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SEISMIC STRATIGRAPHY AND PETROPHYSICAL PROPERTIES IN KALA FIELD, NIGER DELTA.

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ABSTRACT

The study focused on relationship between seismic stratigraphy and petrophysical properties of reservoirs in Kala Field, Eastern Niger Delta. Data used for this research include 3-D Seismic, well logs such as gamma-ray, resistivity, sonic, density and neutron logs to evaluate lithology, porosity, permeability and fluid saturation. This work carried out structural mapping, stratigraphic analysis, seismic facies analysis, lithologic identification, petrophysical analysis, petrophysical modelling, well to well correlation, seismic to well tie and horizon mapping using the petrel software. Based on the results, parasequences were defined for reservoirs E and F within the high stand systems tract (HST). Normal faults in the study area trend NW-SE which have been delineated on seismic. The lateral extent of these reservoirs was determined for reservoirs E and F delineated in blocks A, B and C within the Kala Field has been modelled. Petrophysical analysis results comprise porosity, permeability, net-to-gross, water saturation and stock tank oil initially in place. The average petrophysical values of reservoirs E and F in blocks A, B and C in Kala Field showed that the porosity values in block A is 25%, B is 25%, and C is 23%, permeability (291md (A), 300md (B), 1990md (C)), Net-to-Gross ratio (0.74, (A) 0.80 (B), 0.66 (C)), water saturation (45%,,39%,37%) and Stock tank oil initially in place (54.71mmstb,26.83mmstb, 15.47mmstb,) respectively. The results of the petrophysical properties suggest areas of porosity and permeability values within the reservoirs (HST), indicating they may accumulate significant hydrocarbon. This study has demonstrated the relationship between seismic stratigraphy and petrophysical properties in Kala Field.

Key Words: Prospect Evaluation, Seismic Stratigraphy, Petrophysical Modeling and Reservoir Modeling

INTRODUCTION

Seismic stratigraphy deals with the interpretation of seismic data to extract stratigraphic information (Vail *et al.*, 1977) whereas static modelling requires setting up a computer model of a reservoir to enhance appraisal and taking necessary steps to field development (Stephen, 2007). Seismic stratigraphic analysis is the representation of individual seismic facies units. The seismic facies units are three-dimensionally traced and consist of areas where specific reflection characteristics are detected (Sangree and Widemier, 1977). Petrophysics plays an important role in characterizing reservoirs and examination of any oil field may be undertaken to access the permeable and porous unit (reservoir rock), the rock fluid properties in situ, which could affect the rate of recovery and quantity of oil produced. Integration of results acquired from petrophysics with those obtained from geology and engineering is necessary (John *et al.*, 2013; Wobo & Ideozu, 2022). The aim of this work is to explore the relationship between seismic stratigraphy and petrophysical properties of reservoirs in Kala FieldThe Kala Field is located within the Eastern Niger Delta Basin (Figure 1 – 2). The Niger Delta basin originated from the failed rift junction during the separation of the American plate from the African plate and thereafter the opening of the South Atlantic (Reijers*et al.*, 1997). Rifting ceased completely, during the Cretaceous and gravity tectonism became the main deformational processes. Three formations make up the Niger Delta basin, these formations – Akata, Agbada and Benin Formations are recognized predominantly (Reijers*et al.*,1997; Ozumba, 2013; Owoyemi and Willis, 2006; Wobo and Ideozu, 2022).

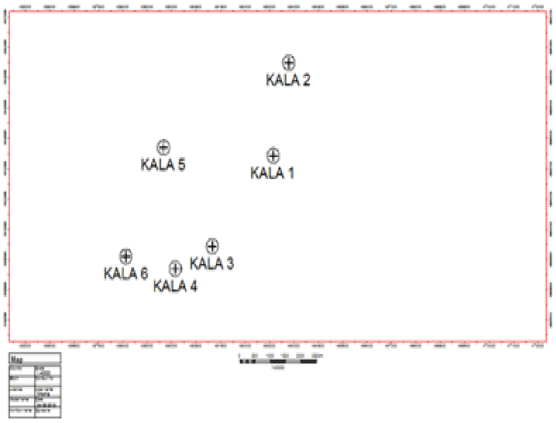

Fig 1: Location of the study area (After Wobo & Ideozu, 2022) Fig 2: Map showing the distribution of the wells in Kala Field (After Wobo & Ideozu, 2022)

MATERIALS AND METHODS

Materials used in this research comprise well log and seismic data and methods used in this research is outlined below:

Well Log Analysis and Well Correlation

Well log information was available for six wells and well headerswere created while well logs for the wells were imported into Petrel software. Well correlation was carried out across the six wells Kala 1, Kala 2, Kala 3, Kala 4, Kala 5 and Kala 6. Log signatures from GR log, deep resistivity logs were utilized to correlate the wells recognition of System Tracts and Key Surfaces on Logs

The recognition of system tracts and key surfaces on well logs and seismic section was based on identification of erosional truncation (top of seismic reflectors), onlap (reflectors termination against sequence boundaries), transgressive surface (seaward-dipping onlap of retrogradational seismic facies), maximum flooding surface – MFS (continuous-high amplitude reflections often associated with condensed sections). identifying the maximum flooding Surface (MFS) on the well logs followed by the recognition of Sequence Boundary (SB). System tracts were interpreted on the basis of Transgressive-regression trend, Stratal stacking patterns and lapout pattern

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(Lapout - lateral termination of a reflection (bedding plane) e.g. downlap, toplap, etc.

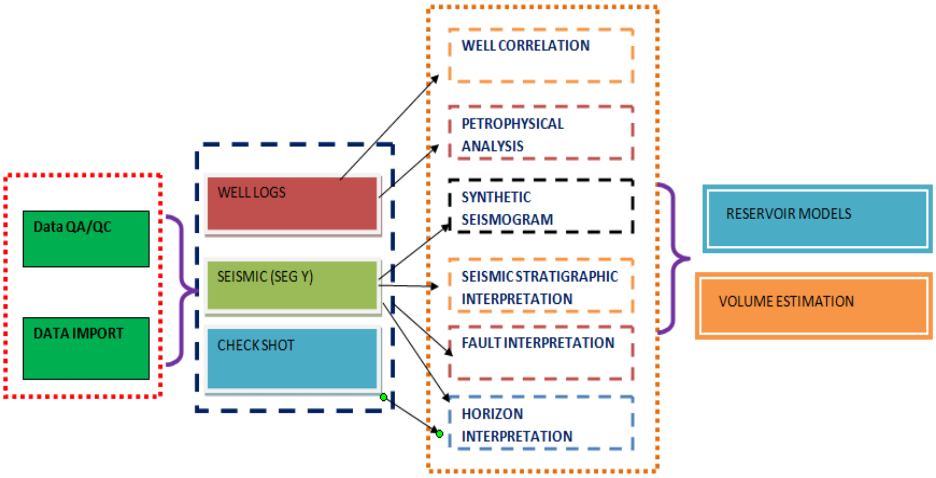


Figure 3: Workflow of the study

Seismic Data Analysis

The seismic volume in Seg -Y was imported into the Petrel Software, cropped with realizations carried out, to reduce the processing time. From the crop-realized volume, inline, crossline and time slice were inserted. A 3D window and an interpretation window were opened to view and map the faults. The faults were mapped on the crosslines and the continuity was viewed on the in-lines. Having grouped the seismic section into different sequences, the sequences are examined based on the internal deposition of reflection and the different signatures they give, helped interpret the environments of deposition responsible for the formation of the sequence and the lithofacies.

Seismic Facies and Structural Analysis

Seismic facies analysis was carried out by first quality checking the data to ensure the data was properly processed (amplitude balance, migrated and noise reduced), the well logs tied to seismic reflections and lithological units. The fault mapping was carried out on the cross lines and the continuity viewed on the in-lines. Conditions for fault mapping used are (a) An abrupt termination of reflections (b) Displacement or distortion of reflection. Normal faults trending NW-SE were picked from seismic and mapped.

Well to Seismic Tie

The wells were positioned and annotated on seismic, with the geologic tops recognized and noted on the seismic section. Well to seismic tie was carried out with the check shot data. The different wells, reservoir peaks and troughs were visualized on a 3D window and superimposed on the seismic lines to ensure that there was an accurate tie linking the well and seismic event. (Tearpock&Bischke, 2003), See Figure 4.

