pseudoguembelina costulata, Pseudoguembelina excolata, Pseudoguembelina striata, Pseudotextularia elegans elegans, Praeglobotruncana delrioensis stephani, Praeglobotruncana repanda, Praeglobotruncana wilsoni, Rugoglobigerina cretacea, Rugoglobigerina esnchensis, Rugoglobigerina rugosa macrocephala, Whiteinella archeocretacea and Whiteinella baltica.*

Whiteinella archeocretacea zone: This belongs to category of partial range zone depicting Early Turonian age (Bolli,1966) by synonymy it is equivalent to *Praeglobotruncana gigantae* zone. The *Whiteinella archeocretacea* zone can be defined as its interval from extinction of *Rotalipora cushmani* to first occurrence of *Helveglobotruncana helvetica*. In the P-well foraminifera study, *Whiteinella archeocretacea* was found in PEL 19 at (1977.5m) and PEL 18 at (1950) occurring along side with *Eoglobigerina spiralis, Globigerina spp, Globigerina bulloides , Heterohelix globulosa, Heterohelix moremani, Heterohelix stiata, Heterohelix reussi and Globigerina bulloides, Heterohelix moremani, Heterohelix pulchra, Heterohelix striata, Heterohelix globulosa, Praeglobotruncana repanda* among many others.

Dicarinella asymmetrical zone: It is a total range zone ,it belongs to the upper part of Early Santonian to Late Santonian age , in the P-well this zone was marked by the presence of *Dicarinella asymmetrical* found in PEL7 at (1290m) it synonym is *Globotruncana concavata carinata zone.* Other planktic species present along with this specie in this zone are; *Globigerina bulloides, Hedbergella sigali, Heterohelix striata* and *Pseudoguembelina excolata* among few others.

Globotruncanita calcarata zone: This belongs to the Late Campanian age, it defines the interval of total range of *Globotruncanita calcarata.* In PEL 5 at (710m) *Globotruncanita calcarata* was found along side with *Globigerina bulloides,Gumbelina reussi, Gumbelina ultimatumida, Heterohelix reussi, Heterohelix globocarinata,Pseudoguembelina costulata and Pseudoguembelina excolata.*

Globotruncana aegyptica zone: It is an interval zone depicting the Early Maastrichtian (Caron, 1985),this zone is interval from first occurrence of *Globotruncana aegptica* to first *Gansserina gansseri.* In this study *Globotruncana aegyptica* was found in PEL 3 at (550m) occurring along side with *Globigerina bulloides, Globigerina linerpata, Globigerina pseudotriloba, Pseudoguembelina costulata, Pseudoguembelina excolata, Pseudoguembelina striata* and *Rugoglobigerina cretacea* among many others.

Petroleum Potential Assessment

The Rock Eval pyrolysis result is presented in the Table 1. The various parameters for assessing the hydrocarbon potential of a source bed are discussed from there. The principal parameters discussed below include: Source Potential (SP), Hydrogen Index (HI), Thermal maturity (T_{max}), Kerogen Types, Production Index (PI) and Total Organic Carbon (TOC).

Source Potential (SP)

The source potential is calculated from the addition of S1 + S2 values and is a measure of the genetic potential of the rock. This is regarded as the total amount of petroleum that might be generated from a rock. This potential usually depends on the nature and abundance of kerogen, which in turn are related to the original organic input at the time of sediment deposition and to the conditions of microbial degradation and rearrangement of the organic matter in the young sediments. Dymann *et al.,* 1996 gave a standard for SP qualities.

