Gamma Ray Log Analysis in Determining the Depositional Environment of Reservoir Sands: A Case Study of Shaka Field, Onshore Niger Delta

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***Abstract*– This research covers the use of gamma ray log as a basic tool in determining the depositional environments of reservoirs. Analysis was carried out on reservoir sands in four wells SHA-001, SHA-002, SHA-003 and SHA-004 across the field. The Sand/Shale cutoff was set at Vsh<0.6 for Sands, 0.6>Vsh<0.85 for Silts and Vsh>0.85 for Shale to determine the Reservoir-Non-Reservoir zones (RNR) and to generate lithofacies logs for lithologic log description. Three reservoirs were delineated A, B and C with variable gamma ray log motif shapes. Reservoir A was interpreted as fining upward, fine to medium grain fluvial channel deposited sands, Reservoir B was interpreted as consistent deposited coarse to fine grain tidal sands lobes and reservoir C was interpreted as variable deposited coarse to fine grain tidal sands lobes with shaley bands sediments from the tidal flats. The grain sizes of these reservoirs trended East-West from coarsest in SHA-004 to finest in SHA-001 and possibly shales out. It was therefore concluded that reservoir sands within the fields was deposited in a prograding coastal depositional environment that was influenced by both fluvial and tidal settings.**

***Keywords*-Gamma Ray Logs, Reservoir, Lithologic Description, Depositional Environments**

I. INTRODUCTION

A reservoir is simply a geologic subsurface feature that has the capacity of accumulating (porosity) and transmitting (permeability) a commercial volume of hydrocarbon, provided all entrapment conditions are in place. The interpretation of reservoir depositional environment cannot be done alone from surface descriptions of outcrops being a subsurface feature, one mustutilize specific data set in order to characterize these reservoirs depositional environments.

Gamma ray log present that basic tool in identifying reservoirs lithologies as well as understanding and interpreting their depositional environment. It is worth mentioning that every depositional environment has its own petroleum play significance that affects the exploration and production of hydrocarbon and so the need of understanding the depositional environments of reservoirs cannot be over emphasized.

The Study Area (Shaka Field)is of Miocene in age, located in the eastern portion of the coastal swamp depobelt, onshore Niger Delta sedimentary basin consisting of four (4) wells designated SHA-001, SHA-002, SHA-003 and SHA-004 which cover an area of about 10,863.02 km^2 with wells having a distance of about 0.61km, 1.27km and 4.49km apart from each other respectively (See Fig. 1). The geology, tectonic history and evolution of the Study Area is basically that of the Niger Delta basin which a lot of authors have carried research and publications on [1], [2].The Niger Delta is located within the Gulf of Guinea, Equatorial West Africa at the southern end of Nigeria bordering the Atlantic Ocean between latitude 4^o and 6^o N and longitude 3^o and 9^o E and extends throughout the Niger Delta province [3], [4]. Reference [2] suggested an area of about 75,000km^2 and has an average sediment thickness of about 12,000m. It was formed at the site of a rift triple junction related to the opening of the Southern Atlantic starting in the Late Jurassic and continuing into the Cretaceous [4]. Reference [4] however suggested that the Niger Delta properly began to develop during the Eocene epoch, accumulating sediments that now are over 10 kilometers thick, depositing first the marine shales of the Akata formation, followed by the intercalation of sands and shales of the Agbada formation before the deposition of the continental sands of the Benin formation (See Fig. 2).