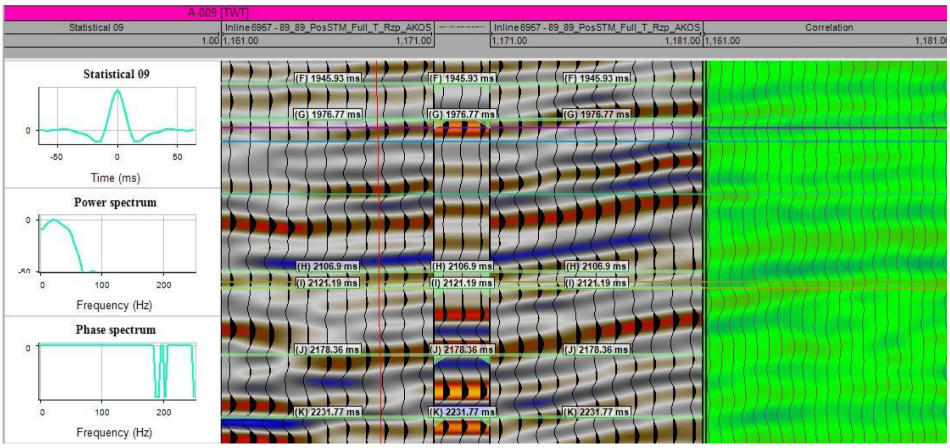


Figure 4 Seismic to well tie

Petrophysical Evaluation

The petrophysical parameters such as Porosity (ϕ), Permeability (K), Water Saturation (Sw), Hydrocarbon Saturation (Sh), Gamma Ray Index (I_{GR}), Formation Factor (F), Volume of Shale (Vsh), Bulk Volume Water (BVW), Irreducible Water Saturation (Swirr), Net-to-gross and STOIIP of the formation were utilized to evaluate the reservoirs.

Porosity

Reservoir Porosity (ϕ) may be estimated indirectly using logs. The formation density logs were utilized to determine the porosity (Frank et al., 2001). The porosity was determined by reading out the values of the bulk density from the density log in different reservoirs and estimating based on the equation by Dresser Atlas (1979).

$$\varphi_{den} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

(ϕ_{den}) = density derived porosity

ρ_{ma} = density of matrix (2.65g/cm^3 for sandstone), ρ_b = bulk density, ρ_f = fluid density= 1.1gm/cm3 (fluid density) and the criteria used to classify porosity given by Baker (1992) is:Ø < 0.05 = Negligible, 0.05 < Ø <0.1 = Poor, 0.1 Ø< 0.15 = Fair, 0.15 < Ø < 0.25 = Good, 0.25 < Ø <0.30 = Very good and Ø > 0.30 = Excellent.

Permeability (K)

It is very vital in estimating well productivity, performance of the reservoir and hydrocarbon recovery (Frank et al., 2001). Owolabi et al. (1994) equation was used in determining permeability in this research. It is shown in the formula below.

Permeability K = $307 + 26552\phi^2 - 34540(\phi \times S_w)^2$(Owolabi et al., 1994)

Where, K = Permeability (millidarcies), Swirr = irreducible water saturation and ϕ = porosity

Volume of Shale (Vsh)

Shale volumes in the reservoirs were estimated with the use of the GR log. The gamma-ray index is calculated using the equation below:

$$Gamma - Ray\ Index\ (IGR) = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad willie\ et\ al$$

Where:

IGR = GR index, GRlog = GR value of the reservoir, GRmin =Lowest gamma ray value (for clean sand),

GRmax = Highest gamma ray value (shale).After calculating the GR index, the value obtained is substituted in the equation below to estimate the shale volume in the reservoir (Dresser Atlas, 1979).

$V_{sh=}\ 0.083(2^{3.7\times IGR} - 1.0)$ (Tertiary consolidated sand)

Water Saturation (Sw)

Water saturation (S_w) estimation is the most demanding of all petrophysical calculations. The hydrocarbon saturation,

$S_{h,}\ (1 - S_w)$.

Udegbunam et al., 1988)

$S_{w\ =}\ 0.082$

Hydrocarbon Saturation

Hydrocarbon saturation is defined as that fraction of pore space that contains hydrocarbons. It is depicted by the symbol Sh.

$S_h = (1 - S_w)$.

Where Sh = hydrocarbon saturation, Sw = water saturation, 1 = unity

Formation Factor

The formation factor is a function of porosity and the type of rock. The formation factor within the target depth interval was calculated using Humble's formula of best averages for sandstones and unconsolidated formations.

$$F = \frac{0.62}{\phi^{2.15}}$$

Where F = formation factor and (ϕ) = porosity

Irreducible Water Saturation (Swi)

This is the water that is occupied in the pore spaces by forces known as the capillary forces. For most reservoir rocks, Swi ranges from less than 10% to greater than 50% (Schlumberger, 1979). It was determined from the equation given by Asquith and Gibson (1982)

$$S_{wi} = \sqrt{\frac{F}{2000}}$$

Estimation of the Pore Volume of Hydrocarbon (HCPV). This is the portion (represented in fractions) of the reservoir volume occupied by hydrocarbon. It is estimated with the formula below:

$$HCPV = \emptyset_{den} \times (1 - S_w) \times V$$

Where ϕden is the average porosity obtained from the density log, the volume (V) is the product of the area of the closure obtained from the depth structure map and the reservoir thickness

Net-To-Gross

It is the ratio of the productive sand body thickness to the gross thickness observed in the reservoir. Net-to-gross can be estimated by using the wireline gamma ray logs. Shales are usually non-productive and can be differentiated from clean or non-shaly formations by measuring and differentiating natural radioactive levels along the borehole (Frank et al., 2001). For this research work, N/G was calculated with the aid of Petrel using:

$$\text{NTG}=\Sigma\text{h}= \frac{\text{Net reservoir}}{\text{Gross reservoir}} \quad \text{(Asquith 1994)}$$

Hydrocarbon Water Contact and Stock-Tank Oil Initially n Place (STOIIP)

The resistivity log was used to delineate the hydrocarbon/water or gas/water contacts. The Volume estimation is the quantity or how much hydrocarbon exists in an accumulation in a reservoir.STOIIP is the volume of hydrocarbon in a reservoir prior to production (Frank et al., 2001). For this work, STOIIP was estimated using:

$$STOIIP = \frac{A \times H \times \emptyset(1 - S_w) \times 7758 \times NTG}{\beta_o}$$

Where; STOIIP = Stock Tank Oil Initially in place, 7758 = barrels per area foot A = drainage area in acres, H = reservoir thickness in ft. ϕ = porosity in decimal, S_H = (1-Sw) hydrocarbon saturation in decimal

NTG= Net to Gross, B_o =oil formation volume factor

$$\frac{\text{Net reservoir}}{\text{Gross reservoir}}$$

$$B_O = 1.05 + 0.5 \times \frac{GOR}{100}$$

$$\text{GOR (gas-oil ratio)} = \frac{\text{Gas in cubic feet}}{\text{oil in barrels}}$$

Estimation of the Pore Volume of Hydrocarbon (HCPV)

The HCPV was estimated with the formula below:

$$HCPV = \emptyset_{den} \times (1 - S_w) \times V$$

Where ϕden is the average porosity obtained from density log, the volume (V) is the product of the area of the closure obtained from depth structure map and the reservoir thickness.

Net-To-Gross (NTG)

The NTG is the ratio of the productive sand body thickness to the gross thickness observed in the reservoir. Net-to-gross can be estimated by using the wire line gamma ray logs. Shales are usually non-productive can be differentiated from clean or non-shaly formations by measuring and differentiating natural radioactive levels along the borehole (Frank et al., 2001). For this research work, N/G was calculated with the aid of Petrel using:

$$\text{N/G} = \frac{\sum h_1}{H} = \frac{\text{Net reservoir}}{\text{Gross reservoir}} \text{ (Asquith 1994)}$$

Synthetic Seismogram

Its concept involves trying to model or create a seismic reflection. It is a direct one-dimensional model of acoustic energy travelling through the layers of the earth. The synthetic seismogram is generated when the reflectivity obtained from digitized acoustic and density log with the wavelet derived from seismic are convolved. By putting the correlation points delineated on the well logs side by side with key reflections on seismic, interpretation process can be boosted. Synthetic seismogram showing a good fit helps us to identify confidence seismic reflections which are reservoir or falls in our zone of interest. A synthetic seismogram was achieved for the well with check shot data.

