Depositional Environment of Red Field in Niger-Delta, Nigeria, Obtained from Gamma Ray Log

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ABSTRACT

Gamma ray log signatures are used in determining the various lithofacies and their depositional environments. A gamma ray log of Red field, Niger Delta was used in determining the lithology, facies and depositional environment. The study area is in the northeastern Niger Delta between longitude $6^0$30'E and $7^0$00' and Latitude $5^0$00' and $5^0$30'N. Results show that there are six sequences with three predominant log shapes; irregular, bell and funnel shapes. The irregular shape occurs at shallowest depths of 4410-4490 ft, 4880-4980 ft and 4060-4500 ft for Red 2, Red 4 and Red 5, respectively, while the deepest depth which the irregular shapes occur are; 5580-5670, 5980-6080 ft and 6060-6140 ft for Red 2, Red 4 and Red 5, respectively. The log shapes also show that the wells have an alternation of clay and shale with the prograding delta and crevasse splay as the depositional environment. The sands were also identified to have been deposited in environment of transgressive marine shelf characteristic of the Agbada formation.

(Keywords: gamma ray log, facies, depositional environment, sand, shale).

INTRODUCTION

Sedimentary facies are a composition of any areally segregated part of a designated rock division whose physical and organic properties differ significantly from other parts (Emujakporue and Eyo, 2016). The term facies has often been used in different ways to denote any type of sedimentary deposit with or without a reference to defined stratigraphic units.

Facies consist of one or more lithofacies. Lithofacies indicate the environment of deposition as well as collective organic and physical properties of any sedimentary rock. The study of lithofacies enables us to interpret the record of depositional environment of any given sedimentary rock because it reflects the distribution and duration of the environment which produced the rocks (Moore, 1949).

In order to effectively analyze lithofacies, description and interpretation of wireline log of clastic reservoir is fundamental (Nwagwu, *et al.,* 2009). The wireline logs relate the identified lithofacies to the physical and biological processes of the sediments (Rider, 2002).

There are different geophysical well logs used in lithology identification, reservoir characterization, formation evaluation and well correlation. Some of them include caliper log, gamma ray (GR) log, porosity log, density log, and self-potential log (Christian, *et al.,* 2019). However, the gamma ray log is often used in facies analysis because their shape (as well as that of spontaneous potential log) delineates sandy and shaly bodies. The gamma ray log also shows different shapes indicative of a particular facies and depositional environment (Dalrymple and Choi, 2007).

Sharp lithological breaks due to sequence boundaries and uncomformities can be noticed by the abrupt change in gamma ray response just as the grain size can be deciphered from variation in gamma ray log character (Nwagwu, *et al.,* 2009). Gamma ray logs record the intensity of natural radioactive source especially potassium which is used in differentiating them from non-radioactive sources like sandstones, limestone and evaporates. Therefore, shale bodies are highly responsive to gamma ray logs and the fluctuation of gamma ray log shows the variation in mineralogy and it is a tool used to identify the various litho-curves and sedimentary facies (Nazeer *et al.,* 2016). The GR log also represents vertical profile of grain size, as the shaly content (radioactivity/shalines content) in sandstone increases with decreases of grain size (Engler, 2012).

Many have studied the radioactive contents of different sedimentary rocks like Russel (1944), Bigelow (1992) and Tzortzis, *et al.* (2003) and they observed that the presence of potassium, uranium and thorium in varying composition depends on the depositional environment thus making GR log trend useful in interpreting subsurface sedimentary facies. Gamma ray logs and seismic characteristics were used by Kessler and Sachs (1995) to study the sedimentary process of sandstones of Ireland. The vertical profile of grain size and the paleo-environment of the Erchungchi was inferred by Chow, *et al*. (2005) using gamma ray log facies of nine wells. Gamma ray log is therefore considered to be the most-suitable method for facies interpretation if core of rock is not present (Chow, *et al*., 2005).

THE STUDY AREA

The Niger Delta Basin is one of the largest sub-aerial basins in Africa. The location map of Niger Delta is shown in Figure 1. It covers an area of 75,000km^2 and the sediment fill has a depth between 9-12km (Ihinale, *et al.,* 2013). The Niger-Delta is highly petroliferous and has about five percent of total hydrocarbon reserves in the world (Emujakporue and Eyo, 2016). It is located between latitudes 03° and 06°N and longitudes 005°E and 008°E and it is in the southern part of Nigeria. There are three main lithostratigraphic units of the Niger-Delta namely, Akata, Agbada, and Benin formations which reflect a coarsening upward sequence in a complex mixture of marine, fluvio-marine, littoral and deltaic plain environment (Doust and Omatsola, 1990).

