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LITHOFACIES CONTROL ON DEPOSITIONAL ENVIRONMENTS IN SHALLOW OFFSHORE NIGER DELTA: IMPLICATION ON RESERVOIR QUALITY

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ABSTRACT

The KEN field lies within latitude $4^{0}52$□44□□ N to $4^{0}53'04''$ N and $6^{0}22'50''$ E to $6^{0}22'26''$ E. The geological and geophysical data sets were used to describe reservoir depositional facies and their environment of deposition. A detailed and accurate environment of sediment delineation is a solid basis to enhance characterization and providing measures for improving hydrocarbon reservoirs. This study aims to presents an effective method for accurately defining depositional environment with different data sets. The data used comprises of biostratigraphy, well logs from three wells and 3D full angle stack seismic data. The biostratigraphic data help to ascertain the age of the formation delineated to be middle Miocene to late Miocene based on the marker shale. It also helps in picking the stratigraphic surfaces. Three depositional sequences were delineated and dated with maximum flooding surfaces of 15.0, 12.6 and 11.5 Ma, respectively. Log sequence analysis reveals the internal geometry and stacking pattern of the mapped sequences. The gamma ray signature varies from serrated cylindrical, funnel to the bell-shaped log motif. The seismic stratigraphy involved facies analysis and reflection termination patterns, which aided the mapping of depositional sequence. The internal geometry is composed of Highstand, transgressive, and lowstand systems tracts. The stacking patterns vary from progradational, aggradational and retrogradational. Based on the seismic facies analysis, the integrated results show that the field of study is of pelagic and debris flow origin deposited in shallow marine settings, which also conform with the other data sets used for this study. The depositional environment of the three delineated reservoirs (Reservoir A, B and C) vary from deltaic upper to lower shoreface channels sand. Reservoir C, which is laterally continuous across the three studied wells shows that the connectivity of reservoir C is loosely amalgamated. The integrated data used for this study indicate that the environment of deposition varies from inner neritic to outer neritic environment. The results of this research are essential for reservoir quality, exploration, appraisal and development phases.

Keywords: Debris, Neritic, Progradation, Aggradational, Retrogradational, Environment, Facies, Reservoir.

INTRODUCTION

As a means accurately quantify reservoir quality, the gross depositional mechanism must take into account a wide range of data sources. The studied region (KEN Field) dates back to the middle to late Miocene and is located at the southern end of the offshore depobelt Niger Delta sedimentary basin, which is a major source of petroleum. From latitude 405244N to latitude 405304N and from longitude 60 22'50"E to 602226E, it is contained within the boundaries of the United States. Ken 01, 02, and 03 are the three wells that were used in this experiment. Due to the fact that data from wellbores is essentially one-dimensional and laterally discontinuous (Lewis et al., 2008), mapping depositional facies in the subsurface has proven difficult. However, depositional facies can change dramatically in three dimensions (3-D) over previously unexplored regions. For frontier sedimentary basins with little well data, such as the shallow offshore Niger Delta, the challenge is exacerbated (Billman, 1992). Consequently, it has been difficult to assess the prospectivity and exploration risks in the area. Sands are deposited into a variety of environments and are distinguished by their log trends, geometries, and dimensions (Allen, 1970). In clastic reservoir rocks, the intricate interplay of processes that take place within a depositional system is mirrored in the physical properties of the rocks. The greatest foundation for evaluating and forecasting reservoir quality and distribution is therefore provided by reconstructing the deposition settings of these various clastic successions (Allen, 1965). The relevance of each depositional environment's petroleum play, which effects hydrocarbon development and production, should not be underestimated; therefore, understanding the depositional environment of the reservoir sand body is critical. Some of the difficulties associated with investigating these types of reservoirs include the delineation and modeling of reservoir quality geometry, sand distribution, and flow capability, among other things (Lewis et al., 2008). By identifying reservoir lithologies, it will be feasible to determine the reservoir depositional facies and their deposition environment using the gamma ray log motif. This will allow for the identification of reservoir lithologies. Combining stacking patterns and facies investigations, the researchers extrapolated the conditions of sand deposition, which are in some respects compatible with previous study in this terrain (Doust and Omatsola 1990; Ajaegwu et al. 2012). With the use of the Biostratigraphy data, we were able to identify the most significant surfaces, which were then used to distinguish one sequence from another along the systems tract. The study's goal is to anticipate lithofacies geometries distant from well controls by integrating biostratigraphy, well logs, and 3D seismic data set utilizing a sequence stratigraphic technique and integrating biostratigraphy, well logs, and 3D seismic data set

Geology of the Study Area

The Late Jurassic rifting between the South American and African plates created a triple junction in the Benue Trough, where the Cenozoic Niger Delta sits, intersecting the South Atlantic Ocean (Whiteman, 1982). During the Cretaceous era, as the African continental margin subsided, oceanic lithosphere was formed and the basin was separated from the continent. The Benue Trough and the Anambra Basin saw marine sedimentation of transgression and regression episodes from the mid-Cretaceous epoch. When the flow of clastic material intensified in the Tertiary, the Niger Delta emerged (Doust and Omatsola, 1990). Progression over continental-oceanic transition zone and onto oceanic crust in the Gulf of Guinea's Oligocene occurred (Evamy et al., 1978, Adesida et al., 1997). For more than a million years, the Niger Delta has degraded from its flanks in Benin and Calabar, resulting in 12 kilometers of sediments covering the delta front (Evamy et al., 1978, Obaje 2009).

Underneath the delta rests the Akata Formation. In the Akata Formation, the pro delta has been depositing turbidite sand and shales since the Paleocene. Small amounts of clay and silt can be found as well. Since

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drilling activities have not penetrated the formation, its thickness can only be estimated to be up to 7,000 meters. This book was written by Reijers and published in 1997.

Paralic siliciclastics found in the Agbada Formation overlaying the Akata Formation cause the reservoir quality and pore throat size to fluctuate greatly. An economic hydrocarbon can be found in the sandstone formation that serves as a reservoir for the hydrocarbon. A coarsening upward trend in gamma-ray logs in the Delta Field indicates that depositional environments in the delta have been receding over time (Haack et al., 2000). Around 3000 feet below sea level is where the Agbada Formation rises from the base of freshwater sands (Owoyemi, 2005). In the direction of the offshore depocenter, the formation thickens as it descends to a depth of 8000 feet below sea level (Haack et al., 2000). (Ojo, 1996).

The Oligocene deposited a recent deposit of fluvial and upper coastal plain facies across the delta. In the delta, the sands of the Agbada Formation lie beneath the Benin Formation (Ojo, 1996).

MATERIALS AND METHODS

In this investigation, three wells (KEN 01, 02, and 03) were combined (see Fig. 1). Biofacies data, Wells logs data (Gamma ray, resistivity, neutron, density, spontaneous potential), Checkshot data, and 3D seismic volume in SEG-Y format were all employed in the analysis process. SEG-Y and Microsoft Excel were utilized in the process of creating the SEG-Y files. In order to ensure that the data was safe to use, it was loaded and tested for any potential concerns. The stacking patterns, system tracts, and depositional sequences of the wells were identified using sequence stratigraphic ideas (Galloway, 1989). These surfaces were marked using biofacies data. A correlation of both strike and dip sections of the wells was then used to map out sand intervals. Maps of horizons and faults were drawn up in an amicable manner.