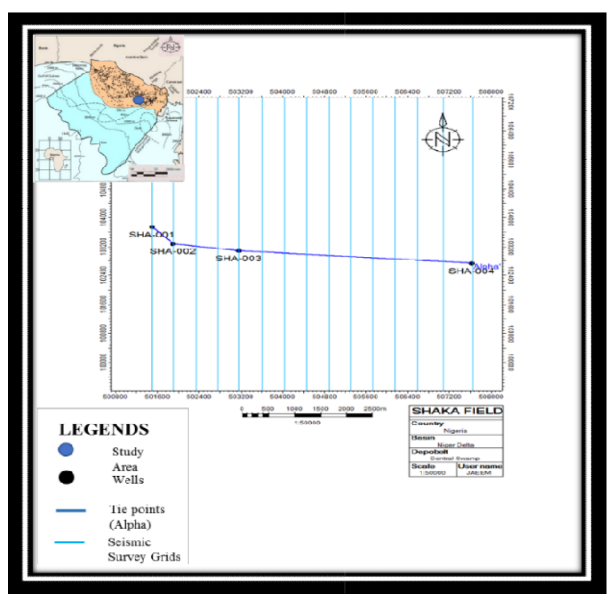

Figure 1: Base Map of the Study Area

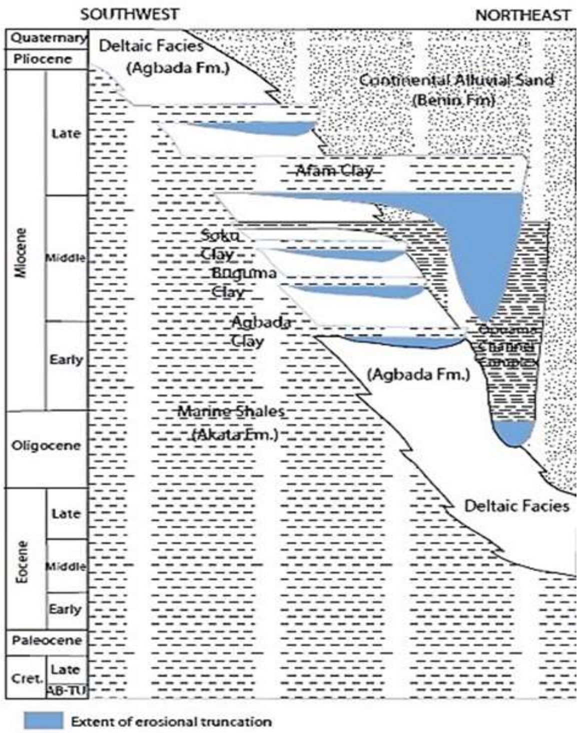

Figure 2: Stratigraphic column showing the three formations of the Niger Delta Basin [1].

II. MATERIALS AND METHODS

A. Samples and sampling

The data set for this research was provided by Shell Petroleum Development Company (SPDC) under the approval from the Department of Petroleum Resources (DPR), Nigeria. The materials used for this research were Well logs data which included; Gamma Ray logs, Vshale logs, SP logs, Resistivity logs, Neutron and Density logs.

B. Gamma Ray Log Analysis

Radioactive sources are observed in most sedimentary rocks especially within the siliciclastic deposits [5], [6]. In siliciclastic depositional settings, each lithological deposit emits varying amounts of Gamma Ray (GR) that contains basic Gamma radiation elements of Potassium 40, Thorium and Uranium and depending on the rate of emission, the lithologies of individual penetrated formation could be inferred [5], [7]. The analysis of Gamma Ray log is very key in understanding not just lithologies containing radioactive isotopes but could also be used to infer grain size distribution of reservoir sands as well as how they were transported and deposited. The radioactive sources occurring in varying compositions are dependent on the depositional environment and for this reason, the Gamma Ray logs could be used in the absence of Cores to interpret subsurface sedimentary facies [7].The interpretation of Gamma Ray logs could be achieved based on the type of Gamma Ray motifs displayed by the log as each type of Gamma Ray log motifs has a unique characteristic that could describe theamount of shale content, the grain size distributions as well as interpreting the environment of deposition [8].References [9] - [11] helped in characterizing Gamma Ray log motifs (log curves) into five categories based on their log motif shapes and these have been used over the time to interpret the depositional environment of reservoir sands (See Fig. 3).The types of Gamma Ray log motifs shapes are; Cylindrical/box shape, Funnel shape, Bell shape, Bow shape (Symmetrical shape) and Irregular shape (Serrated or Saw tooth shape) (See Fig. 3).