Figure 1: Location Map Niger Delta.
(Nwagwu, *et al.*, 2009)

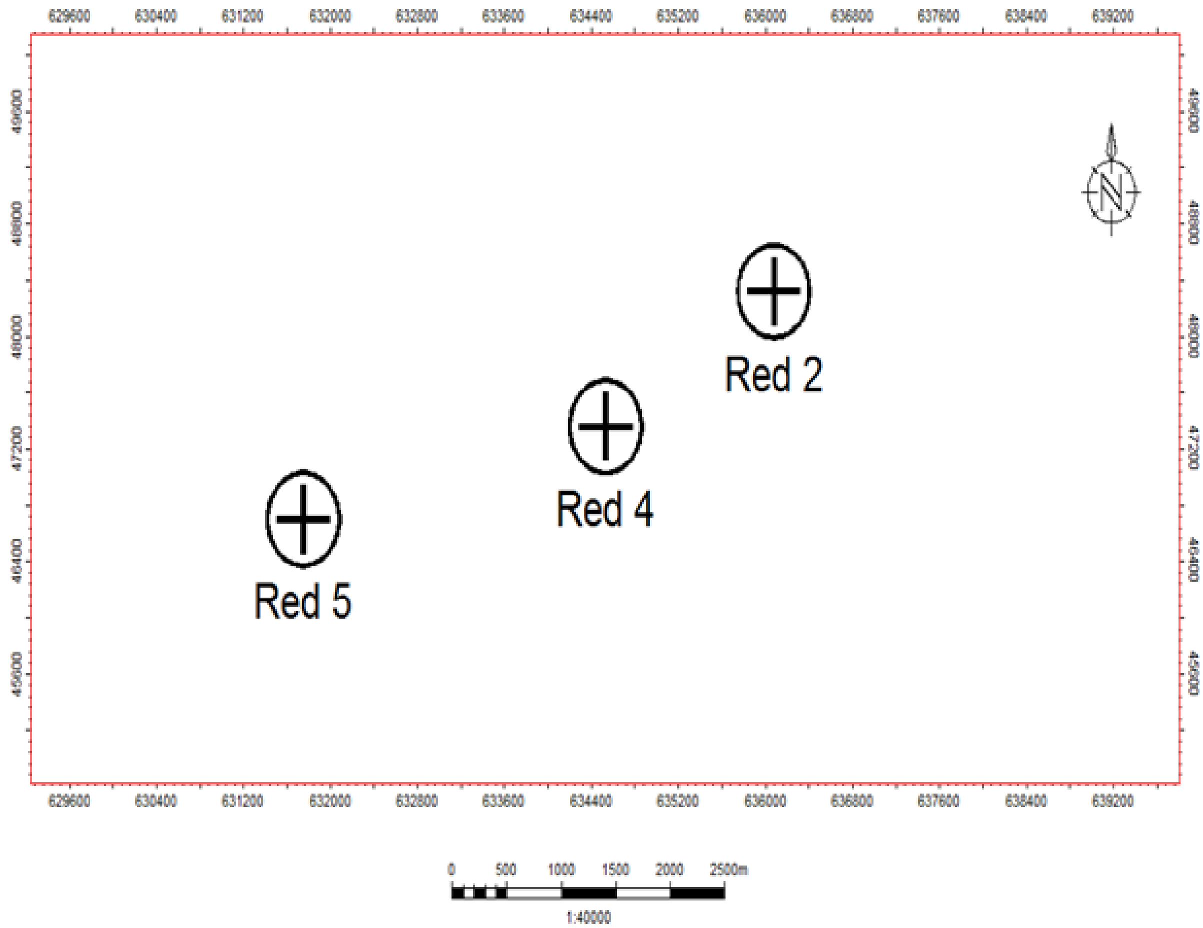


Figure 2: Based Map of Red Field.