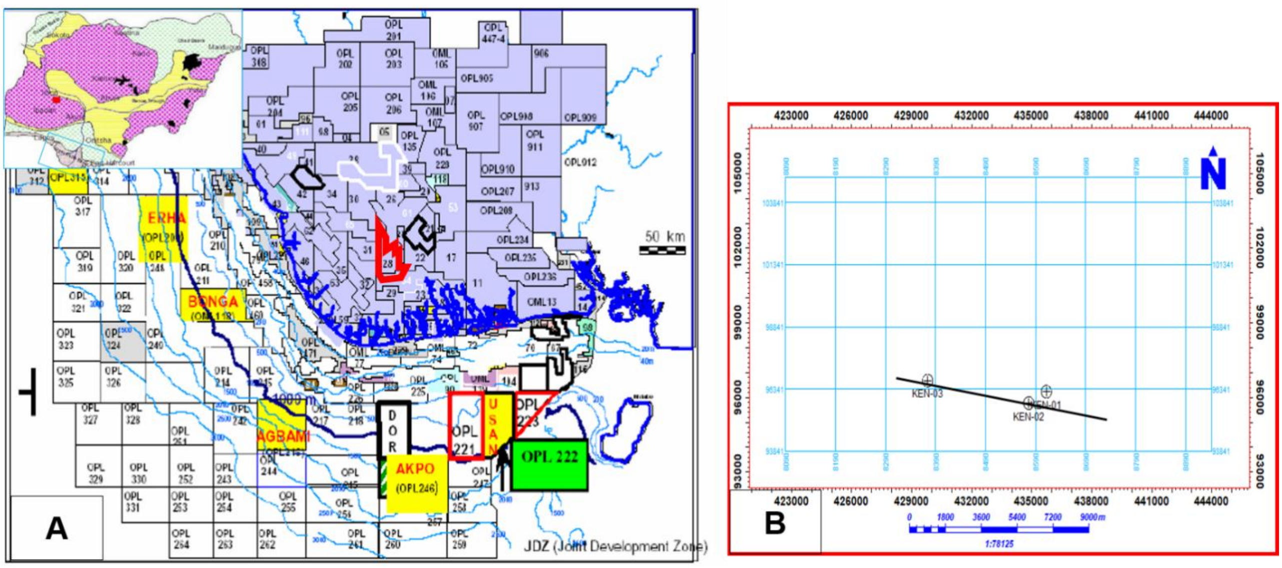

Fig.1: (**A**) Niger Delta Oil Concession map showing various oil blocks and the location of the study area (marked in red colour) (modified from Adegbite and Okiemute,2008); Inset is a Geological map of Nigeria showing the position of the Niger Delta basin. (**B**) Base map of the KEN-Field showing the position of the three wells under study

RESULTS AND DISCUSSION

Sequence Biostratigraphic Interpretation

Biostratigraphic analysis based on the sequence, biofacies data for KEN 01 were used as a control to establish the age, and key stratigraphic surfaces (Fig.2). Three major depositional sequences were mapped and delineated across the entire field and are located within the paralic Agbada Formation of the Niger Delta Basin. These sequences are defined by 3 maximum flooding surfaces (MFS) dated from below as 15.0, 12.8 and 11.5 Ma and two sequence boundaries (SB) dated 13.1 and 12.1 Ma (middle to late Miocene in age). The sequence boundaries were identified by the abrupt shallowing of faunas and also variation of thick sand on shale ratio;while the maximum flooding surface were marked by high pollen and fauna population and diversity (Fig.3). These surfaces correspond with the regional Niger Delta chronostratigraphic chart and they give rise to corresponding lowstand, transgressive and highstand systems tracts. The delineation of depositional sequence adopted here was from Galloway,1989.

Lowstand System Tract (LST)

In the sequence border, the Lowstand System Tract is located directly and could exhibit backstepping, onlapping, retrogradational, aggrading kind of clinoforms that thickens up dip (Posamentier and Allen,1999). They give the impression of being filled in an indented valley. The LST are packages that are predominantly sandy. There are TST and HST bonds on both sides of the structure.

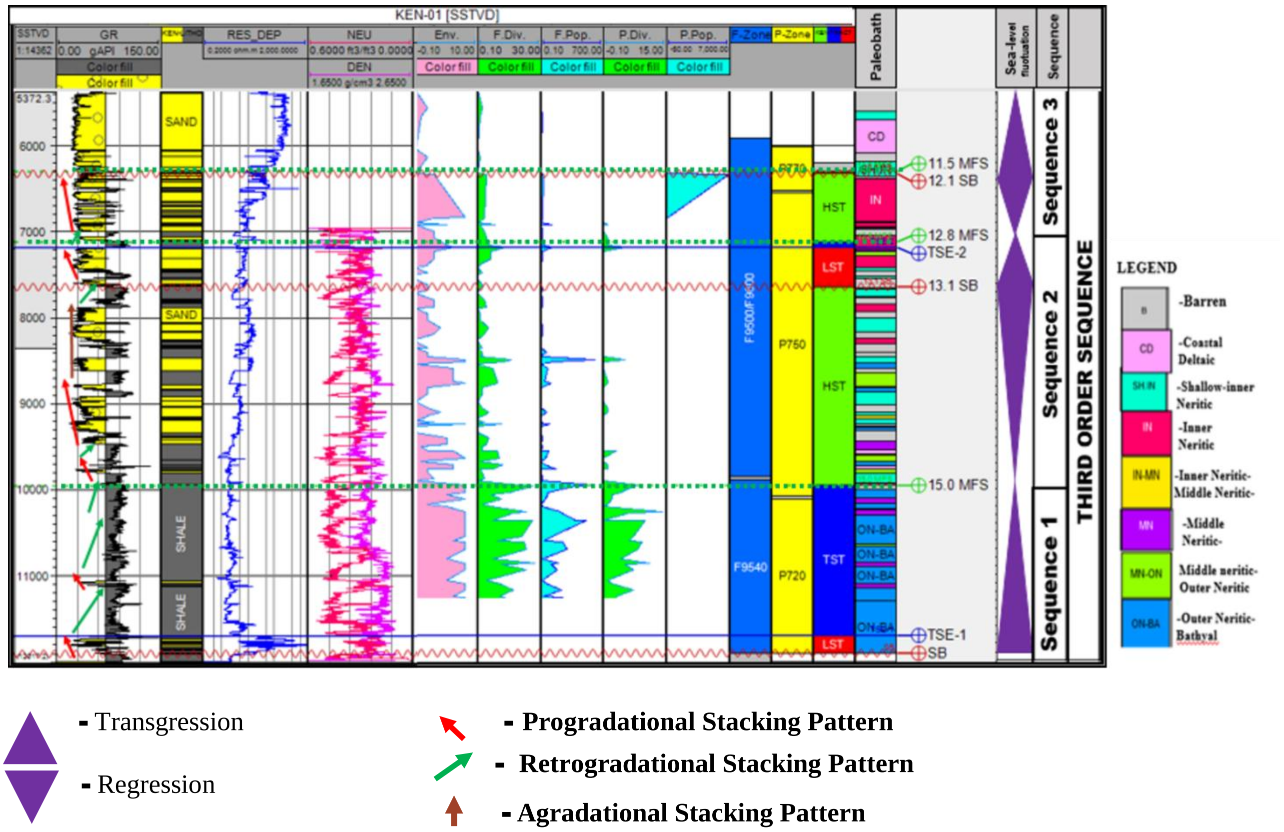

Fig. 2: Calibration of sequence stratigraphic surfaces, third-order sequences and systems tracts with the KEN-01 well. DEN=density porosity; NEU=neutron log; P.P=pollen population; P.D=pollen diversity; F. D=foram diversity; F. P= foram population; GR=gamma-ray; HST=highstand systems tract; IN= inner neritic; RES= resistivity log; LST= lowstand systems tract; MFS=maximum flooding surface MN= middle neritic; ON= outer neritic; P.Zone=palynomorph zone; F.Zone= foram zone, SB=sequence boundary; SH-IN=shallow inner neritic; SSTVD= subsea total vertical depth;

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Transgressive System Tract (TST)

The TST lies directly on the transgressive surface. The continuous reflectors on the TST allow it to be identified also by a shaly package. Their Stacking patterns exhibit backstepping, onlapping retrogradational chinoforms that thickens landward and thins basin ward.

