PETROPHYSICS AND STRATIGRAPHIC INTERPRETATION OF PAU FIELD OFFSHORE NIGER DELTA

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ABSTRACT

Nine different wells were carefully studied on "PAU" field and their results were integrated for thorough understanding of the reservoir sand bodies within the field. These studies include; stratigraphic well correlation, rock physics analysis, sequence stratigraphy, petrophysical evaluation of wells and reservoir volumetric evaluation in order to understand the prospectivity of the field. Depositional environment and facies change analysis suggest that the field has multiple reservoirs, with shale intercalations.
Well logs, Rock physics and sequence stratigraphic methods was employed for reservoir mapping and evaluation of PAU field and The lithologic attributes were integrated with wireline log motifs (gamma ray and resistivity) for paleoenvironmental deductions.

The thickness of the reservoir sand body suggests high economic feasibility of exploitation processes. It can also be inferred from seismic facies analysis that deposition occurred from north to south. Lithologic attributes obtained from ditch cutting sample description and wireline log motifs indicate that the studied section belongs to the Agbada Formation and can be divided into two lithofacies unit: Opuama channel (clay fill) (11250 – 5636ft.) and Transitional/ Paralic Agbada (5636 – 5490ft.). Sequence stratigraphic analysis based on the integration of lithologic characteristics of the sediments and wireline log motifs aided the recognition of four sequence boundaries at depth 7043ft (5.5Ma), 8046ft (6.3Ma), 9770ft (8.2Ma) and 10635ft (10.5Ma) and Maximum Flooding Surfaces at 5786ft (5.0Ma), 7182ft (5.8Ma), 9170ft (7.0Ma), 9970ft (9.2Ma) and 11088ft (11.6Ma) respectively.
This integrated study shows that "PAU" field shows good prospectivity for hydrocarbon exploitation.

Keywords: Well logs, stratigraphic interpretations, fluid distribution, sequence stratigraphy and rock physics.

INTRODUCTION

A field in petroleum geology is the collection of or association of two or more oil or gas pool occurring together within the same geological features, either stratigraphic or structural features (faults). A study of a field is imperative in order to know the condition of the various reservoirs within the field. These reservoirs contain the oil or gas pool or the combination of the two which is the target of every petroleum exploration project. Petroleum exploration is a high capital intensive project and thus a level of precision is a necessity in the processes involved. This required a thorough integrated study of the components of petroleum system that can aid the accumulation of petroleum in economic quantity. These components involve source rock reservoir, trap and seal.

Correct determination of reservoir characteristics and properties through structural analysis of the subsurface geology and delineation of the quantity and economic worth of hydrocarbon in prospect, using data from the aforementioned processes are one of the major challenges facing oil producing industries. These problem span across the issue of reservoir units, reservoir stratigraphy, sedimentology and reservoir volumetric (hydrocarbon potentials) out of others. These mentioned problems and more related problems are what this research work aimed to solve in the study of "PAU" field (as named in this research work). This involves the use of well log data to evaluate the field reservoir properties/characteristics (petrophysical characteristic and stratigraphy) and reservoir volumetric, which avail improved understanding of hydrocarbon potential and economic value of PAU field.

These processes involved the determination of reservoir dimension, (thickness and area extent), which serves as basic data for volumetric analysis; the involvement of well log data to determine hydrocarbon containing reservoir and to calculate reservoir petrophysical properties; employing geological knowledge to study the 3D stratigraphical features of the field (closure system), all these and many more processes as well summarized in the methodology section of this research work, serves as veritable information and data for the determination of the field hydrocarbon potential.

LOCATION AND GEOLOGY OF THE STUDY AREA

The studied field "PAU" field is located in the Niger Delta Oil province; southern part of Nigeria, precisely at the coastal swamp depobelt of the basin. The Niger Delta (of Nigeria) is situated in the Gulf of Guinea between longitude 5^0E -8^0E and latitude 4^0N and 9^0N. The structural configuration of the study area entails a large simple rollover structure. The sedimentation type within the area is paralic sand and shale sequence. The shale sequence become more prevalent deeper down between 1930 and 2050 metres sub-sea (Onyekuru *et al.*, 2012). The sedimentation style and lithostratigraphic arrangements is based on the general Niger Delta sedimentation pattern (Onyekuru *et al.*, 2012). The area of study is shown diagrammatically in the following base map (figure 1).