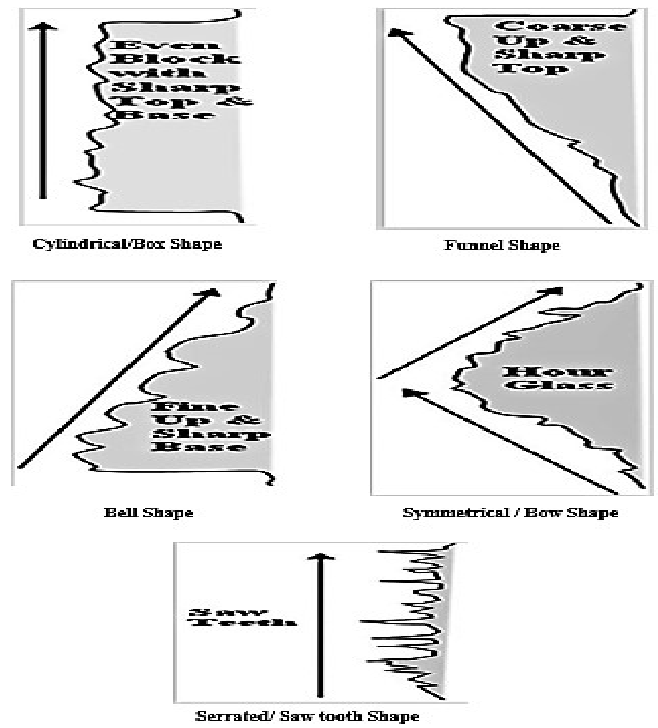

Figure 3: Types of Gamma Ray Log Motif Shapes [8] – [11].

C. Stratigraphic Correlations of Reservoir Sands

Stratigraphic correlation of reservoir sands across wells were achieved using the interpretation of Gamma Ray log motifs as individual motifs displayed the characteristics of a specific depositional environment or groups of depositional environments [7], [10]. In attempting to carry out a stratigraphic correlation across wells, one must understand the regional settings of the hydrocarbon field through seismic sections, field base maps or by developing a cross section along wells; this will enhance a better stratigraphic correlation [12]. Reference [12] also suggested the importance of having cross sections for the entire field in performing stratigraphic correlation of reservoir sands across the field as this will reveal a regional section of the exploration field as well as the sequence in which these formations were deposited. However, it is worth mentioning that Stratigraphic correlation can be carried out effectively with well logs cross sections in the absence of seismic sections.

Based on the Log motif characteristics, top and bottom horizons were selected to mark each identified reservoir, and then correlation was carried out across wells using this identified log motif to understand the stratigraphy of the reservoir sands which includes both lateral continuity as well as termination of reservoir sands across the field.

D. Lithofacies Analysis of Reservoir Sands from Well Logs

The identification of lithofacies can be achieved using well logs (especially the gamma ray logs) in the absence of live core data [7]. From the gamma ray log, grain sizes as well as lithologies can be inferred and basically used for lithofacies analysis and interpretation. However, it is worth mentioning that a more accurate interpretation will be obtained when integrating live core data with gamma ray logs as core data will produce an interpretation of a higher resolution than that of the gamma ray logs as not all details of the interested lithology can be captured by the gamma ray logs such as the lithology colour, degree of roundness or angularity, degree of sorting, sedimentary structures, etc. However, not all sections in the wells can be cored as it is very expensive to perform all through the well borne and therefore makes gamma ray logs interpretation very important in understanding the lithologies of reservoirs as well as interpreting their depositional environment. In the identification of reservoir lithologies, thevolume shale (vshale) was calculated and a cut of was established to differentiate the sands from the shales making it easier toestablish the reservoir from the non-reservoir zones (See Eq.1).

$$\boldsymbol{V_{SH} = 0.083 * \left(2^{(3.7 * GR_{index})} - 1\right)} \ldots\ldots \text{(Eq. 1)}$$

Equation after [13] of non-linear relationship for Tertiary rocks, where;

