

Hydrocarbon Potential of Late Miocene to Early Pliocene Source Rocks of Shallow Offshore, Niger Delta Basin, Nigeria

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ABSTRACT

The shallow offshore of the Niger Delta basin has significant hydrocarbon potential. Source rock potential and 1-D burial model of the Late Miocene-Early Pliocene source rocks in the shallow offshore have not been extensively discussed. Results of Rock-Eval analysis of ten (10) Late Miocene-Early Pliocene subsurface shale samples from an exploration well were used to evaluate Late Miocene-Early Pliocene source potential and to reconstruct a 1-D basin models in order to determine the timing of hydrocarbon generation and expulsion. The Total Organic Carbon (TOC) content values of all the samples exceed minimum thresholds value of 0.5 wt. % required for potential source rock. The relationship between (S1+ S2) and TOC suggests that the Late Miocene-Early Pliocene samples could be regarded as poor to excellent source potential. Pseudo-Van Krevelen plot for shale samples indicates Type III/IV and Type III organic matter. The 1-D basin model shows that the Late Miocene-Early Pliocene source rock entered the early oil generation window during the Miocene age with transformation ratio of less than 1% suggesting that enough hydrocarbons have not been significantly expelled to adjoining reservoir rocks.

(Keywords: source rock, shallow offshore, hydrocarbon potential, Niger Delta Basin)

INTRODUCTION

The Niger Delta Basin ranks amongst the world's most prolific petroleum producing Paleogene-Neogene deltas that together account for about 5% of the world's oil and gas (Ajaegwu *et al.*, 2014). Shallow offshore of the Niger Delta basin (Figure 1) has significant hydrocarbon potential (Fadokun and Abrakasa, 2014). All major oil and

gas discoveries in the Niger Delta Basin occur in Eocene to Pliocene sandstones of the Agbada Formation (Mattick, 1982; Bustin, 1988).

The presence of a viable source rock is an important factor governing the natural accumulation of hydrocarbon (Dahl *et al.*, 1994) and understanding its characteristics and ability to generate hydrocarbon is a major consideration for successful exploration (Fadokun and Abrakasa, 2014). Published works on source rocks of Late Miocene-Early Pliocene (in the shallow offshore) are rare. This study attempts an evaluation of Late Miocene to Early Pliocene source rocks (organic richness and kerogen type) and to reconstruct 1-D basin models in order to determine the timing of hydrocarbon generation and expulsion.

GEOLOGICAL SETTING

Two arms of a triple junction comprising of collapsed margin of south Atlantic gave rise to the Niger Delta following the early Cretaceous subsidence of the African continental margins and deposition of clastic materials (Ehinola and Ejeh, 2009). During the middle and late Eocene times regional deltaic deposition has been established with sediments largely derived from the weathering flanks of Niger-Benue drainage system (Stacher, 1994). In the Tertiary, it prograded into the Atlantic Ocean at the mouth of the Niger-Benue river system producing a delta (Ehinola and Ejeh, 2009).

Well sections through the Niger Delta generally display three vertical lithofacies subdivisions, namely the Akata, Agbada and Benin Formations (Figure 2) corresponding to pro-delta, delta front and delta plain respectively (Ajaegwu *et al.*, 2014).

