Sequence Stratigraphy of Organic-Rich Rocks in the Niger Delta

Benson Akinbode Olisa and Abiola Adekunle

The Federal University of Technology, Akure, Nigeria.
(Department of Applied Geophysics)

DOI: 10.31364/SCIRJ/v9.i10.2021.P1021886
http://dx.doi.org/10.31364/SCIRJ/v9.i10.2021.P1021886

Abstract: Total organic carbon (TOC) analysis from well logs is combined with sequence analysis to develop a model for marine accumulation of organic-rich rocks in the Niger Delta. Pologbene-001 is selected for the analysis. Four sequences of HTB are recognized. The first is at a depth 9120 (2780m). The second HTB is at depth 9125ft (2781m). The HTB units were recognized by the combined characteristic patterns of gamma ray (GR), resistivity and sonic logs. TOC continuous sampling identified the system tracts, transgressive system tract (TST), lowstand system tract (LST), highstand system tract (HST) and the condensed sections. There are two possible areas for sedimentation, the marine and nearshore environments. The marine is devoid of oxygen whereas the nearshore is oxygenated. The marine sedimentation is recognized geophysically by high resistivity and transit-time whereas the reverse is the case in the nearshore.

Keywords: Transit-time, total organic carbon (TOC), stratigraphy, system tract.

Introduction

The understanding of total organic carbon (TOC) zonation within sequence stratigraphy is valuable for correlation in source rock studies.

Geologic data recorded in drill holes constitute data sets in which each observation is identified by its position in the vertical sequence. In analyzing data of the drill hole, it is necessary to identify distinct, internally homogeneous and positionally contiguous subsets within the profile. Their recognition and identification provide insight into the variability pattern of the raw data which might, in turn, lead to interpretations related to the existence of distinct contributing populations (e. g. lithologic units, biozones) or to the occurrence of distinct events (e. g. formation tops).

Oil-prone source rocks comprise sediments that are rich in organic carbon and contain organic material sufficiently hydrogen rich to convert mainly to oil during thermal maturation (Creaney and Passey, 1993). The organic materials that are generally richest in hydrogen include marine plankton, freshwater algae, spores, pollen, leaf curticle, tree resin and anaerobic bacterial. These materials are oil-prone and are classified as type I and II kerogen. The depositional environments are different and can be divided into marine and non-marine.

Gas-prone, organic rich rocks contain hydrogen-poor organic matter (type III kerogen) and tend to occur predominantly in the delta plain/lagoonal environment.

Previous sequence stratigraphic studies had been sedimentological with difficulty of correlations and TOC sequence studies is resisted to other basins

e. g. North Sea. Attempt is made to extend the analysis to the Niger Delta and carryout regional correlation. While there is a well-defined log response of organic rich rocks in these other basins, in the Niger Delta, the organic response to well logs is poorly defined on the logs.

Depositional Environments of Source Rocks and Kerogen Types

A simplified classification of oil-prone organic-rich rocks with the basins in which they occur is outlined in Table 1. Gas- prone source rocks contain hydrogen poor organic matter (type III) and tend to occur predominantly in the delta plain/lagoonal environment.
Based on depositional environments of organic-rich rocks, sediments can be divided into type I and type II organic matter types. Type I organic matter has very high TOC (increase resistivity and sonic in the opposite direction) while type II organic matter has low TOC (resistivity and sonic tends to zero values). Type I is found at the distal end of marine environment and type II is found at the proximal end. Type I organic matter has high resistivity and transit time (Figure 1).

Geology of the Niger Delta

The Niger Delta is located on the Gulf of Guinea, between longitudes 5^0 E to 8^0 E and latitudes 3^0 N to 5^0 N (Figure 2).

The Niger Delta consists of three formations in ascending order namely, Akata, Agbada and Benin Formations. Akata Formation is a time-transgression, thick marine shale, sit atop on Upper Cretaceous sedimentary sequence (Benesh et al. 2014). The shale is believed to be one of the major source rocks for hydrocarbons. Above the Akata Formation lies the Agbada Formation. This Formation is Eocene to Pleistocene in age and is believed to be the dominant petroleum-bearing unit in the Niger Delta. The Agbada Formation is recognized based on high and low gamma ray readings because of intercalations of shales and sands (Short and Stauble, 1967). The Benin Formation overlay the Agbada Formation. It is entirely continental sands. The gamma ray is generally low.

