Stratigraphic subdivision of Tertiary sediments Of Well 1 using total organic carbon (TOC) and gamma ray (GR) log: Case study, the Niger Delta

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Abstract: Traditional methods of stratigraphic subdivision are based on biostratigraphy and well log analyses. The Tertiary Niger Delta is divided into Paleogene and Neogene. When biostratigraphic and well log data are not available, the method of total organic carbon (TOC) and geophysical responses of organic matter might be used. TOC (wt%) is related to gamma ray (API). TOC is first calculated from the GR log. The calculated TOC, GR(TOC) is plotted against depth. Results show that TOC decreases with depth. Miocene section (Neogene) has the highest value of TOC and Eocene (Palaeogene) has the lowest. There is a discontinuity surface between Oligocene and Miocene at 4500ft. This coincides with marker shale Bolivina 27 about 27.1Ma. Between Eocene and Oligocene in Well 1, the discontinuity is at 7100ft. This coincides with marker shale *Uvigerinella* 8 at about 38Ma.

INTRODUCTION

Study of stratigraphic evolution is done using high resolution biostratigraphy, Rull (2002). Fossil remains preserved in sediments are used for stratigraphic analysis. These sediments, most especially shales, can be processed and examine under the microscope for taxonomic purposes.

Using laboratory method for chronostratigraphic subdivision has requirements that are difficult to meet. For example, samples are required for analysis. The samples have to be moved from the field to the laboratory. Geophysical method of well log analysis could be an alternative to the laboratory method, because results of analysis will represent in-situ- conditions.

Organic carbon is the remains of organisms preserved in sediments as kerogen, and after burial they undergo transformation due to pressure and temperature and are converted to hydrocarbons. The kerogens could be related to different age groups in the geological time scale.

The gamma ray log has responses to organic matter (kerogen) in sediments. If matrix and fluids effects could be removed, the gamma ray log have a direct relationship with radioactivity in the sediments, Meissner (1978), Jia *et al.* (2012).

In stratigraphic subdivision, the organic matter is assessed from the sediments by calculating total organic carbon (TOC) from

gamma ray log and then related to stratigraphy. Results show that TOC calculated using the GR log are comparable and could be used in each case for stratigraphic interpretation.

Geology of Niger Delta

The Niger Delta, Figure 1, a passive continental margin is situated between longitude 3° and 9°N and latitude 4° and 6°N (Amigun *et al.* (2013).

Evolutionary history

The Tertiary Niger Delta sediment is made of Paleogene (Palaeocene, Eocene and Oligocene) and Neogene (Miocene, Pliocene and Peistocene), Figure 1 and Table 1.

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Figure 1: Paleogeographic regions of the Niger Delta (Short and Stauble 1967).

Depositional history

The Niger Delta sediments had been divided into 29 palynological zones and subzones, Table 1, each having an alphanumeric code (e.g., P630), Evamy *et al.* (1971).

Table 1: Chronostratigraphic equivalence of the palynological zonation for the Niger Delta

System	Period	Epoch	Age (Ma)	Formations		
Tertiary	Neogene	Miocene	Messinian	P850	Benin Formation	Agbada Formation
			Tortonian	P820		
			Serravalian	P770		
			Langhian	P720		
			Burdigalian	P650		
			Aquitanian	P630		
			Chattian	P580		
			Rupelian	P520		
			Priabonian	P480		
	Paleogene	Eocene	Bartonian	P470	Akata Formation	
			Lutetian	P420		
			Ypresian	P330		
		Paleocene	Thanetian	P200		
			Selandian			
			Danian			
Cretaceous						

Paleocene and Eocene (P200-P480)

During the Paleocene and earliest Eocene (P200) times, marine shales were deposited over much of the southern Nigerian sedimentary basin. Near the end of late Eocene (P480), a major transgression commenced which accelerated the expansion of the Niger Delta. This regressive phase has continued until the present, frequently interrupted by generally minor regressions.

Oligocene and early Miocene (P520-P580)

During this period the successive depocenters in the west considerably overlapped, reflecting in general a pronounced subsidence and a relatively slow advance of the delta front toward the wet and southwest. This pattern of overlapping depocenters resulted in a rather thick development of paralic sediments over the western part of the delta. By contrast, the successive depocenters in the east generally do not overlap, and they reflect a more rapid advance of the delta front.

Miocene to present (P630-P680)

Later in the early Miocene, the hitherto separated depocenters gradually merged, and the enlarged delta began to prograde along a wide front (P680). The more rapid subsidence, and corresponding slower rate of advance of the delta front, continued to characterize the western part of the delta.

Depocenters continued to develop during the later Miocene. A large depocenter of late Miocene age (P860) is present in the eastern offshore.

Materials and method

Wells- 1 (Figure 1 and 2), located in the northern depobelt was used for the analysis. The well is 9446ft, deep. Total organic carbon (TOC) data and biostratigraphic data (Palynology and microfossil) from laboratory were available for Eocene section (Tables 2, 3 and 4) as well as GR log (Figure 2). A modified stratigraphic chart of the Niger Delta is also available, Table 1.

Figure 2: Lithology sequences of Well 1.

