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A Novel Perspective of Electrofacies and Electro Sequence Analysis: A Case Study of Gracious Field, Niger Delta, Nigeria

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ABSTRACT

Electrofacies and electorosequencecharacterization of 'Gracious' Field, Niger Delta, were studied, with the aid of tenwireline logs and 3D seismic data volume, to make precise prediction ofthesource rocks and reservoir rocks in the study area ofresearch and also delineate a sequence stratigraphic analysis of the Field. Lithofacies is delineated by analyzing well logs using gamma ray signatures, cross-plotting of neutron density logs and analysis of seismic facies. Using diagnostic characteristics of gamma ray log indicative of a given depositional environment, the detected lithofacies were subjected to electrofacies analysis.The subsurface facies ofGracious field revealedthree (3) sequences that are bounded by four (4) sequence boundaries (SBs) that were mapped and delineated as unconformities due to erosionhavingfour maximum flooding surfaces (MFSs).DelineatedSequences includesthetransgressive-systems-tracts (TST), low-stand-systems-tracts (LST), and high-stand systems tracts (HST). These were revealed during various stages of base level shifts, as depositional systems. Deposits delineatedinside the low-stand systems tracts are fluvialchannel sands, while transgressive systems tracts, overlaid the low-stand systems tracts facies. High-stand systems tracts are composed of upward coarse and superficial deltaic marine (fluvial)sands.The sand units of the distributaries and tidal channels having a thicknessof 60 m and 75 m, and porosity of 21% and 23% respectively were viewed to have good quality for hydrocarbonreservoir.The sequences were deposited in intermediate to superficial marine environments. The reservoirs of the low-stand-systems-tracts and high-stand-systems-tracts and seals from the marine shaleof the transgressive-systems-tracts andhigh-stand-systems-tracts could create stratigraphic traps for hydrocarbon accumulation in the Gracious Field. This study would be a gainful means to guidehydrocarbon exploration and production plans in this field.

Keywords: Electrofacies, Unconformities, Hydrocarbon, Systems Tracts, Exploration

INTRODUCTION

The application of geophysical borehole log investigation in geoscience disciplines is developing, but only slowly over the years. Traditionally, logs areused to correlate one well in comparisonto another, and in between the two, lines are drawn. This is a primitive strategy, and logs have a better and far greater potential for logging. and applicability in the modern subsurface geophysical and geological analysis. New subsurface geological and geophysical analysis can and should employ a thorough, comprehensive, and sophisticated analysis of wireline logs data.The prime purpose of an electrofacies annotation isto prepare the log set for an ultimate interpretation forwhatever geological and geophysical information that can be obtained from the wireline logs, such aslog sequence, depositional environment, or facies.Facies in the usual geological sense, may not beselfsame to the electrofacies.Once established, the log shape system can be used in several ways. Maps made of the geographicaldistribution of log shapes are effectively both facies distribution, and paleogeographic maps once an interval is reliably identified. The contrasts in log signaturebetween the studiedwindow give an evidence of facies variations and hence, an indication of paleogeography.More recently. As a tool for sequence stratigraphy with variations in log shapes (usually gamma-ray), log shapes have been used to indicate facies relationships within para-sequences, para-sequence stacking patterns, or facies changes at sequence boundaries. Indeed, a strong reliance is often placed on log shapes.

'Electrosequence Analysis' is a tool to interpret sedimentology and stratigraphy. A system for identifying and analyzing log-based or log-based systems or electrosequence sequences is described. Sequential analysis, formerly called (Rider, 1986). An electrosequence is a wireline log interval that is defined through which log responses and characteristics are consistent or consistently changing, to separate it from other electrosequences, it is sufficiently distinctive. Usually, it will be tens of meters thick and match the facies (i.e. a sequence)sedimentological succession. The aim of the analysis for electrosequence study is to obtain as abundant geological data as conceivablefrom the logs by classifying stratigraphic units: depositional, stratigraphic, and eventually sequence, vertically continuous.An interval may be interpreted lithologically asentirely shale; an electrofacies annotation will bring outthe fact that there are two distinct types of shale withinthis interval and that an unconformity separates them. There is much more in the logs than justlithological information, and the electrofacies annotationwill show this.

Lithology can be interpreted from wireline logs using avariety of log types, such as gamma-ray, sonic, resistivity,density, and photoelectric (Selley, 1998). Electrosequenceanalysis of reservoir plays prominent role in determination ofhydrocarbon bearing intervals (Torghabeh et al., 2014,
Kuroda, et al., 2012, Zee, 2011).

LOCATION OF STUDY AREA AND GEOLOGY

Gracious field (Figure 1) is located in Niger Delta in the margin of the Gulf of Guinea in southern Nigeria. (Figure. 2), is made up of materials deposited under marine to continental settings (Frankl & Cordry, 1967).The stratigraphy(Figure. 2) and geological setting of the

Delta have beenwell studied (Short & Stauble, 1967; Burke, 1972; Avbovbo, 1978; Whiteman, 1982; Kulke1995). The Niger Delta stratigraphyis separated intothree major Megasequences of the Akata Formations, the Agbada Formations and the Benin formations(Figure. 3). The tertiary succession of the Niger-Delta areacomprises of the marine Akata Formation that is characterized by ahomogenous shale development which formed thehydrocarbon kitchen. The overlying paralic AgbadaFormation has been described by Weber (1986) to be cyclicsequence of sandstones and shales. Most hydrocarbonsproduced so far in the Niger delta have been hosted in thesandstone unit of the Agbada Formation. The sequence iscapped by the continental Benin Formation which is made offreshwater bearing sandstones that islocally interbedded withthin shales considered to be of braided stream origin. Thisformation is of little petroleum hosting strata. Tectonically,the Niger delta can be regionally divided into the western andsouthern lobes separated by the Charcot Fracture Zone(Corredor *et al.,* 2005). The Chain Fracture zone confines thewestern lobe to the north while the Fernando Po restricts thesouthern delta lobe to the southeast. Five depobelts whichinclude the, Greater Ughelli, offshore depobelts ,Centralswamp,Northern depobelt, and Coastal swamp are preservedin the studied area of Niger-Delta according to Lawrence et al., 2002. Three main structural styles are frequent in the Niger delta. They include extensional (growth fault), translational (diapirs), and compressional (imbricate trust) zones. Growth faults and associated rollover anticlines are ubiquitous in virtually all depobelts of the Niger Delta. The duo combined to form the dominant structural traps for hydrocarbon in the delta. The aim of this research was to establish the sedimentary facies, their succession, and deposition environments through electrosequence analyses of geophysical logs. This approachis novel in that it is less rigorous and inexpensive wayto evaluate the study area 's hydrocarbon potential.