Horizon Interpretation

Two different layers of rocks are separated by the surface called a horizon. These surfaces are recognized by distinguishing reflection termination patterns that is identified on a layer that large coverage. The identification of the prospective sands is from the composite log available. Two horizons was identified.

Generation of Time and Depth Structure Map

The grids produced from the horizons were transformed into points of value, and then the computer contours it to best fit with consistent contour spacing specified. Since the horizons are in time domain, generated a time structure map, to generate the depth structure map, the horizons in time have to be transformed to depth domain using a velocity model. Time to depth conversion was achieved with the use of the check shot survey data, and the corresponding structural maps produced.

RESULTS AND DISCUSSIONS

The results of this research are presented in Figures 5 – 37 and Tables 1 – 3.Well correlation of Kala Field wells was with the aid of Gamma Ray and Resistivity logs. The six wells given were correlated and the reservoir sand and shale sequence were established, the well tops and bases were also identified (Figure ***5 -6***). The overall stratigraphic framework of the wells shows a composition of intercalations of sand and shale layers. There is an increase in shale layer with depth and a ***c***orresponding decrease in sand layer with depth. This is an indication of transition from Benin to Agbada Formation.

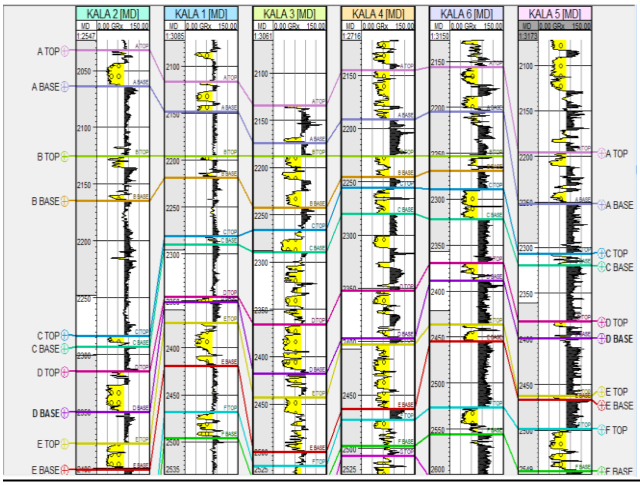


Fig. 5 Well correlation of sands A to E

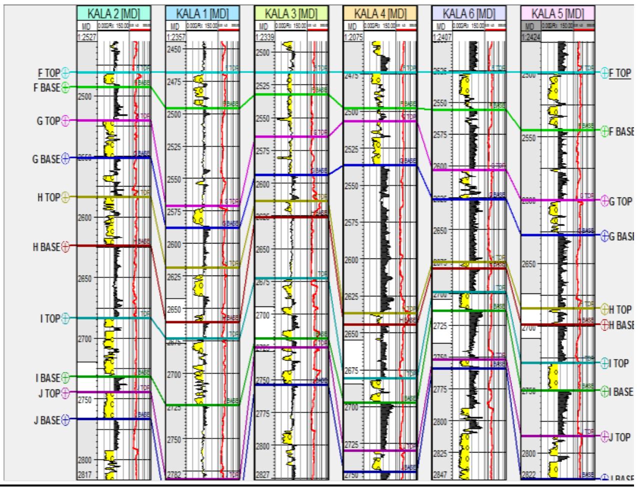


Fig. 6 Well correlation of sand F to J

Seismic Facies Interpretation and Sequence Stratigraphic Interpretation

The seismic facies analysis of the field shows that the area is characterized by three distinct seismic facies, seismic facies 1, 2 and 3 (Fig. 7 – 9). Sequence stratigraphic analysis of wire line logs isin analyzing subsurface datasets, the well log data allow lithology and depositional setting to be placed on the seismic, thus integrating seismic facies, rock properties and sedimentological facies (See Fig. 10 – 12). Sequence stratigraphic analysis revealed that the succession consists of four sequence boundaries dated 24.9 Ma, 27.3Ma, 29.3Ma and 32.4Ma respectively and four maximum flooding surface dated 26.2 Ma, 28.1 Ma, 31.3Ma and 33.2Ma. The identified parasequences of reservoirs E and F showed that they are within the high-stand system tracts (HST). (See Fig. 10 – 12).

Fault and Horizon Interpretation

Normal faults trending NW-SE direction were identified on the seismic section, and four faults were mapped which is synonymous which is similar to is obtained in the Niger Delta (Fig. 13 - 14) (Wobo & Ideozu, 2022). The Kala Field is a complex south-west dipping anticlinal structure from the results. The horizons of the tops of the reservoirs were picked which ensured that the interpretation process was consistent. Two horizons with hydrocarbon bearing reservoir E and reservoir F were delineated and mapped. Horizons E and F were identified at the time levels of 1900ms and 2000ms on the seismic section. The depth equivalents of these horizons are 2350m and 2460m respectively (Fig. 13 - 14).

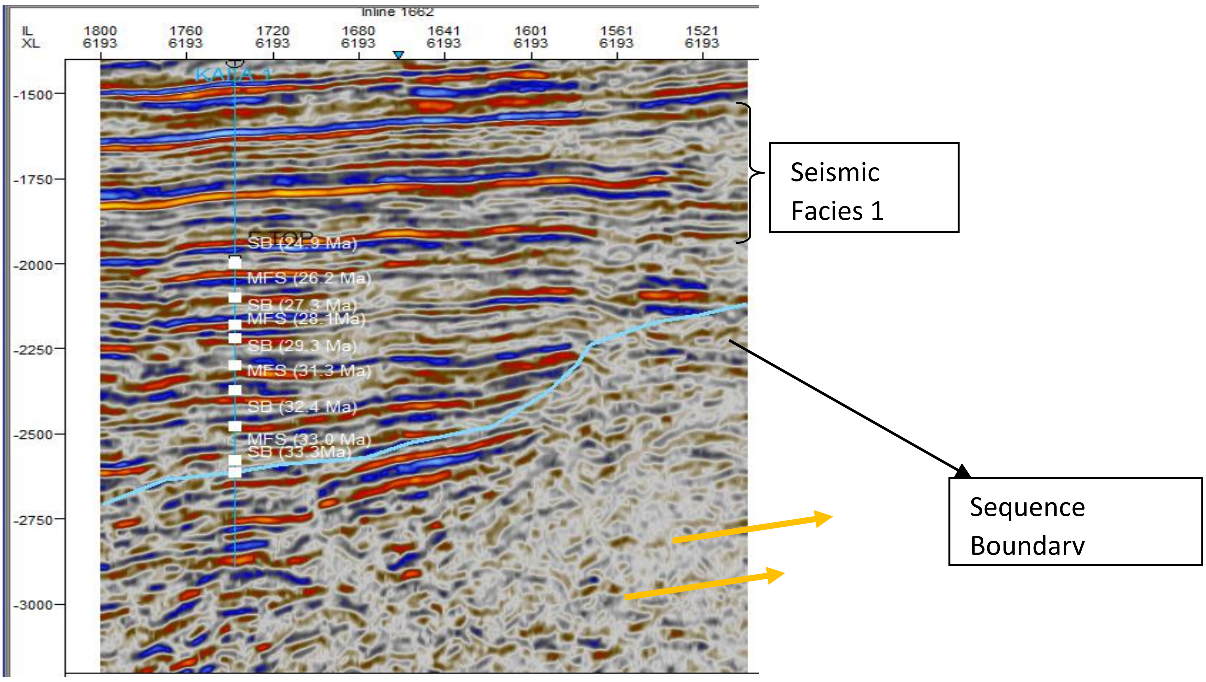


Fig. 7 Seismic facies pattern and sequence boundary in Kala Field

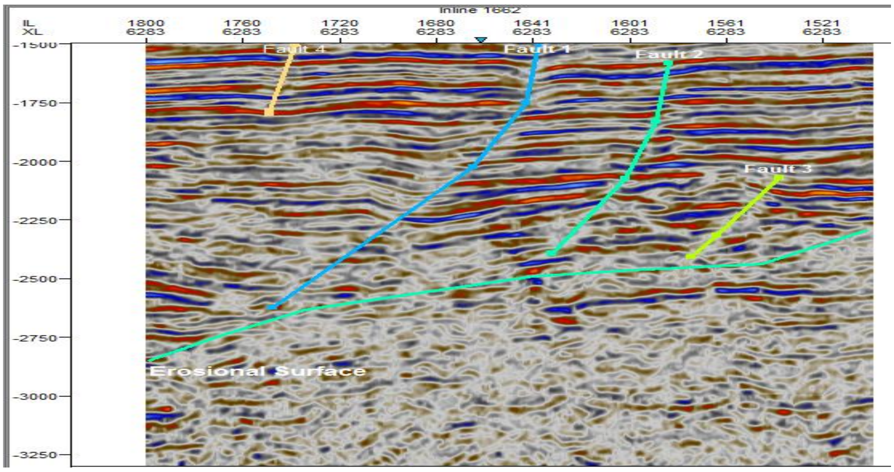


Figure 8 Seismic facies pattern and Erosional surface.

