Reservoir Characterization of "Meri_T" Field (South Western, Niger Delta) from Well Log Petrophysical Analysis and Sequence Stratigraphy.

Olushola Taiye Adeoye, M.Tech.[1] and Merrious Oviri Ofomola, M.Tech.[2*]

[1]Department of Applied Geophysics, Federal University of Technology, Akure, Nigeria.
[2]Department of Physics, Delta State University, Abraka, Nigeria.

E-mail: ovirimerrious@yahoo.com*

ABSTRACT

In this study, reservoir petrophysical analysis, and sequence stratigraphy of the "Meri_T" field, Southwestern Niger Delta, has been carried out using well logs with a view to characterizing the reservoir. Petrophysical analysis began with lithology identification. Lithologic panels interpreted from well log data show that the study area is characterized by sand-shale interbedding. The reservoirs were interpreted for their fluid content using appropriate logs. Consequently, hydrocarbons versus water bearing zones were delineated. In all five hydrocarbon bearing sands were discovered, and porosity estimates in the reservoirs were very high varying between 0.17 and 0.39. Sequence stratigraphic interpretation was carried out to interpret the depositional environment of the area using well log motifs. Sequence stratigraphic interpretation of the area shows that the four main depositional environments that are dominant in the area include the following: channel sands and shoreface sands, reworked sandstones, coastal deposits, and the basin floor fan environment. From these depositional environments, the shoreface sand, reworked sandstones and channel sands are located within hydrocarbon bearing zones.

It is predicted that the shoreface sands will be the most favorable region for hydrocarbon accumulation as reservoir petrophysical properties like porosity has shown high values recorded in this area. The interpretation that there have been slope stability, unhurried deposition of sediments and longer period of deposition in the region has been predicted to be one of the contributing factors for the hydrocarbon accumulation observed in the area.

The purpose of this paper is to illustrate why petrophysics is so important to hydrocarbon exploration and to demonstrate how carefully interpreted analysis can help the geoscientist relate the petrophysical analysis to environment of deposition.

(Keywords: stratigraphy, shoreface, lowstand, shaliness, facies)

INTRODUCTION

In an oil prone area like the Niger Delta, even though Hydrocarbons are within the subsurface, they cannot impulsively gush to the surface when penetrated by a production well (Aiyedogbon and Iyayi, 2007). On the contrary, most reservoir hydrocarbons reside in the microscopic pore spaces or open fractures of sedimentary rocks (sandstones and limestone) (Schlumberger, 1989). To produce them, detailed geological and petrophysical knowledge and data are needed to guide the placement of production platforms and well paths. This can consequently help to optimize hydrocarbon recovery, and to improve predictions of well and reservoir performance.

In addition, studying the spatial uniformity of the saturating reservoir fluids (essentially, hydrocarbon) can be crucial to oil and gas production. Also, the employment of petrophysics to study the lateral change in content of fluids in reservoirs can be very useful in the sense that it helps presume the lateral continuity or extent of the reservoir when seismic data is not available and thus reduces failure in oil/gas exploration (Adeoye and Enikanoselu, 2009).

Estimates of lithology, fluid content, and porosity are indispensable. Also in the evaluation of clastic reservoirs such as obtained in the Niger Delta, shaliness which is a measure of the cleanliness of the reservoir is a parameter to be considered as it can give a wrong impression of estimated petrophysical values like porosity and hydrocarbon saturation when they are not corrected for (Aiyedogbon and Iyayi, 2007).

Well-log sequence stratigraphy on the other hand, being an integral part of well-log seismic sequence stratigraphy allows the geoscientists to divide a rock section into series of genetic units bounded by condensed section and their associated maximum flooding surface using wire line log signatures (Nton and Esan, 2010).

Each sequence can be sub-divided into smaller sediment packages called systems tracts on the basis of characteristic well-log patterns (Ola-Buraimo *et al*, 2010). Sequence analysis and system tract study can allow us to predict the environment of deposition and this can be related to the petrophysics value obtained.

The objectives of this study however is to evaluate the hydrocarbon potential in the field by petrophysical inference and analysis, and also to identify and describe the depositional environments and the relationship between physical properties of rocks (from petrophysical analysis) and the depositional environment of the area.

MATERIALS AND METHODS

The area of study is located in the southwestern part of Niger Delta (Figure 1). The datasets employed were provided by the Shell Producing Development Company, Nigeria. These includes soft copy data of composite well logs comprising mainly gamma ray, resistivity, volume of shale, density and neutron logs from three wells. *Petrel* software was used to interpret the data. A Base map showing well locations in the field was also provided. The 3 wells of MERI_T field are all located around the centre of the field (Figure 1). A typical gamma ray well log through the Agbada Formation in MERI_T field has values that are very high near the base of the Formation. In the upper part of the successions, within the Benin Formation gamma ray values are generally low.

Gamma-ray logs measure natural radioactivity in formations, therefore enabling qualitative identification of zones of shale (high gamma readings) from sand (low gamma readings). High gamma ray values between 80-150 API units were classified as shaly intervals. On the other hand intervals with low gamma ray values in the range of 0-70 API units were considered sand units.

In Niger-Delta, the sand units are regarded as the reservoir units because shales are not porous enough to retain and release fluid. Therefore in the sand units delineated, differentiation between reservoir fluids (hydrocarbon and water) was done using the resistivity log. Since the resistivity of hydrocarbon is higher than that of the formation water (Schlumberger 1989), hydrocarbon sand units were inferred from high resistivities values observed from the deep resistivity reading tool provided namely: Rt_0 which measures the uninvaded zone resistivity (true formation resistivity).

Porosity values for the hydrocarbon reservoirs were estimated. The amount of internal space or voids in the rock is a measure of the amount of fluid (notably, oil or gas) the rock will hold. The porosity log utilized was the bulk density log which records only the bulk density of the formation; therefore, density porosity was estimated using Asquith equation (2004) for the intervals of interest (hydrocarbon bearing intervals).

$$\varphi = (\ell ma - \ell b) / (\ell ma - \ell f) \qquad \textbf{(1)}$$

Where:
φ = density porosity
ℓ_b = Measured bulk density from log,
ℓ_f = fluid density (flushed zone),
ℓ_{ma} = rock matrix density.

Because of the considerable presence of shale in the reservoirs, the measured porosity was corrected for the volume of shale using Dewan (1983):

$$\varphi_{corr} = \varphi_d - V_{sh}{}^{*} \varphi_{Dsh} \qquad \textbf{(2)}$$

Where:
φ_{corr}=shale corrected density porosity
φ_d =Density porosity
V_{sh}=Shale volume
φ_{Dsh}=density porosity of nearby shale.

To understand the probable reason for the change in petrophysical values laterally, sequence stratigraphy interpretation was done to classify the depositional environments.