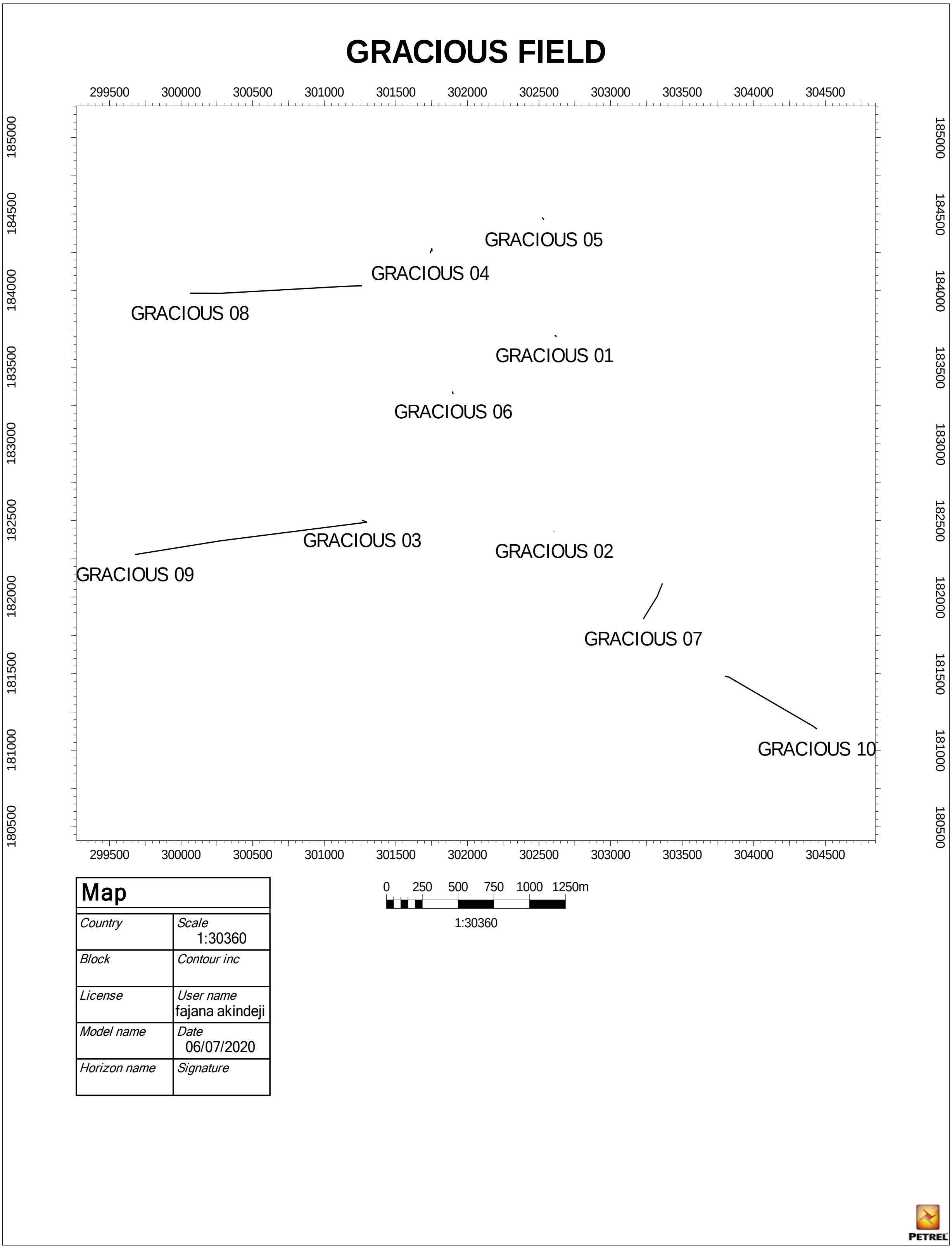


Figure1: Base map of Gracious Field

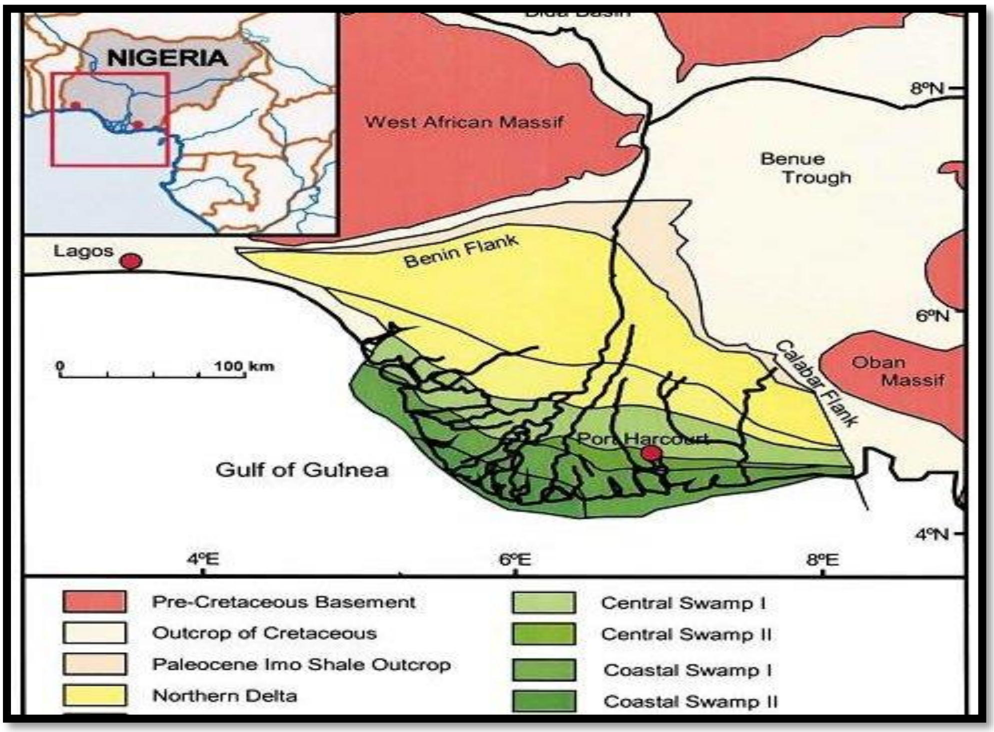


Figure2: Niger Delta showing the Nigeria margin of the Gulf of Guinea

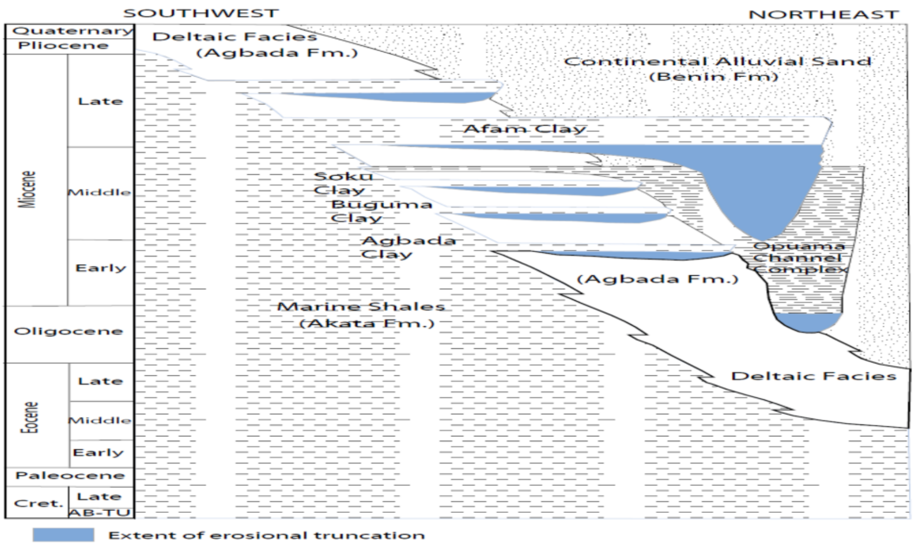


Figure 3: Stratigraphic column showing the three formations of the Niger Delta. (Short & Stauble, 1967; Burke, 1972; Avbovbo, 1978; Whiteman, 1982; Kulke 1995)

METHODOLOGY

Anelementarysystem and approach to classifying sand packages in the area of the Niger Delta in Nigeria.The shape of the GR log is based on the on such classification, and SP logs sideways with its mirror duplicate (occasionally) the wireline log of resistivity. The common shape obtained was the bell,the Cylinder and the funnel, (Figure 4), this