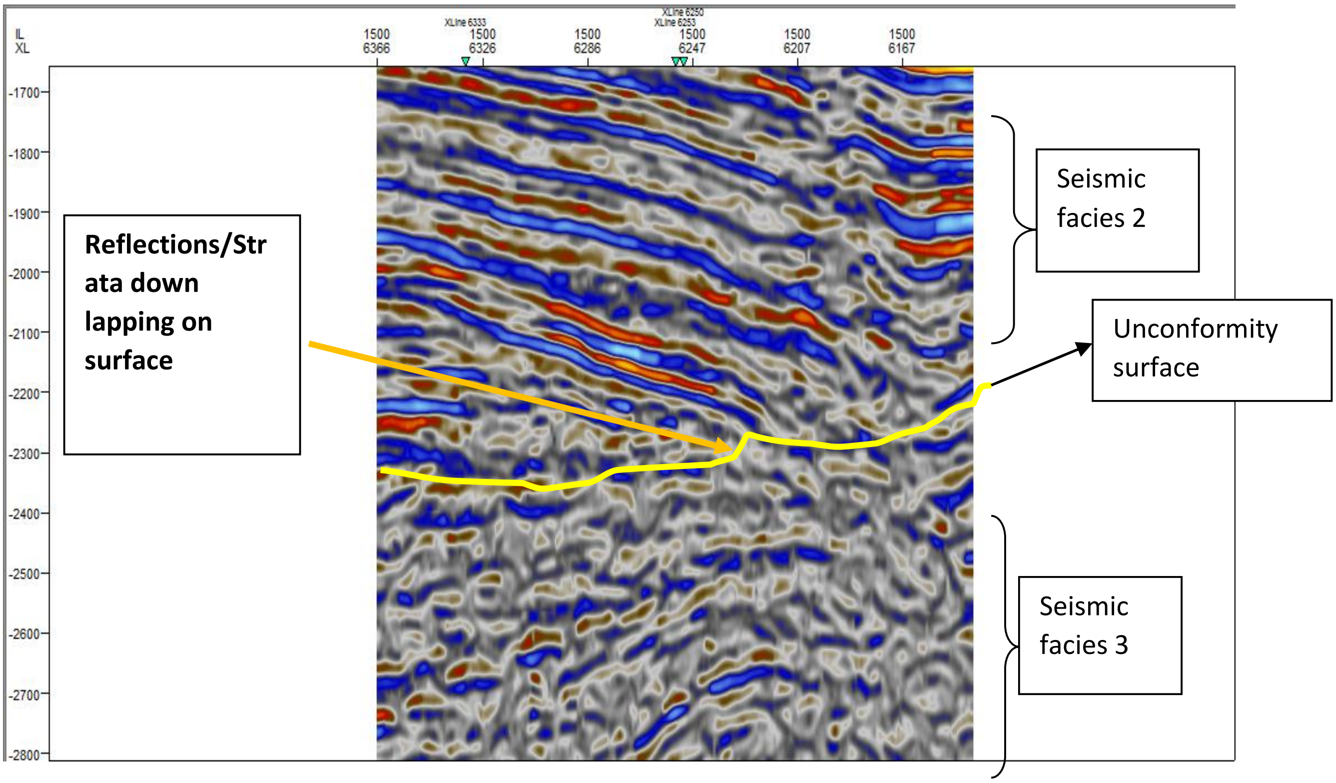


Figure 9 Unconformity Surface

Time and Depth Map

Time and depth structural maps of the identified Horizon E and F defined top of sand bodies (Fig. 15 - 16). The Horizon E and F of the structural contour maps show similar structural relationship. Figure 16 shows the depth of structural map of horizon-E. The depth map revealed the crest of the anticline at 1,900ft, which tied with the that of the well logs. The anticline dip closure established the trap for this reservoir. The throw of the fault indicate the faults are sealing based on Whiteman (1982); faults are still conductive as long as their throw is less than or equal to 500ft. Since it is less than 500ft it is sealing because it will be justaposed by shale an impermeable which prevent the migration of hydrocarbon. The depth of the reservoirs ranged 1500ft to 2500ft. Horizon F has similar features with horizon E. On the depth structural map, the up-dip

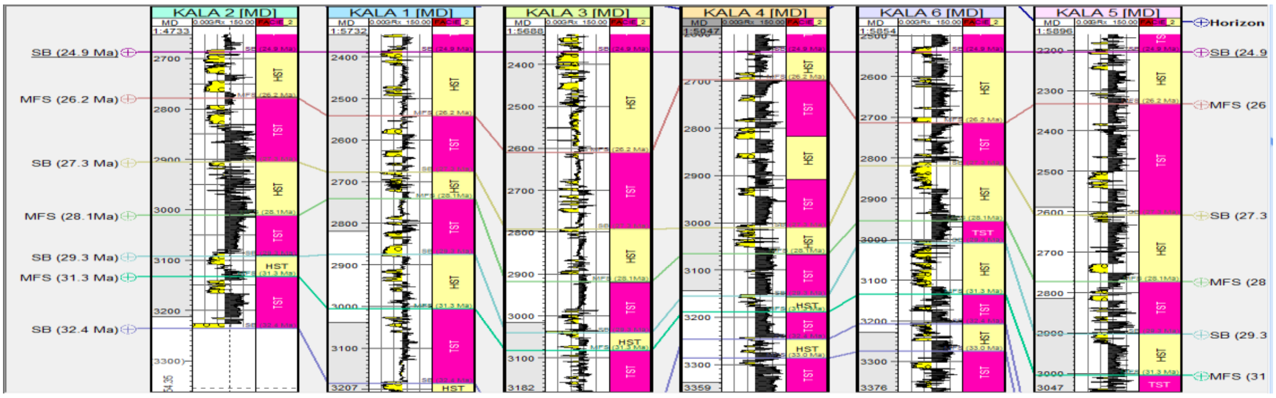


Figure 10 Sequence Stratigraphic Interpretation

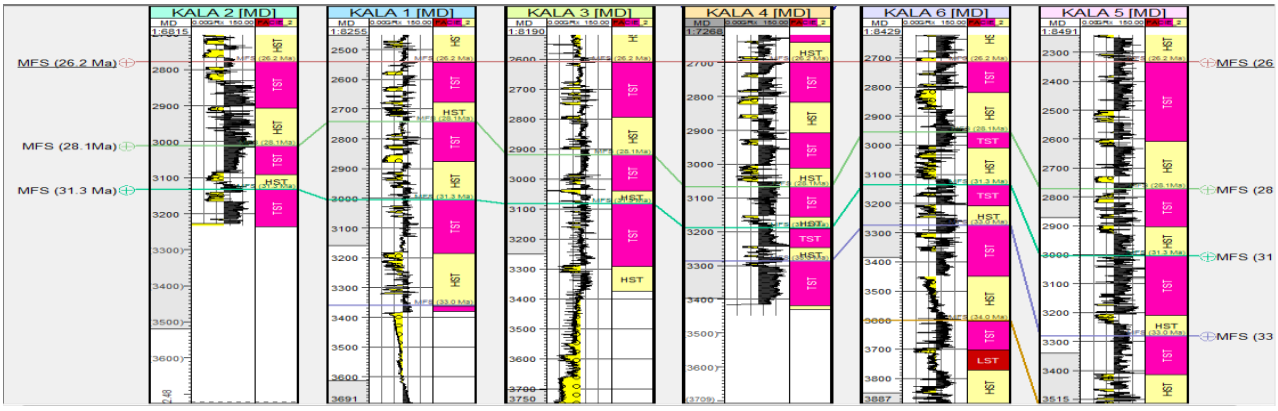
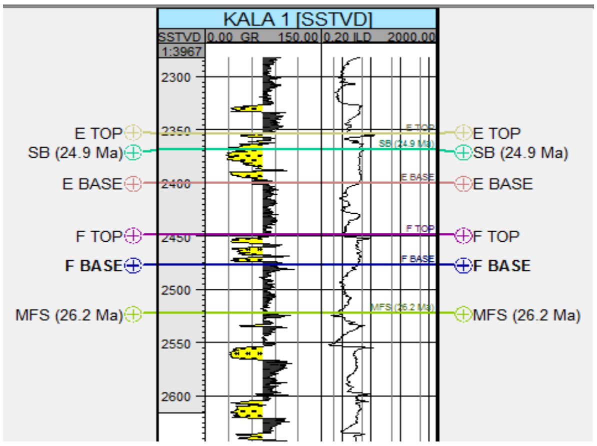