The Akata formation forms the base of the lithostratigraphic units with about 6,500m of marine shales of the Palaeocene to Recent age and it is the major source of hydrocarbon in the Niger-Delta (Ola-Buraimo, *et al*., 2010). The Agbada formation overlies the Akata formation and it is made of paralic, fluvial, and coastal deposits of alternating sandstones, mudstones and shales with a thickness of about 4,500m. The age is of the Eocene to recent (Aturamu *et al*., 2015). The Benin formation is the youngest of the stratigraphic units with a thickness of about 2000m. It is composed of continental deposits, including alluvial and upper coastal-plain deposits that are mostly at the center of the basin (Azunna *et al.,* 2017). It is of the Miocene to recent age and are made of sands which are mostly medium to coarse grained, pebbly, moderately sorted with local lenses of poorly cemented sands and clays. Petrographic analysis of Benin formation indicates that the composition of the rocks is as follows: 95-99% quartz grains, 1-2.5% of Na+Kmica, 0 -1.0% of feldspar and 2-3% of dark colored minerals (Azunna, *et al*., 2018)

The Red field used in this study is located within concession OML58 block in the northeastern Niger Delta. Geographically, the field lies between longitude $6^0$30’E and $7^0$00’ and Latitude $5^0$00’ and $5^0$30’N. Figure 2 shows base map of the Red field.

MATERIALS AND METHOD

Gamma ray log data of red field Niger-Delta named Red 2, Red 4, and Red 5 were obtained from Nigerian Agip Exploration Limited and was loaded into Schlumberger Petrel software 2009 for analysis and interpretation. Gamma ray composite logs were obtained for each of the fields and the logs were thereafter correlated for comparative studies. The well co-ordinates were used to convert the log data into Subsea True Vertical Depth (SSTVD). The three wells were drilled to a SSTVD of 4200ft. The gamma ray log ranges from 0 – 150 API. Low API values indicate sand and the curve is deflected to the left while high API values indicate shale and the curve is deflected to the right.

RESULTS AND DISCUSSION

The correlated gamma ray log signatures for Red fields 2, 4 and 5 are as shown in Figure 3 while Figure 4 shows the gamma ray composite log for easy identification of the pattern. The parts with the highest shale content are regarded as the Maximum Flooding Surfaces (MFSs). The major flooding surface called Transgressive Surface (TS) marks the beginning of the increasing rate and relative rise in sea level and it follows the sequence boundary (SB). SBs as well as unconformities are indicated by abrupt changes in the gamma ray log responses. Facies and depositional environments were thereafter determined from the log signatures obtained. Sharp break in gamma ray curves indicate rapid change in the energy distribution and it distinguishes shale and sandy units (Nwagwu, *et al.*, 2009).

There are six sequence boundaries where there is an abrupt decrease in gamma ray log response. Gamma ray log shapes and results from core analysis were used to define the log facies and depositional environments by Nazeer *et al.*(2016) in Table 1.

Table 1: GR log Shapes Showing Different Facies, Grain Size, and Environment of Deposition. Modified after Nazeer, *et al, (*2016)

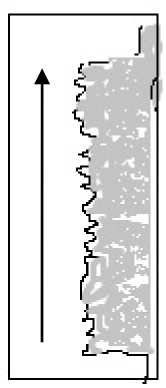
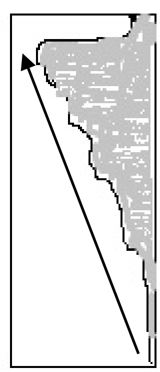
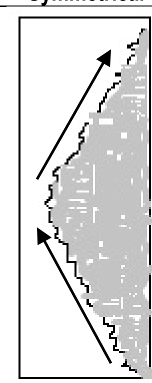
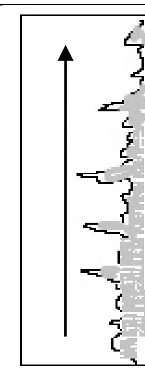
	Type of log motif shape				
	Cylindrical/Box	Funnel	Bell	Symmetrical	Serrated
GR trend					
	Even block with sharp Top and base	Coarse up and sharp top	Fine up and sharp base	Hour glass	Saw Teeth
Sediment supply	Aggradation	Progradation	Retrogradation	Petrograding and retrograding	Aggrading
Characteristic	Shsarp top and base with consistent trend	Abrupt top with coarsening upward trend	Abrupt base with fining upward trend	Ideally rounded base and top	Irregular pattern/spikes of GR log
Grain Size	Relative Consistent lithology	Grain size increases	Grain size decreases	Cleaning upward trend change into dirtying up sequence from top	Inter-bedded shales and sands
Depositional Environment	Aeolin (sand Dunes), fluvial channels, carbonate shelf (thick carbonrate), reef, submarine canyon fill, tidal sands, prograding delta distributaries	Crevasse splay, river mouth bar, delta front, shoreface, submarine fan lobe	Fluvial point bar, tidal point bar, deltaic distributaries, proximal deep sea setting	Sandy offshore bar, transgressive shelf sands and mixed tidal flats environment	Fluvial flood plain, mixed tidal flat, debris flow and canyon fill