Highstand System Tract (HST)

The Highstand System Tracts is delineated by equal deposition. Here accommodation space equals depositional rate. By the sequence boundary, and below by a maximum flooding surface, it is defined.

Depositional Sequence 1

Analysis on the depositional sequence was done to interpret the Gross depositional environment. The depositional environment was supported by using paleobathymetry results. This is the oldest of the three sequences in the study area and it is bonded at the base by an undetermined MFS and at the top by 15.0 Ma MFS respectively. It is mapped by an undeterministic sequence boundary. The depositional sequences are mapped in wells KEN 01, 02 and partially visible on well 03. This depositional sequence cut across all the three wells in study (Fig. 3).

Depositional Sequence 2

This depositional sequence directly overlies the depositional sequence one, and it is bounded by 12.8Ma MFS at the top and 15.0Ma MFS at the base. The depositional sequence has a sequence boundary dated 13.1ma that caps the HST (Fig.3). This depositional sequence cut across Ken well 01 and 02 only and thickens towards the south eastern part of the field. It discontinues on the Ken 03 well, probably that it thins out or it was been eroded. Reservoir A and B are seen in depositional sequence 2.

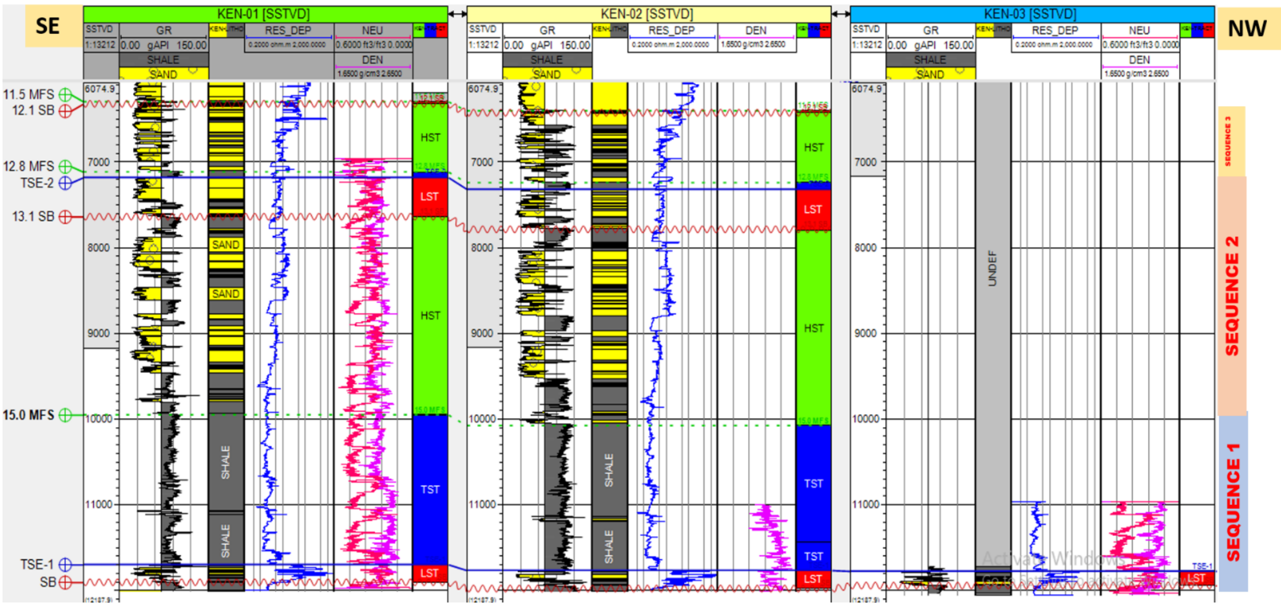

Fig.3: Delineation of Genetic sequence (adopted from Galloway 1989) and Chronostratigraphic Correlation of KEN-01, 02 and 03 Wells

Depositional Sequence 3

As the youngest of the depositional series, it is capped by MFS at the top and base of 11.5 million years (Ma) and 12.8 million years (Ma) respectively. This depositional sequence features a sequence boundary with a date of 12.1 million years ago that marks the end of the HST. As a result, this third depositional sequence does not have any reservoir sand bodies, and it does not contain the petroleum system that is necessary for a suitable stratigraphic trapping mechanism to be met.

Lithology/Gamma ray log motifs identification

The lithology was determined by the use of gamma ray log measurements, which are a function of the presence of radioactive materials. In siliciclastic depositional conditions, each lithology produces gamma radiation elements of potassium 40, uranium, and thorium, and the lithology can be established based on the rate of emission. Shale lithology is connected with a strong gamma-ray response, whereas sandstone lithology is associated with a low gamma-ray reaction. As well as being used to assess the distribution of grain sizes, the gamma ray log can also be used to quantify the amount of depositional energy present. The outcome of this is that very high Gamma Rays value implies a high mud-to- sand ratio, and an extremely low gamma ray value suggests an ultra-low mud-to-sand ratio (Fig. 4).

Each of the gamma ray log motifs has a distinct characteristic that can be used to infer information about the deposition environment, shale concentration, and grain size distribution. It was discovered in the investigation that there are three different shape types of gamma ray log motifs: serrated cylindrical log shaped, Funnel shape, and Bell shape (Fig. 5,6,7).