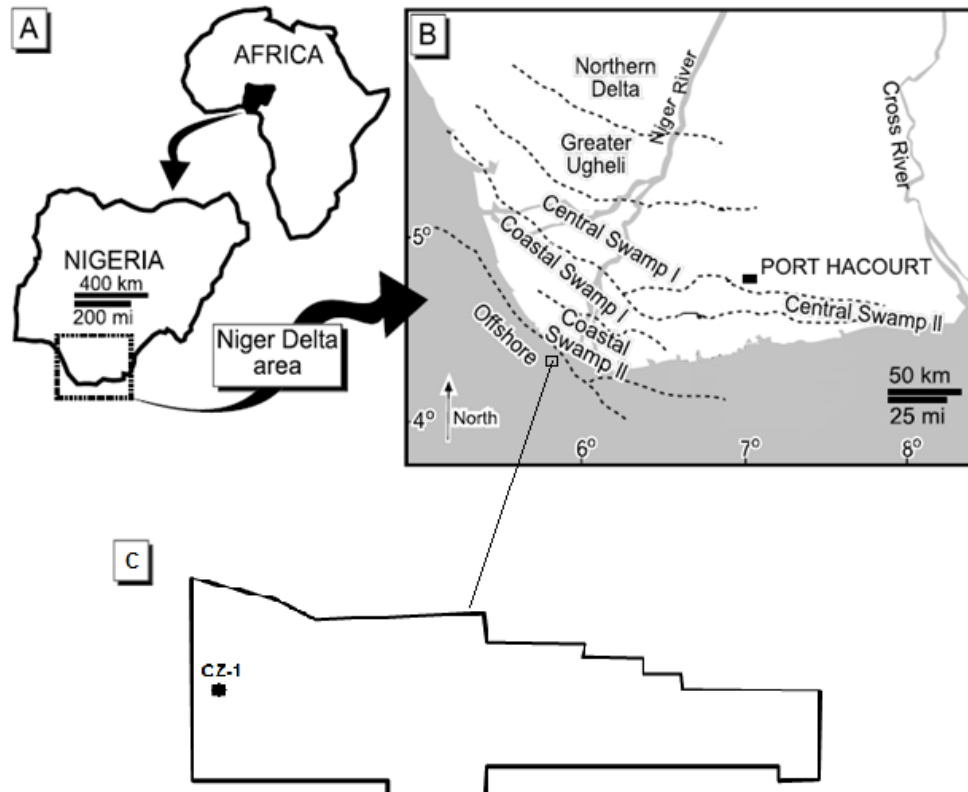


Figure 1: (A) Location of Niger Delta along the West Coast of Africa, (B) structurally defined sub-basins in the Niger Delta clastic wedge (map modified from Magbagbeola and Willis, 2007). (C) Location of studied exploration well.

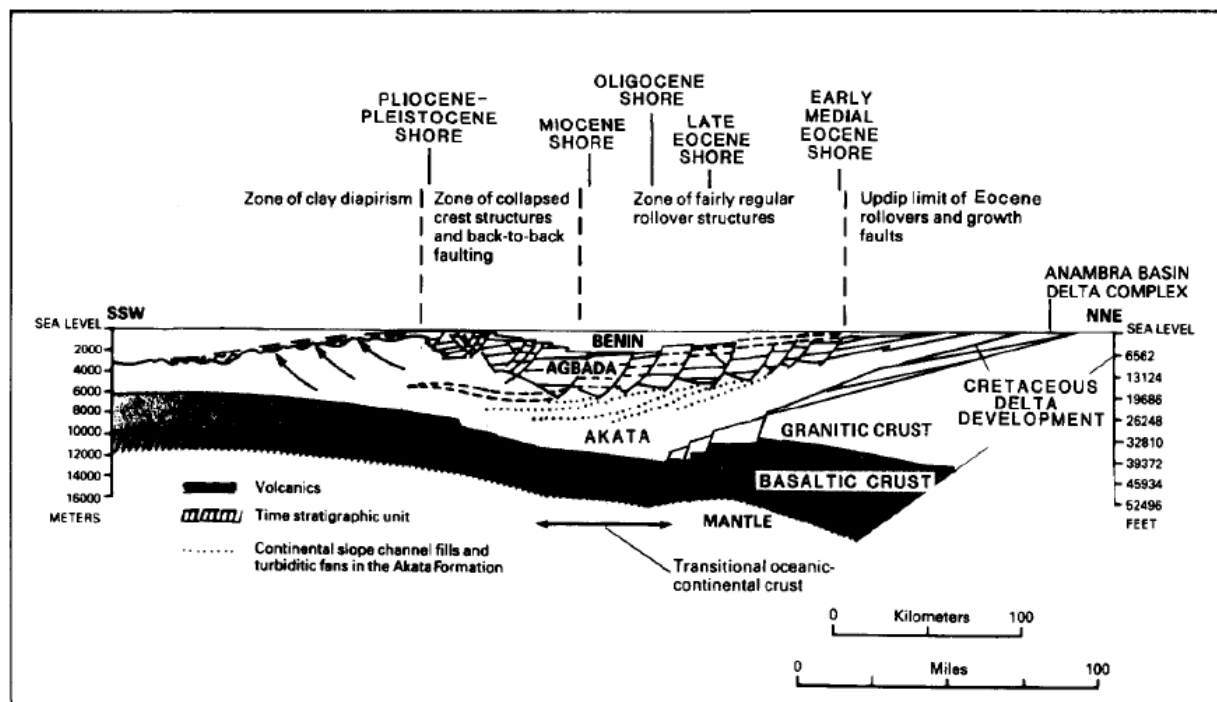


Figure 2: Schematic structural cross section through Niger Delta showing stratigraphic succession and main tectonic elements (Bustin, 1988).

The Akata Formation comprised mainly marine shales, sandy and silty beds, which are thought to have been laid down as turbidites and continental slope channel fills (Ajaegwu *et al.*, 2014). The environment of deposition of Akata Formation grades laterally into the holomarine environment which is not affected by deltaic activity (Short and Stauble, 1967).

Agbada Formation consists of paralic, mainly shelf deposits of alternating sands, shales and mudstone (Oluwajana *et al.*, 2017; Oluwajana, 2018). The sediments of Agbada Formation comprise of brackish-water lower deltaic plain (mangrove, swamps, flood-plain basin, marsh) and the coastal area with its beaches, barrier bars, and lagoons (Short and Stauble, 1967). The sediments in this environment are distinctly fine-grained than in the continental environment.

Reservoir intervals in the Agbada Formation have been interpreted to be deposits of highstand and transgressive systems tracts in proximal shallow ramp settings (Evamy *et al.* 1978). The continental Benin Formation consists of predominantly massive, highly porous, freshwater-bearing sandstones, with local thin shale interbeds considered to be of braided-stream origin.