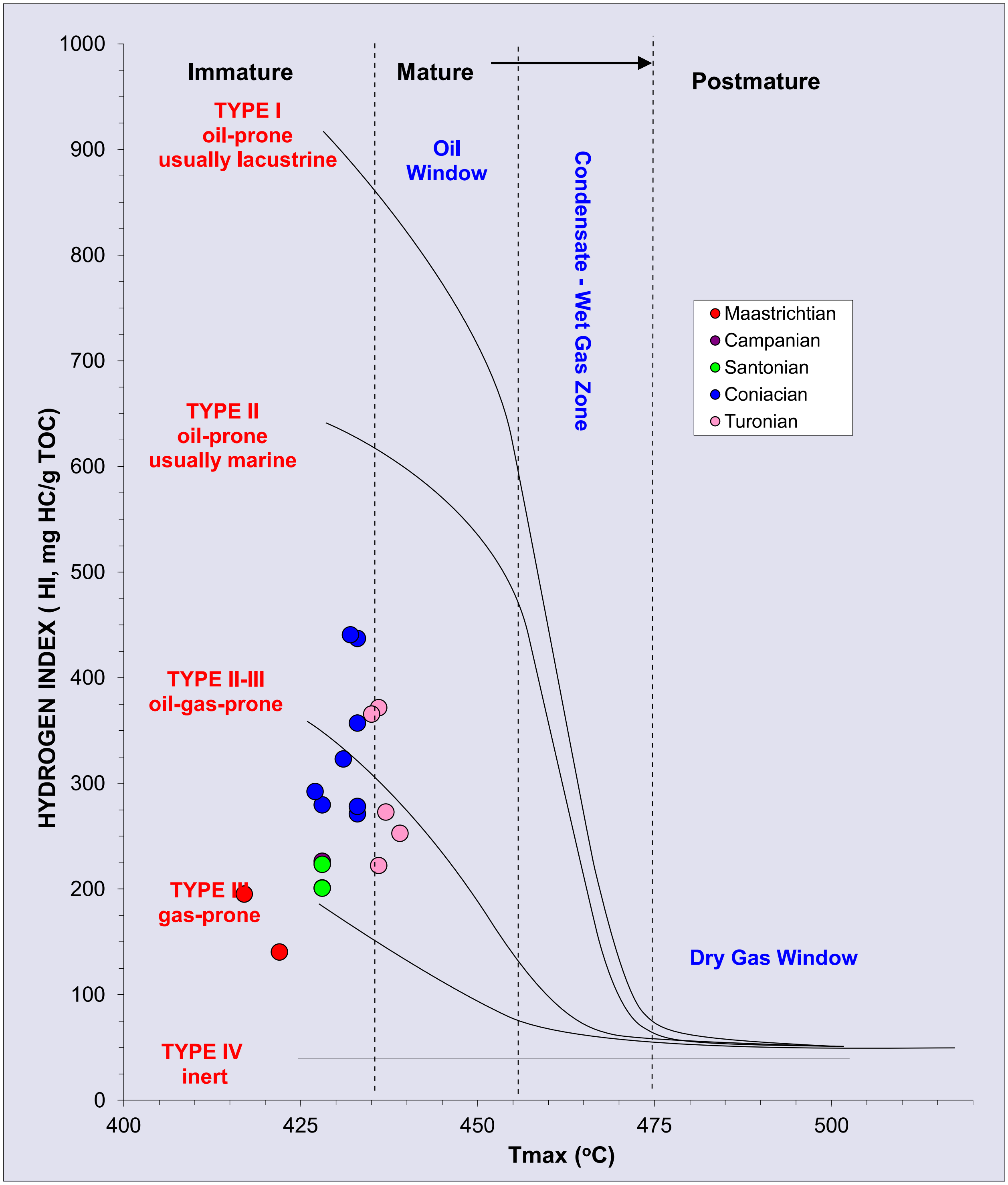

Figure 4: The plot of Hydrogen Index (mg HC/gTOC) against Tmax(°C) to show the stages of hydrocarbon formation and kerogen types.