structure was envisioned to the cataloging of log shapes to aid correlation in Gracious field, which is essentially a geometrical approach.

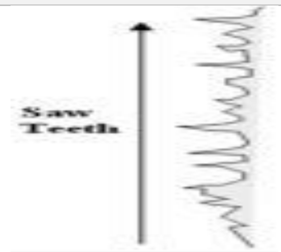
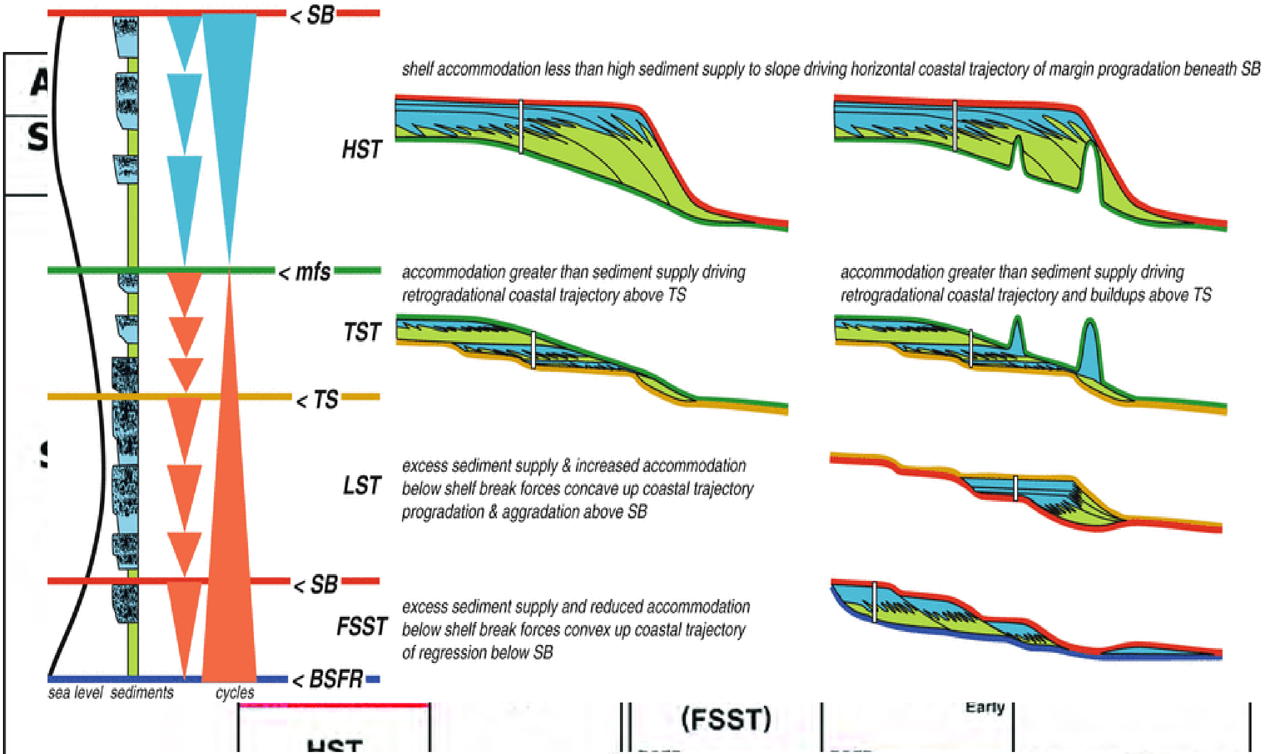
Type of log motif shape	**Cylindrical/box shape**	**Funnel shape**	**Bell shape**	**Symmetrical shape**	**Serrated/saw tooth shape**
Sediment supply	Aggradation	Progradation	Retrogradati on	Petrograding & retrograding	Aggrading
GR trend					
Characteristic	Sharp top and base with consistent trend	Abrupt 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 shale's and sands
Depositional Environment	Aeolian (sand dunes), fluvial channels, carbonate shelf (thick carbonate), 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