LITHOSTRATIGRAPHY OF NIGER DELTA

The Lithostratigraphy of Niger Delta is divided into three major Formations which includes Akata, Agbada and Benin Formation (Short and Stauble, 1967). The Akata Formation make the base of the Niger Delta sequence and the formation consist of hemipelagic, pelagic and prodelta shale deposited in marine environments. The Agbada Formation comprises a paralic sequence of interbedded sandstones and shales. This represents the actual deltaic portion of the sequence. The sandstones were deposited in prograding transitional or coastal environments that consisted of lagoon, brackish water, bay, beach, shoreface, fluvio-deltaic and barrier islands of a delta front, delta topset and fluvio-deltaic environments. The shale interbeds are prodelta to hemipelagic in origin. The Agbada Formation is Eocene to Recent in age about 3,500 m thick. The Benin Formation is the last laid Formation in the Niger Delta lithostratigraphical arrangement, serving as the cap for other Formations (Akata and Agbada). The Formation is overlaying Agbada formation. The Benin formation is mainly arenaceous and consists of marginal-marine to continental sandstones deposited in fluvial to coastal environments. It has various environment of

ISSN 2229-5518

deposition which includes braided streams and meander-belt systems of the continental upper delta plain. According to Doust and Omatsola (1990), lack of faunal has made direct dating of the formation difficult but an age range of Oligoncene to Recent have been assigned to it.

Table1: Data obtained for this study

LOG/ WELL	1	2	3	4	5	6	7	8	9
GR	✓	✓	✓	✓	✓	✓	✓	✓	✓
RES	✓	✓	✓	✓	✓	✓	✓	✓	✓
CAL	✓	✓	✓	✓	✗	✗	✗	✓	✓
DEN	✓	✓	✓	✓	✓	✓	✓	✓	✓
PHIE	✓	✗	✓	✗	✓	✗	✓	✓	✓
SW	✓	✗	✓	✓	✓	✗	✓	✓	✓
CHECK-SHOT	✓	✓	✓	✓	✗	✓	✓	✓	✓
SONIC	✗	✓	✓	✓	✓	✗	✗	✓	✓

Nine wells have been drilled some of which are water bearing. Some are side tracks with incomplete logging details. Only six (6) of the wells which were used for this study have complete logs. Well log data are available for all wells in the field. The data is generally of good quality. The log types used for quantitative analysis in this study is seen in table 1.

Net-to-gross analysis on the well log was carried out to determine the actual thickness of the pay zone that will aid the integrated properties into reserves evaluation. The interpretation of this data was used to guide the Net-to-gross analysis on the well log carried out to determine the actual thickness of the pay zone that will aid in reserves evaluation.

MATERIALS AND METHOLOGY

The data used for this study for confidentiality was renamed "PAU" and they include: Base Map, Digitized Well logs data (Ascii Format), Checkshot survey data. A comprehensive study of PAU Field was carried out using Schlumberger's Petrel 2014 suit on a workstation for well correlation, reservoir delineation, volume calculation and reserve calculation.