Table 2: Data (GR and Rock-Eval) for Well 1

Well 1		
Depth	GR (API)	Lab (TOC):wt%
8930	72.91	3.1
8960	71.26	3.6
9000	81.99	3.7
9030	74.26	4.2
9050	72.26	3.7
9090	86.46	3.4
9110	78.01	4.2
9150	78.51	3.3
9180	80.76	2.9
9200	69.22	3.7

9240	75.56	2.9
9260	62.22	4.3
9300	51.27	3.4
9330	71.96	3.3

Table 3: Palynological zones of Well 1

Well 1				
Top Depth	Bottom Depth	P-Zones	Reliability Gradient	Remarks
0	2000	Not Studied		
2230.0	2690.0	P670	1	QB <i>Magnastratites howardii</i> (9)
2730.0	2830.0	Indeterminate	3	
2870.0	3078.0	P630/?P650	2	Low <i>M. howardii</i> (9); high occurrence <i>Praedapollis flexibilis</i> (420)
3140.0	4504.0	P620	1	Top <i>Praedapollis africanus</i> (443)
4570.0	6340.0	P520-P580	1	<i>Cicatricosisporites dorogensis</i> / <i>Gemmatriporites</i> sp. (30 / 573); Base <i>Racemonocolpites hians</i> (250)
6356.0	6450.0	Indeterminate	3	
6670.0	9276.0	P470-P480	1	Top <i>Doualaidites laevigatus</i> (550)
9306.0	9470.0	P450	1	Quantitative top <i>Monocolpites marginatus</i> (237)

Table 4: Well 1: Sequence Strat

Depth	Ages	Microfossils (foraminifera)/marker shales
4500	28.1	<i>Bolivina</i> 27
4800	29.3	SB

5280	31.3	<i>Uvigerinella</i> 5
5450	32.4	SB
5720	34.0	Un-named
5890	35.4	SB
5970	35.9	Orogho Shale
6475	36.3	SB
6800	36.8	Un-named
6970	37.3	SB
7487	38.0	<i>Uvigerinella</i> 8
7750	38.7	SB
8600	39.4	Un-named
8900	40.1	SB
9440	41.0	Umutu Shale

Lithological analysis

The GR log is used to divide the sediments into sand and shale. The Gamma ray log measures radioactivity in the sediments. Organic matter is more concentrated in shale than sand, Passey *et al.* (1990), therefore the gamma ray reading is more in shale than in sand. To identify shale from sand, 70% cut-off is used (Olisa and Oke 2014, Olisa and Okafor 2014).

Total organic carbon (TOC) analysis

The lithologic components of the Niger Delta are shales and sandstones (Short and Stauble, 1967). In the analysis the sand intervals were removed in order to concentrate on the shale sections. The Organic rich shales are present on top of Akata and base of Agbada sequence. The Organic richness is due to the presence of organic matter in the sediments and the organic matter present is disseminated in the rock. Organic rich rocks (shales) contain more than 1wt% of TOC. Organic lean (sandstones) rocks have less than 1wt% TOC, Meyer and Nederlof (1984). In the Niger Delta, TOC averaged 1.4 to 1.6% (Bustin, 1988), Organic rich rocks are made of three components; the matrix, the pore fluids (water, oil or gas) and organic matter, Passey (1990). The response of GR log in sediments is a result of all components combined. To determine the response of the geophysical log to organic matter, the influence of the matrix and the fluids has to be removed. This is done by application of necessary hypothesis to the logs and organic matter (Olisa *et al.* 2018a). Derived equation to calculate the TOC is:

$$Y = 29.649x - 31.732 \quad 1$$

Y is GR, and x is TOC.

Stratigraphic analysis

Palynological data, Table 3 was used to subdivide the sediments into their respective epochs in the well. The microfossils were

used to identify the sequence boundaries. Equation 1 was used to calculate TOC from GR log at 1 ft interval down the hole. Calculated TOC result for the well is plotted against the entire depth, Figure 3. Points of discontinuities are marked on the plot and then located on the well. Marker shales positions from biostratigraphic analysis were located on well. Points of discontinuities are determined. These points are correlated with biostratigraphic data for calibration.

Figure 3: Plot of GR(TOC) versus Depth

Results and discussions

Table 5: Stratigraphy of well 1.

Well 1					
Depth range(ft)	Thickness (ft)	Stages	Epoch	GR av.	GR (TOC)
1058-4466	3408	P620-P670	Miocene	87	3.98
4466-7466	3000	P520-P580	Oligocene	82	3.93
7466-9232	1766	P480/P470	Eocene	79.	4.26

Table 5 shows variations of GR (TOC) with depth. There are discontinuities at 4500ft and 7500ft which represent Oligocene-Miocene and Eocene-Oligocene boundaries respectively. Top of marker shales Bolivina 27 (28.1Ma) and Uvigerinella 8 (38Ma) are located at the respective depths.

The thickness of Miocene section is 3408ft with 34 shale sections. The calculated GR (TOC) range is 4.14-4.88wt% (Average is 4.22wt%). The TOC decreases with depth.

The Oligocene section has a thickness of 3000ft with 46 shale sections. The calculated GR (TOC) range is 3-4.51wt% (average is 4.2 wt%). The TOC decreases with depth.

The thickness of Eocene section is 1766ft. The calculated TOC (gamma ray) range is 3.94-4.37wt% (average is 4.18wt%). The TOC increases with depth.

Conclusion

TOC derived from geophysical log was used for stratigraphic subdivision in the Niger Delta. There are two geological boundaries delineated in well 1. The boundary between Eocene and Oligocene is 4465ft. This corresponds to top of the marker shale Bolivina 27 (28.1Ma) at 4500ft from the laboratory (biostratigraphy). At well 2, the geological boundary is at 6647ft. The geological boundary is at 4976ft in well 3.

The TOC decreases with depth from Miocene to Eocene.

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