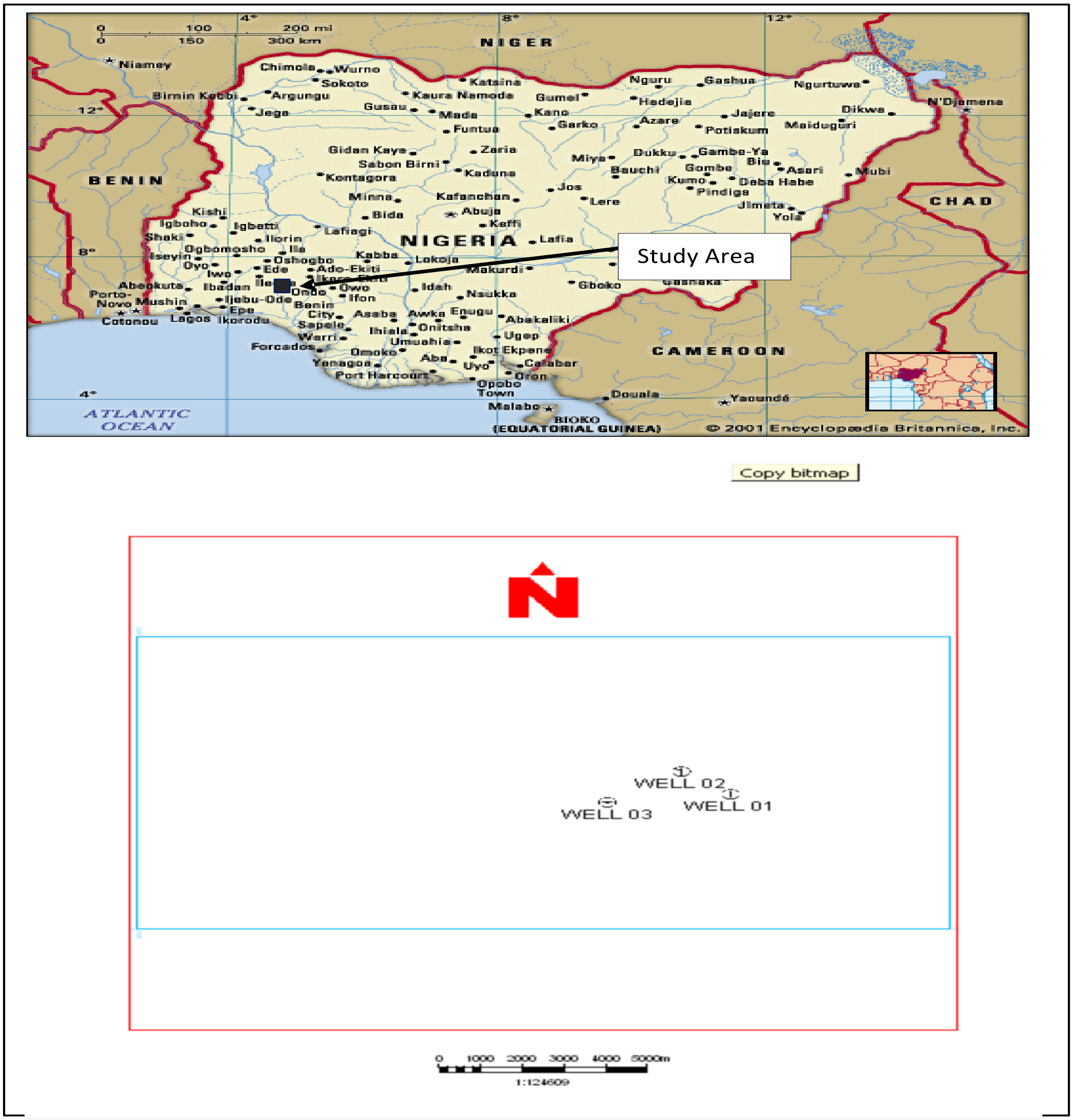


Figure 1: Study Location and Base Map of the Study Area.

The most important of stratigraphic surfaces, and the first identified on the well logs, were the maximum flooding surfaces (mfs) and Sequence boundaries. Each surface was recognized by their distinct log motifs.

Maximum flooding surfaces were defined by thick high-gamma-ray value intervals that separate overall fining upward from coarsening upward intervals within sequences. This is also associated with low resistivity values. In most cases they coincide with the top of the transgressive system tract.

Sequences were then interpreted in the logs because they are the building blocks for stratigraphic interpretation. Sequence boundaries, were defined by looking for abrupt bases of thick low-gamma ray- value intervals on the well logs because abrupt changes in gamma-ray logs response are commonly related to sharp lithological breaks (Cateneau, 2006).

Within the Agbada Formation which contains the reservoir rock, three general log signatures were used to classify the system tracts and depositional environments, observed over the stratigraphic intervals.

Intervals that start with low gamma ray values and then gradually increase upward are interpreted to signify a gradual fining-upward trend and these are characteristics of reworked sand units and shoreface sands environments.

Intervals with high gamma ray values that gradually decrease are interpreted as upward-coarsening trend and the depositional environment inferred was coastal deposits and shoreface sands in the highstand system tract. “Blocky” intervals were defined by cylindrical pattern of the gamma ray log motif value, and essentially was interpreted to be the basin floor fan environment in the lowstand system tract.

DISCUSSION OF RESULTS

Lithology

The gamma ray logs of the three wells studied were interpreted for lithology identification. Within the study intervals, the lithology is dominated by alternating sand and shale, the sand occurring more frequently at the top of the log whereas the shale occur more frequently as the logging deepens (Figure 2). Based on the varying grain sizes indicated by well log motifs, silts may also be interpreted and present. However, core data and core cuttings may be needed before the final verification is done; and these were not included in the data. Therefore, to minimize uncertainties in interpretation, lithology type has been narrowed down to sand and shale lithology.

Characteristic of Reservoir Sands

In differentiating the fluids saturating the reservoir, Wells 01, 02 and 03 were studied and different reservoirs were encountered. In this study, well 01 (Figure 3) is used as the case study while the results from the other wells (02 and 03) are presented in Tables. The reservoirs sands marked TT, UU and VV in wells 01 respectively are all probably water bearing evidenced from the resistivity log signatures that records low resistivity values within these intervals (Figure 3).