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RESULTS AND DISCUSSIONS

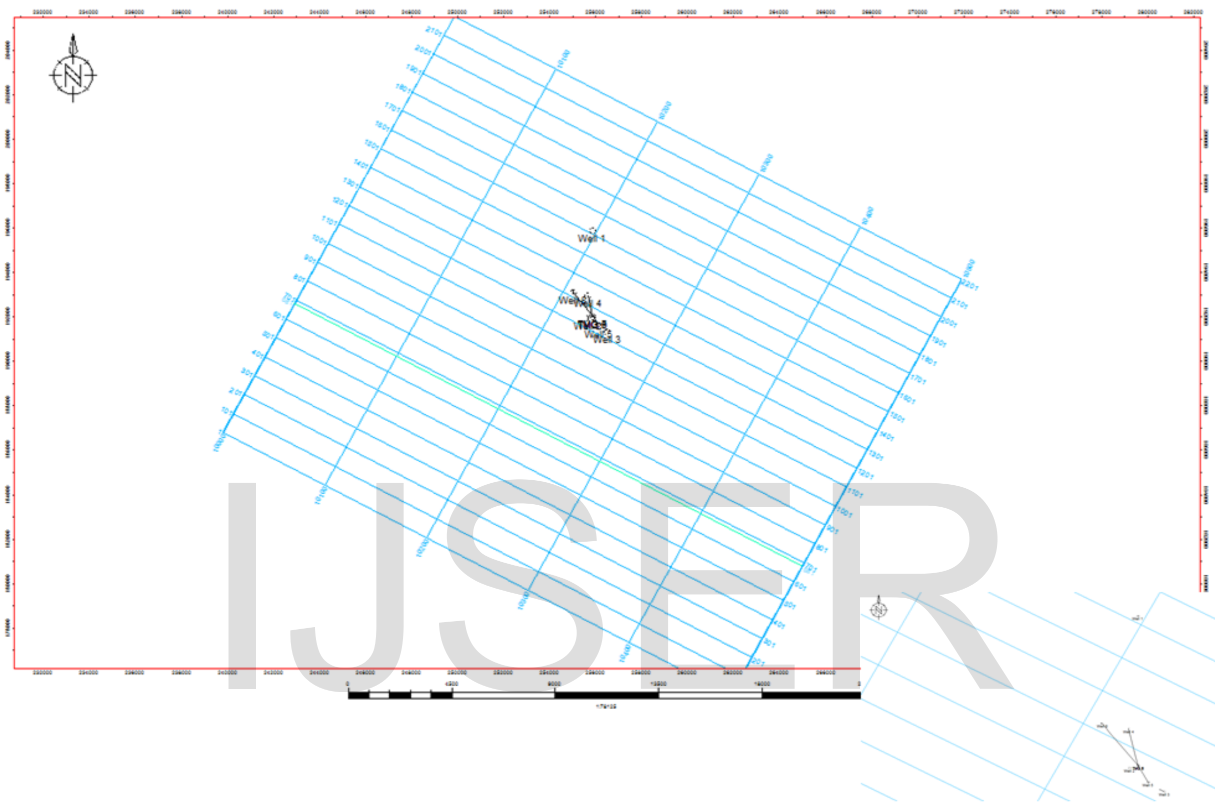

Fig 1: Basemap of PAU Field showing the wells spacing and clusters

ROCK PHYSICS INTERPRETATION

Reservoirs S30, T40, U50 and V60 are generally less dense than the overlying and underlying shale with Reservoir S30 having the lowest density. The velocity characterization for the sands are not very distinct from the background shale, though velocity appears to be faster in Reservoir V60 than the overlying shale, possibly due to greater depth of burial. Overall, the reservoir sands are relatively of low impedance than the background shale but the impedance differences are not very remarkable. The impedance is Vp (Velocity) driven as the impedance varies with depth (Fig 2) the exception being at Reservoir V60 where impedance trend follows the density curve to some extent. Implication to seismic interpretation: On a conventional zero-phase reflection seismic data, reservoirs are expected to be defined by trough (negative amplitude) relative to peak amplitude expected for background shale.