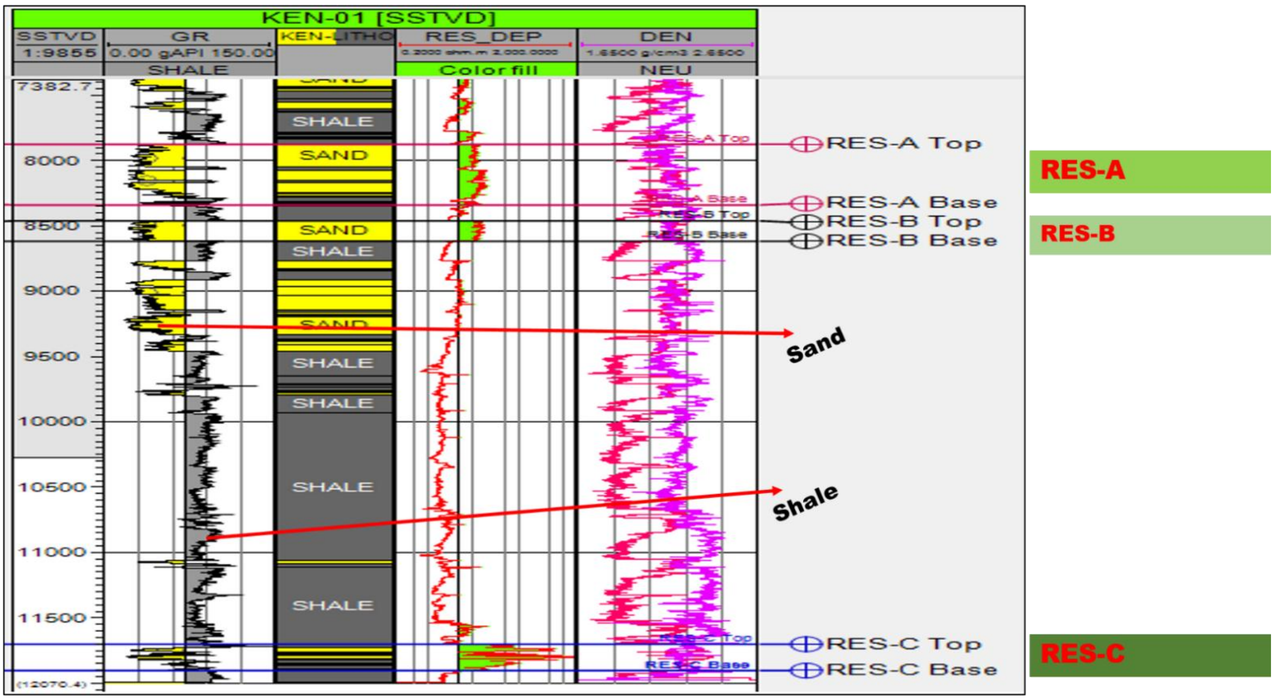

Fig. 4: Lithology Delineation of sand shale unit and Reservoir identification

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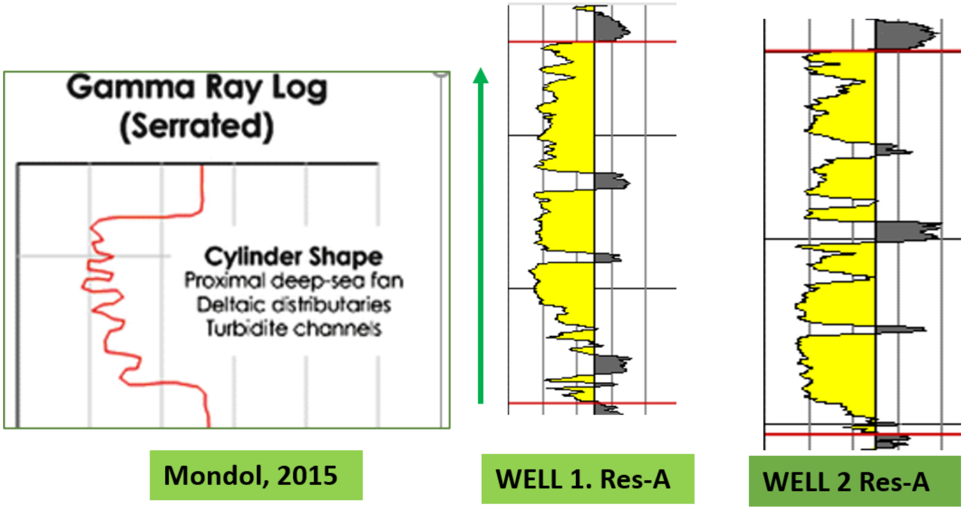
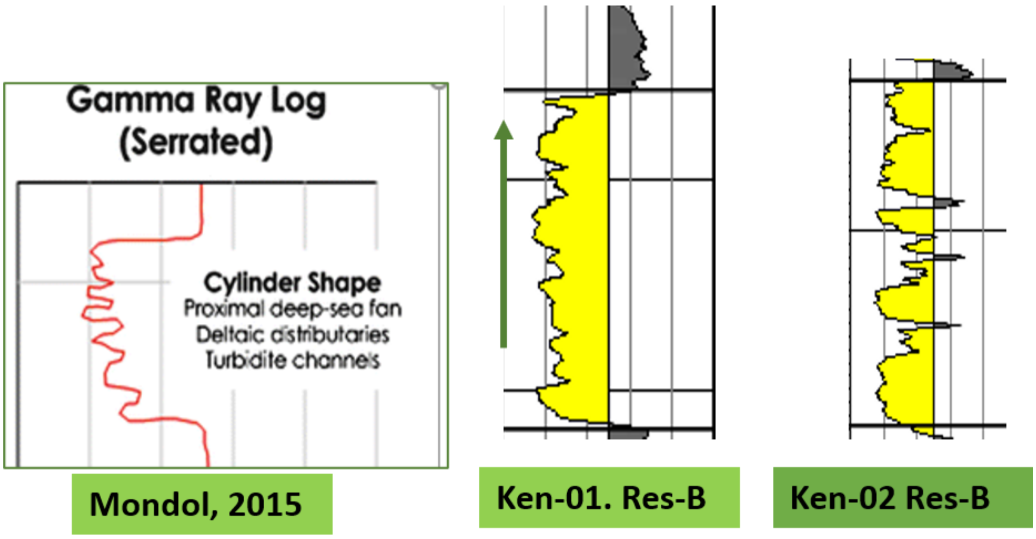


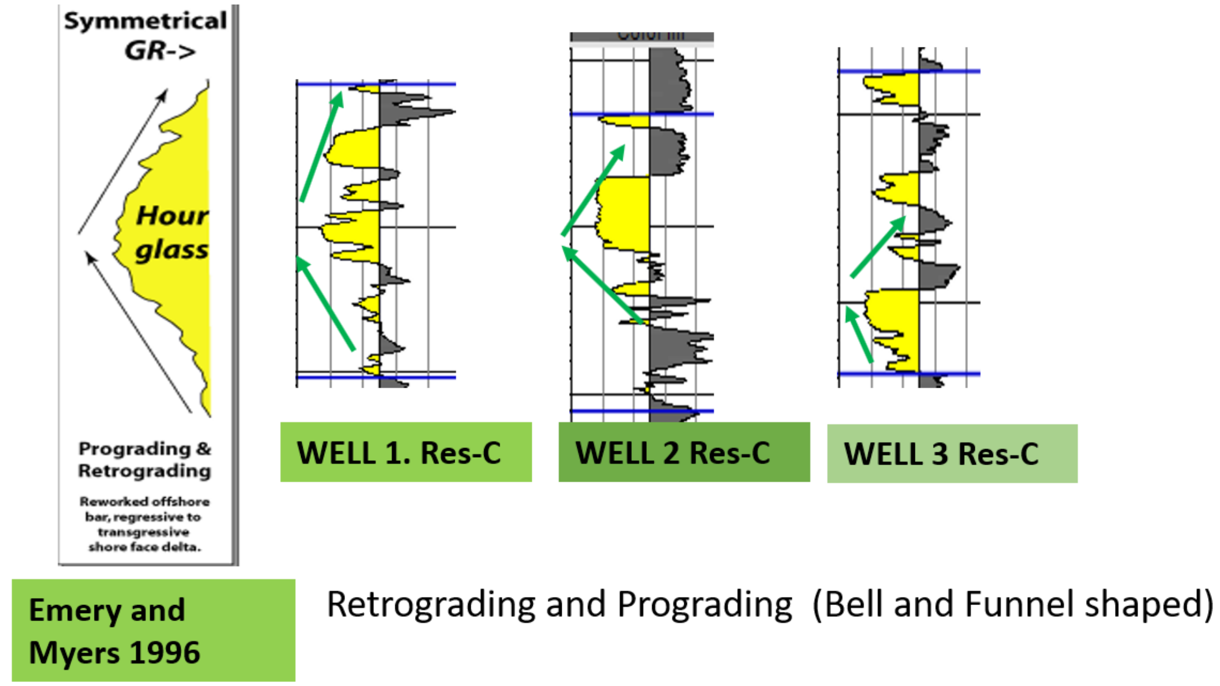
Suggestive Depositional Environment
Serrated cylindrical log-shaped curve typical of deltaic distributary channel representing uniform deposition (Aggrading)

Fig.5: Stacking pattern analysis and environment of deposition using log motif for Reservoir-A (After Mondol 2015)



Suggestive Depositional Environment
Serrated cylindrical log-shaped curve typical of deltaic distributary channel representing uniform deposition (Aggrading)

Fig.6: Stacking pattern analysis and environment of deposition using log motif for Reservoir-B (After Mondol 2015)



Suggestive Depositional Environment
Regressive to transgressive shoreface delta, Reworked offshore bar

Fig.7: Stacking pattern analysis and environment of deposition using log motif for Reservoir-C (After Emery and Myers 1996)

Serrated cylindrical log shape: It is associated with equal deposition, with sharp lower and upper limits having an aggradational stacking pattern.