Figure 4: Types of Shape of the GR log and classification of sand bodies in the Gracious field

Step 1: Interpretation of lithology
The electrosequence analysis is undertaken using all the well logs plotted and, depth-correlated and at the same scale.
Step 2: Electrofacies annotation
Once the lithology is established, the logs can beexamined for features seen on the traces whichmay or may not have geological importance. Thesecharacteristics, baselines, trends, shapes, abrupt breaks, and anomalies will be examined.Together, they make up what is called an ‘electrofacies,’ which can be defined so as to enable the separation from other electro-facies as a group of wire-line log signature, attribute and featuresadequately distinctive. The comments that are labeled on the wireline logs as detailedunderneath in a rational order of veryeasy to increasingly compound baselines. A baseline is a vertically constant log value. Ithas both lithological and stratigraphic significance. Thename may perhaps be misleading as a baseline in thepresent context is considered rather as a ‘base value oreven ‘average’ value, which is constant vertically for atleast some tens of meters but possibly up to hundreds ofmeters.
Highaverage values (high baseline) indicating clean shale andlow baseline values indicating clean sand (i.e., the sandand shale lines). However, this technique shows that neither the shales nor the sands change vertically, hence the consistent log responses, which means they are from the same formation in stratigraphic terms. When theformation changes, baselines change.Baselines or base values can be used with all logs. Notjust the gamma-ray. So that if any logshows vertically constant values. It suggests that eitherthe lithologies are constant,or there is no change offormation (Figure 5).
The following abrupt breaks are identifiable:
1)Lithologically related,breaks,Erosion,Flooding,(catastrophe)
2)Non-lithological,breaks,Unconformity,Fault(diagenetic change)(fluids change)
Anomalous log values are important - excessively high or excessively low peaks (values) may havegreat stratigraphic importance.
Step 3: Electro-sequence study of wireline logconstructedclassifications, depositional environment, and facies, after established a lithology and built up an annotationof electrofacies, the only remaining preparation is to build the verticalsuccession of electrofacies into log-based electrosequences, which can be construed in terms of conditions of depositional potential, facies, successions of facies and stratigraphic fractures, faults and inconsistencies (Figure 6). Theevidence for the construction comes from each precedingstep.

Fig. 5. Nomenclature of sytems tracts, and timing of sequence boundaries for the various sequence stratigraphicapproaches (modified from Catuneanu et al., 2011)



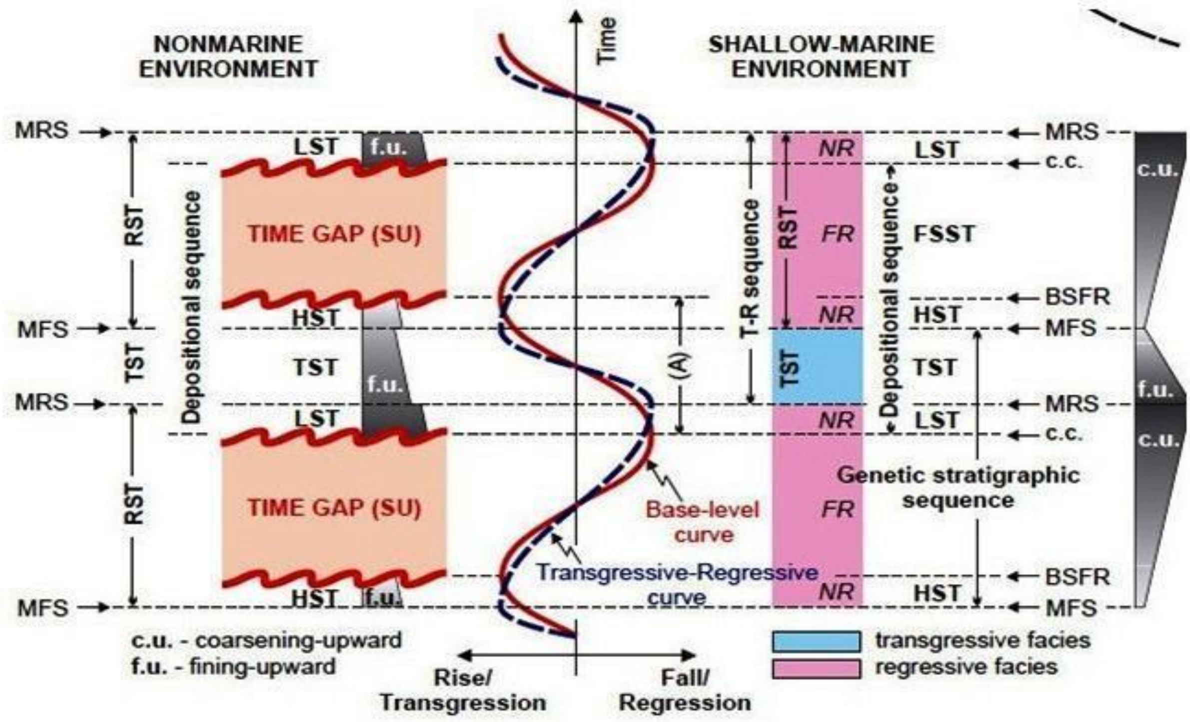


Figure 6. Systems tracts, and stratigraphic surfaces defined in relation to the base-level and to the transgressive-regressive curves (after Catuneanu et al., 2011)

RESULTS AND DISCUSSION

The building blocks of sequence stratigraphy are hierarchical and the key surfaces mapped allow each block to be recognized (and defined). The lowest order of the hierarchy mapped in this study area is the parasequence which is bounded by flooding surfaces. There are essentially three systems tracts, lowstand, transgressive and highstand. A sequence may be made up of all three tracts or some combination, especially a transgressive followed by a highstand systems tract.