Table 2: Gamma Ray Log shapes of Red Field and their depth of Occurrence.

Sequence	Gama Ray Log Shape	Depth of Occurrence (Ft)		
		Red 2	Red 4	Red 5
6	Irregular	4410-4490, 4660-4680	-	4060-4500, 4620-4660 4860-4880
	Funnel	-	5520-5540	4010-4020
	Bell	4480-4490, 4510-4540, 4570-4600	4580-4620	4040
5	Irregular	4775-4870	4880-4980, 5140-5210	-
	Bow	-	-	5280-5320
	Funnel	-	5040-5060,	5020-5040
	Bell	-	-	4920-4940, 4960-5000
4	Irregular	5030-5050	5350-5450	5160-5180
	Funnel	5000-5020	-	-
	Bell	4980-4990	-	5200-5240
3	Irregular	5110-5150	-	-
	Funnel	5080-5100, 5190-5210	5540-5560, 5600-5610	5310-5360, 5380-5400
	Bell	-	-	-
2	Irregular	5240-5330	-	5510-5560, 5640-5680, 5760-5880
	Funnel	-	-	5460-5470
	Bow	-	5700-5800	-
1	Irregular	5580-5670	5980-6080, 6120-6150, 6280-6488	6060-6140
	Funnel	-	6160-6180	-
	Bell	-	-	-

The lithology of the study area as revealed from the log signatures is an alternation of sand and shale. From the five types of log curves as defined by Nazeer *et al.* (2016) and Nwagwu *et al.* (2009) in Table 1, the main shape identified from the gamma ray signatures of Redfield is the irregular shape with the bell and funnel shapes appearing at intervals as tabulated in Table 2.

There are, nevertheless, the presence of bow shape only in Red 4 field at depth of 5,280- 5320 ft and at 5,700 – 5800 ft. These shapes are used to determine the depositional environments of the rocks as will be discussed subsequently.