Previous work

Determination of organic-rich rocks in sedimentary basins had been described by Passey et al 1990. This methodology is adopted in this work to calculate total organic carbon (TOC) from sonic and resistivity logs. The method employs the overlaying of properly scaled

http://dx.doi.org/10.31364/SCIRJ/v9.i10.2021.P1021886

sonic log on resistivity curve. In water-saturated organic-lean rocks, the two curves parallel each other. However, in hydrocarbon reservoir or organic rich rocks, the two curves separate.

Creaney et al. 1993 combined sequence stratigraphy with TOC analysis from well logs, cores and cuttings to develop a model for TOC accumulation in marine source rocks. The discovered that routine well profiling of TOC in marine source rocks has revealed that recurrent patterns in the vertical distribution of TOC occur (HTB unit) can be explained with sequence stratigraphic concept.

Materials and Methodology

Logs: Sonic, resistivity and gamma ray logs.

Source rock thickness at least 100ft thick.

Source rock value: TOC values above 2% by weight.

Well Pologbene-001

Methodology

Vertical Distribution of Organic Matter

During routine identification and quantification of source rocks, it was apparent that marine organic-rich shales are often composed of discrete sedimentary units, which have the highest TOC values near their bases, Creaney et al (1993). Within a single unit, the organic carbon content gradually decreases upwards to background levels at, or near 1% by weight. These relatively high TOC, sharp-based units occasionally occur singularly, but more typically they can be stacked one on top of each other.

In analysing the facies, both the well log and organic matter characteristics were used. In a sequence of the source rocks, the maximum flooding surface has the highest TOC. At this surface, the gamma-ray, the sonic and resistivity values should be very high, but the density values should be very low.

Results and discussion

Pologbene-001

Figure 3 shows the responses of a source rock to well logs in Pologbene-001. The figure shows that the responses are poor compared to other basins e. g. Uinta and North Seas basin (Figure 4).

The MFS is the point where TOC is the highest in the sequence. To analyse each of the subsection the log analysis was carried out.

There are four HTB units in the section.

The first HTB is at a depth 9120 (2780m) (Figure 5) has the following characteristics.

http://dx.doi.org/10.31364/SCIRJ/v9.i10.2021.P1021886

The gamma ray curve fines upward, the transit time increases upward, resistivity curve increases upward and the density curve increases downward. This subsection has sonic and resistivity curves in the same direction, a typical HTB unit. It is a mature source rock. All these characteristics for the well logs are correct for this subsection.

Tables 2 and 3 show the well log and TOC values of the section respectively and Figure 6 shows the log response of the interval. There are four sequences (subsections) established using maximum flooding surface (MFS).

The Total organic carbon (TOC) characteristics are as follows (Table 2):

GR (TOC) increases upward, transit time (TOC) increases upward and the density (TOC) increases downward. This is correct condition for the maximum flooding surface.

The second HTB is at depth 9125ft (2781m) has the following characteristics:

The gamma ray log shows coarsening upwards, and the resistivity and sonic curve exhibit HTB, increases upward (Table 3).

System Tracts

Figure 7 shows identification of system tracks by TOC continuous samplings. The condensed section is identified by fining and coarsening upward sequence. The lowstand is above the sequence boundary while the highstand is on top.

Conclusion

Total organic carbon (TOC) distribution was used in sequence stratigraphic interpretation in Pologbene-001. The TOC is distributed in a predictable vertical sequence with high TOC at the top and low TOC at the base. The depositional environments are oil-prone organic-rich and gas-prone organic lean source rocks at their respective positions. The condensed section coincided with fining upwards sequence with a high TOC at the top. Resistivity and transit-time curves have a relationship with the TOC content which were then to identify the marine and non-marine (nearshore) environments. The depositional environments were lowstand, highstand, transgressive system tracts.