The sands and sandstones may represent point-bar deposits, channel fills, or crevasse splays, whereas the shales may represent backswamp deposits (Nwachukwu and Chukwura, 1986).

Oil and gas occurrences in Niger Delta are concentrated in sandstone reservoirs at various levels of the Agbada Formation (Nwachukwu and Chukwura, 1986). The age of the producing sand intervals of the Agbada Formation ranges from Eocene to Pliocene (Ejedawe, 1981).

MATERIALS AND METHODS

Ten (10) ditch-cutting samples from an exploration well in the shallow offshore of Niger Delta Basin were sampled and analyzed by Shell Petroleum Development Company of Nigeria (SPDC). The exploration well for proprietary reason was named as CZ-1 well. This study utilized Gamma-Ray log (Figure 3) and Rock-Eval pyrolysis results of Late Miocene-Early Pliocene source beds (Table 1).

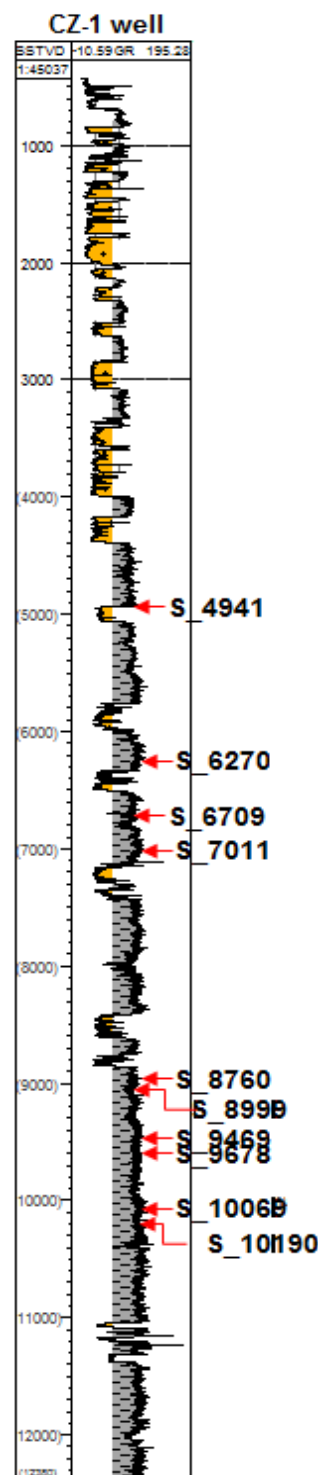


Figure 3: Well profile of Late Miocene-Early Pliocene in CZ-1 well. Gamma ray log response assists in the identification of the shale beds.

Table 1: Results of Rock–Eval pyrolysis and TOC content analyses of Late Miocene-Early Pliocene source beds in well CZ-1, shallow offshore, Niger Delta Basin.

Depth (ft)	Depth (m)	TOC (wt.%)	Rock-Eval pyrolysis						
			S ₁ (mgHC/gTOC)	S ₂ (mgHC/gTOC)	S ₁ + S ₂	T _{max}	OI (mgHC/gTOC)	HI (mgHC/gTOC)	PI (mgHC/gTOC)
4941	1506	0.5	0.26	0.4	0.66	418	256	50	0.39
6270	1911	0.6	0.27	0.17	0.44	426	163	28	0.61
6709	2045	1.8	1.57	0.81	2.38	121	127	45	0.66
7011	2137	1.9	3.06	1.52	4.58	423	130	80	0.67
8760	2670	1.9	1.59	1.08	2.67	424	103	57	0.6
8999	2743	14.4	6.29	24.37	30.66	426	79	169	0.21
9469	2886	2.1	0.73	1.11	1.84	428	82	63	0.4
9678	2950	1.4	0.75	0.66	1.41	423	88	49	0.52
10069	3069	2	1.34	1.51	2.85	420	119	70	0.47
10190	3106	2.6	0.88	1.64	2.52	426	112	60	0.35

1-D basin model was simulated using IES GmbH PetroMod 1D Express in order to infer the timing of hydrocarbon generation and expulsion from deeply buried Late Miocene-Early Pliocene source intervals. The input data for the stratigraphic modelling included age, and thicknesses, lithology of different sedimentary layers and duration of deposition (Ehinola and Oluwajana, 2016; Oluwajana, 2018).

Paleobathymetry data are used in the reconstruction of the total subsidence that occurred within the basin (Underdown and Redfern, 2008). Paleobathymetric values for the Niger Delta Basin used in this study were obtained from the proprietary Shell Petroleum Development Company chart and published works of Hardenbol *et al.* (1998) and Gradstein *et al.* (2004).

The reconstruction of thermal histories of sedimentary basins is always simplified and calibrated against maturity profiles such as vitrinite reflectance (Yahi *et al.*, 2001). The heat flow values were determined by streaming modelled and measured vitrinite reflectance data (Oluwajana, 2017). Figure 4 shows a good and reasonable correlation between measured (Table 2) and modelled vitrinite reflectance values for the exploration (CZ-1) well. Modelled vitrinite reflectance values were calculated after Easy%R_o. Sweeney and Burnham (1990). Constant

modelled heat flow value of 35 mW/m² was applied during stimulation.