Figure 11 Sequence Stratigraphic Interpretation (Cont'd)

Areas were observed with closure signifying anticlinal structures where hydrocarbon may be trapped (Figure 17). This may serve as potential location where wells can be penetrated to improve development of the sands in the reservoir using the reservoir models generated.

Reservoir Models

Reservoir modeling, helped evaluation of Kala Field and the model was generated for petrophysical parameters like porosity, permeability, NTG, and water saturation (Fig. 19 - 28. The two horizons interpreted were subdivided into blocks A, B and C. Block A and C had good petrophysical values (Fig. 20 - 21). The Oil water contact and fluid distribution was delineated using the resistivity log and the results show block B in both Reservoir E and F have predominantly water, while block A and C in both reservoirs has hydrocarbon of commercial importance. (Fig. 23 - 28).



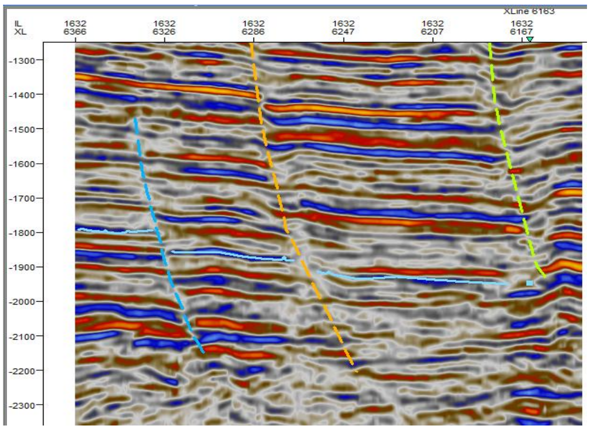


Fig. 12 Reservoir E and F Parasequences definition

Fig. 13 Interpreted Faults

Petrophysical Interpretation

Characterizing a reservoir begins with the determination of reservoir properties/parameters such as porosity (Φ), permeability (K), fluid saturation, NTG among others. The petrophysical curves of two wells Kala 1 and Kala 2 indicated reservoirs E and F petrophysical attributes are economically viable (Fig. 28 – 29, Table 1).

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Porosity Model

Blocks A and C in Reservoirs E and F have porosity values of 25%, 25%, 22% and 23% respectively (Fig. 30 – 31, Table 2 -3). These porosity values indicated that the reservoirs have excellent porosities to accommodate appreciable quantity of hydrocarbon

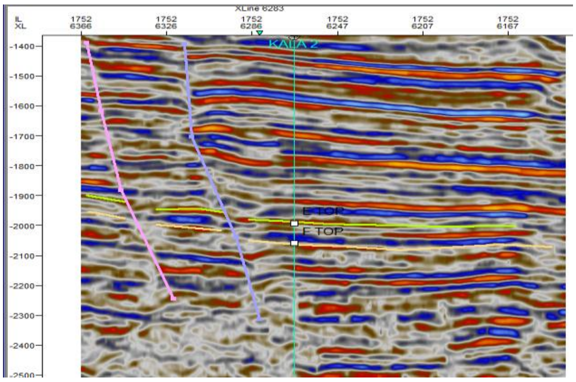

Fig. 14 Interpreted horizon E and F

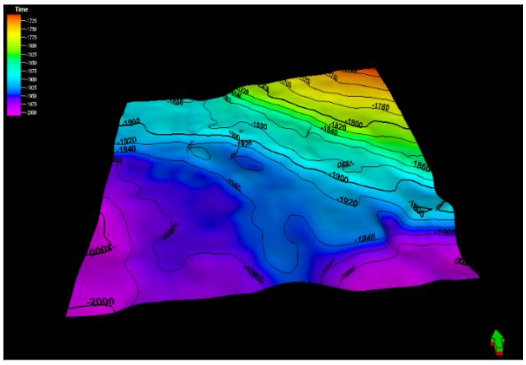

Fig. 15 Reservoir E time surface map

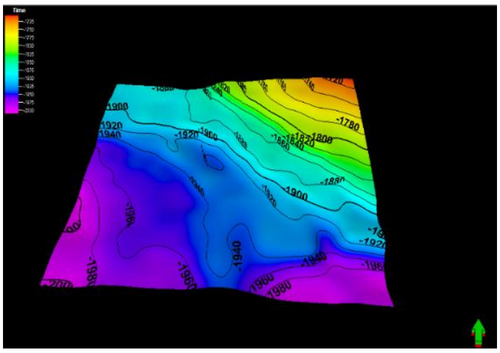

Fig. 16 Reservoir F time surface map

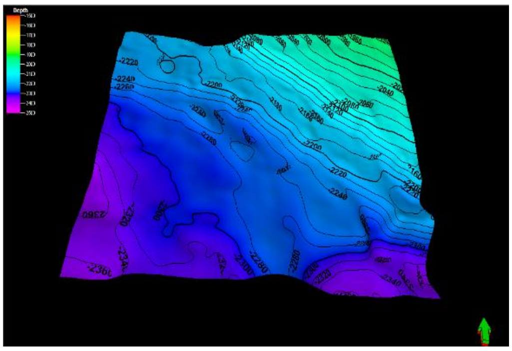

Fig. 17 Reservoir E depth map

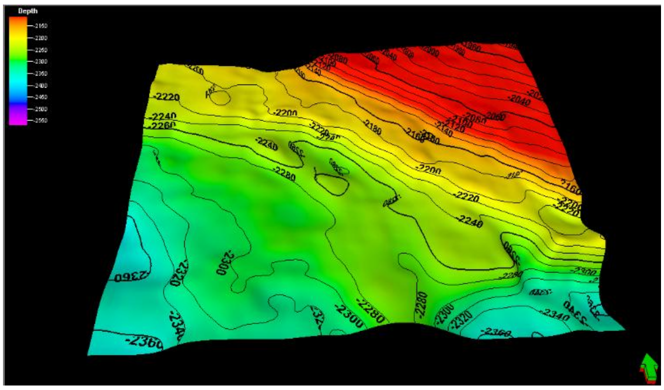

Fig. 18 Reservoir F depth map

Permeability Model

The permeability model shows that the permeability values of block A and C in both reservoir E and F indicate it is a good reservoir (Fig.32 – 33, Table 2 -3).