Reference

[1] Creaney S. and Q. R. Passey, (1993), Recurring Patterns of Total Organic Carbon and

Source Rock Quality within a Sequence Stratigraphic Framework: Bulletin American. Association of Petroleum Geologist, v. 77, p. 386-401

[2] Passey Q. R., S. Creaney, J. B. Kulla, F. J. Moretti and J. D. Stroud, (1990), A Practical

http://dx.doi.org/10.31364/SCIRJ/v9.i10.2021.P1021886

ISSN 2201-2796

Model for Organic-Richness from Porosity and Resistivity Logs: Bulletin American. Association of Petroleum Geologist, v. 74, no. 12, p. 1777-1794.

[3] Nathan P. Benesh, Andreas Plesch, and John H. Shaw (2014), Geometry, kinematics, and displacement characteristics of tear-fault systems: An example from the deep-water Niger Delta: Bulletin American. Association of Petroleum Geologist, V. 98, P 465-482

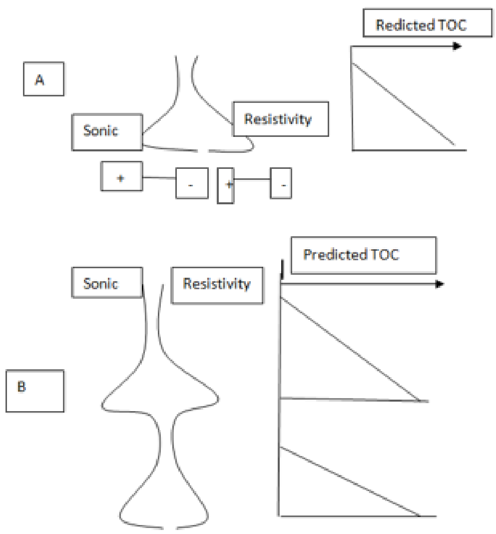
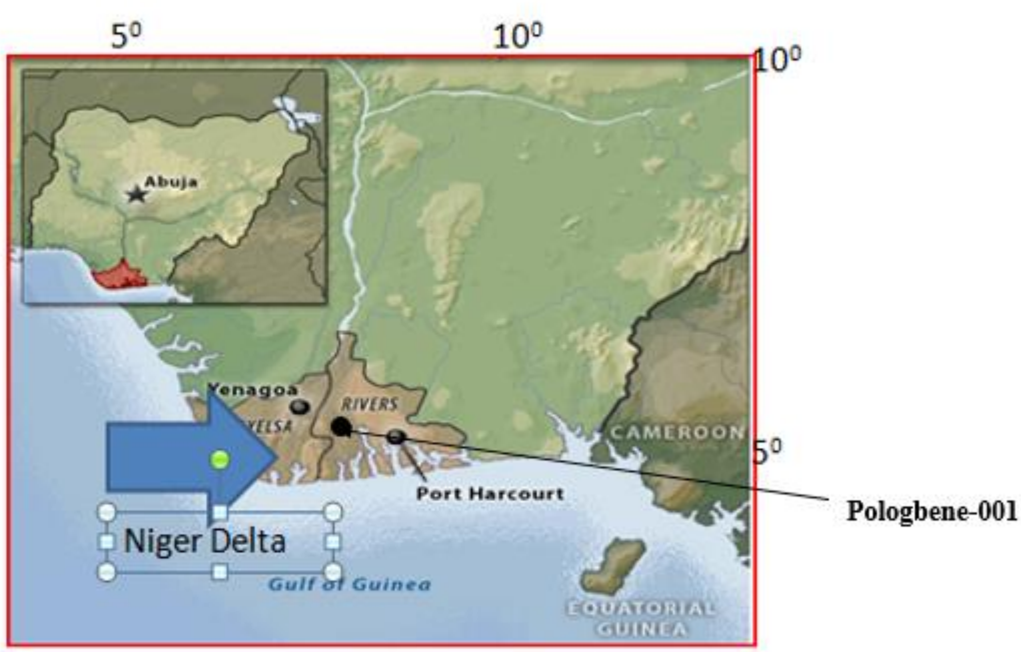