Funnel-shaped: This is associated with an upward decrease in gamma-ray response, it involves an increase in sand content. The trend indicates an increase in energy level, the stacking pattern is a prograding type.

Bell-shaped: This is associated with a high gamma-ray value response, here the lithology is mostly fine-grains. The trend indicates a decrease in energy level, the stacking pattern is that of retrogradational type.

Reservoir Sands Stratigraphic Correlation

The interpretation of gamma ray was used to distinguish between distinct lithologies, as well as resistivity to identify reservoir sand bodies to accomplish reservoir sand correlation. Regional setting of hydrocarbon field has to be understood for one to carry out a better stratigraphic correlation through seismic session field base maps or by developing a cross section along wells. Vakareloy (2016) suggested the importance of getting cross sections for the whole field in performing stratigraphic correlation of reservoir sands across the sector as this may reveal a regional section of the exploration field as well as the sequence in which these formations were deposited. The top and bottom of horizons were identified to mark each identified reservoir through seismic section, the correlation was carried out across the entire wells using gamma ray log, resistivity and neutron density. Three reservoirs were identified and were delineated

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as reservoir A, B and C and were correlated across the three wells, (see Fig.8). This was done to understand the lateral and vertical continuity. Reservoirs A and B fall in the depositional sequence 2, they thicken towards the south eastern portion of the field. Reservoirs A and B have gross thickness of 444ft and 212ft respectively. Reservoirs A and B were not laterally continuous to Ken 03. Reservoir C fall between depositional sequence 1 and was laterally continuous across the entire wells and has a gross thickness of 181ft, Isopach depth map was use to confirm the thickness of each reservoir and where it thickens to, see Fig. 9,10,11.

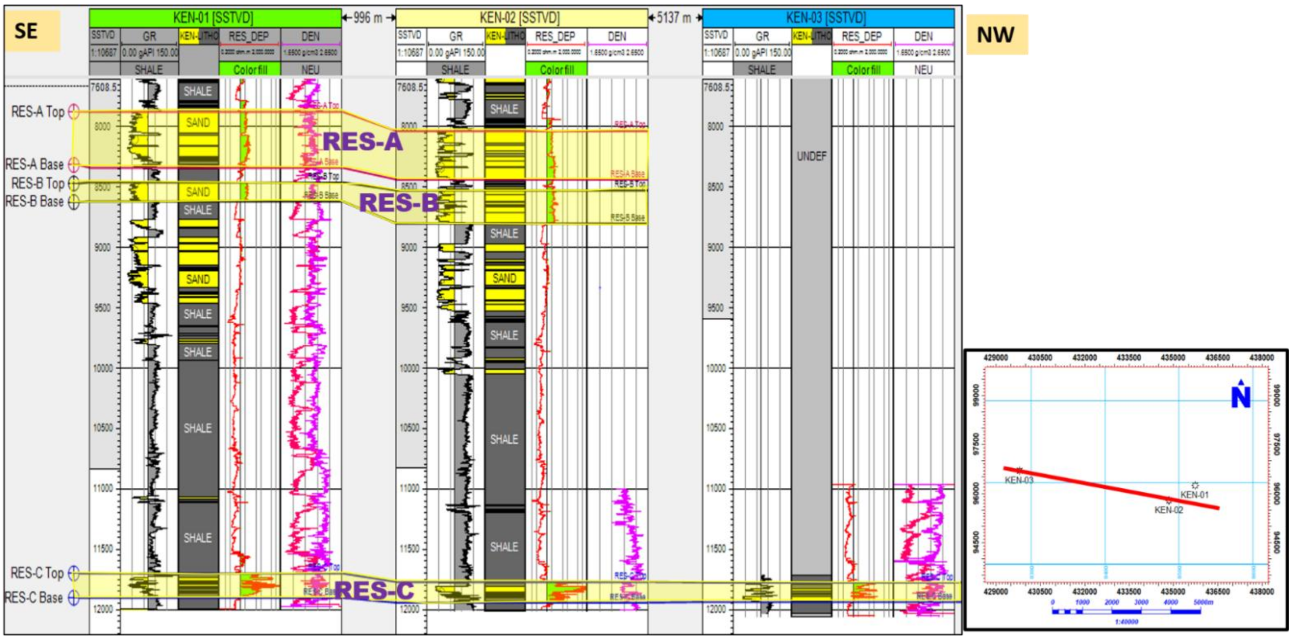

Fig.8: Stratigraphic position of the various KEN reservoir sand mapped along SE –NW

Isopach (depth) Map of the Reservoir Sand Body

The isopach (depth) maps of the studied reservoir sands, Fig.9,10,11, shows that the structure and the trajectory of thickest sand development are comparable with earlier observation of (Fig.8). The entire reservoir sand body attained its highest thickness at the south eastern margin of the depositional axis, they thin out at the North western part of the depositional axis of the entire field of study.

Isopach (depth) Map of Reservoir A Sand

An isopach depth map of reservoir A sand prepared shows that its geometry and the direction of thickest sand development is consistent with the earlier interpretation as shown in (Fig.8). The reservoir sand attained its highest development at the south eastern part of the section Fig.9.

Isopach (depth) Map of Reservoir B Sand

An isopach (depth) map of reservoir B sand prepared shows that its geometry and the direction of its thickest sand development is at the flank edge of both side of the map Fig.10.

Isopach (depth) Map of Reservoir C Sand

The isopach (depth) map of reservoir C sand prepared shows that the geometry and the direction of the thickest sand development is at the edge on the right part of the map which is tending at the southeastern part of the field Fig.11.

The depth structural map also takes almost the same structures as those of time structural maps Fig.12,13,14 which implies the appropriateness of the velocity model used in the conversion. It can be observed from the maps that the probable trapping mechanism responsible for hydrocarbon accumulations is fault assisted anticlinal structure that can serve as a seal to prevent further hydrocarbon migration.