V_{SH} = Volume of shale

I_{GR} = Gamma ray index that describes a linear response to shale content

The Sand/Shale cutoff was set at Vsh<0.6 for Sands, 0.6>Vsh<0.85 for Silts and Vsh>0.85 for Shale

III. RESULT AND DISCUSSION

A. Delineation of Reservoirs

Three (3) reservoirs A, B and C were delineated across four wells SHA-001, SHA-002, SHA-003 and SHA-004 (See Fig.4). This was achieved after analysis on motifs from gamma ray logs (GR) and volume shale logs (Vsh) to delineate sand/shale lithologies. Reservoir fluid characteristics were delineated with the analysis on resistivity logs (RT) and neutron-density logs (NPHI-RHOB).

B. Stratigraphic Correlation of Reservoirs

Stratigraphic correlations of delineated reservoirs were carried out to understand the lateral and vertical continuity as well as terminations of reservoirs (see Fig. 4). From stratigraphic correlation of reservoirs, six (6) reservoir horizons A-Top, A-Bottom, B-Top, B-Bottom, C-Top and C-Bottom were mapped out to mark both lateral and vertical boundaries of delineated reservoirs A, B and C. Reservoir A constitute of good sand development throughout the reservoir region with consistent lateral stratigraphy having a gross thickness of about 70ft, Reservoir Bconstitute of good sand development throughout the reservoir region with slightly consistent lateral stratigraphy having a gross thickness of about 160ft while Reservoir Cconstitute of good sand development throughout the reservoir region with variable lateral stratigraphy having a gross thickness of about 150ft (see Fig. 4.).

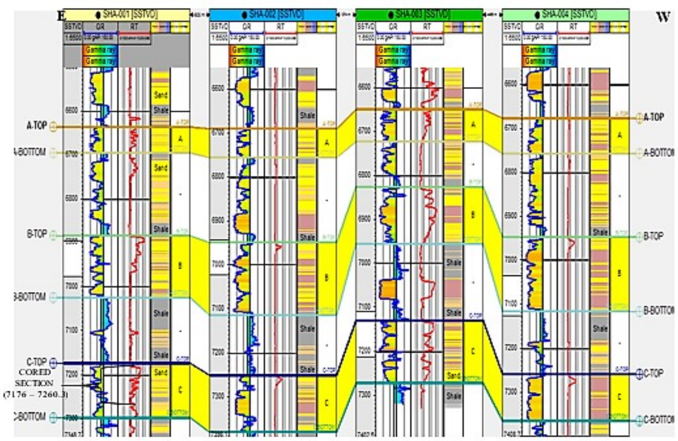

Figure 4: Stratigraphic correlations of reservoirs A, B and C

C. Interpretations of Depositional Environments from Gamma Ray Logs Motifs

Depositional environments of reservoir sands were interpreted from the analysis of shapes of gamma ray motifs. The depositional environments of reservoir sands ranges from the fluvial channels, fluvial point bars, tidal channels, tidal flats, delta fronts to coastal plains depositional environments. Table 1 summarizes the depositional environments of reservoirs from gamma ray log motifs shapes; figures 5 – 13 further explains the various depositional environments interpreted from gamma ray log motifs shapes.

Table 1: Depositional Environments of Reservoirs Inferred from Gamma Ray Log Motifs Shapes [7], [10].

Type of log motif shape	Reservoirs	Characteristics	Grain size	Inferred Depositional Environments
Cylindrical / Box Shape	A-well-003, B-well-004, C-well-004, parts of C-well-001 and parts of C-well-002	Sharp top and base with consistent trend	Relative consistent lithology	Fluvial channels, Tidal sands, Prograding delta distributaries.
Funnel Shape	Parts of A-well-002, parts of C-well-002, parts of C-well-003	Abrupt top with coarsening upward trend	Grain size increases	Crevasse splay, River mouth bar, Delta front, Shoreface.