Figure 1: Schematic Δ Log R and Resulting Predicted TOC Profile (Creaney *et al.*,1993).



http://dx.doi.org/10.31364/SCIRJ/v9.i10.2021.P1021886

Figure 2 Location Map of the Niger Delta

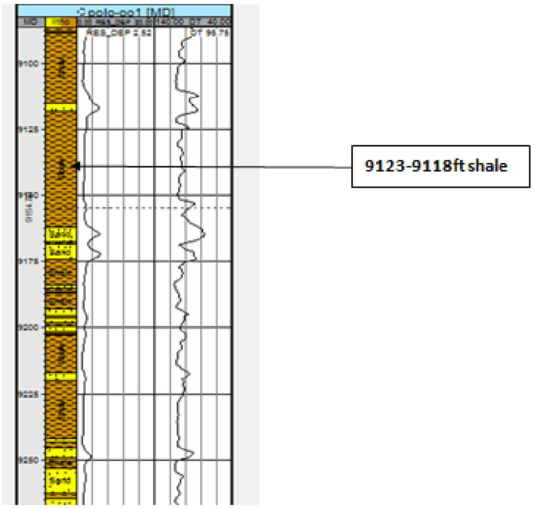


Figure 3: Resistivity and Sonic log Response of Organic-Rich Shales at Pologbene-001

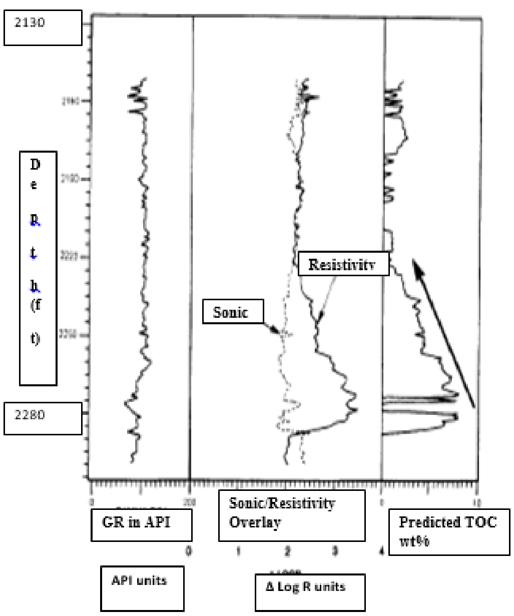


Figure 4: Decreasing upward unit from the Toarcian of Paris basin.

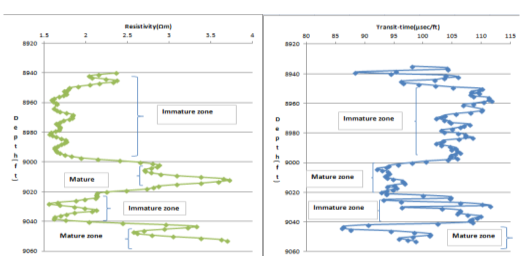


Figure 5: Plot of Resistivity (Ωm) and transit-Time (μsec/ft) against depth at Pologbene-001