However, rather than just identifying and classifying log signatures, motifs and shapes, also an attempt was made to understand why such log shapes exit.It is necessary to understand the reaction of these wireline logs. In terms of clay/ shale content variations, the GR log motif can be explained. The rise in GR-radiation is related with an rise in clay / shale composition, which is correlated with a decrease in the size of the sand grain. A wireline log motif of the bell shape observed in the studied region can be interpreted as indicating a fining-up, fluviatile, point bar Sandstone. GR funnel Shape log motif represents a successions Coarsening-upwards shallow marine sand. Succession programs, estuarine Shorelines, are interpreted as having been deposited. Therefore, the funnel shape log motif is an indication of coarsening Prograding estuarine Shoreline Sand body successions in the study area (Figure 7) shows a typical bell shape on the gamma ray log response. The increase in gamma radiation corresponds to a regular upward increase in the content of the clay. The rise in clay content is correlated with a drop in the size of the sand-grain. Therefore, the bell shape can be interpreted as indicative of a sandstone fining-upwards, fluviatile, point bar.Moreover, Figure 7 shows gamma ray funnel shapes with the corresponding high resistivity.Each funnel shape is a sequence of coarsening-up from bioturbated, offshore muds to silts to bioturbated shallow marine sands capped by shale and root beds. It is interpreted that the successions are deposited in prograding, estuarine shorelines. The funnel shape is therefore indicative of coarsening-up, prograding estuarine shoreline successions in this case.

These results show the close relationship possible between the gamına ray log and grain-sized sandstone. It is possible to interpret shapes on the gamma ray log as grain-size trends and as successions of facies. An increase in grain size will be indicated by a decrease in gamma ray values: small grain sizes will match higher gamma ray values (Figure 8).(frequently radioactive) as the compositional elements which vary independently against clay content which gives the textural element.

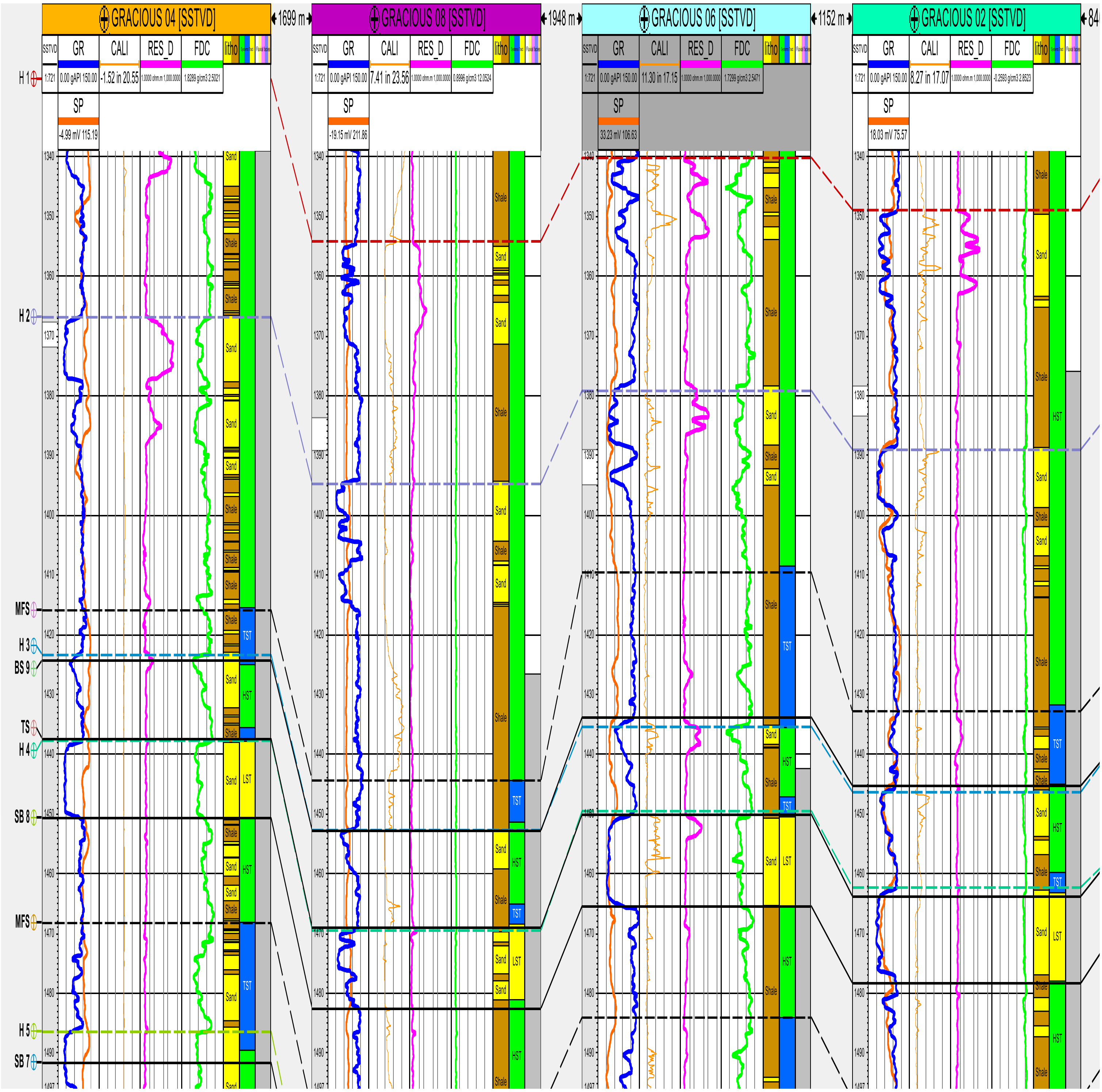


Figure 7: shows a typical gamma ray log responseand Lithostratigraphic correlation section across wells