Bell Shape	A-well-001, A-well-004, parts of C-well-001, parts of B-well-002	Abrupt base with finning upward trend	Grain size decreases	Fluvial point bar, Tidal point bar, Deltaic distributaries.
Symmetrical Shape / Bow Shape	B-well-003	Ideally base and top like a bow shape	Cleaning upward trend change into dirtying upward sequence from top	Transgressive shelf sands and mixed Tidal flat environment.
Serrated / Saw tooth Shape	B-well-001, parts of C-well-003	Irregular pattern / spikes of GR logs	Interbedded shales and sands	Fluvial flood plain, mixed Tidal flat, Debris flow.

i. *Bell Shaped Gamma Ray Log Motifs*

A number of four (4) beds in reservoirs exhibited this gamma ray log characteristic (See Fig. 6 and 7), these were; Reservoir A in Well SHA-001, Reservoir A in Well SHA-004, Parts of Reservoir C in Well SHA-001 and Parts of Reservoir B in Well SHA-002.

This motif generally shows an increasing upward values of gamma ray which indicates an increasing shale content and a fining upward depositional sequence. This diagnostic motif is usually an indicative of fluvial channels, fluvial point bar, tidal channels or deltaic distributaries channels depositional environments[7].

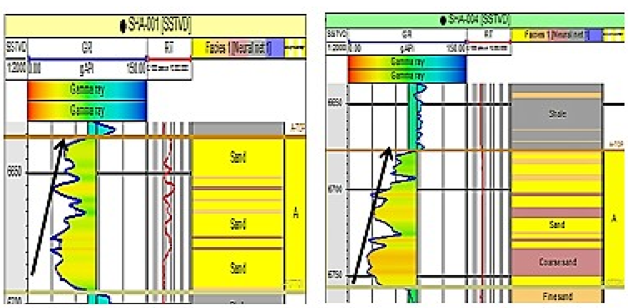

Figure 5: Bell Shaped Gamma Ray Log Motif of Reservoir A-Well SHA-001 and Reservoir A-Well SHA-004

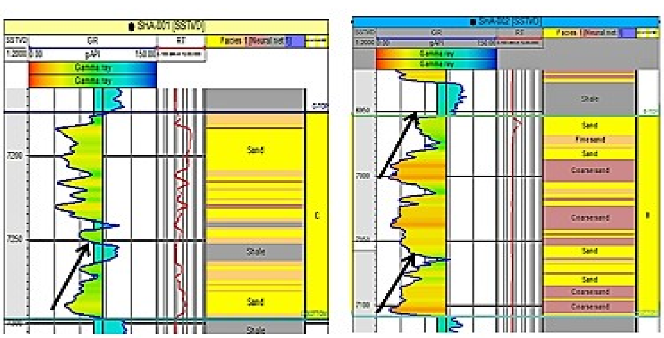

Figure 6: Bell Shaped Gamma Ray Log Motif of Lower Parts of Reservoir C-Well SHA-004, Upper and Lower Parts of Reservoir B-Well SHA-002

ii. *Cylindrical Shaped Gamma Ray Log Motifs*

A number of six (6) beds in reservoirs exhibited this gamma ray log characteristic (See Fig. 7-9), these were; Reservoir A in Well SHA-003, Reservoir B in Well SHA-004, Reservoir C in Well SHA-004, Parts of Reservoir B in Well SHA-002, Parts of Reservoir C in Well SHA-001 and Parts of Reservoir C in Well SHA-002.

This motif is generally characterized by relatively constant values of gamma ray with sharp boundaries at the upper and lower limits which indicates a relatively uniform lithology, having an aggradation depositional pattern. This diagnostic motif is usually an indicative of fluvial channels, tidal sands, or deltaic distributaries channels depositional environments[7].