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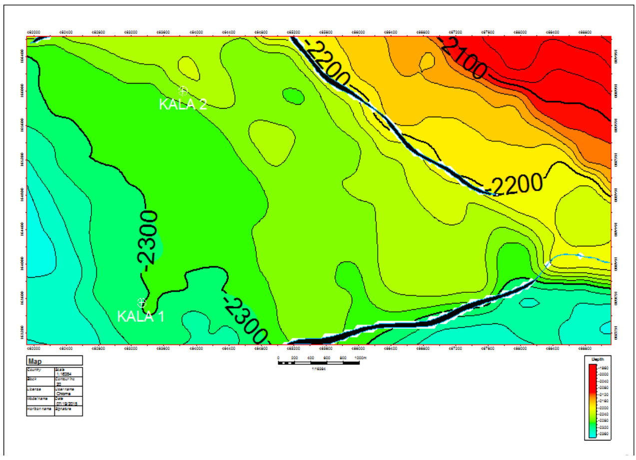


Fig. 18 E top Structural map

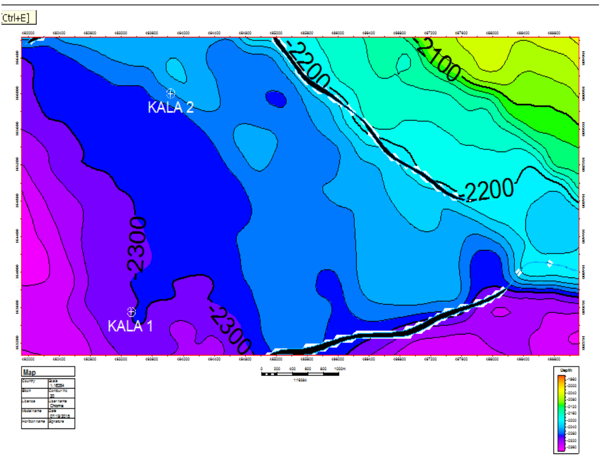


Fig. 19 F top Structural map

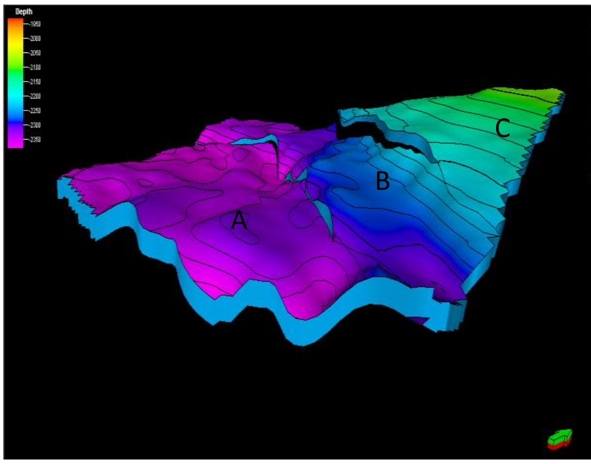


Fig. 20 E Reservoir Model

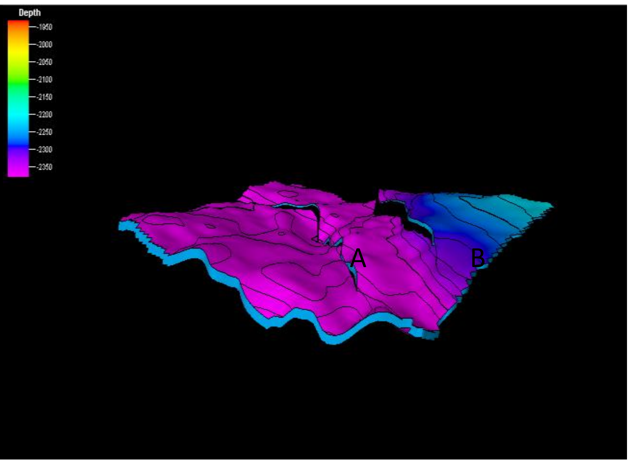


Fig. 21 F Reservoir Model

Net-To-Gross Model (NTG)

The NTG model suggests high volume of hydrocarbon bearing rocks. The blocks A and C of Reservoirs E and F denote a good prospect evident from their high NTG value (Fig. 34 -35).

Water Saturation Model

From the water saturation model, blocks A and C depicts low water saturation and in turn, high hydrocarbon saturation, Block B having high water saturation was not captured in the water saturation model. Areas with 100% water saturation were cut off (Fig. 36 – 37).

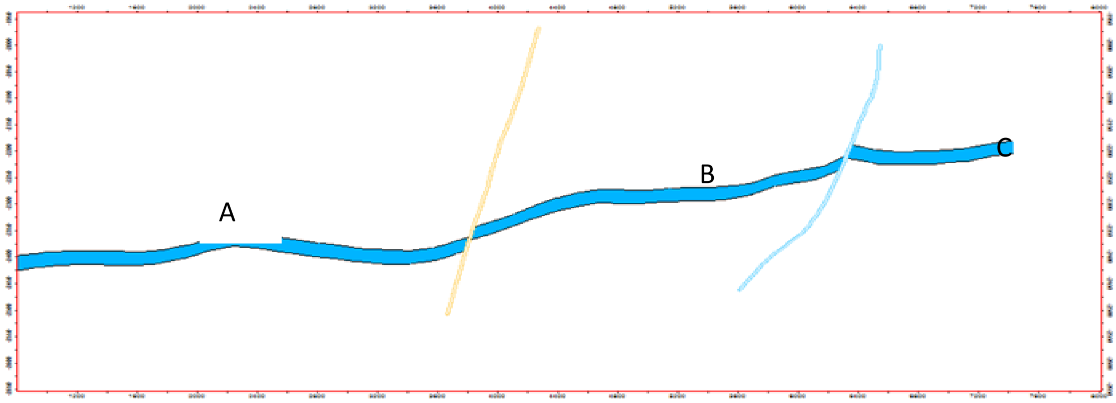


Fig. 22 Cross section of E Reservoir

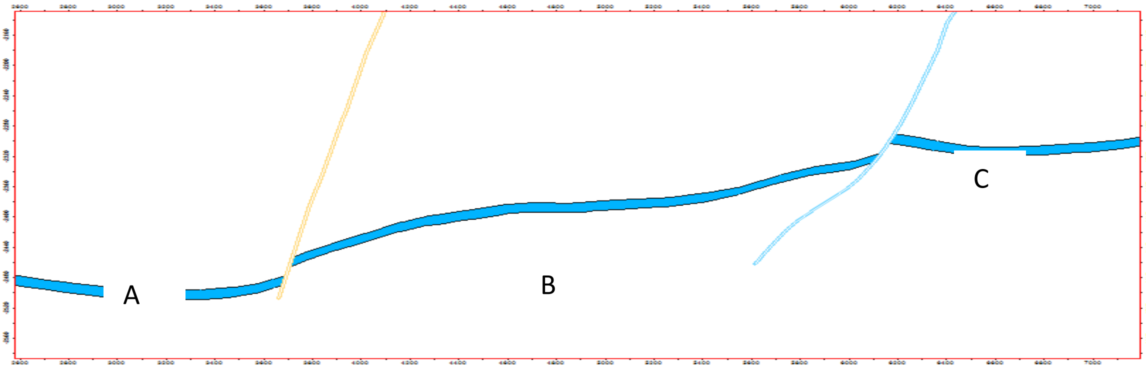


Fig. 23 Cross section of F Reservoir

CONCLUSION

Reservoirs E and F are hydrocarbon bearing delineated, mapped and identified at time levels of 1900ms and 2000ms with depth equivalents of 2350m and 2460m respectively. Parasequences defined for reservoirs E and F are within the HST while structural traps have partitioned Reservoirs E and F into blocks A, B and C. Blocks A and C are hydrocarbon bearing while B is water bearing. The petrophysics of reservoirs E and F indicate large accumulations of hydrocarbon, whereas the STOIIP showed economic viability. This work has demonstrated the relationship between seismic stratigraphy and petrophysical properties of reservoirs and provide a basis for elucidating geological factors that influence the areal distribution of reservoirs, facies, and the establishing prospects 1 and 2 in Kala Field.