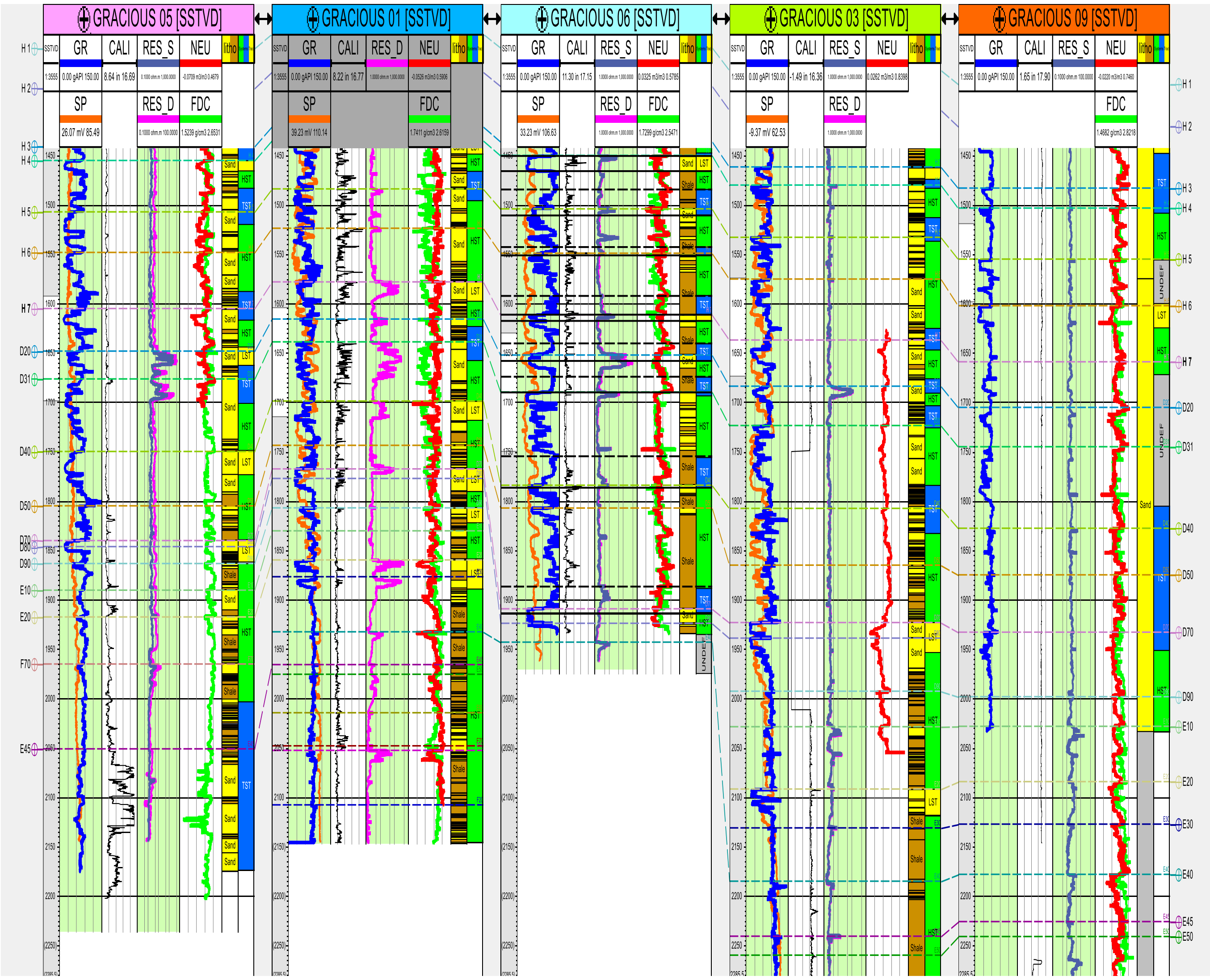


Figure 8: shows a typical gamma ray log responseand Lithostratigraphic correlation section across wells

Secondly, the relationship between the volume of clay and the size of the grain. There is no misunderstanding that there is a correlation between grain size and clay content. It is, however, by no means, a constant one. Good relationships are commonly seen in deltaic and fluvial environments, where deposition is primarily controlled by flowing current energy. However, in many cases, changes in grain size that are necessary for the identification of sedimentary structures or sequences do not involve changes in the clay content or, at least, abundant changes that affect the gamma-ray content..The recognition of abrupt breaks in a log sequence is very important. They can indicate changes in lithology, structural breaks, changes in fluids but, most importantly, they may indicate a break in 'depositional logic', that is a break in the vertical flow of (laterally) related facies. In this sense, abrupt breaks are especially important in sedimentological reconstructions and sequence stratigraphic analysis. In the analysis for electrosequences, an abrupt break refers to any abrupt and substantial change in log values. Obviously, the suddenness or rate of change will vary between tools but

will normally be within the diameter of the depth of investigation of the tool concerned A rapid baseline shift may also identify an abrupt break. Abrupt breaks may fit logically into a lithological (and depositional) patter, such as the erosional base of a sandstone bed over shale, or they may be entirely unrelated to the lithological sequence, such as a fault or an unconformity.
The lithology analysis indicates a moderately thick sand interval with thick shale intervals above (figure 8). The electrofacies annotation indicates log trends that show the sand to have a gradational base and be part of a typical cleaning-up succession. The top of the sand is separated from the overlying shale by an abrupt break indicative of a flooding surface. The electrosequence therefore consists of a set of log trends indicating diminishing shale upwards into a clean sand which is capped by an abrupt break indicating flooding (figure 9)

FACIES ANALYSIS

In the Gracious Sector, using the gamma ray (GR) log motifs, two facies and their depositional environments were portrayed. Successions of logs that steadily decrease in GR value and then quickly increase are interpreted as programming delta deposits for the use of traditional explanations for the Agbada Formation. Fluvial channel deposits are perceived to be log successions that abruptly decrease in GR value and have "blocky" or steadily rising patterns. High GR value intervals of 'serrated' are considered to be occupied by shales with varying concentrations of thin sandstone beds and are viewed as a fluvial floodplain (Figure 9). GRs with low and high values have been interpreted as tidal channels and are "bell-shaped".