The reservoir sand AA in well 01 is hydrocarbon bearing, this is inferred from the high resistivity log reading. Moreover, neutron-density overlay show the predicted gas–oil contact to be around 5800 ft. while the oil-water contact is 5880 ft. This reservoir occurs from 5805 ft. – 5907 ft. with net sand (i.e., shale fraction /_intercalation has been removed) thickness of 88 ft. More hydrocarbon reservoir sands were interpreted in this well, for instance, reservoir sand BB occurs from 6088 ft.- 6180 ft. with net sand thickness of 92 ft. Sand CC occurs from 7060 ft.- 7140 ft. with net sand thickness of 80 ft. Sand DD is shaly and also very thin. It occurs from 7400 – 7428 ft. with net sand thickness 20 ft. (see Tables 1, 2 and 3 for details of reservoir analysis in other wells)**.**

Hydrocarbon Indication

From the above, the hydrocarbon designated reservoir sands include AA, BB, CC and DD (inference from high resistivity log reading in the range of 0.44 ohm/m – 3326 ohm/m) and they are within the specified interval discussed above, from two of the three wells (wells 01 and 02). In well 02, the extension (continuity) of reservoir sands AA, and BB were found (Figure 6). Also in well 02, hydrocarbon sand that is not related to previously identified hydrocarbon reservoirs was identified. However in well 03, the reservoir sands were unidentified because of the absence of resistivity log which can indicate hydrocarbon show. It is expected that theses reservoirs will however have high hydrocarbon saturation values if they contained hydrocarbon, due to general observation of high porosity in the reservoirs when compared with others.

Volume of Shale

The average volume of shale within the hydrocarbon sands AA, BB, CC, and DD ranges from 0.10 to 0.66, respectively. In the reservoir sands, in well 01 and 02, the shale content was generally low (average value of 0.1 in Figure 7). Low shale content occurrence recorded at these intervals indicates the hydrocarbon reservoir is fairly clean.

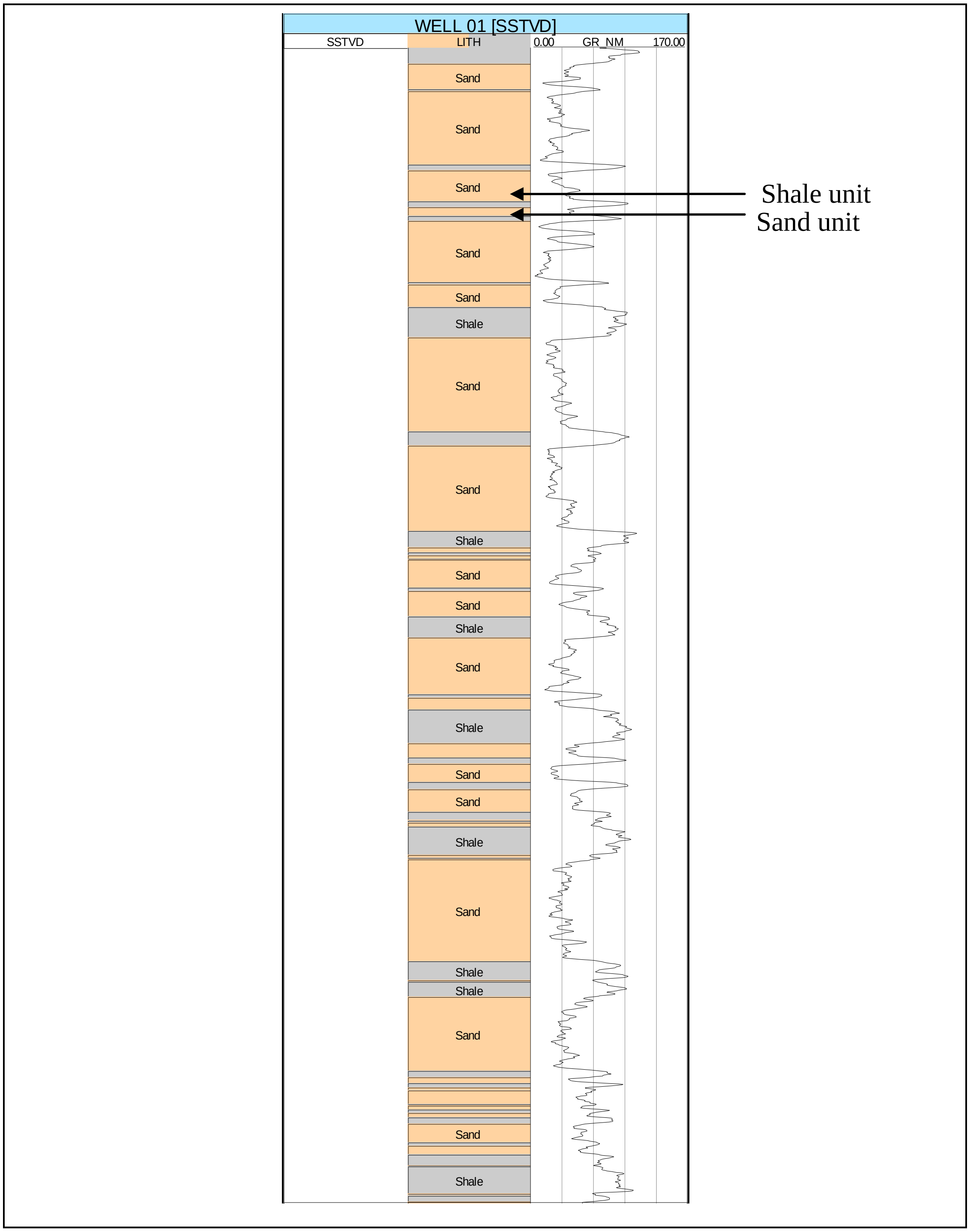


Figure 2: Lithology Identification was done using the Gamma Ray Signature.