http://dx.doi.org/10.31364/SCIRJ/v9.i10.2021.P1021886

ISSN 2201-2796

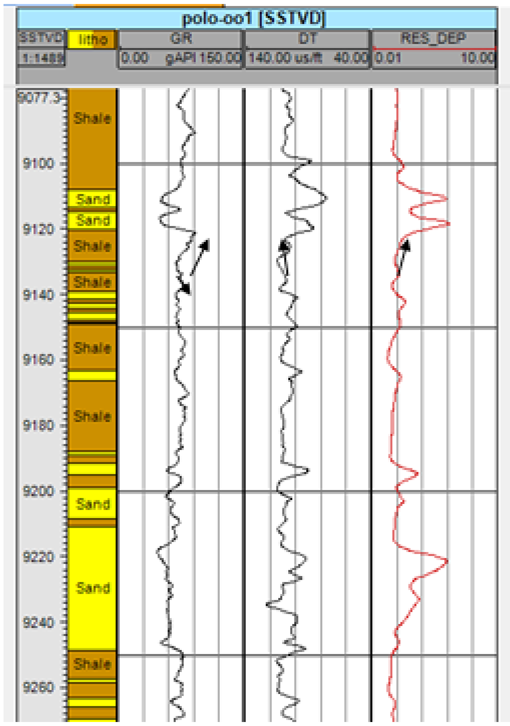


Figure 6: Log Signature of Section 9123-9118 ft (2781-2779 m) at Pologbene-001

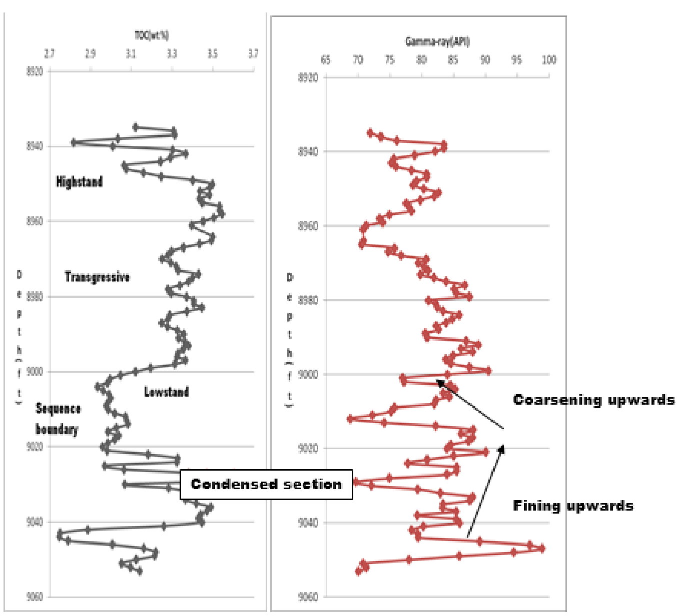


Figure 7: Subsurface Sequence Tracts.

Table 1: Classification of oil-prone organic-rich rocks

http://dx.doi.org/10.31364/SCIRJ/v9.i10.2021.P1021886

ISSN 2201-2796

Depositional Environments	Kerogen Type	Basin of Occurrence
Low-Oxygen Lakes	Type II kerogen. Marine Plankton + Anaerobic Bacteria.	Middle East (Jurassic)
Low-Oxygen Coal Swamps and Lagoonal Muds	Type II or III Kerogen. Spores, Pollens, Curticles, Fresh water Algae, Vitrinite, inertinite, + Anaerobic bacteria.	Niger Delta, Nigeria (Tertiary)
Large-low Oxygen lakes	Type I Kerogen. Fresh water Algae + Anaerobic bacteria.	Uinta Basin, United States of America (Eocene)

Table 2: Sequences (using Well Log) in Shale Section 9161-9118ft at Pologbene-001