Facies 1: the sandstone facies of Shaly. These facies consist of fine-grained sandstone with shale intercalations. It is defined by a GR log pattern which is blocky to slightly finished (Figure 10). A very common characteristic of a deltaic fluvial environment is this pattern.

Facies 2: Facies with sandstone. These facies consist of sand bodies that are distinguished in the GR log motif by a stack of coarsening-up units (Figure 8). This log pattern depicts uniform deposition and a channelized region is peculiar to the facies. It is interpreted that these facies are deposits of fluvial channels within the estuary. Tidal impact may be indicated by the presence of notching (serration).

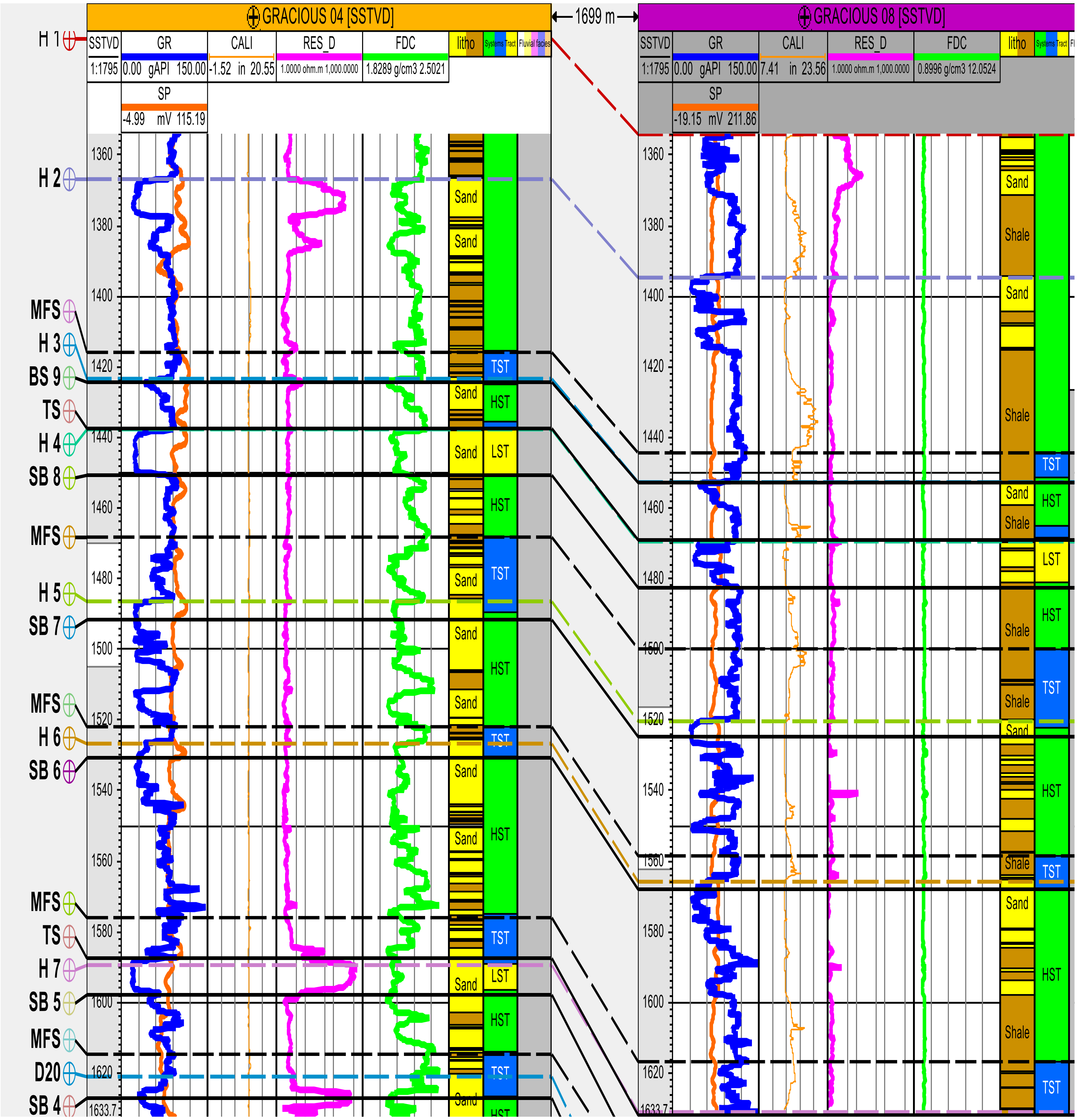
Stratigraphy of the Gracious Field.

The difference in stratigraphy of the Agbada Formation of the Gracious Field gives back the regression of depositional environments within the Niger Delta Basin by shifting widely from fine-grained deposits directly above deeper boreholes, underlying the Akata Formation shales (high GR log values), to gradually coarser-grained deposits below the overlying Ben boreholes. Within the boreholes of the Gracious Field, stratigraphic surfaces were correlated (figure 9). There were three sequences denoted and delineated. The depositional sequences within the Gracious Field include three sequences that have been mapped as a result of the interplay of variation in sea level and accommodation rates with their system tracts. LST, TST, and HST comprise the depositional systems in the Gracious Field. In the Gracious Field, sediments identified within the LST consist mainly of marine (fluvial) channel sands.

The erosion of canyons into slopes as well as the incision of fluvial valleys into the shelf are linked to these sands. These fluvial channel sands have outstanding reservoir characteristics. Low-stand systems tracts (LST) facies were capped by the transgressive systems tracts (TSTs) in the field and consist mainly of marine shales. Tracts of high-stand systems (HSTs) are composed of coarsening and upward superficial intervals with fluvial and deltaic sands near the top of the unit. In most of the boreholes surveyed in the Gracious Field, HSTs are very thick. As also observed in the Gulf Coast, this may be due to high subsidence rates , high input of sediments and instability caused by underlying shale (Winker, 1982). In the Gracious Field, the potential reservoirs are mainly LST channel sands and HST point bars that show low and higher GR and resistivity values, respectively (Figure 9).