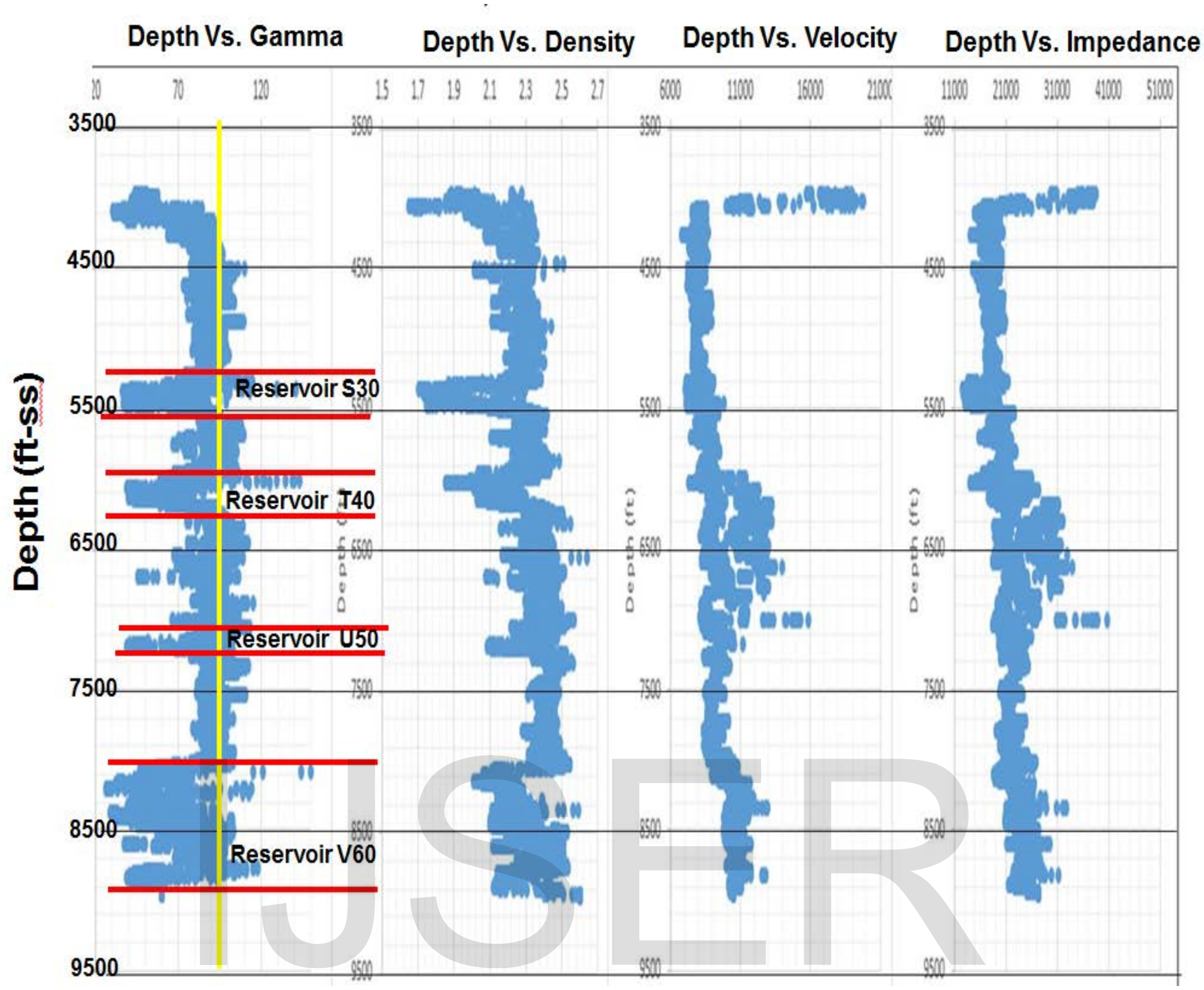

Fig 2: Rock Physics Analysis

WELL LOG INTERPRETATION

The wells in the PAU field are generally a cluster of wells with well 1 drilled far from the other 8 wells. The eight (8) well clusters was geologically interpreted as having closely related properties, features and characteristics different from well 1 and as such, a cross section was drawn across the basemap to select visible wells on the map which was used for sand to sand correlation and reservoir correlation (Fig 3).