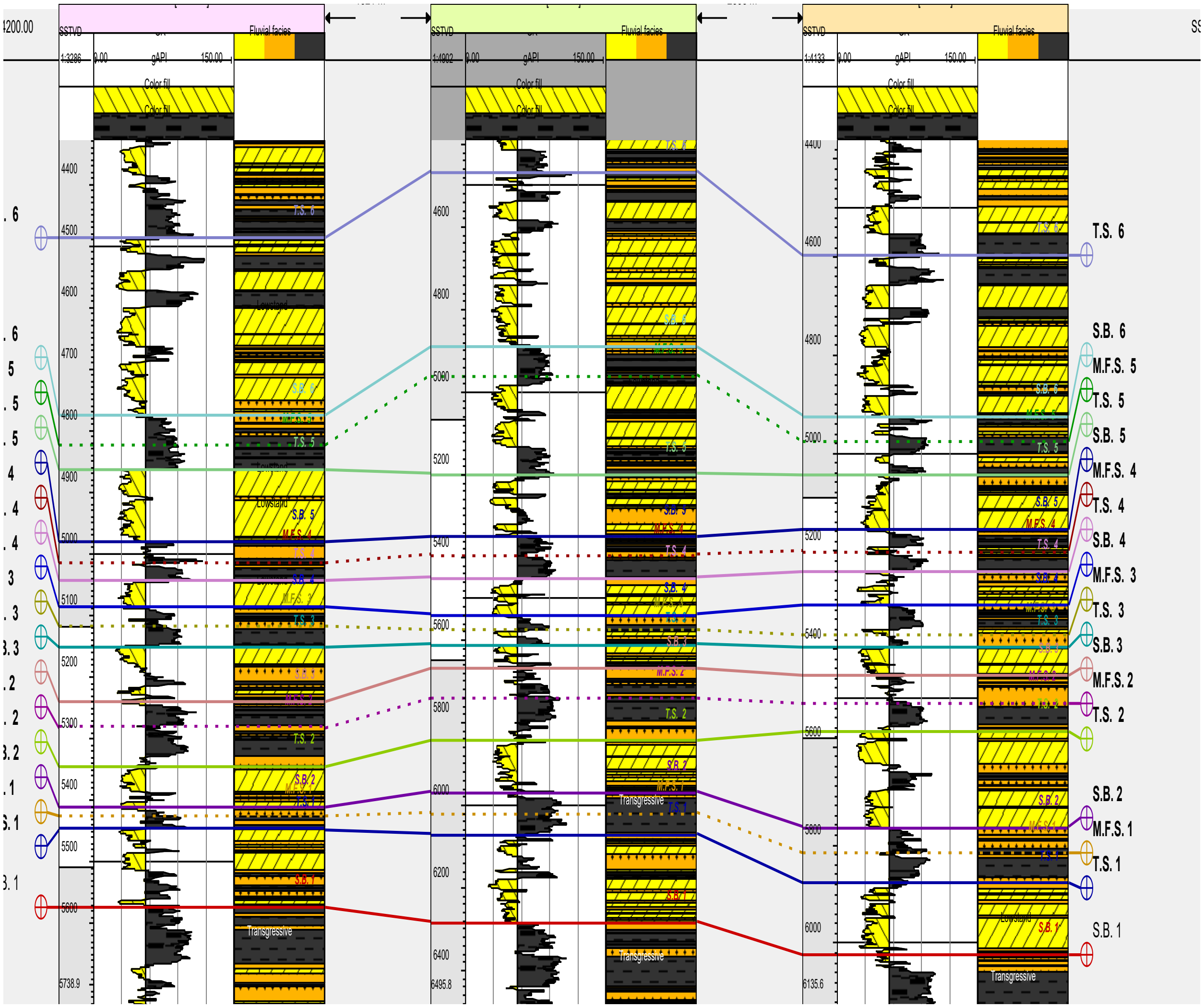


Figure 3: Correlated Gamma ray Log Showing the Facies.

(a) Irregular Shape

The irregular shape is noticed when there is an irregular pattern of the gamma ray log or a spike. It has inter-bedded shale and sand. The depositional environment is the fluvial flood plain, mixed tidal flat, debris flow and canyon fill. The irregular shape of gamma ray log in the analysis classifies the log facies as belonging to a basin plain environment and also represents the slope deposits or turbidities which shows the flow of debris along the slope.

(b) Funnel Shape

This is revealed by a coarsening upward trend with an abrupt top showing coarsening upwards of thick sediments with rapid deposition in clastics (Chow *et al.,* 2005). The depositional environment of funnel-shaped log curves according to Selley (1978) and Cant (1992), is crevase splay or prograding delta, regressive barrier bars, progressive submarine fan lobe, delta front and shoreface.