With regard to the quality and geometry of reservoirs in the Out Field, the most significant are point bars of fluvial channels cut by sand-filled channels. The TST marine shales identified in the Gracious Field are likely to serve as the potential source of hydrocarbon rocks found in the Gracious Field reservoirs. Some sand units that occur at greater depths than in adjacent units are shown by the results of lithostratigraphic correlation. In the Gracious Field, these were interpreted as a result of syndepositional faulting (Figure 10). These faults are likely to serve as the major traps for hydrocarbon accumulation. However, in the reservoir sands within Gracious Field, the shales of the TST and those of HST could both provide seals for hydrocarbons. Therefore, the LST and HST reservoir rocks and the TST and HST marine shale caprock could unite to form stratigraphic hydrocarbon accumulation traps.

Figure 9:Log facies of Gracious Field and its depositional system



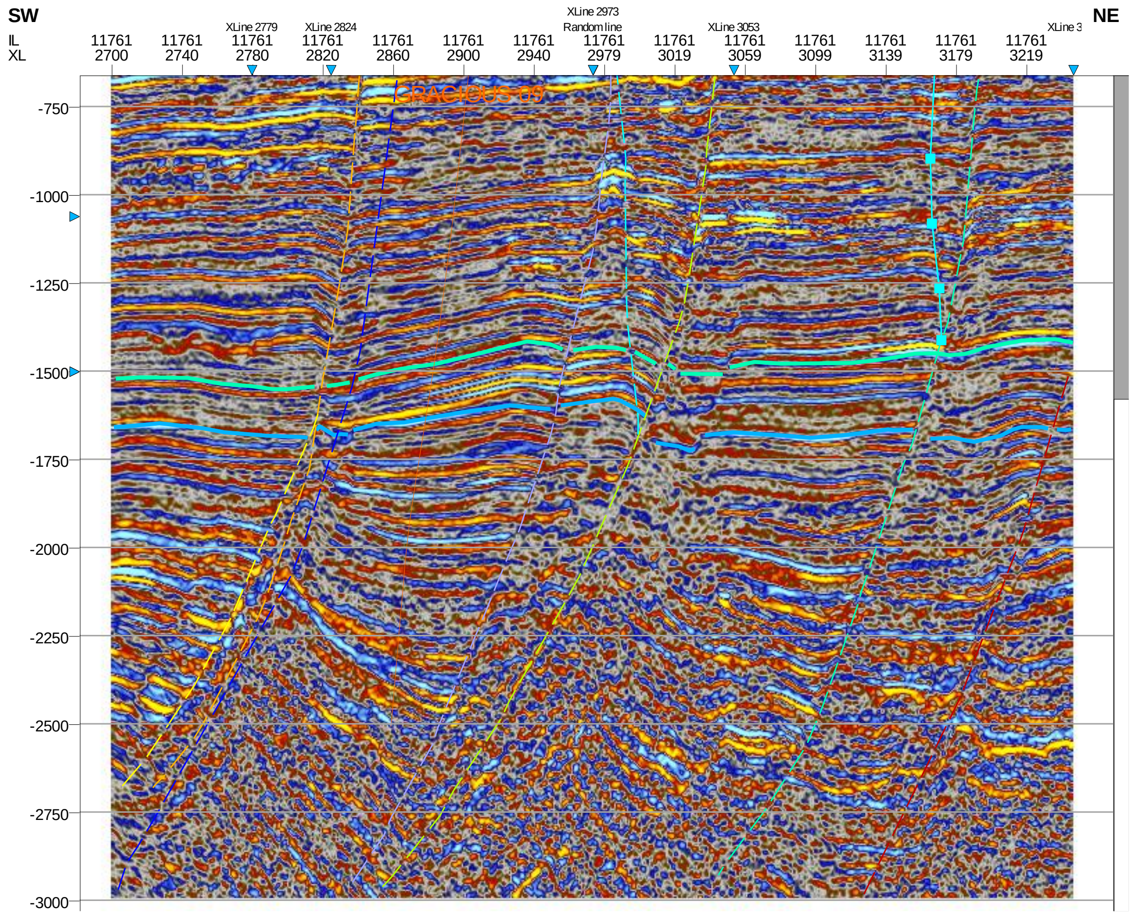


Figure 10: Typical interpreted seismic section of inline 11761.

CONCLUSION

These results of this research demonstrate the close possible relationship between the log of the gamına ray and the size of the sandstone grain. Forms on the gamma-ray log can be interpreted as trends in grain size and as successions of facies. Small grain sizes correspond to higher gamma-ray values: a decrease in gamma-ray values stipulates an increase in grain size. The sedimentological impact of this relationship leads not only to the bell shape and funnel shape as discussed, but to a direct correlation between facies and log shape for a whole variety of shapes. They all rely on the relationship between log shape and grain-size patterns in sandstone bodies.A bell shape suggests a fining-up series that can be an alluvial / fluvial channel but also a transgressive shelf sand. A funnel shape is a succession of coarsening-up that may be a deltaic program or a shallow marine program. In these cases, rather than individual bodies, the log shapes are those of overall successions. The shapes are due to the decrease in bed thickness associated with the decrease in grain size instead of the direct change in grain size itself. In conclusion, the appealing concept that log shapes indicate depositional environments of sandstone is too simplistic. Neither the relationship between the value of the gamma ray and the volume of the clay nor the relationship between the volume of the clay and the size of the grain is consistent, as it should be if the size and shape of the gamma ray log is to be used as an indicator of facies that is generally applicable. Core to log comparisons, however, show that these relationships are often sufficiently consistent for log shapes to be useful indicators of facies. But they must be used with great care. The Niger Delta's Agbada Formation is distinguished by stratigraphic characteristics that control the trapping of hydrocarbons within its deposits. Three sequences divide the subsurface facies of the Gracious Field. A bell shape shows a set of fining-ups that may be an alluvial / fluvial channel but a transgressive shelf sand as wellon the basis of reservoir quality in the Gracious Field. The LST and HST reservoir rocks and the TST and HST marine shale seals could together form stratigraphic traps in the Gracious Field for hydrocarbon accumulation. To complete the results, additional data such as biostratigraphic, core and porous data is required so as to create a furtherdependable and unfailingresults in the field of study.

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