Present-day Total Organic Carbon (TOC) value of 3.0 wt.% TOC and Hydrogen Index (HI) value of 67 mgHC/gTOC were used in the modelling. The basin modelling simulation was performed by applying forward modelling method. Simulated model was presented visually.

RESULTS AND DISCUSSION

Organic Matter Richness

Total Organic Carbon (TOC) contents of Late Miocene-Early Pliocene shale samples in CZ-1 well vary from 0.5 to 14.4 wt. % (mean value of 2.92 wt. %) suggesting good to very good source rocks (Figure 5). The TOC values of all the samples exceed minimum thresholds value of 0.5 wt. % required for potential source rock (Tissot and Welte, 1978). Plot of TOC content and S₂-generative hydrocarbons (Figure 6) of the sample showed that most of Late Miocene-Early Pliocene shale are within poor generative potential (Peter and Cassa, 1994; El Nady *et al.*, 2005). The Hydrogen Index (HI) values range from 28 to 169 mgHC/gTOC. The lower Hydrogen Index (HI) values of upper Miocene to Pliocene strata indicate lower percentages of autochthonous organic matter (Bustin, 1988).

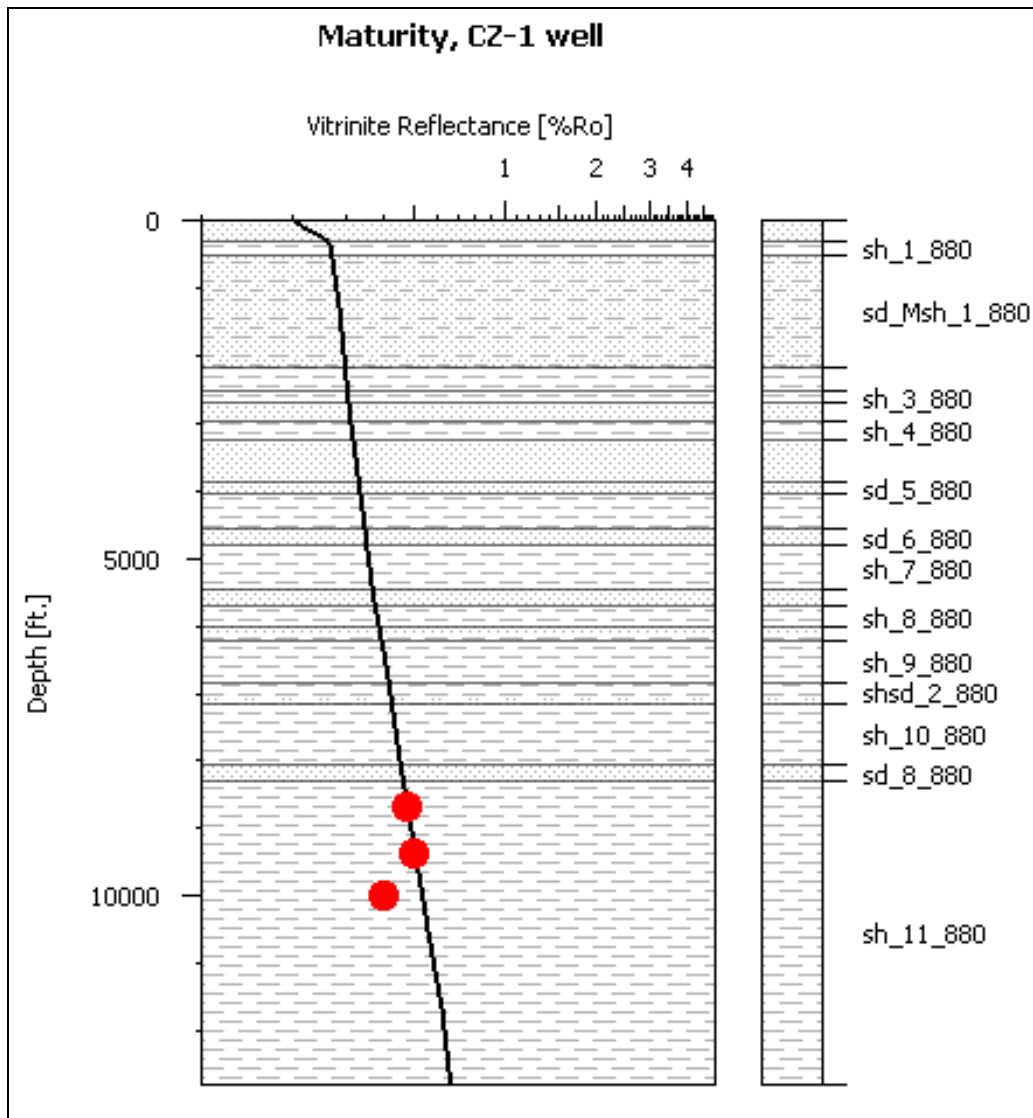


Figure 4: Correlation of measured and modelled vitrinite reflectance data for (a) CZ-1 well.