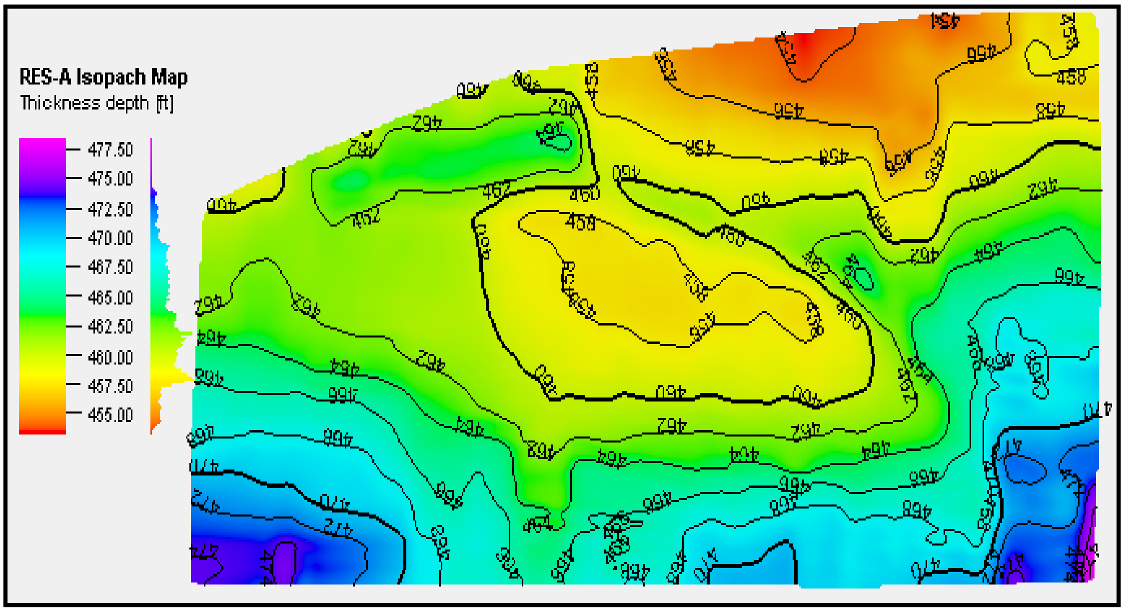

Fig.9: Isopach Map of RES-A

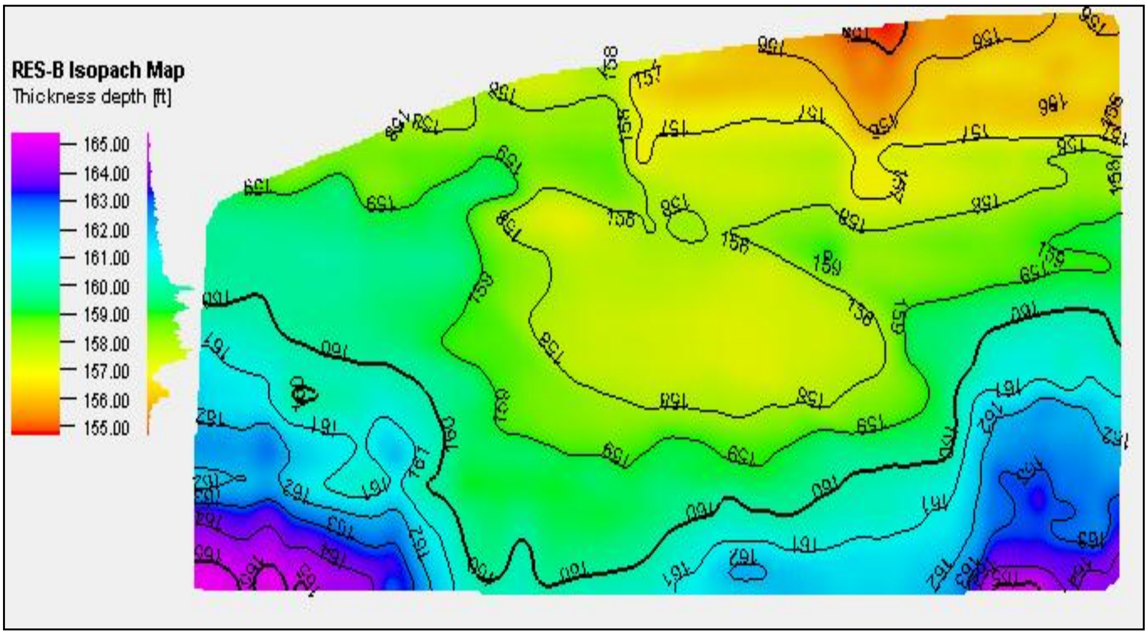

Fig.10: Isopach Map of RES-B

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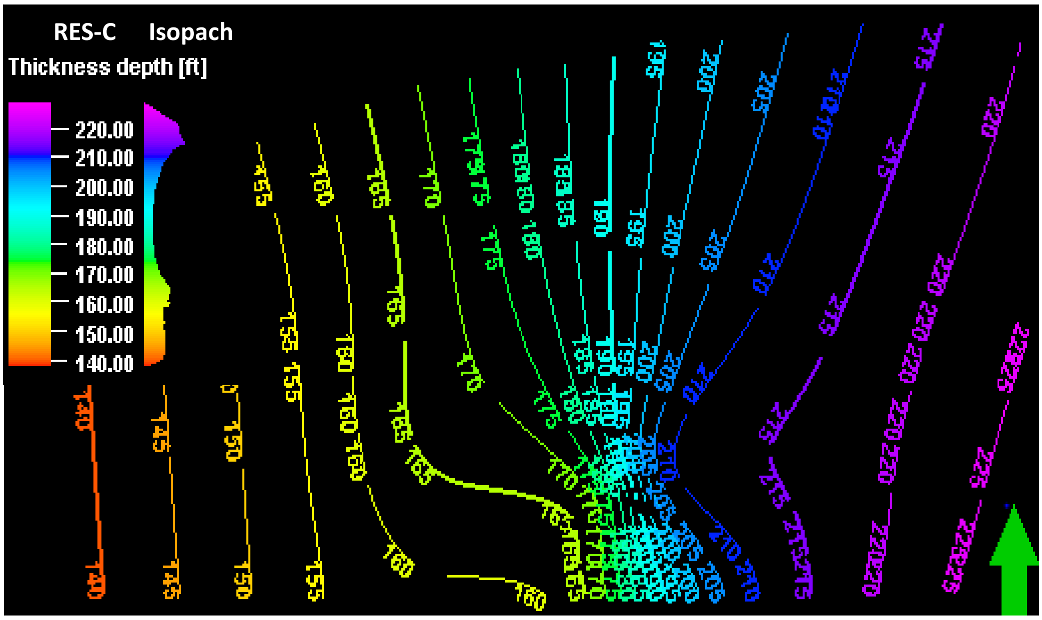