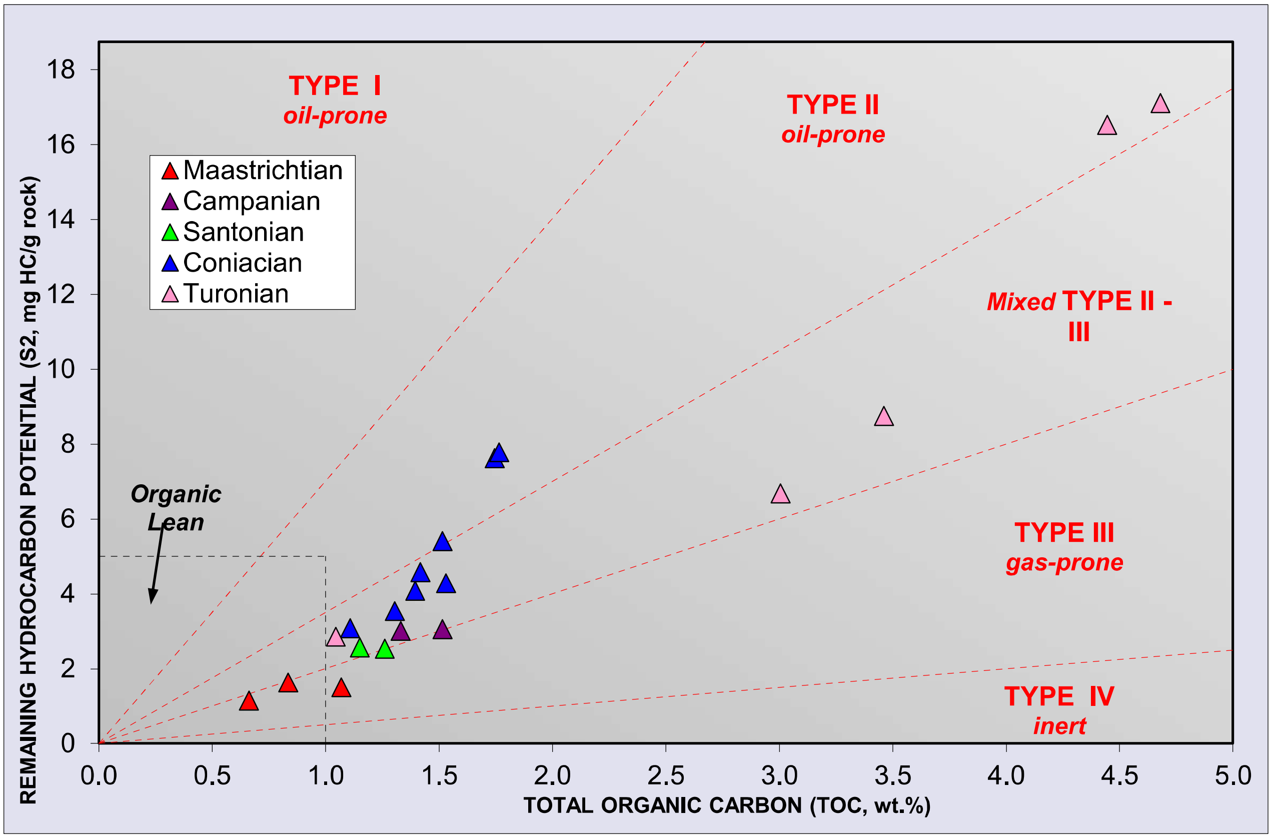

Figure 5: Plot of Remaining Hydrocarbon Potential against Total Organic Carbon.

From Table 1, the source Potential (SP) values range from 1.8mg HC/g -19.4 mg HC/g and mean value of 6.337mg HC/g. The Pre Santonian samples (PEL 8-20) have higher SP values range of 3.19 -19.4 mg HC/g indicating moderately good to good source potential. The Santonian samples (PEL 6&7) have 2.99-3.29 mg HC/g and Post Santonian samples (PEL 1-5) range from 1.8-3.96 mg HC/g indicating moderately good source potential. Using the standard of Dymann *et al.,* (1996) the SP values suggest that the shale sediments in the P-well can serve as source rock which have moderate to good source rock quality to generate oil and gas.

Hydrogen Index (HI)

HI is proportional to the amount of hydrogen contained in the kerogen and higher HI indicates a greater potential to generate hydrocarbon. Peters and Cassa, 1994 gave geochemical parameters describing kerogen types and the quality in their work. In the P-well the HI values of the shale samples analysed generally exceed 200mgHC/gTOC. The values range from 140 - 441mgHC/gTOC (Table 1) with an average value of 276.25mgHC/gTOC indicating mixed oil and gas prone Type II/III kerogen. The Pre Santonian samples (PEL 8-20) have higher HI values (441-222mgHC/g TOC) indicating potential to generate oil and mixed oil & gas. The Santonian samples (PEL 6 &7) HI values range from 201-223 mgHC/g TOC) indicating potential for mixed oil and gas while Post Santonian samples (PEL 1-5) values range from 140-226 mgHC/g TOC indicating ability to yield gas and mixed oil &gas (Figs 4 & 5).

Thermal maturity

Thermal maturity describes the extent of heat driven reactions which convert organic matter in sedimentary rocks into petroleum. Depending on the relation to the oil generative window, organic matter can be described as immature, mature or post mature. The Tmax values represent the temperature at which the largest amount of hydrocarbons can be produced in the laboratory when a whole rock sample undergoes a pyrolysis treatment. Figure 6 shows the stages of hydrocarbon formation and kerogen types.