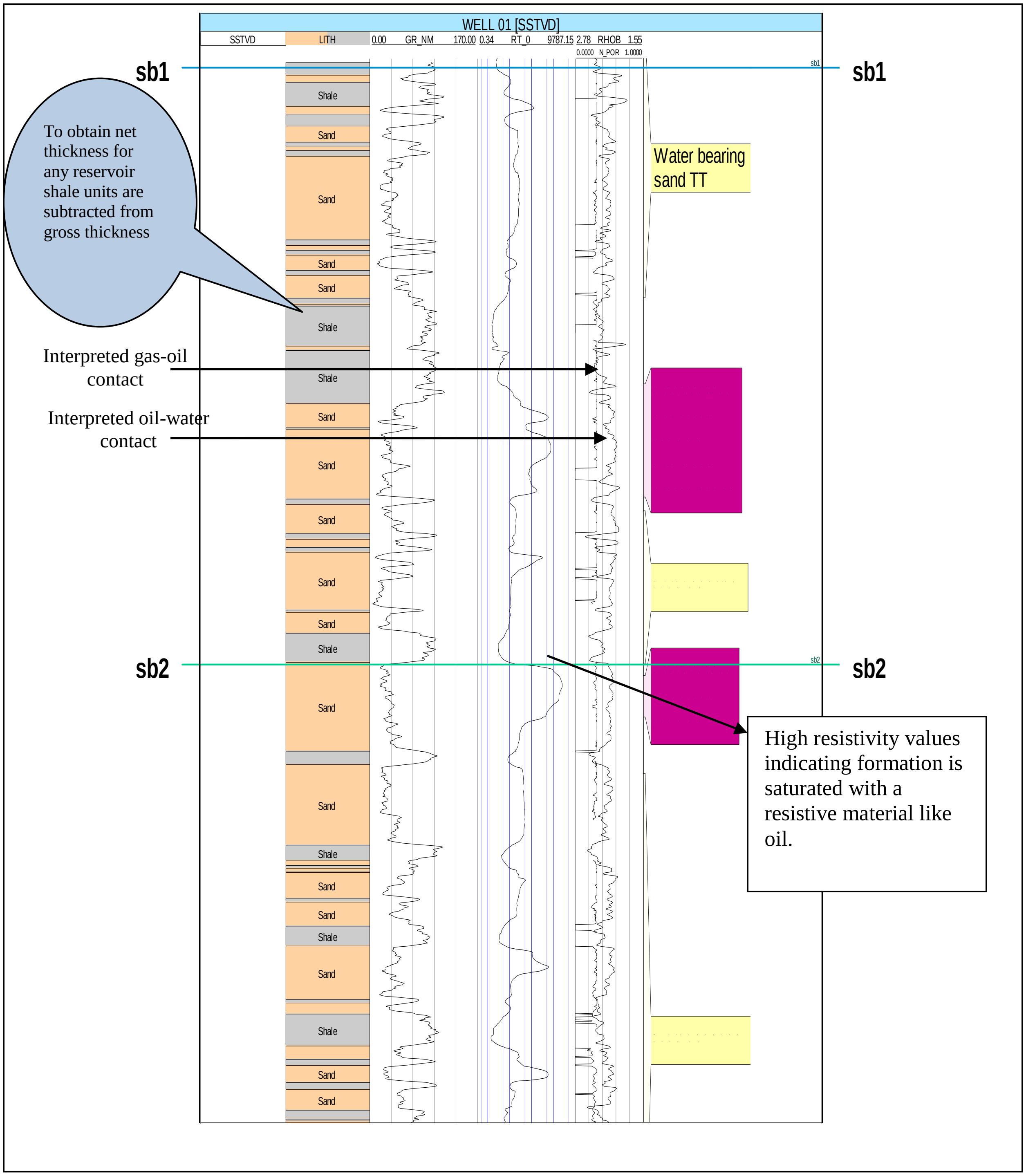


Figure 3: Hydrocarbon Identification, and Reservoir Characteristics (Fluid Contact and Reservoir Thickness) of Different Reservoir Sands in Well 01.

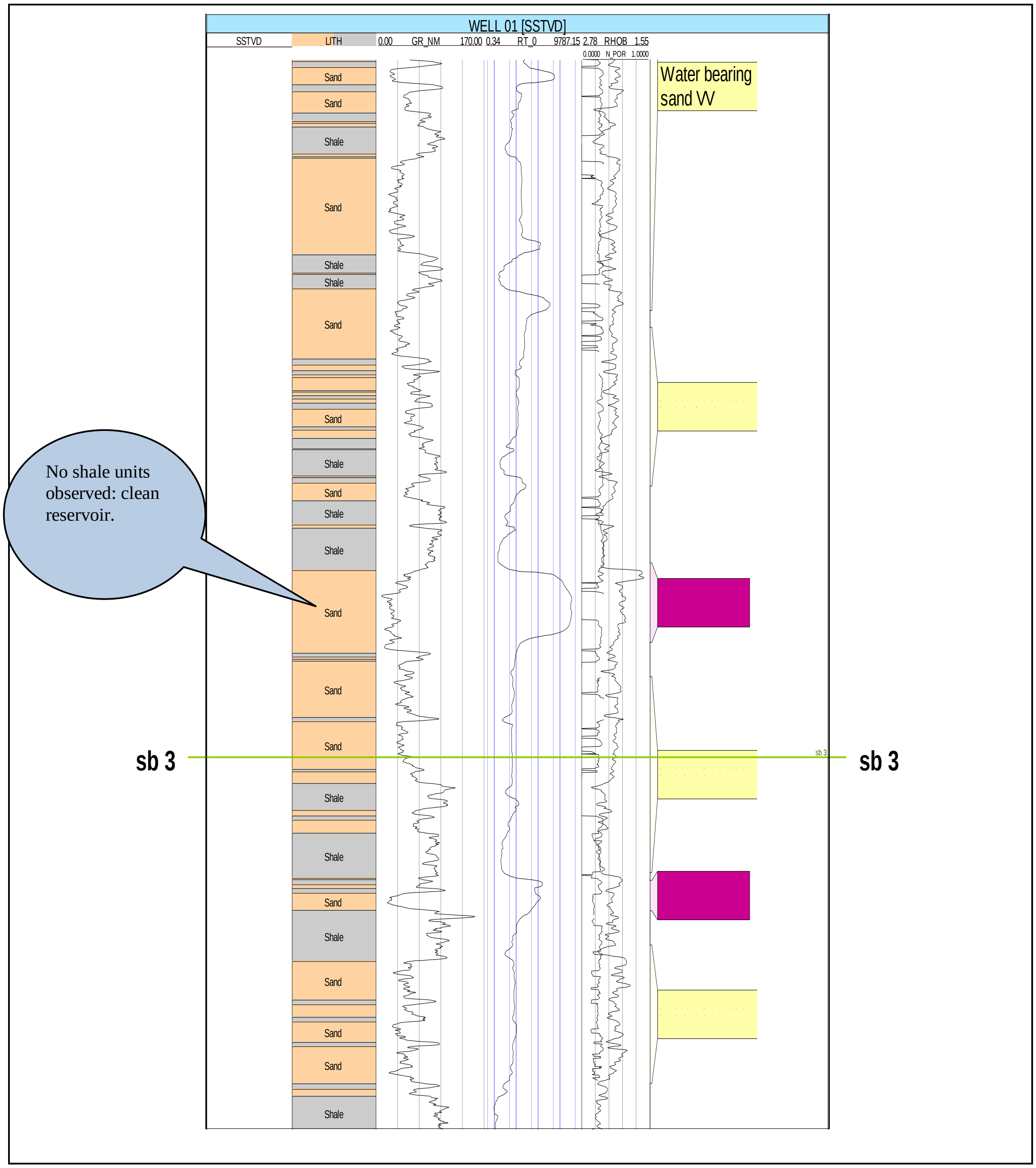


Figure 4: Hydrocarbon Identification, and Reservoir Characteristics (Hydrocarbon and Water Reservoir Sands) are Differentiated in Well 01.