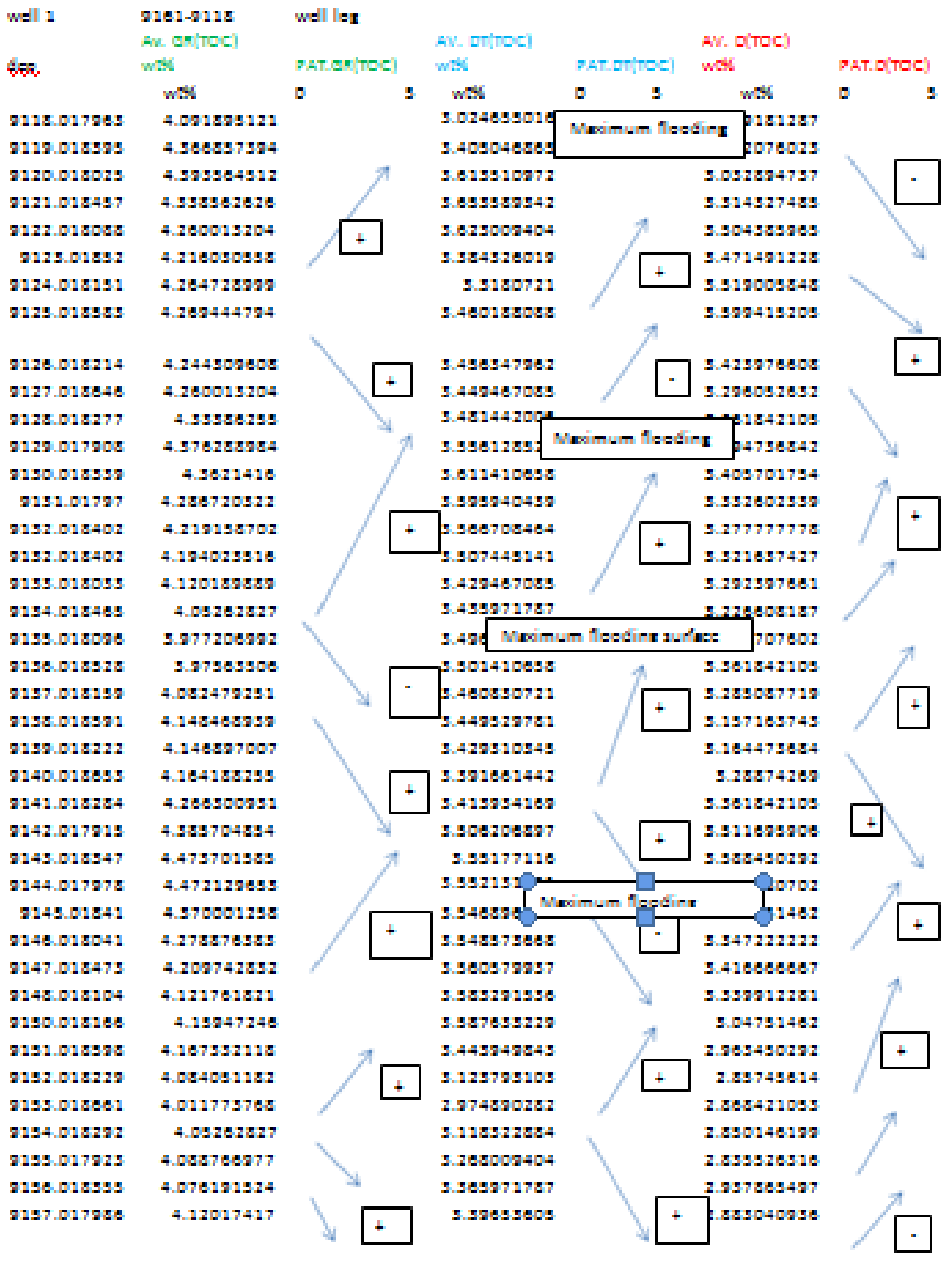
http://dx.doi.org/10.31364/SCIRJ/v9.i10.2021.P1021886

ISSN 2201-2796

	dep.	AV. (GR)	PAT(GR)	AV.(DT)	PAT.(DT)	AV (resist)	PAT. Resist	
		API	0 -150	µsec/ft	140 -40	Ωm.	0.2 2	
	9118.018	76.511		91.3865		4.34		
	9119.018							
Fining upward		85.257		103.521		3.3305		HTB unit
	9120.018	86.1065		110.171		2.7685		
	9121.018	84.357		111.4495		2.5725		
	9122.018	81.8585		110.474		2.5625		
	9123.019	80.4595		102.86		2.566		
Coarsening upward	9124.018	82.0085		100.7465		2.546		
	9125.019	82.1585		105.28		2.4085		HTB unit
	9126.018	81.359		105.1575		2.2055		
	9127.019	81.8585		104.938		2.0905		
	9128.018	84.2075		105.958		2.0165		
	9129.018	85.557		108.3405		1.9665		
	9130.018	85.107		110.104		1.9605		
Fining upward	9131.018	82.708		109.6105		1.992		Opposite trend
	9132.018	80.559		108.678		2.014		
	9132.018	79.7595		106.7875		2.018		
	9133.018	77.411		104.3		2.018		
	9134.018	75.262		104.5075		2.01		
	9135.018	72.863		106.448		2		
Coarsening upward	9136.019	72.813		106.595		2		HTB unit
	9137.018	76.2115		105.3005		2.016		
	9138.019	78.3105		104.94		2.0405		
	9139.018	78.2605		104.295		2.0465		
	9140.019	78.8105		103.094		2.014		
	9141.018	82.0585		103.8045		1.976		
	9142.018	85.8565		106.748		1.943		
Fining upward	9143.018	88.6555		108.2015		1.9075		Opposite trend
	9144.018	88.6055		108.213		1.8735		
	9145.018	85.357		108.046		1.8375		
	9146.018	82.4585		108.0995		1.806		
Fining upward	9147.018	80.2595		108.4825		1.774		Opposite trend
	9148.018	77.461		109.207		1.7295		
	9150.018	77.361		109.3455		1.7105		
	9151.019	79.96		104.762		1.845		
Coarsening upward	9152.018	77.861		94.549		2.0785		HTB unit
	153.019	74.662		89.799		2.3145		
	154.018	73.263		94.3745		2.484		