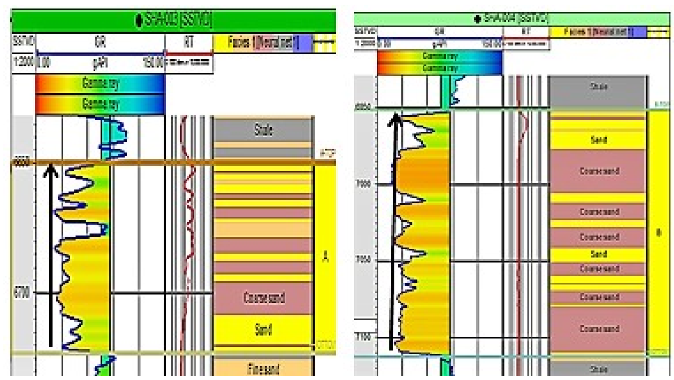

Figure 7: Cylindrical Shaped Gamma Ray Log Motif of Reservoir A-Well SHA-003 and Reservoir B-Well SHA-004

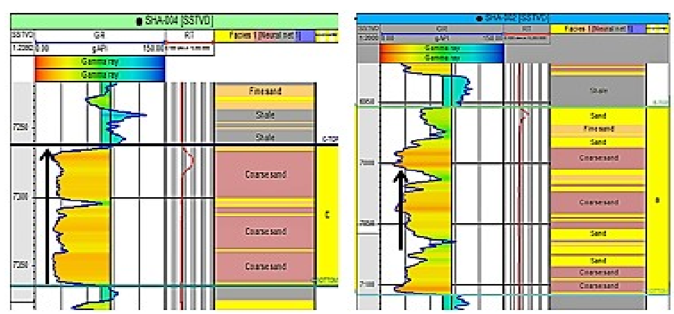

Figure 8: Cylindrical Shaped Gamma Ray Log Motif of Reservoir C-Well SHA-004 and Middle Parts of Reservoir B-Well SHA-002

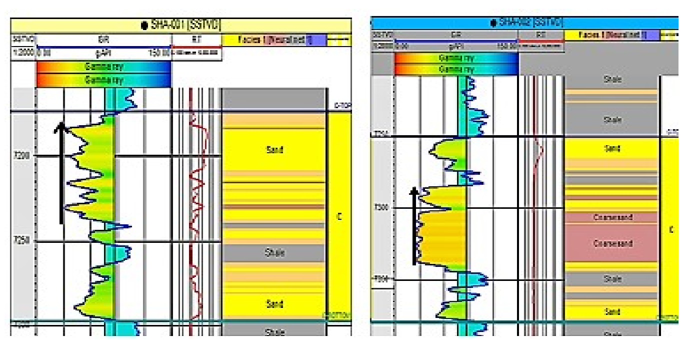

Figure 9: Cylindrical Shaped Gamma Ray Log Motif in Upper Parts of Reservoir C-Well SHA-001 and Middle Parts of Reservoir C-Well SHA-002.

iii. Funnel Shaped Gamma Ray Log Motifs

A number of three (3) beds in reservoirs exhibited this gamma ray log characteristic (See Fig. 10 and 11), these were; Parts of Reservoir A in Well SHA-002, Parts of Reservoir C in Well SHA-002 and Parts of Reservoir C in Well SHA-003.

This motif is generally characterized by a relatively decreasing values of gamma ray which indicates a decreasing shale content, increasing sands and a coarsening upward depositional sequence. This diagnostic motif is usually an indicative of crevasse splay, river mouth bar, delta front or shoreface depositional environments [7].

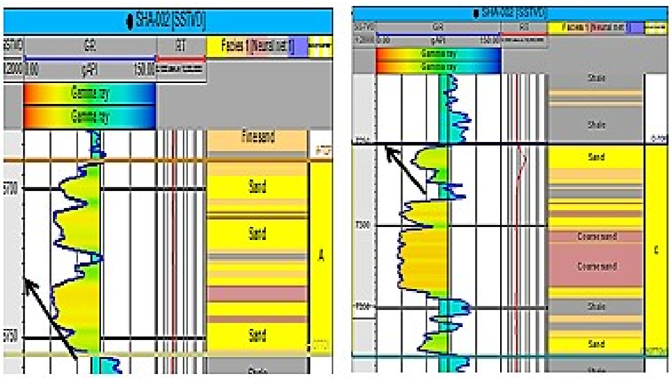

Figure 10: Funnel Shaped Gamma Ray Log Motif in Lower Parts of Reservoir A-Well SHA-002 and Upper Parts of Reservoir C-Well SHA-002.