Fig.11: Isopach Map of RES-C

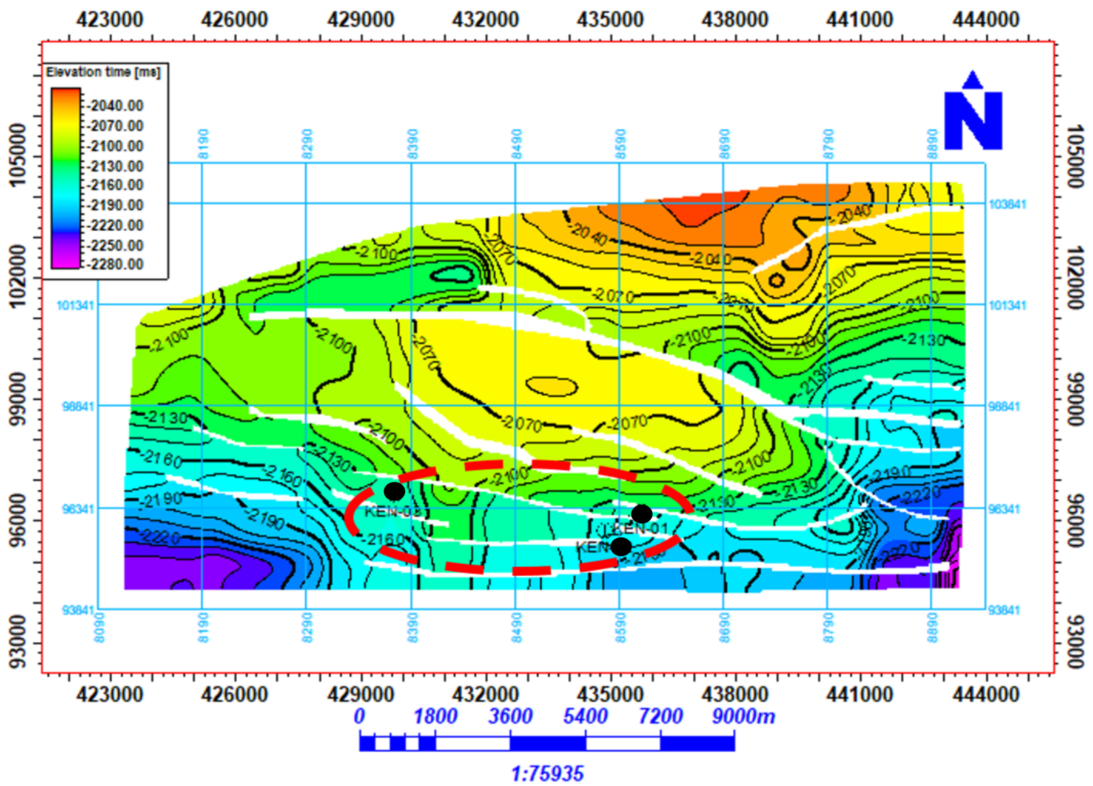

Fig. 12: Time structural map for reservoir A-sand top, at the red cycle it depicts the position of the three wells used for this study and also showing the numerous faults on the study field.

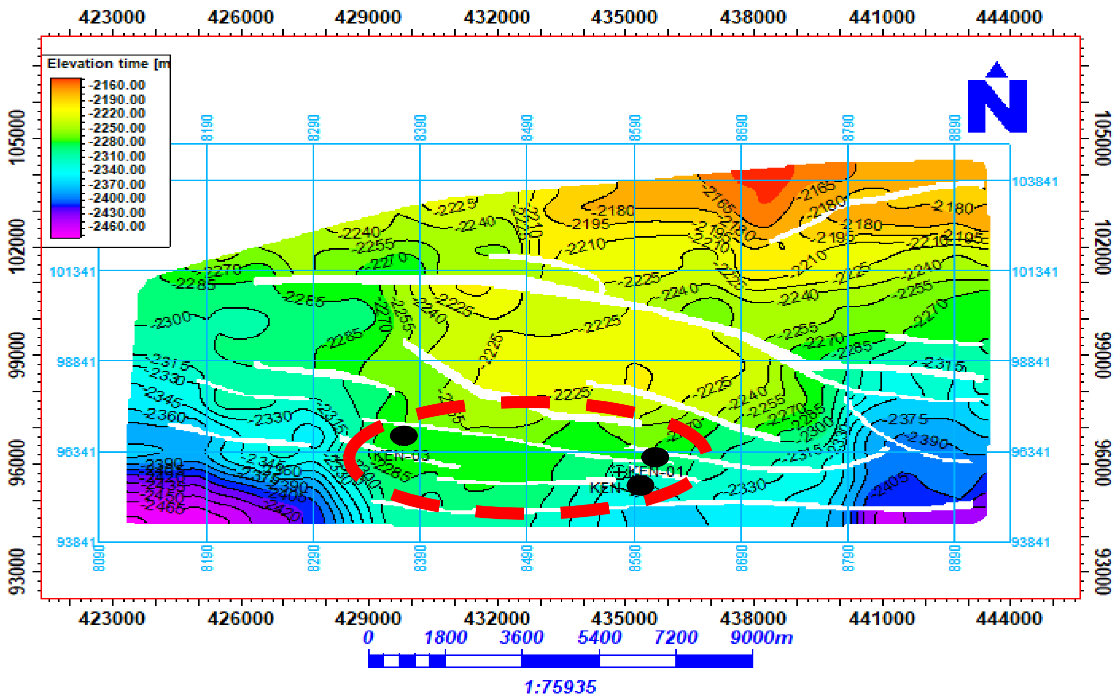

Fig. 13: Time structural map for reservoir B-sand top, at the red cycle it depicts the position of the three wells used for this study and also showing the numerous faults on the study field.

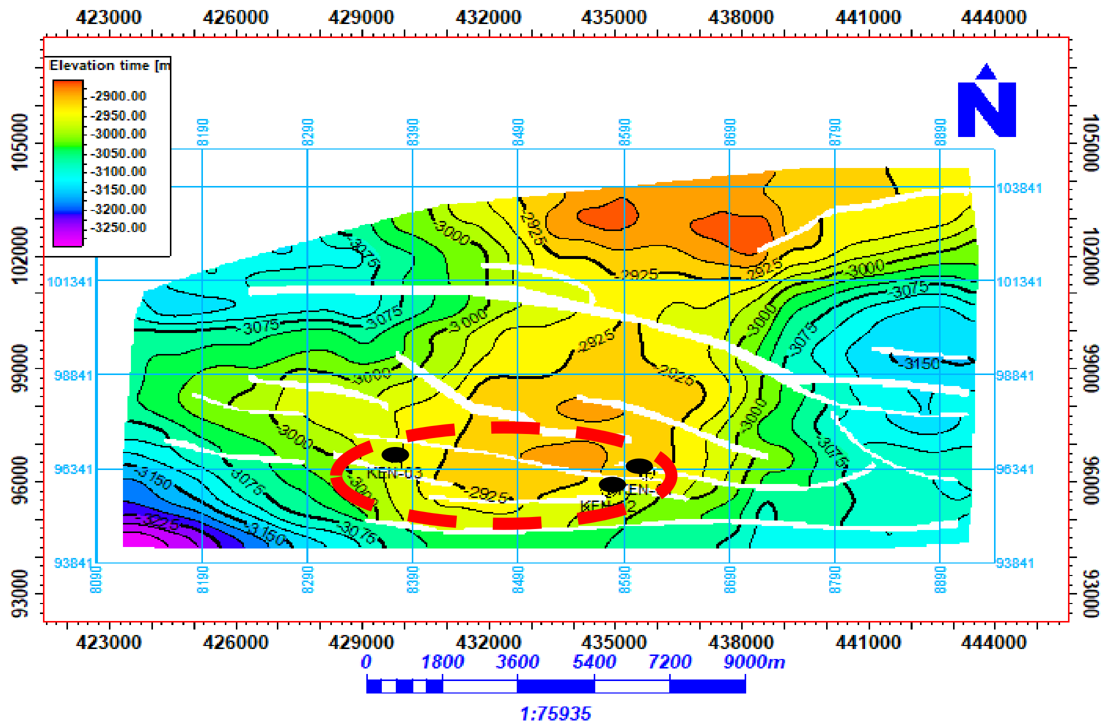

Fig. 14: Time structural map for reservoir C-sand top, at the red cycle it depicts the position of the three wells used for this study and also showing the numerous faults on the study field.

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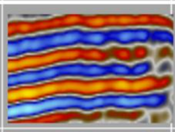
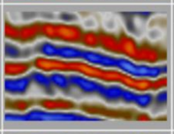
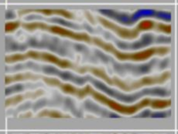
Seismic Facies Interpretation base on environment of deposition

The seismic facies section was used to support the depositional environment as seen in the log motif analyses. High amplitude to low amplitude discontinuous facies, chaotic facies were among the seismic facies interpreted based on their morphology, frequency, and amplitude characteristics. The observed seismic signatures were mostly on reflection configuration, Parallel to Chaotic reflections. On the reflection continuity what was observed was continuous, continuous to semi continuous and then to discontinuous. For reflection amplitude high to low type of amplitude were notice and then for frequency low to high characteristics were observed (Table.1). The difference in reflectivity and continuity likely resulted from changes in lithologic composition, variable sand contact and deferential compaction that resulted in high impedance contrast within surrounding bodies of rock.