Table 3: Sequences (using TOC) in Shale Section 9161-9118ft at Pologbene-001

http://dx.doi.org/10.31364/SCIRJ/v9.i10.2021.P1021886



Dep.	Av. GR(TOC) wt%	PAT.GR(TOC) 0 5	Av. DT(TOC) wt%	PAT.DT(TOC) 0 5	Av. D(TOC) wt%	PAT.D(TOC) 0 5
9118.017963	4.091895121		3.024655016		[illegible]9181287	
9119.018395	4.366857394		3.405046865		[illegible]2076023	
9120.018025	4.393564512		3.615510972		3.032894757	
9121.018457	4.355362626		3.655589542		3.314327485	
9122.018088	4.260015204		3.625009404		3.304385965	
9123.01852	4.216050558		3.384526019		3.471491228	
9124.018151	4.264728999		3.3180721		3.319005848	
9125.018583	4.269444794		3.460188088		3.399415205	
9126.018214	4.244509608		3.456547962		3.425976608	
9127.018646	4.260015204		3.449467085		3.298052632	
9128.018277	4.35586255		3.48144200[illegible]		[illegible]1842105	
9129.017908	4.376288984		3.3561285[illegible]		[illegible]4736842	
9130.018339	4.3621416		3.611410658		3.405701754	
9131.01797	4.288720322		3.595940439		3.352602339	
9132.018402	4.219158702		3.566705464		3.277777778	
9132.018402	4.194025516		3.507445141		3.321637427	
9133.018033	4.120189889		3.429467085		3.292397661	
9134.018465	4.05262627		3.435971787		3.226608187	
9135.018096	3.977206992		3.49[illegible]		[illegible]707602	
9136.018528	3.97563508		3.501410658		3.361842105	
9137.018159	4.082479251		3.460830721		3.285087719	
9138.018591	4.148468939		3.449529781		3.157163743	
9139.018222	4.146897007		3.429510345		3.164473684	
9140.018653	4.164188255		3.391661442		3.28874269	
9141.018284	4.266300951		3.415934169		3.361842105	
9142.017915	4.385704854		3.506206897		3.511695906	
9143.018347	4.475701585		3.35177116		3.388450292	
9144.017978	4.472129855		3.35215[illegible]		[illegible]0702	
9145.01841	4.370001258		3.34659[illegible]		[illegible]1462	
9146.018041	4.278876383		3.348573668		3.347222222	
9147.018473	4.209742832		3.360579937		3.416666667	
9148.018104	4.121761821		3.385291536		3.359912281	
9150.018166	4.15947248		3.387633229		3.04751462	
9151.018598	4.167352118		3.443949843		2.965450292	
9152.018229	4.084051182		3.125795103		2.85745614	
9153.018661	4.011773768		2.974890282		2.868421053	
9154.018292	4.05262627		3.118522884		2.850146199	
9155.017923	4.088766977		3.268009404		2.855526316	
9156.018355	4.076191524		3.365971787		2.957865497	
9157.017986	4.12017417		3.39653605		[illegible]885040936	

http://dx.doi.org/10.31364/SCIRJ/v9.i10.2021.P1021886