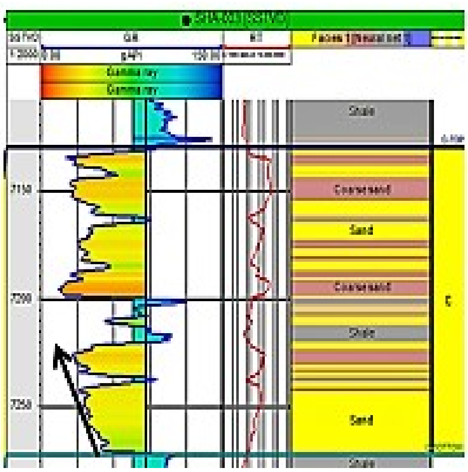

Figure 11: Funnel Shaped Gamma Ray Log Motif in Lower Parts of Reservoir C-Well SHA-003

iv. Bow Shaped Gamma Ray Log Motifs

Only one (1) bed in a reservoir exhibited this gamma ray log characteristic (See Fig.12), this was; Reservoir B-Well SHA-003.

This motif is generally characterized by a relatively increasing values of gamma ray followed by a relatively decreasing values of gamma ray which practically indicates a relatively increasing shale content (decreasing sands) followed by a relatively decreasing shale content (increasing sands) to form a bow shape depositional pattern. This diagnostic motif is usually an indicative of tidal channels sands or mixed tidal flats depositional environments[7].

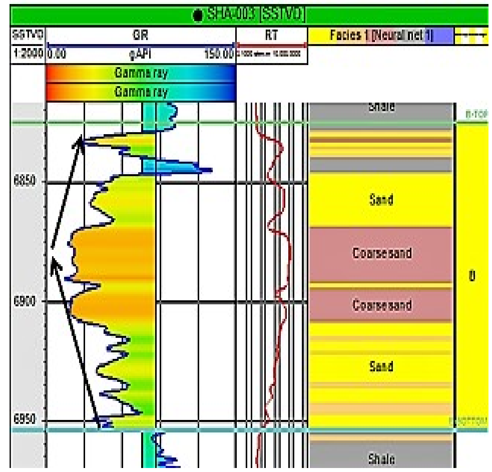

Figure 12: Bow Shaped Gamma Ray Log Motif of Reservoir B-Well SHA-003

v. Serrated/Saw Tooth Shaped Gamma Ray Log Motifs

A number of two (2) beds in reservoirs exhibited this gamma ray log characteristic (See Fig.13), these were; Reservoir B in Well SHA-001 and Parts of Reservoir C in Well SHA-003.

This motif is generally characterized by fluctuating increasing and decreasing values of gamma ray which indicates a mixture of various grain sizes of sands and shale lamina within the lithology. This diagnostic motif is usually an indicative of fluvial flood plain, mixed tidal flat and debris flow depositional environments [7].

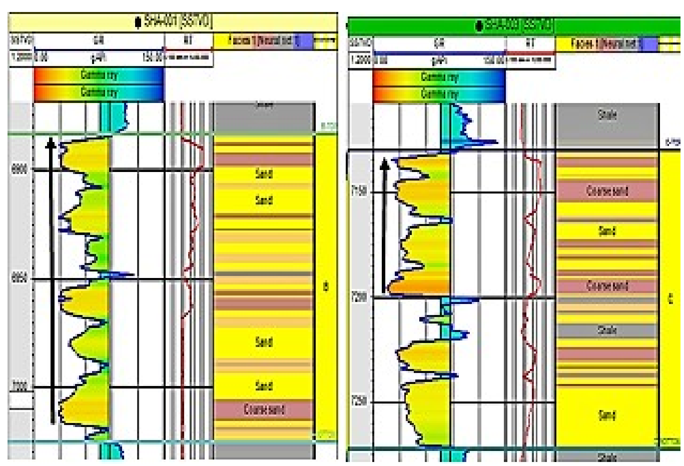

Figure 13: Serrated/Saw Tooth Shaped Gamma Ray Log Motif of Reservoir B-Well SHA-001 and Upper Parts of Reservoir C-Well

D. Discussions

The behavioral patterns of gamma ray logs have been utilized to establish key depositional environments for reservoirs in Shaka field, onshore eastern Niger Delta basin.