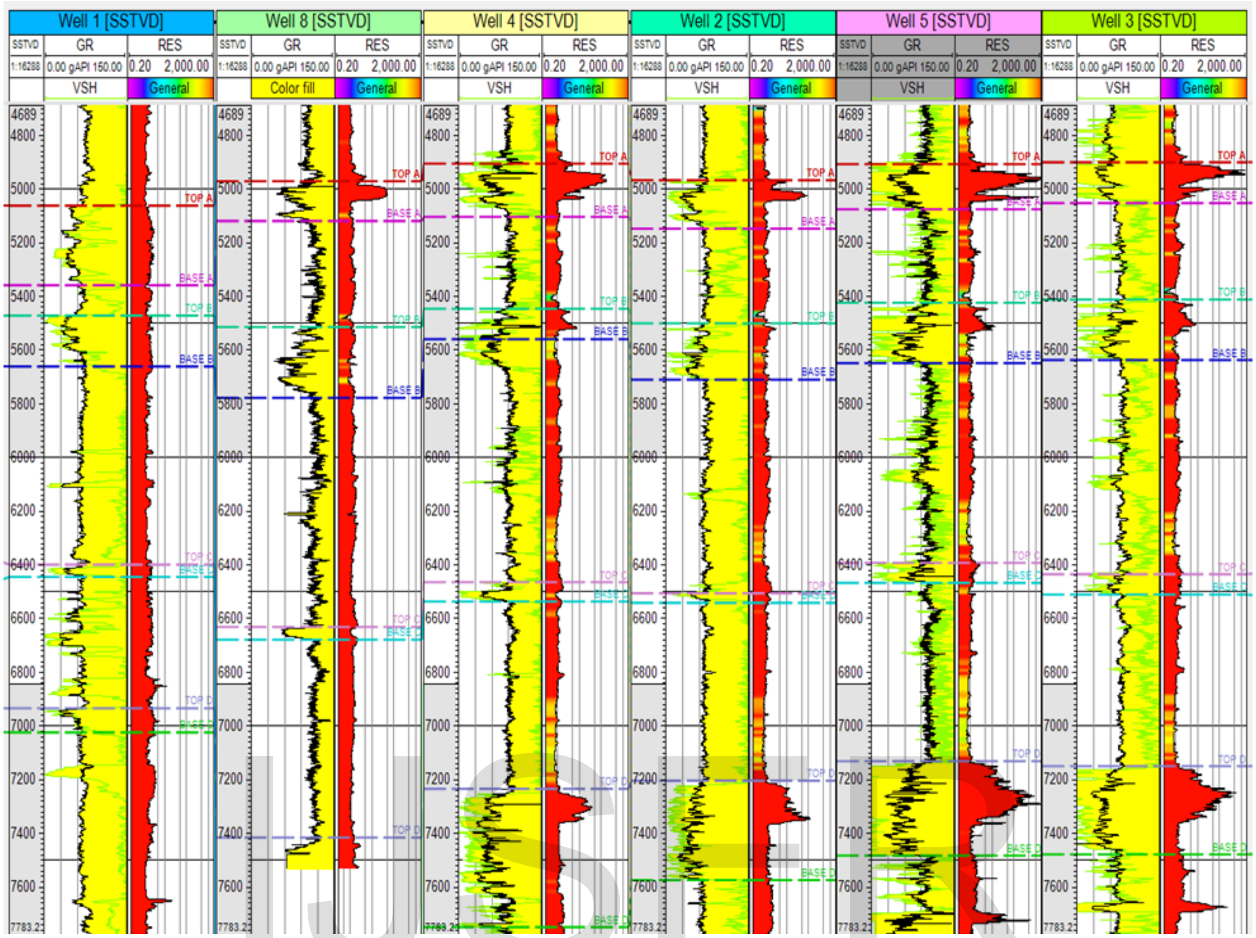

Fig 3: Well log correlation across sands

Lithological interpretation of the well logs is typically a sand-shale sequence which generally comprises of four reservoirs, the interpreted sequence stratigraphy of the field using GR log generally shows a coarsening upwards sequence.

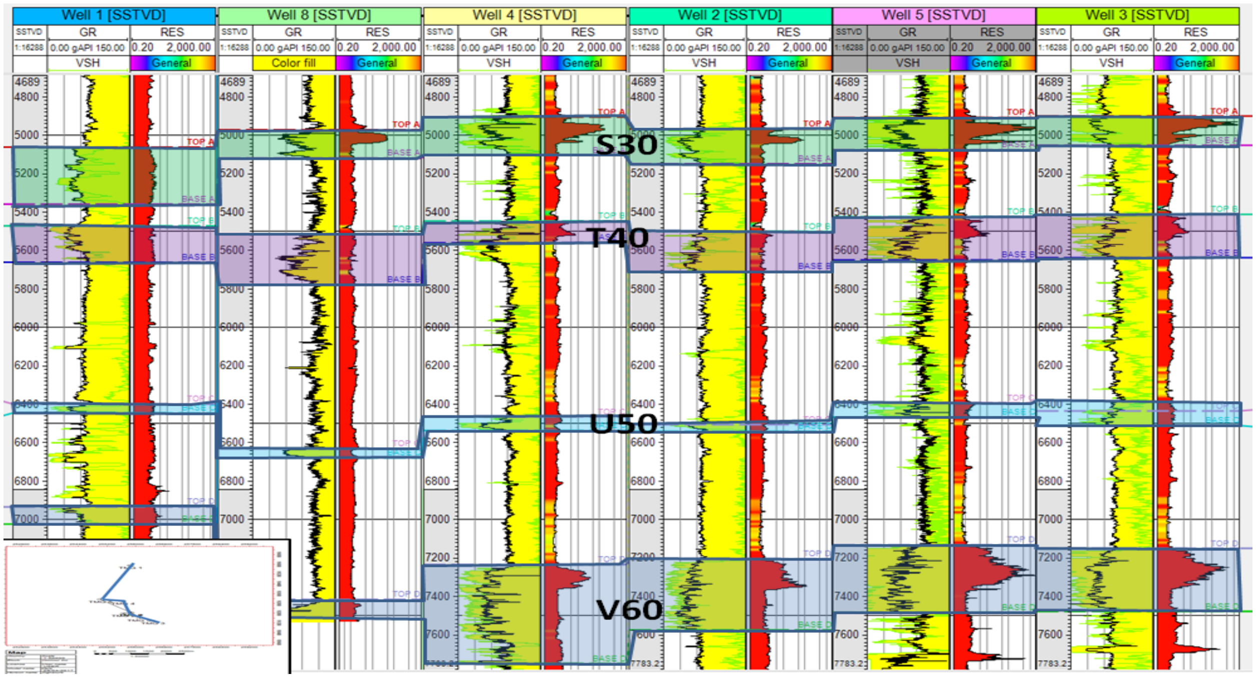

Fig 4: Correlation of PAU Field across reservoir

This **S30** reservoir ranged from intervals 4854 – 5065ft, predominantly sands with shale intercalations, Sands found in this zone are fine to medium grained and moderately well sorted. On the gamma ray log (Fig 4), the motif exhibits irregular shapes, which reflects the overall silty nature of the shales. The intercalated sands exhibit a characteristic serrated cylinder shaped motif with occasional high - thin resistive peaks which indicates water – wet. The abundance of shales over the sequence suggests slow sedimentation in a predominantly low energy marine setting. The sands within the sequence may represent occasional bursts of energy in the otherwise quiet environment. It is sealed by the predominant shale at the base between **5065 – 5437** and the thickness of the sand generally indicates a good seal for the reservoir.