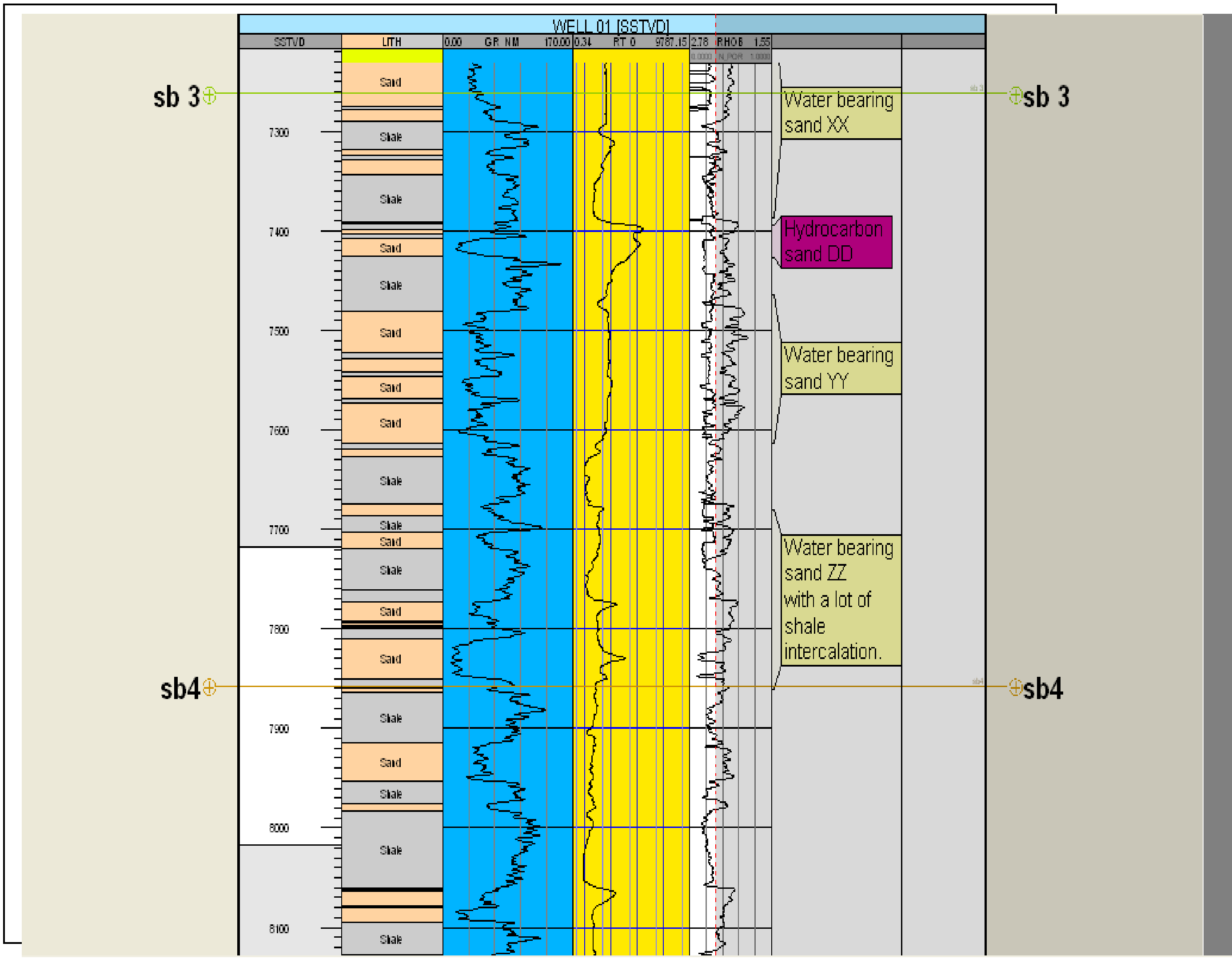


Figure 5: Hydrocarbon Identification (Hydrocarbon and Water Reservoir Sands are Differentiated. Depth of 7860 ft (where Sequence Boundary 4 is Observed) Demarcates the Vertical Extent of Study).

Table 1: Computed Petrophysical Parameters in Well 01.

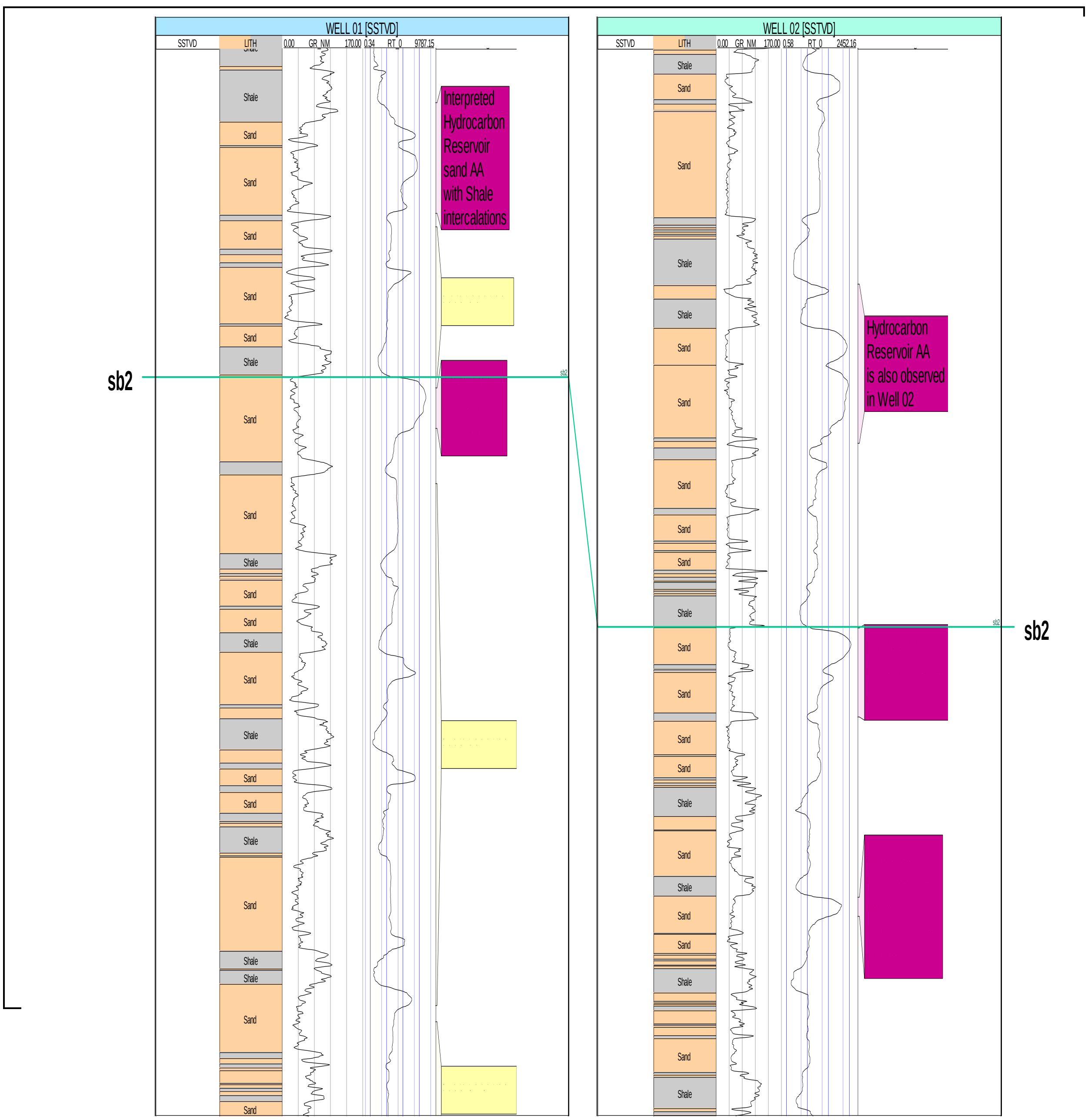
WELL 01	TOP (MD) ft.	BOTTOM (MD) ft.	THICKNESS (NET) ft.
RESERVOIR AA	5805	5907	88
RESERVOIR BB	6088	6180	92
RESERVOIR CC	7060	7140	80
RESERVOIR DD	7400	7428	20