Reservoirs exhibiting the bell shape gamma ray motifs revealed how sediments were transported either by suspension, saltation or rolling in medium to high energy regime, then deposited as the energy of the transporting medium reduces. The coarser grain sediments begins to deposit gradually followed by the medium to fine grain sediments until the energy of the flowing medium totally reduces. Deposits of this kind forms a fining upward depositional sequencefrom the clean sands of the continental channel runoff to shaley sediments of the coastal/shallow marine environment. This is mainly diagnostic of the fluvial channel sands as majorly seen in reservoir A.

Reservoirs exhibiting the cylindrical shape gamma ray motifs revealed how the availability of sediments were possibly more that the flow energy required to transport these sediments as a results sediment where been deposited uniformly in an aggregational pattern to form a cylindrical or blocky like shape motif. The sediments in these depositional settings are usually well sorted that was possibly caused by regular reworking from the transporting medium such as tidal or wave currents when depositing newer sediments. This is mainly diagnostic of the tidal channel sands as majorly seen in reservoir B.

Reservoirs exhibiting the funnel shape gamma ray log motifs revealed similar but a reversed characteristic of that of the bell shape gamma ray log motif. Sediments here where possibly transported from the marine environment towards the continents in a process whereby the coarser sediments were deposited first by the high energy of the transporting medium and the finer sediments were deposited as the transporting medium regresses basin ward. This is exhibited by a coarsening upward depositional pattern where the grain sizes gradually decrease downwards to fines sands and shales which is diagnostic of the delta fronts, tidal or shoreface depositional environment as minorly seeing in reservoir C and A.

Reservoir exhibiting the bow shape gamma ray log motifs revealed a dual behaviour of the transporting medium carrying the sediments for deposition. Sediments were deposited in the processes that supports a coarsening upwards depositional pattern followed by a fining upwards depositional pattern. This possibly occurred when the transporting medium carried sediments from the basin and deposited them landwards while sediments from the continents where equally transported and deposited basinward. Sediments within these areas are constantly reworked by the transporting medium, well sorted and are diagnostic of the tidal channel sands as seen in parts of reservoir B.

Reservoir exhibiting the serrated shape gamma ray log motif revealed the deposition of heterolithic mixture of variousgrain size sediments. The energy of the transporting medium was not strong enough to carry much loads and therefore deposited the mixture of several grain size sediments in order to continue flowing. These sediments were deposited in a clam and low energy environments that had no possibility of been reworked making them to be moderately to poorly sorted. The sediments within this depositional setting is mainly diagnostic of that of the mixed tidal flats or coastal plains as seen in parts of reservoir B and C.

IV. CONCLUSION

After a holistic analysis of gamma ray log motif of reservoirs in Shaka field, Onshore Niger Delta, it was concluded that reservoir sands within the fields was deposited in a prograding coastal depositional environment that was influenced by both fluvial and tidal settings. Reservoir A was interpreted as fining upward, fine to medium grain fluvial channel deposited sands, Reservoir B was interpreted as consistent deposited coarse to fine grain tidal sands lobes and reservoir C was also interpreted as variable deposited coarse to fine grain tidal sands lobes with shaley bands sediments from the coastal plains. The grain sizes of these reservoirs trended East-West from coarsest in SHA-004 to finest in SHA-001 and possibly shales out going further away from SHA-001. It was recommended for further studies to be carried out such as cores analysis to reveal the physical lithologic descriptions of these reservoirs and to authenticate the interpreted depositional environments of reservoirs.

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