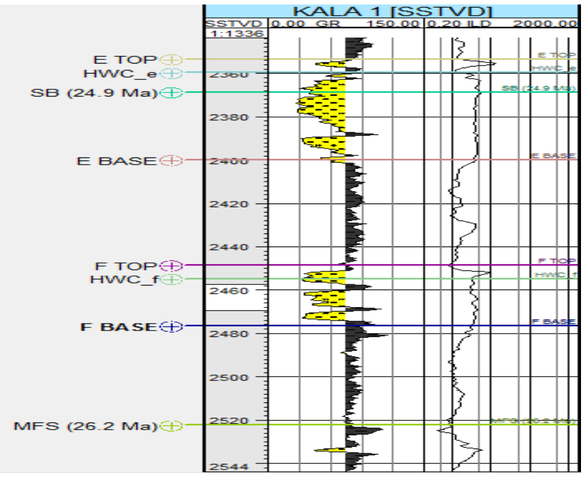
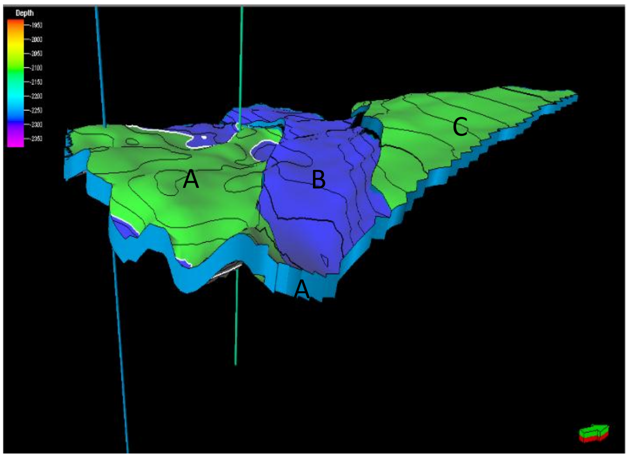


Fig. 24 Contact delineation for Reservoir E and F



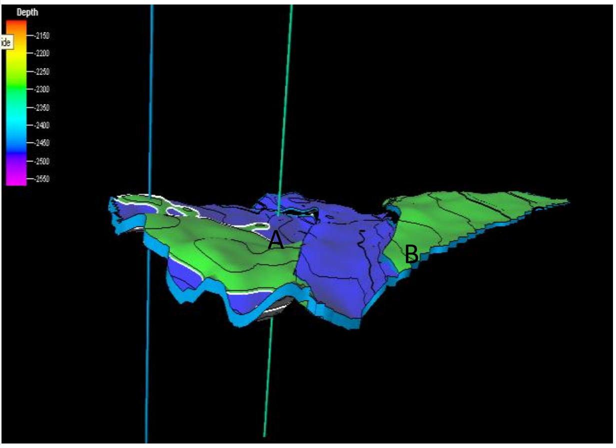


Fig. 25 Reservoir E fluid distribution

Fig. 26 Reservoir F fluid distribution

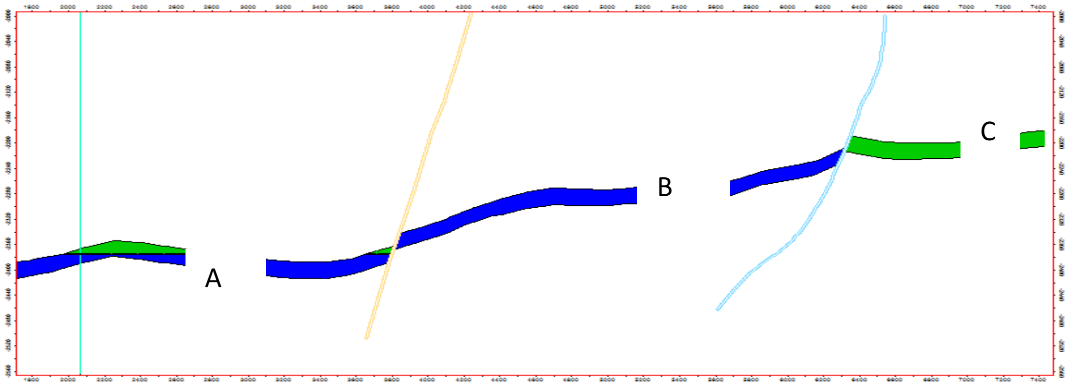


Fig. 27 Cross section of fluid distribution for Reservoir E

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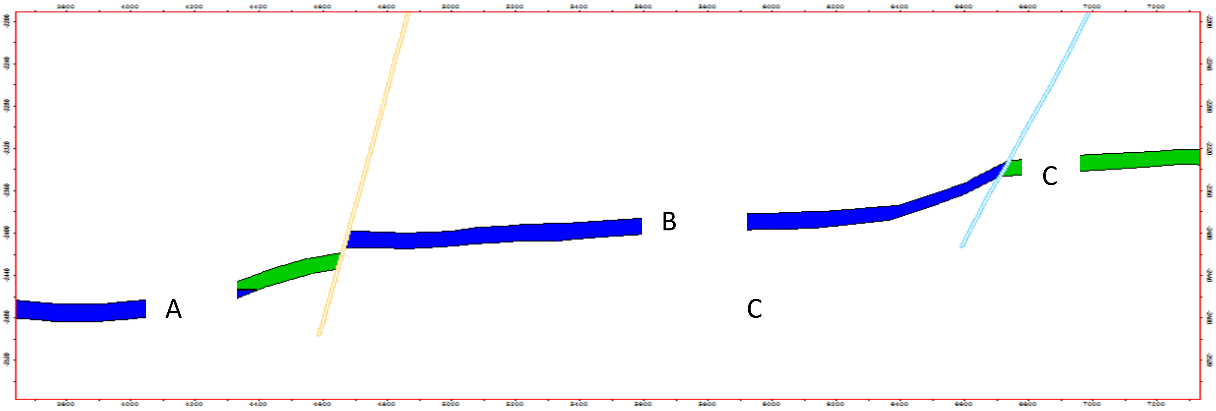

Fig. 28 Cross section of fluid distribution for Reservoir F

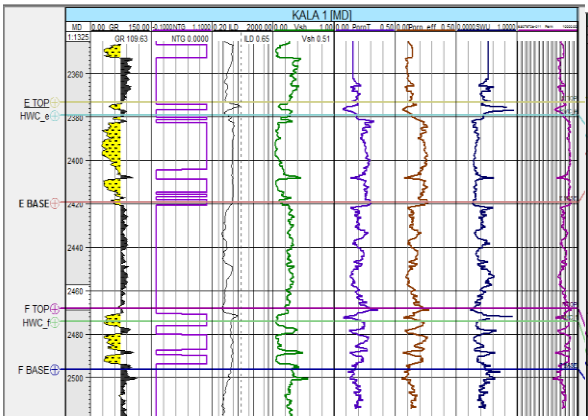

Fig. 28 Petrophysical curves for Kala 1

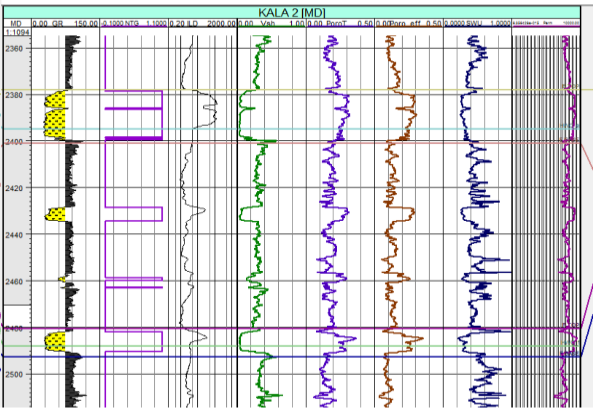

Fig. 29Petrophysical curves for Kala 2

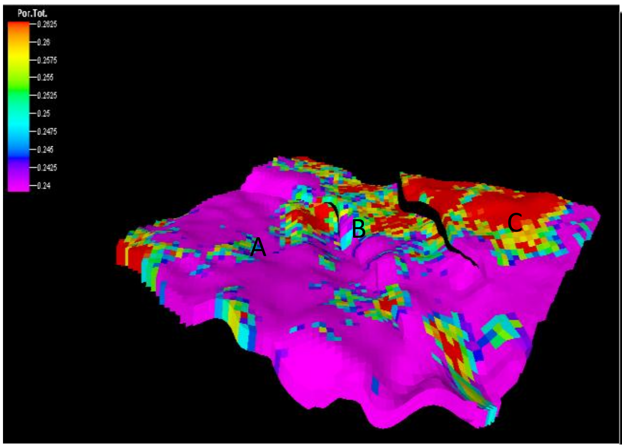

Fig. 30 Reservoir E porosity Model

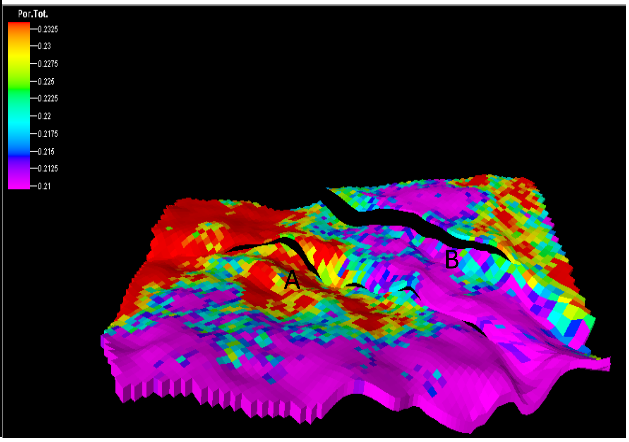

Fig. 31 Reservoir F porosity Model

Table 1 Average Petrophysical values for block A and C

Properties Reservoir	**NTG %**	**Porosity %**	**Permeability (MD)**	**Water Saturation %**
RESERVOIR E (Block A)	74	25	291	0.45
RESERVOIR E (BlockC) Prospect 1	**80**	**25 (Very Good)**	**300 (Very Good)**	**0.34**
RESERVOIR F (Block A)	64	22	1850	0.39
RESERVOIR F (Block C) Prospect 2	**66**	**23 (Very Good)**	**1990 (> 1000- Excellent)**	**0.37**