The T40 reservoir ranges from interval 5437- 5667ft and is a gross sand and shale intercalations, the sand/shale intercalations of the sequence suggest frequent alternation of high and low energy sedimentary regime. The sands are generally thicker than the shales (Fig 4) with which they are intercalated. Sands are predominantly fine to medium grained and well sorted and were deposited in a predominantly outer neritic to bathyal environments. The amplified sand units within the shales consist of a stack of sands exhibiting upward coarsening profile.

The U50 reservoir is a gross interval from 6492- 6555ft with predominantly sand and a low shale response on the gamma ray log. This response with regards sedimentation is indicative that deposition occurred at the time of high energy marine setting, it shows a coarsening- upwards profile (Fig 4) which is also indicative of a high stand systems tract, because of low resistivity log motif which is indicative of the presence of water, though with the thick sand, this reservoir is completely water – wet and hence, has the no potential for a good reservoir. The grain sizes ranges from medium to coarse grained sand.

The V60 reservoir marked from 7201- 7911ft is grossly sand - shale intercalations and marked as **V60,** sands found in this zone are fine to medium grained and moderately well sorted. On the gamma ray log (Fig 4), the motif exhibits irregular shapes, which reflects the overall silty nature of the shales. The intercalated sands exhibit a characteristic serrated blocky shaped motif with occasional high - low resistivity peaks which indicates hydrocarbon and water. The sand/shale intercalations of the sequence suggest frequent alternation of high and low energy sedimentary regime. The huge shale below the reservoir is indicative of a high seal property which also makes it a good reservoir.