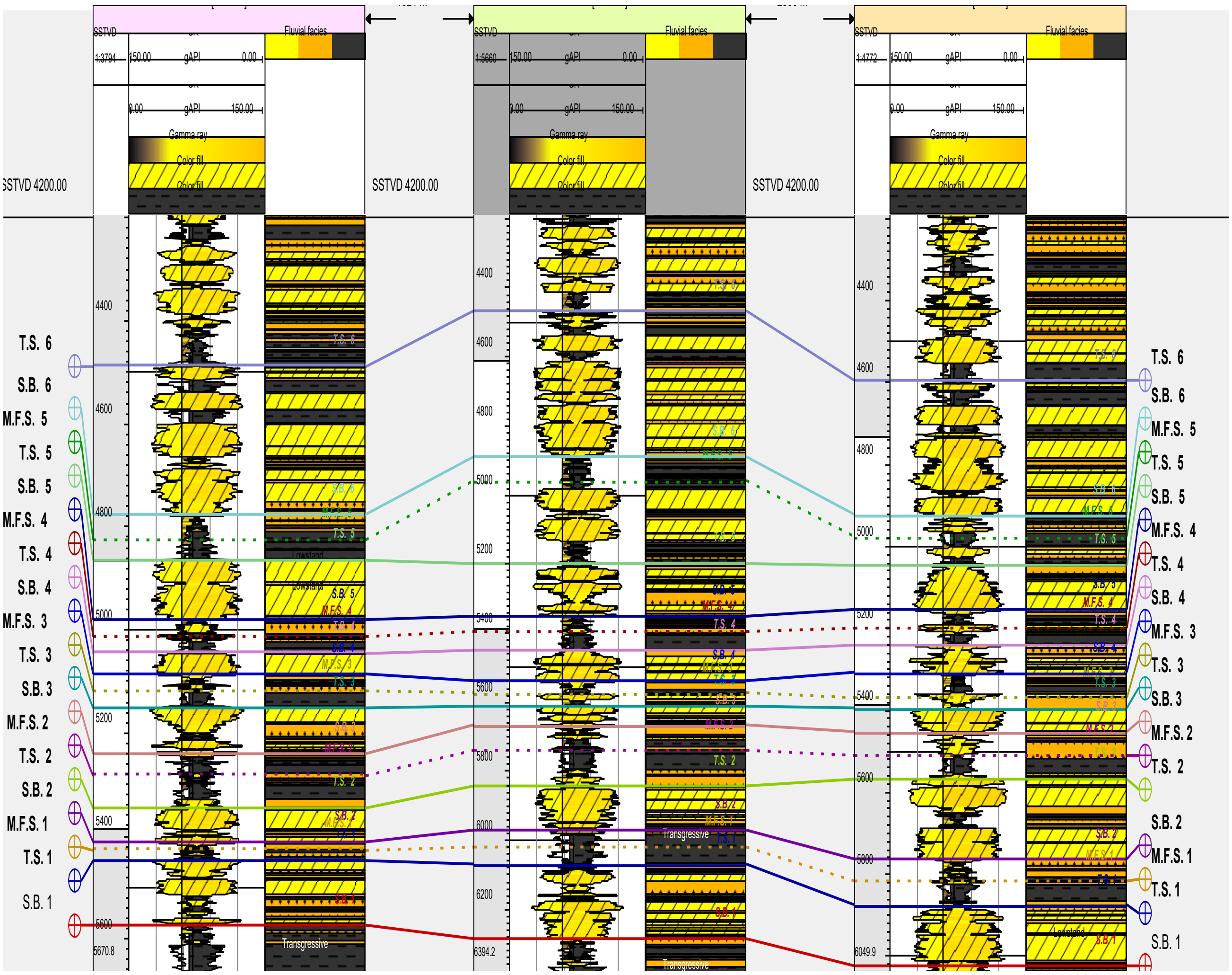


Figure 4: GR-Composite with Facies Analysis.

(c) Bell Shape

This is identified by the consistent upward increase of gamma ray values from minimum values indicating increasing shale content and forming fining upward trend with abrupt base. This therefore indicates transgressive sand, tidal channel or deep tidal channel and fluvial or deltaic channel as depositional environment. Fluvial point bar, tidal point bar, deep sea channels, detail distributaries, braided streams and proximal deep-sea setting are also associated with bell shape (Selley, 1978).

For the Red Field, the predominant irregular shape and the serrated edges of the funnel and bell shapes show a varying lithology of clay and shale. The facies from the funnel shaped signatures is that of the prograding marine shelf and Crevasse splays belonging to parts of a deltaic system characteristic of the Agbada formation. The thin bel-shaped successions indicated that the sands were deposited in environment of transgressive marine shelf. Majority of the sand bodies are those of marine sand deposits and paralic sand sediments of the Agbada formation.

CONCLUSION

Gamma ray log is an invaluable tool used in lithology, lithofacies and facies succession determination. The gamma ray log signatures and their trend help in determining the facies and depositional environment of the sediments. In addition, the depositional cycles, including the key surfaces of modern stratigraphy and the respective depositional sequences, can also be delimited from the gamma ray log analysis. The Red field of Niger-Delta has three predominant gamma ray log shapes: irregular, funnel and bell shapes. This therefore shows an alternation of clay and shale with prograding marine shelf and crevasse splays. The sands are transgressive with a deltaic system characteristic of Agbada formation.

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