Table 1: Seismic Facies Analysis Delineating Environment of Deposition after Olubola and Taiwo 2016)

Reservoirs/Seismic Facies	Observed Seismic Signature	Reflection Configuration	Reflection Continuity	Reflection Amplitude	Frequency	Environment of Deposition	Interpretation
1.		*Parallel*	Continuous	High	low	Pelagic	Shoreface Delta
2.		*Semi-Parallel*	Continuous-to semi continuous	High	High	Debris flow	Deltaic Channel
3.		*Semi-parallel*	Continous-semi continous	High	High	Debris flow	Deltaic Channel
4.		Chaotic	Discontinous	Low	-	Platform interior	-

Fault

The entire seismic section showed a large number of normal and significant faults, which can be categorized as major growth faults with accompanying synthetic and antithetic plays. There is a strong likelihood that these faulted anticlines in the study area indicates a high hydrocarbon potential. They go north to south and dip in the same direction. In addition to shale volume, throw and juxtaposition of permeable and impermeable strata across fault planes are all important factors to consider. The flaw in the research area acts as a seal for the hydrocarbon already in the ground (Fig. 15). As depicted in Fig. 16, the variance edge also reveals the major and small defects.

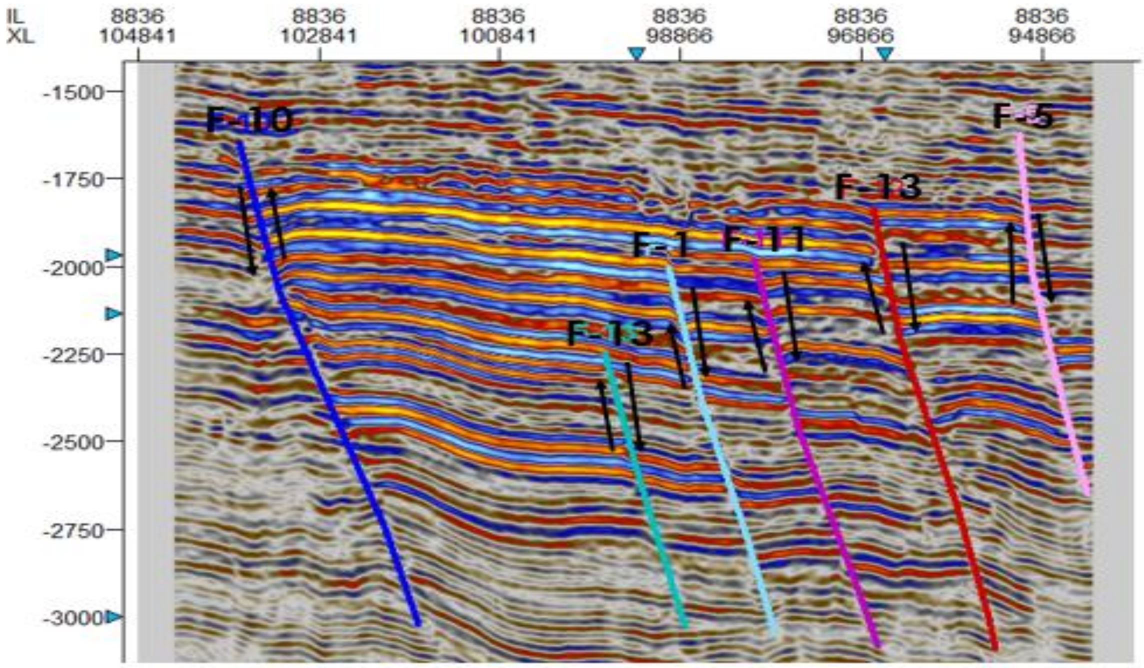


Fig.15: Interpreted fault on the Seismic Inline 8836

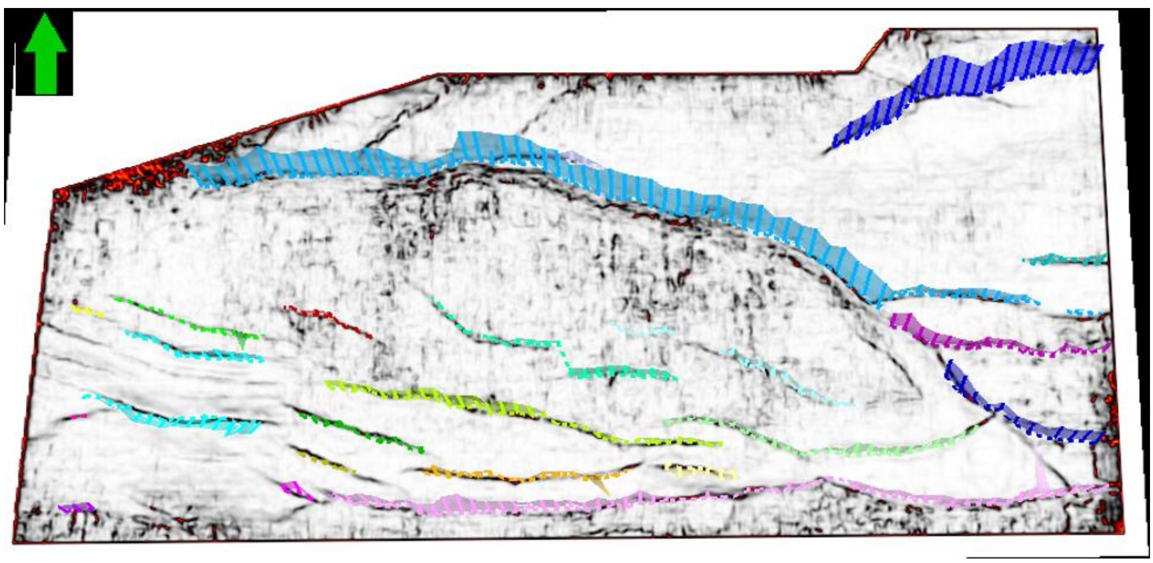


Fig. 16: Variance Edge Attribute showing the major and minor faults.

CONCLUSIONS

The results of the sequence biostratigraphic study revealed three maximum flooding surfaces (11.5Ma MFS Dodo Shale, 12.8Ma MFS Cassidulina 7, and 15.0Ma MFS Bolivina 25), two sequence boundaries (12.1Ma SB and 13.1Ma SB), and three maximum flooding surfaces (11.5Ma MFS Cassidulina 7 and 15.0Ma MFS Bolivina 25) across the entire field, an explanation for three third-order depositional sequences resulted as a result of this. The depositional sequence two contains two reservoir facies (A and B), which evolved in the field's center and southern eastern portions, respectively, during the course of the depositional sequence. The

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reservoir facies were either not penetrated or eroded in the northwestern portion of the depositional axis, depending on your point of view. It was discovered that the reservoir facies of the second depositional phase contained a mostly serrated cylindrical log pattern, which is indicative with aggrading deltaic distributary channels. Seismic facies sections revealed that each of the three depositional sequences had a majority of parallel, high amplitude to continuous reflections, which is also typical of shoreface to deltaic deposits, and that this finding supports the conclusion obtained from the gamma ray log motif. The attribute map also demonstrates that the reservoir facies were better developed in the central and southern portions of the field, as well as in the southern and eastern portions of the field.

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