The T_{max} of the P-well range from 3860C - 4390C (mean 428.50C). This indicates that the shales are immature to marginally mature. The Pre Santonian samples (PEL 8-20) have higher T_{max} values 4270C -4390C indicating immature to marginal maturity, Santonian samples (PEL 6 &7) have 4280C indicate immature stage and Post Santonian samples (PEL 1-5) have values ranging from 3860C-4280C indicate immature stage of kerogen maturation. From the range of Tmax values the shale sediments penetrated by the P-well falls in stages of immature to marginal mature. Only the Turonian sediments made it to early maturity to generate oil while other samples from the Coniacian to Maastrichtian are essentially immature.

Total Organic Carbon (TOC)

High concentrations of organic matter tend to occur in sediments that accumulate in areas of high organic matter productivity. Environments of high productivity can include nutrient rich coastal upwelling, swamps, shallow seas and lakes. The TOC is a direct measurement of the organic matter richness of a given sedimentary rock. It is the measure of the quantity of organic matter (OM) present in a rock. According to North (1985) the TOC values of any rock can be classified as poor, fair, good, very good and excellent.

The TOC content of samples in P-well have values ranging from 0.66w% to 4.68 wt% with an average TOC value of 1.81wt%. Most of the samples having TOC values in such level of organic richness are considered as good to excellent source rock for hydrocarbon generation (Peters and Cassa, 1994).The Pre Santonian samples (PEL 8-20) have higher TOC values ranging from 1.05-4.86wt% indicating good to excellent quality for hydrocarbon generation. The Santonian samples (PEL 6 &7) have 1.15-1.26wt% indicating good quality to generate hydrocarbon and the Post- Santonian samples (PEL 1-5) have a range from 0.66-1.52wt% suggesting fair to good quality to generate hydrocarbon.

According to Tissot and Welte, 1978 TOC values >0.5wt% is the minimum threshold value for hydrocarbon generation in siliciclastic rocks. The TOC values of the P-well suggests that the shales have adequate organic matter constituents for hydrocarbon generation. Figure 5 shows the plot of remaining hydrocarbon potential versus TOC and from the figure, only the Maastrichtian sediments have lean organic contents. The plot shows the kerogen quality of the sediments as they fall in kerogen Types II, II-II and III.

Source rock potential assessment using TOC indicates generally good to excellent amount of organic matter richness. It is noted that the dispersed organic matter in the source rock facies is composed mainly of Types II, III and II/III kerogen which are capable of generating oil and gas. The hydrocarbon potential parameters decreases upward from the Turonian to Maastrichtian interval.

CONCLUSION

The P-well penetrated shale and sandstone sediments in the Seme field, Benin Republic in the Dahomey basin. The well was logged, measured and sampled. The total depth of the well is approximately 2257m. The base of the well is mainly sandstone which is overlain by grey shale and it ranges in age from Turonian to Maastrichtian age. Twenty carefully selected shale samples were assessed through rock eval pyrolysis for hydrocarbon potential and the results show the Total Organic Carbon (TOC) values ranging from 0.66 - 4.68 wt% averaging 1.81 wt%, Hydrogen Index (HI) values range from 174 - 441 mgHC/gTOC, Source Potential (SP) values varied from 1.8 – 19.4 mgHC/g rock and Tmax values range from 386°C - 439°C. The plot of Tmax (°C) against Hydrogen Index (mgHC/gTOC) shows that the shale sediments fall mainly within the oil and gas and gas generation zones. The plot of remaining hydrocarbon potential (S2 mg HC/g rock) against Total Organic Carbon (TOC wt%) shows high organic richness that produce essentially kerogen Types II, III and II-III. The shale sediments are thermally immature to marginally mature for hydrocarbon generation. The shale sediments of the Cenomanian-Turonian age has the highest potential to generate hydrocarbon while the post Santonian shales have fair potential.

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5. Repositioning and Adapting Geosciences Education Curriculum for Future Energy Dynamics - Manpower Training, Development and Retention
6. International and Local Energy Business and Investment Landscapes – Regulatory framework, financing and viability

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DEADLINES:

July 31, 2023: Abstract Submission Deadlines
August 31, 2023: Acceptance Letter Issuance

September 30, 2023: Full Paper Submission
September 30, 2023: Issuance of Letters for Judges

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