Table 2: Computed Petrophysical Parameters in Well 02.

WELL 02	TOP (MD) ft.	BOTTOM (MD) ft.	THICKNESS (NET) ft.
RESERVOIR AA	5690	5865	175
RESERVOIR BB	6070	6180	110
THIN RESERVOIR	6380	6410	30
RESERVOIR CC	7105	7120	15

Table 3: Computed Petrophysical Parameters in Well 03.

WELL 03	TOP (MD) ft.	BOTTOM (MD) ft.	THICKNESS (NET) ft.
UNIDENTIFIED RESERVOIR I	5090	5410	29.28
UNIDENTIFIED RESERVOIR II	5590	5820	30.00
UNIDENTIFIED RESERVOIR III	5920	6200	37.76
UNIDENTIFIED RESERVOIR IV	6800	6910	29.22



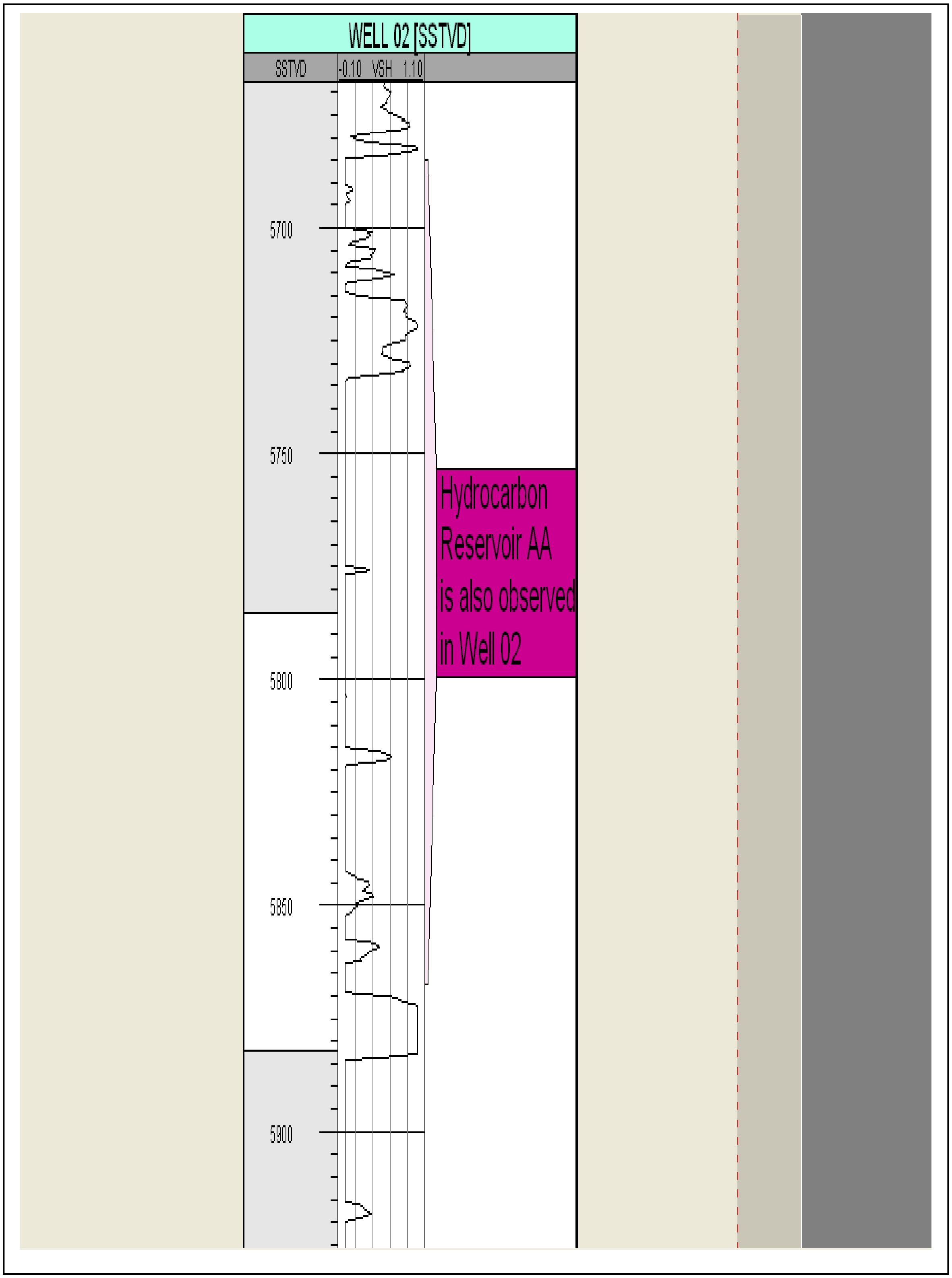


Figure 7a: Low Shale Content within Hydrocarbon sand AA Observed in well 02.