Table 2: Vitrinite reflectance measurements of Late Miocene-Early Pliocene source rocks stratigraphic levels in the CZ-1 well.

Well	Depth (ft.)	Depth (m)	Vitrinite Reflectance values (VR _o)
CZ-1	8760	2670	0.47
CZ-1	9469	2886	0.54
CZ-1	10069	3069	0.4

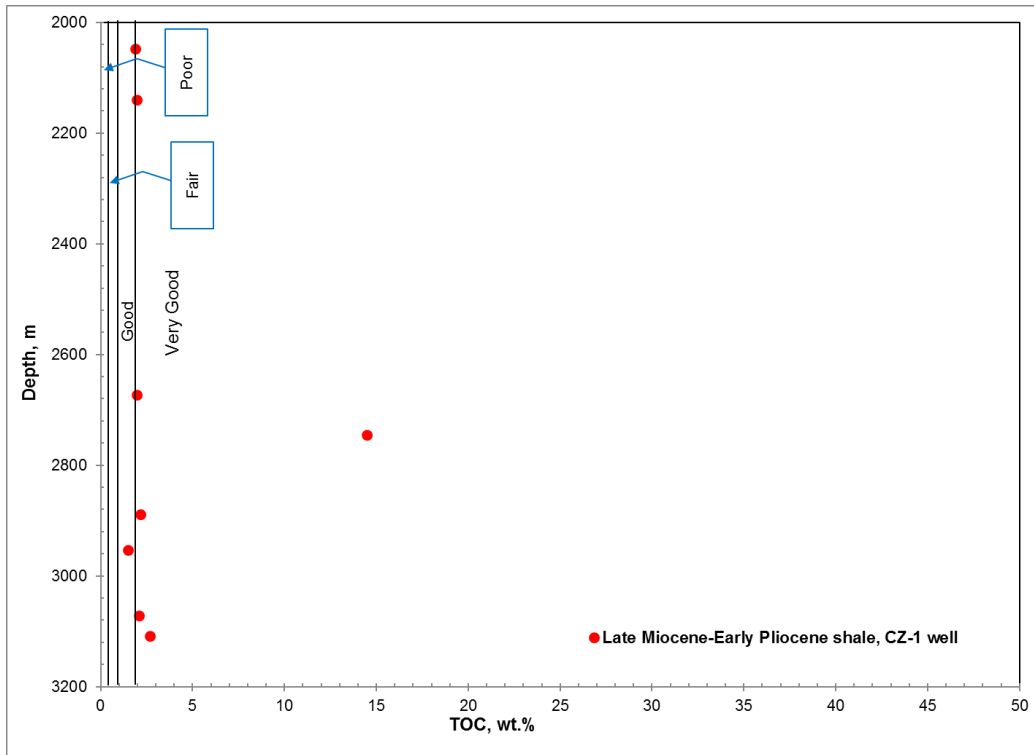


Figure 5: Organic richness of Late Miocene-Early Pliocene source rocks in CZ-1 well.