FLUID DISTRIBUTION ACROSS WELLS

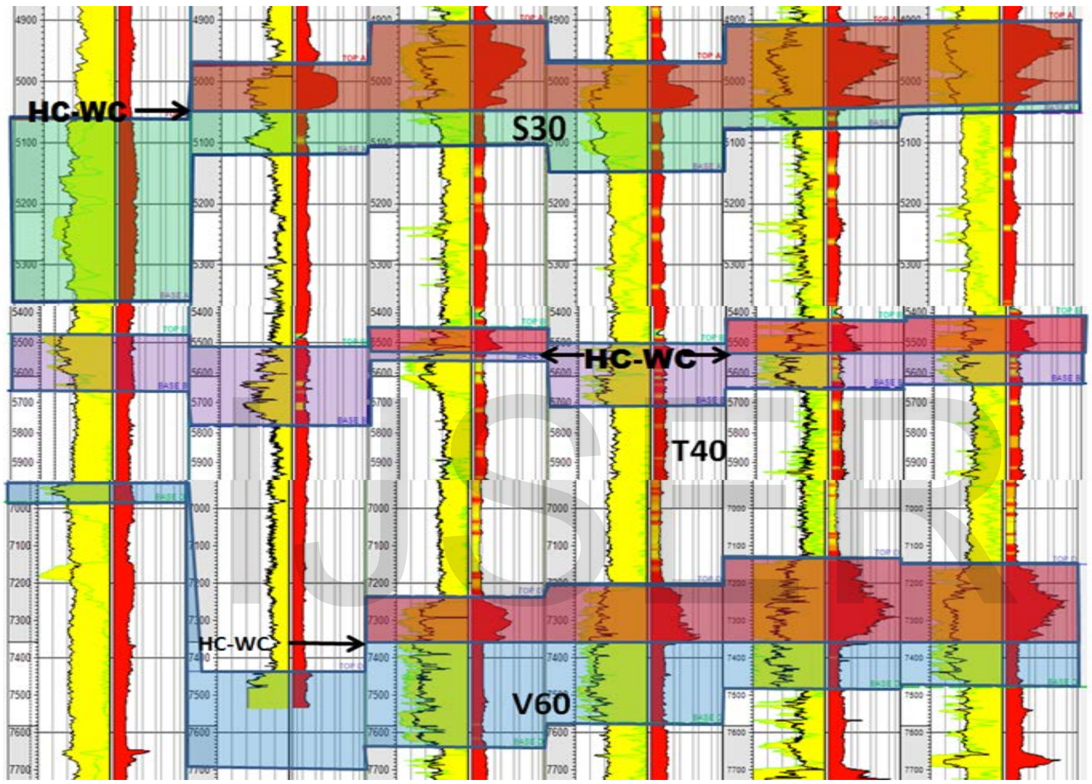

Fig 5: Fluid distribution of PAU field

The study of resistivity log in the S30 reservoir shows that well 1 even with good sand thickness is water wet while the remaining 5 reservoir sands are hydrocarbon bearing because of its high resistivity. Since neutron log was not provided, delineating the Gas Oil Contact or Oil Water Contact was not possible because a display of neutron and density log on the same track and forming a cross over is required for delineation of the Gas Oil Contact and Oil Water Contact. With the resistivity log, only the Hydrocarbon Water Contact (HC-WC) was delineated at 5050ft for S30 reservoir, the Hydrocarbon Water Contact (HC-WC) for T40 reservoir was delineated at 5550ft TVDSS, Interpretation of U50 reservoir (fig 5) from resistivity log shows that despite the good sand thick, the entire reservoir is completely water wet and as such does not contain hydrocarbon and V60 reservoir Hydrocarbon Water contact (HC-WC) at 7350ft TVDSS (fig 5).

The natural drive mechanism for this reservoir is water drive considering the volume of water below the HC-WC.

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SEQUENCE STRATIGRAPHIC INTERPRETATION

A qualitative study was carried out with the objective of establishing the sequence stratigraphic framework (Fig 6) for the field which was later transposed to the seismic and well log for reservoir delineation. This involves subdividing the geologic section into chronostratigraphic correletable horizons, determination of ages, and understanding the sequence stratigraphic framework of all sequences penetrated by the well. The lithologic attributes were integrated with wireline log motifs (gamma ray and ILD) for paleoenvironmental deductions. Paleoenvironmental interpretations are based on wireline log responses and lithologic characteristics of sediments. Sequence stratigraphic analysis based on the integration of lithologic characteristics of the sediments and wireline log motifs aided the recognition of four sequence boundaries marked as follows: 7043ft (5.5Ma), 8046ft (6.3Ma), 9770ft (8.2Ma) and 10635ft (10.5Ma) and Maximum Flooding Surfaces at 5786ft (5.0Ma), 7182ft (5.8Ma), 9170ft (7.0Ma), 9970ft (9.2Ma) and 11088ft (11.6Ma) respectively.

SEQUENCE 1:

MFS 11088ft (11.6Ma) is a Transgressive Systems Tract (TST) which shows a Fining- Upward profile to a Highstand Systems Tract (HST) and the Sequence boundary capping the HST is marked at 10635ft (10.5Ma) which marks the first significant increase in shale within the shale-prone section. The MFS within this section was drawn from the high Gamma Ray at 11088ft.

SEQUENCE 2:

This sequence is seen between 10635 - 9770ft, it is a prograding lowstand which exhibits a fining upwards profile to transgressive systems tract (10283-9970ft) and a Highstand systems Tract (HST) at 9970 -9770ft which exhibits a coarsening upwards profile. The Maximum flooding surface (MFS) marking the top of the TST was defined from the Gamma Ray at 9970ft and sequence boundary (SB) at 9770ft.

SEQUENCE 3:

This sequence is seen between 9770 – 8046ft and generally comprises of Transgressive System Tract at 9770-9170ft and a Highstand Systems Tract at 9170 – 8064ft. The MFS was correlated with the 7.0Ma flooding event with a Sequence Boundary at 8046ft.

SEQUENCE 4:

This sequence occurs between 8046 – 7043ft and comprises of a Transgressive Systems Tract (TST) seen at 8046 – 7182ft and a Highstand Systems Tract (HST) at 7182 – 7043ft and thus shows a coarsening-upward profile and the Sequence Boundary (SB) capping the HST is defined 7043ft and dated 5.5ma.

SEQUENCE 5:

This sequence occurs between 7043 – 5500ft and shows a coarsening-upwards, a Trangressive Systems Tract (TST) at 6144 – 5786ft which also shows a fining- upward profile. The Maximum Flooding Surface marking the top of the TST is defined at the high gamma ray reading at 5786ft. A Highstand Systems Tract (HST) at 5786 – 5500ft shows a Coarsening-upward profile.