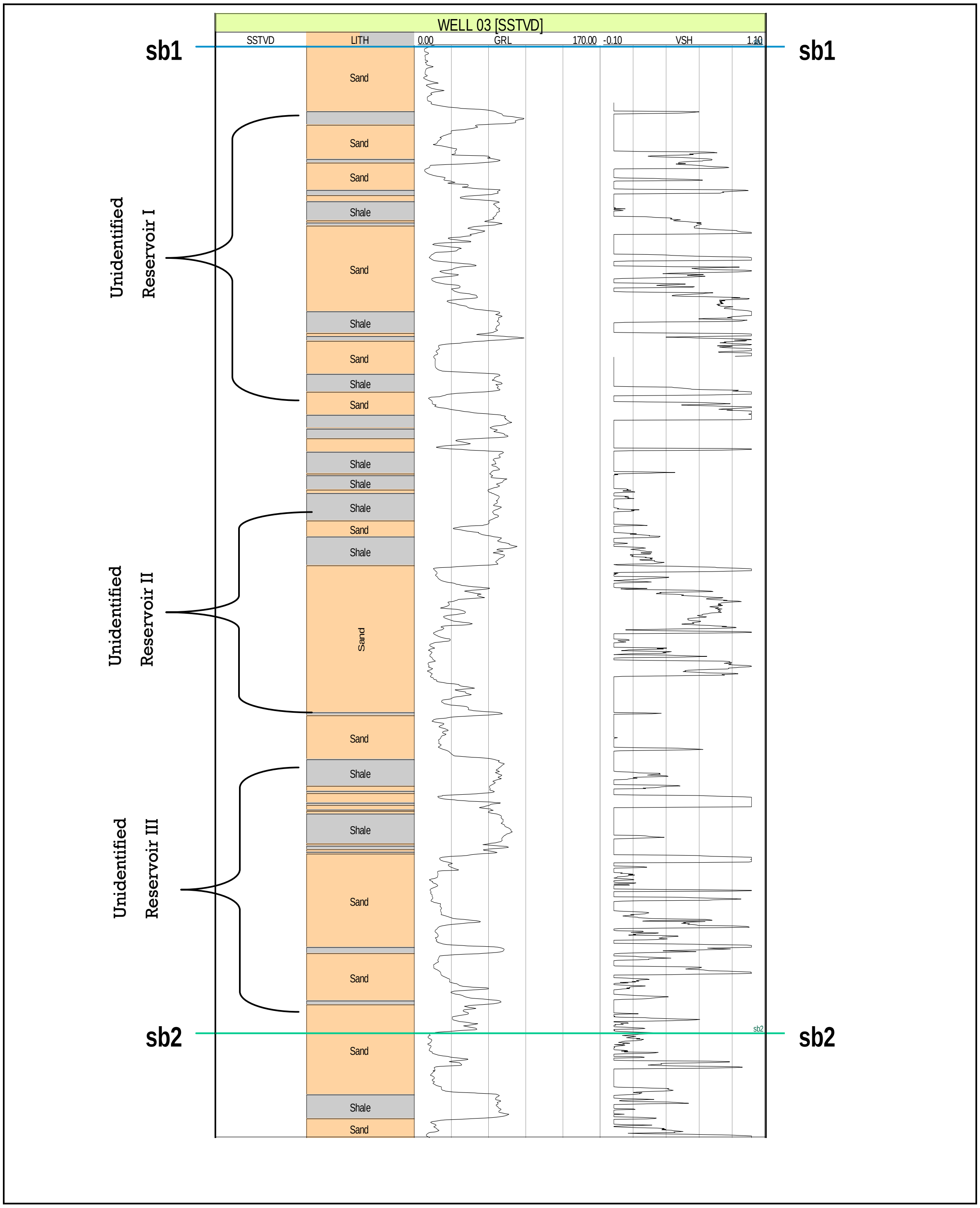


Figure 7b: No Resistivity Log was Supplied in Well 03 so Hydrocarbon Indication was Difficult to Predict but much Shaliness was Observed as Recorded by Volume of Shale (vsh) Log.

However in well 03, (Figure 8), much shaliness of the reservoirs was encountered. Unfortunately, there was no resistivity log to identify hydrocarbon reservoir sands. However, the porosity values obtained in these intervals were corrected for shale.

Porosity (Φ)

The porosity (DPHI) values were calculated from formation density log for the hydrocarbon intervals using Asquith equation (2004). In instances where shale content may affect porosity values, shale effect was corrected for. Porosity within the reservoir sands are fairly uniform and the average effective porosity (estimated from the density porosity log in each well) from the wells ranges from 0.17 and 0.39 in the hydrocarbon reservoir sands. Tables 4 and 5 are a summary of individual porosity values obtained from individual reservoirs in each well. Reservoir DD (in well 01) has the lowest with porosity of 0.17 while unidentified reservoir II (in well 03) has the highest porosity value of 0.39. These values considered to be quite appreciable for commercial hydrocarbon production.

Sequence Stratigraphic Interpretation

Four sequence boundaries were defined with the gamma ray and resistivity log. Three corresponding sequences were therefore delineated. Instance of sequence stratigraphic interpretation that was carried out is shown from well 01.

Highstand system tract of sequence tops the sequence and consist of upward coarsening log patterns. In most of the wells, no hydrocarbon sand was located in this region. The depositional environments interpreted from these signatures include coastal deposits and shoreface sands. Hydrocarbon reservoir sands AA is located in the transgressive system tract of sequence with its characteristic fining upwards log patterns. The depositional environments interpreted from these signatures include reworked sand and shoreface sands. This signature is also observed and consistent in other wells (well 02 and well 03).

The transgressive system tract is truncated on its top by the shale blanket that represents the maximum flooding surface in most cases. Based on the separated interval (variably preserved) of fining upward log sequence, this environment is interpreted to be within the reworked sandstone units and shoreface sands.

The figure shows a maximum flooding surface at the depth of 5690 ft in well 01 (Figure 8). This represents the maximum level of landward incursion. The maximum flooding surface was defined by pronounced high gamma ray log signature throughout all the wells where it was observed. The maximum flooding surface in all these wells may be associated with condensed sections (widespread shale rich in fauna) which may serve as good seals for the hydrocarbon embedded in the transgressive intervals.

The Blocky log patterns observed in the lowstand system tract of the sequence at the basal part suggest the basin floor fan depositional environment. It was observed all the three wells (That of well 01 is shown in Figure 8). Log response for a basin floor fan environment are usually blocky, with a sharp top and bottom bracketing clean sand (Cateneau 2009). Reservoirs BB, CC and DD are located in the lowstand system tract.

THE RELATIONSHIP BETWEEN PETROPHYSICAL VALUES AND INTERPRETED DEPOSITIONAL ENVIRONMENTS

Petrophysical properties were determined for only the hydrocarbon bearing sandstones units of the basin. These reservoirs are five in number and they include: reservoir sand AA, BB, CC, DD, and EE. On the other hand, the depositional environments interpreted include: fluvial channels, reworked sand units and shoreface sands, coastal environments, and basin floor fan environments.

Fluvial channels sandstones exhibit a wide range of porosity (0-18%) (Peter, 1977) and this was discovered to be true for the intervals where they have been observed.

Channel deposits also have hydrocarbon reservoirs within them and comprise the best reservoir quality bodies within a delta system (Scheihing and Atkinson, 1992). Therefore hydrocarbon reservoirs within this environment have probably very good accumulations.