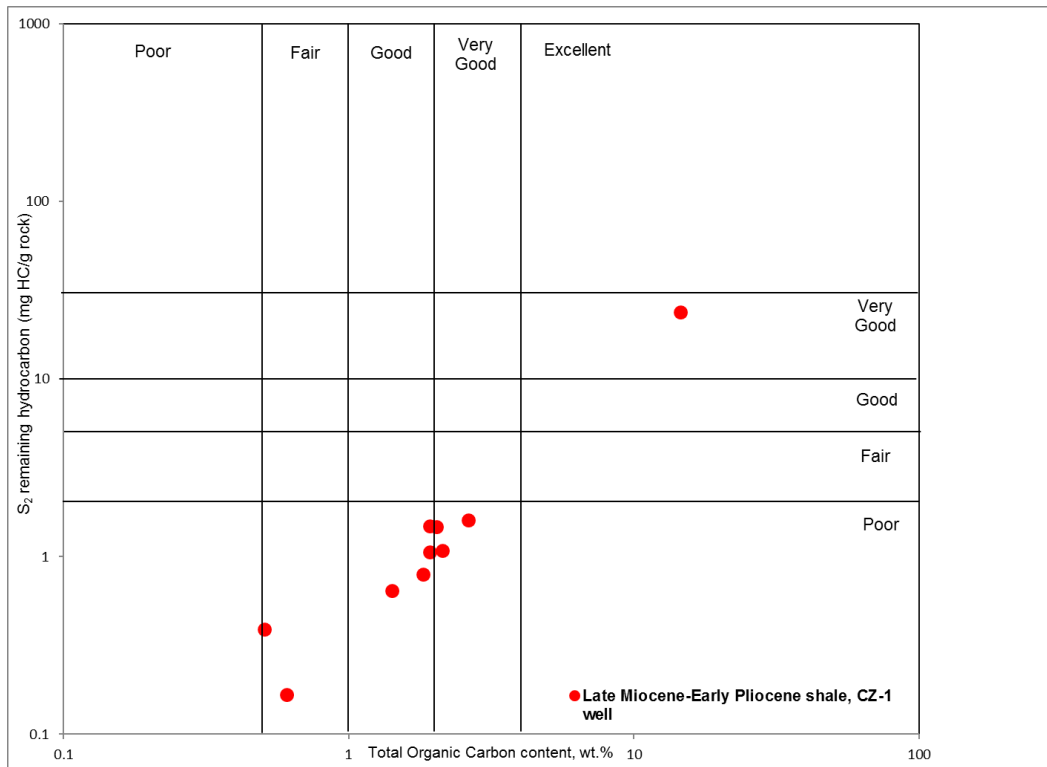


Figure 6: Cross-plot of Total Organic Carbon (TOC) against Rock-Eval S₂ (generative hydrocarbons of the sample) values of Late Miocene-Early Pliocene source rocks in CZ-1 well.

Generating Potentialities

The sum of the values S_1 (free hydrocarbons present in the sample) + S_2 (generative hydrocarbons of the sample) is regarded as generative potential. The generative potential of Late Miocene-Early Pliocene shale samples in CZ-1 well vary from 0.66 to 30.66 mgHC/gTOC with average of 5.00 mgHC/gTOC. The relationship between ($S_1 + S_2$) and TOC (Waples, 1985) indicates that the Late Miocene-Early Pliocene samples in the well are regarded as poor to excellent source potential (Figure 7).

Type of Organic Matter

The quality of hydrocarbon is directly related to the type of organic matter contained in any potential source rock (Tissot and Welte, 1978). The kerogen type of the Late Miocene-Early Pliocene shale samples in CZ-1 well were identified using Pseudo-Van Krevelen diagram (Figure 8). The type of organic matter identified from the cross plot shows the presence of

Kerogen type III/IV and vitrinite kerogen composition of gas-prone Type III in shale samples recovered from CZ-1 well. Source rocks of middle Eocene to Pliocene contain predominantly terrigenous organic matter (Haack, 2000)

HYDROCARBON GENERATION AND EXPULSION

Timing of Hydrocarbon Generation

1-D Basin model was used to reconstruct the timing of hydrocarbon generation of Late Miocene-Early Pliocene source rock samples in CZ-1 well located in the shallow offshore of the Niger Delta. Hydrocarbon generation from the Late Miocene-Early Pliocene source rocks started during the Pliocene (~ 3.06 Ma). The top of the liquid hydrocarbon window in CZ-1 well was identified at 10,394 ft (3,168 m) and indicate that the Late Miocene-Early Pliocene shale intervals in CZ-1 well is presently in early oil generation window (Figure 9).

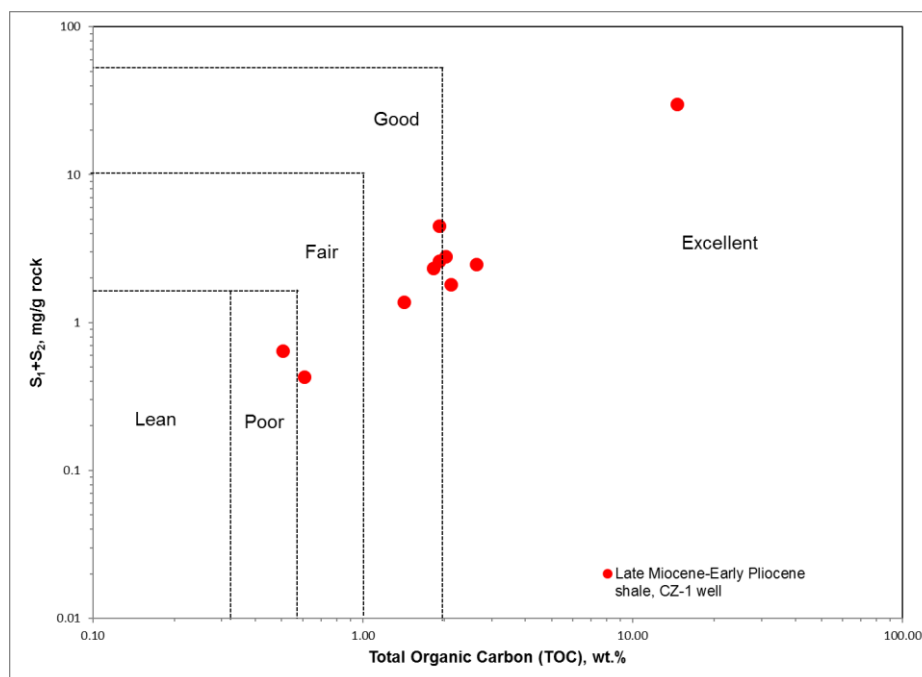


Figure 7: Plot of TOC against Rock-Eval S_1 (free hydrocarbons present in the sample) + S_2 (generative hydrocarbons of the sample) values of Late Miocene-Early Pliocene source rocks in CZ-1 well.