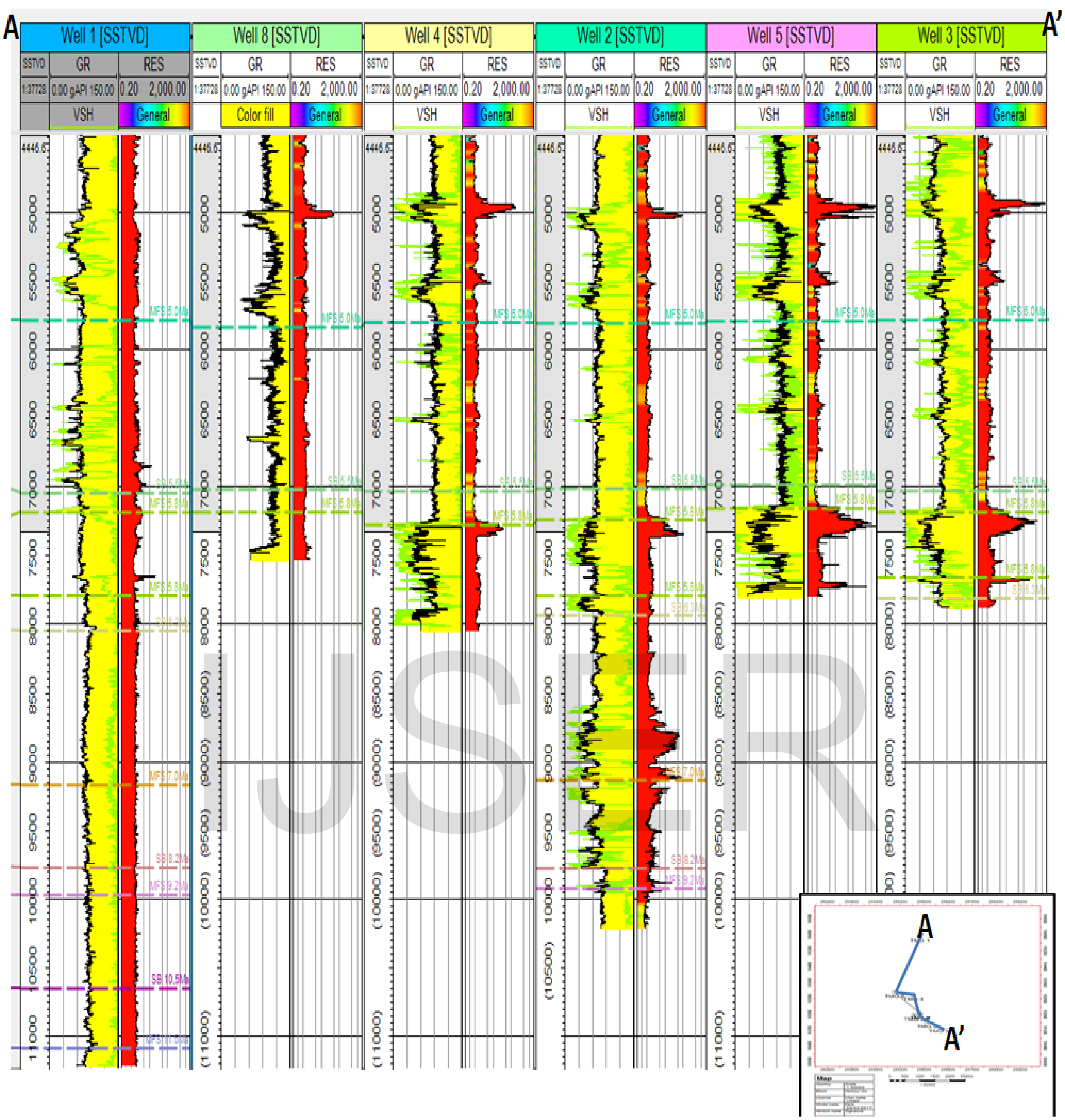

Fig 6: Sequence stratigraphic correlation across wells

CONCLUSION

The reservoirs identified in the field occurs in multiple and ranges from S30, T40, U50 and V60 with S30 reservoir being the most prolific reservoir. The individual sands and their sub-units are separated by thick to thin shales. Shaliness increases towards well 3 and can generally be interpreted that well 3 is closer to marine depositional environment during the sedimentation processes, stratigraphic interpretation of this field shows that the natural drive energy of PAU field is water drive and this is seen in the stratigraphic

ISSN 2229-5518

correlation of the field and further justified from the water saturation model of all 3 hydrocarbon bearing reservoirs.

The sequence stratigraphic interpretations shows that the field is generally a High stand sequence tract and displaying a coarsening upwards sequence and it is indicative of the presence of a channel system and a prograding complex. The well section consists of clay deposits in a submarine channel overlain by amplified stacks of barrier bar sand intercalated with shales exhibiting upward coarsening profile. Environments of deposition of the analysed section vary from predominantly outer neritic to upper bathyal at the lower section (11250 – 5636ft.) to middle/outer neritic settings upsection.

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