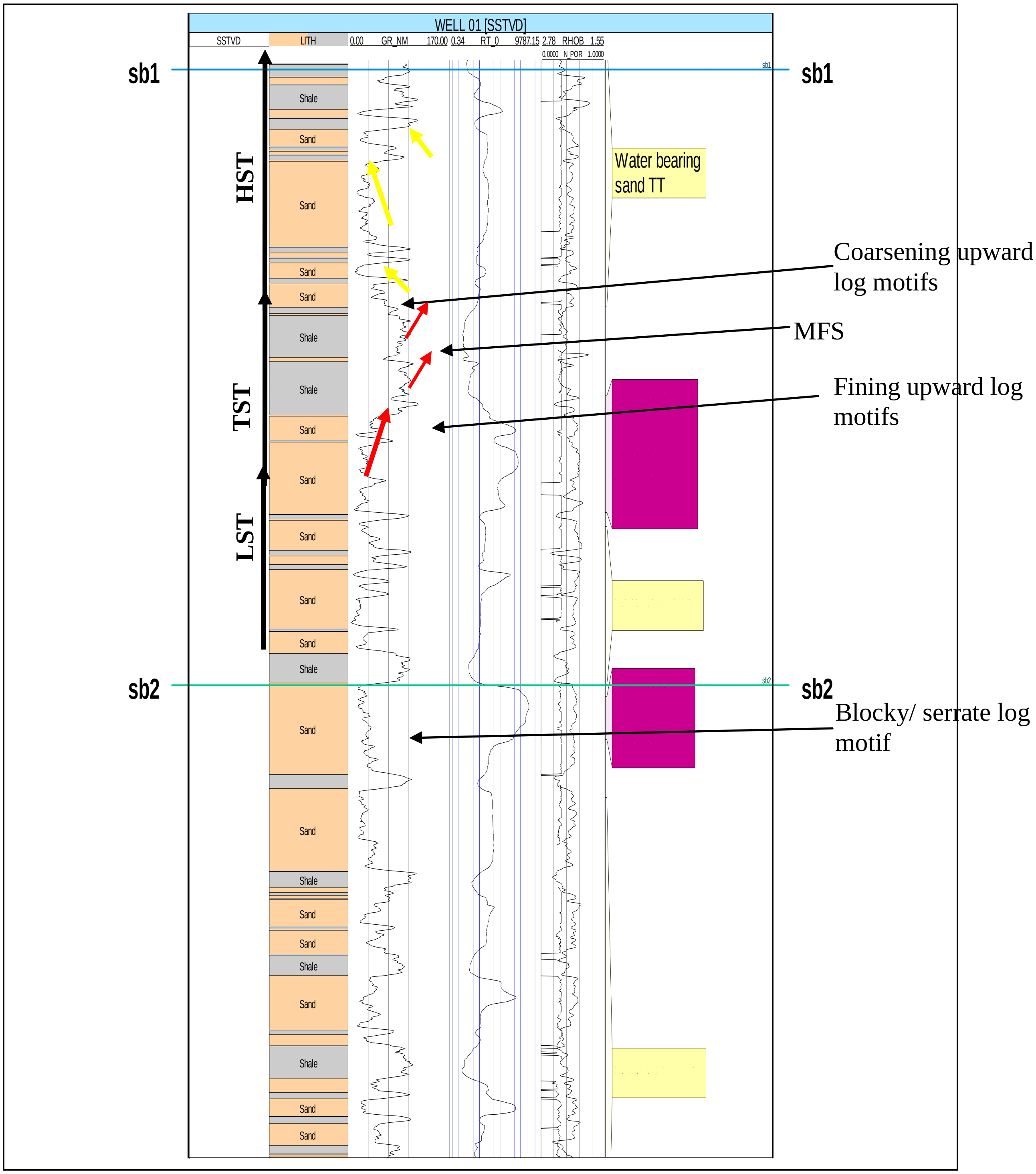


Figure 8: Sequence Stratigraphic Interpretation showing Sequence Boundaries 1 & 2, System Tracts, and Hydrocarbon Reservoirs. Depositional Environments were Inferred Accordingly.

Table 4: Porosity Values Obtained from the Reservoirs in Well 01 and 02.

WELL	Reservoir AA Porosity	Reservoir BB Porosity	Reservoir CC Porosity	Reservoir DD Porosity
01	0.25	0.22	0.30	0.17
02	0.28	0.24	0.36	0.19

Table 5: Porosity Values Obtained from the Reservoirs in Well 03.

Unidentified Reservoir I (Porosity)	Unidentified Reservoir II (Porosity)	Unidentified Reservoir III (Porosity)	Unidentified Reservoir IV (Porosity)	Unidentified Reservoir V (Porosity)	Unidentified Reservoir VI (Porosity)	Unidentified Reservoir VII (Porosity)
0.25	0.20	0.28	0.22	0.39	0.27	0.19

The basin floor fan, have customary porosity values (average of 0.22), but basically, slope fans can exhibit several depositional styles depending on the vertical gradient of the slope (Peter, 1977). The characteristics of the basin floor fans reservoirs identified were the thin thicknesses of the reservoirs. This coupled with the rapidly alternating lithologies in the depositional environment probably reflects a multitude of discrete depositional events and/or significant variation in sediment supply.

The most favorable reservoir petrophysical properties therefore and the paramount region envisaged to be the best hydrocarbon production zone from the sandstones reservoirs are associated with fluvial channels and shoreface facies within the transgressive system tract. This has been interpreted to have formed in areas where there is slope stability, prolonged deposition and unhurried deposition of sediments. This depositional environment can be traced laterally (if seismic data was available) to know the reservoir extent laterally.

CONCLUSION

Detailed petrophysical analysis and well-log sequence stratigraphy of three wells in "Meri_T field", southwestern Niger Delta, has been carried out by the use of a suite of well logs. Adequate lithologic interpretation and description was carried out. In addition, hydrocarbon bearing reservoir sands were delineated. Five hydrocarbon-producing reservoirs were identified namely: reservoirs AA, BB, CC, DD and EE.

Porosity estimates in these reservoirs vary from 0.17 to 0.39 and the net thicknesses of the reservoir sand ranges from 20 ft to 175 ft. These have been deemed to be appreciable for commercial hydrocarbon production.

Three depositional environments have been interpreted namely: the channel and shoreface environment, fluvial channels and shoreface sands and the reworked sandstone units. Porosity estimates is highest observed in the channel and shoreface environment. Therefore it is assumed that this environment supports hydrocarbon accumulation. This may be because they have been formed in areas where there is slope stability and unhurried deposition of sediments.

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ABOUT THE AUTHORS

Olushola Taiye Adeoye, M.Tech., is a graduate student in the Department of Applied Geophysics, Federal University of Technology. His research interests focus on hydrocarbon exploration, including reservoir characterizations.

Merrious Oviri Ofomola, M.Tech., is an Assistant Lecturer in the Department of Physics, Delta State University, Abraka, Nigeria. His research focus is on environmental geophysics, groundwater modeling in sedimentary and basement terrains, and hydrocarbon exploration studies.

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