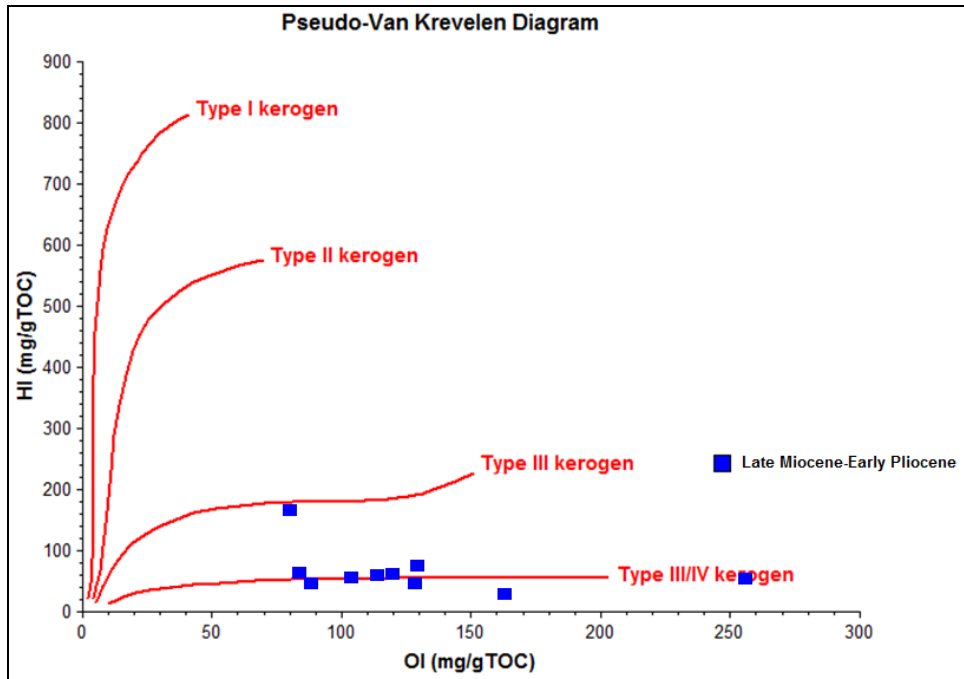


Figure 8: Pseudo-Van Krevelen Diagram for kerogen typing of Late Miocene-Early Pliocene shale samples in CZ-1 well.

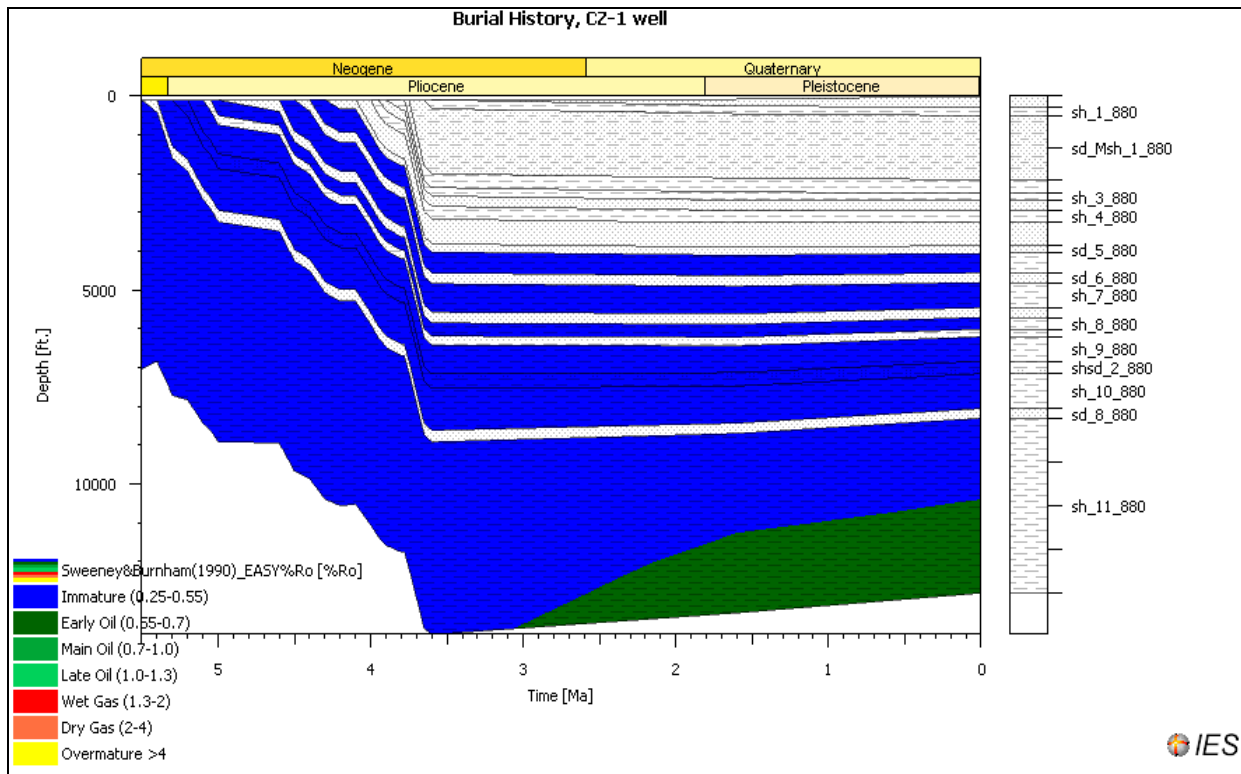


Figure 9: Burial history of an exploration (CZ-1) well overlay with the maturity data.

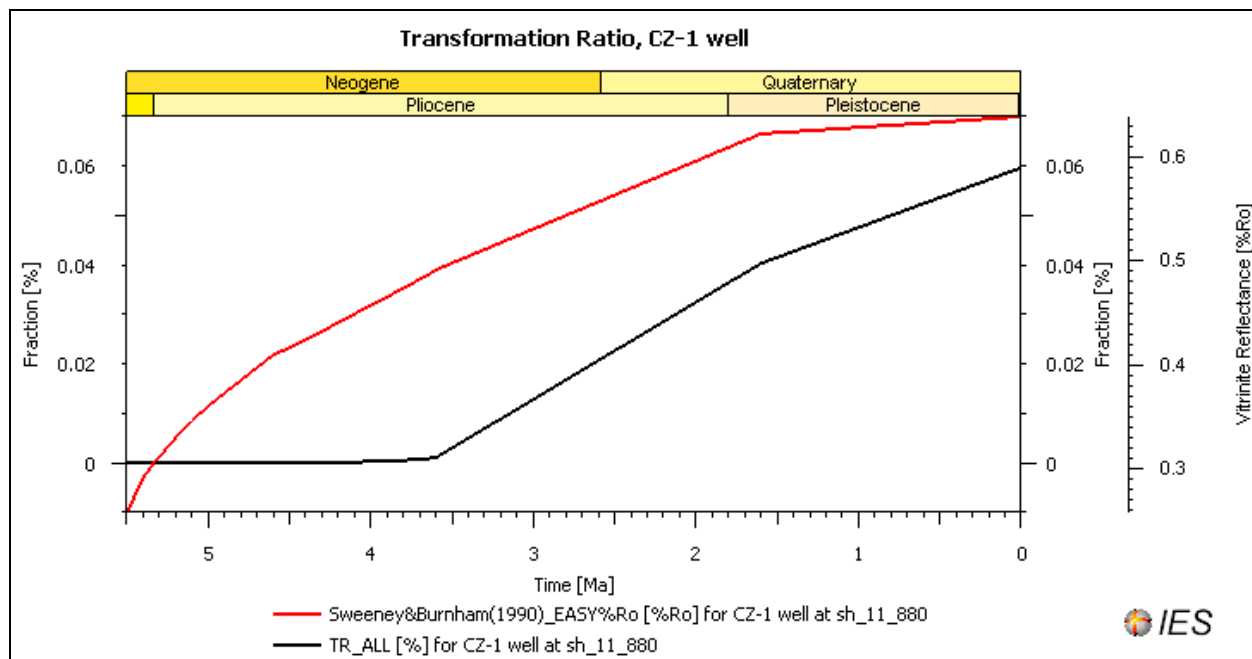


Figure 10: Transformation ratio (TR) and Vitrinite reflectance (VR_o) plots for exploration (CZ-1) well.

Transformation Ratio

The modelled present-day transformation ratio value of deeply buried Late Miocene-Early Pliocene source samples in the exploration (CZ-1) well is 0.06 % (Figure 10). It implies that only small percent (< 1%) of the organic material in Late Miocene-Early Pliocene source samples has been transformed and enough hydrocarbons have not been significantly expelled. The source rock intervals may have contributed to the charging of Late Miocene-Early Pliocene sand bodies in Agbada Formation.

CONCLUSION

The offshore depobelt of the Niger Delta Basin has significant hydrocarbon potentials. Source rock potential of the Late Miocene-Early Pliocene source rocks in shallow offshore has not been extensively discussed. This present study used results of Rock-Eval analysis to evaluate Late Miocene-Early Pliocene shale samples from an exploration well (CZ-1 well) to determine the organic richness and kerogen type, and also reconstruct the timing of hydrocarbon generation and expulsion.

The TOC values of all the samples exceed minimum thresholds value of 0.5 wt. % required for potential source rock. The relationship between (S₁+ S₂) and TOC indicates that the Late Miocene-Early Pliocene samples could be regarded as poor to excellent source potential. The samples show characteristically Type III/IV and Type III organic matter.

The 1-D basin model indicates that the Late Miocene-Early Pliocene source rock entered the early oil generation window during the Miocene age with transformation ratio of less than 1% suggesting that enough hydrocarbons have not been significantly expelled to any adjoining reservoir rocks. This study presents information that improves our understanding of the Late Miocene-Early Pliocene source rocks in the shallow offshore Niger Delta Basin.

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