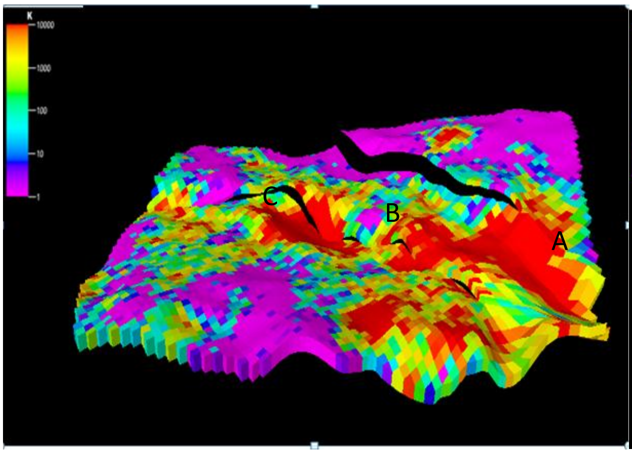

Fig.32 Reservoir E Permeability Model

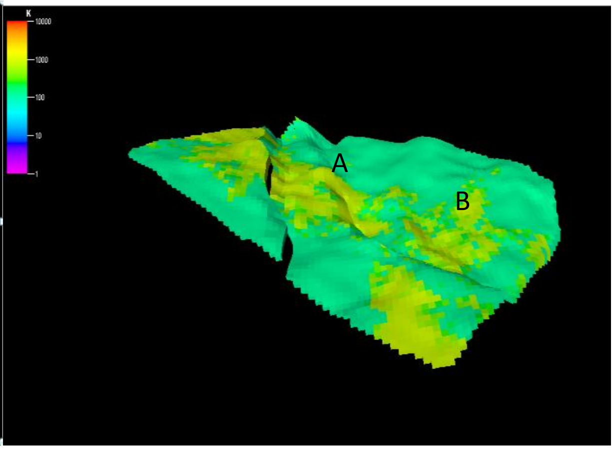

Fig. 33 Reservoir F Permeability Model

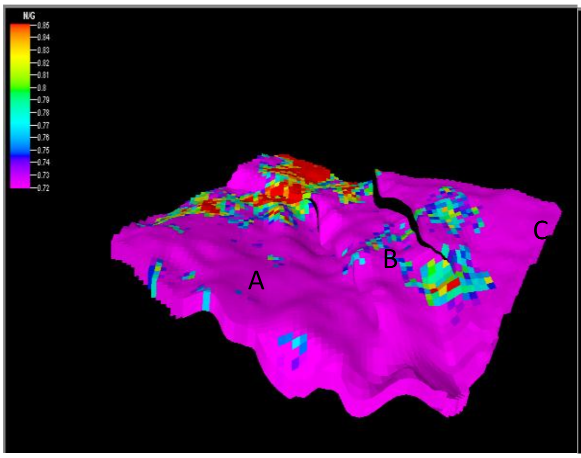

Fig. 34 Reservoir E NTG Model

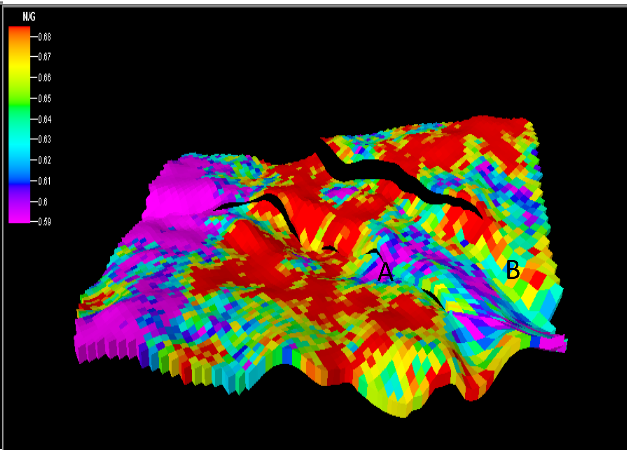

Fig. 35 Reservoir F NTG Model

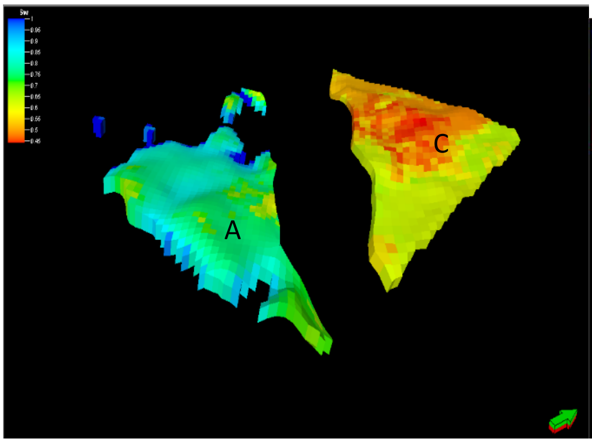

Fig. 36 Reservoir E Water Saturation Model

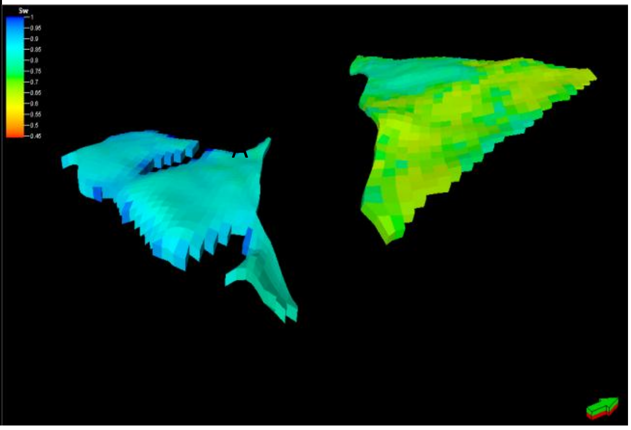

Fig. 37 Reservoir F Water Saturation Mode

Table 2 Reservoir E Volume Estimation

Case	**Bulk volume $[10^{*}6m^{3}]$**	**Net volume $[10^{*}6m^{3}]$**	**Pore volume $[10^{*}6m^{3}]$**	**HCPV oil $10^{*}6m^{3}]$**	**HCPV gas $10^{*}6m^{3}]$**	**STOIIP (in oil) [10*6STB]**
Case E	418	303	74	48	0	81.54
Zone 1	418	303	74	48	0	81.54
Segments						
Block A	284	205	50	32	0	54.71
Block B	0	0	0	0	0	0
Block C Prospect 1	134	98	25	16	0	26.83

Table 3 Reservoir F Volume Estimation

Case	**Bulk volume $[10^{*}6m^{3}]$**	**Net volume $[10^{*}6m^{3}]$**	**Pore volume $[10^{*}6m^{3}]$**	**HCPV oil $10^{*}6m^{3}]$**	**HCPV gas $10^{*}6m^{3}]$**	**STOIIP (in oil) [10*6STB]**
Case F	161	103	23	14	0	23.56
Zone 1	161	103	23	14	0	23.56
Segments						
Block A	107	70	15	9	0	15.47
Block B	0	0	0	0	0	0
Block C Prospect 2	55	36	8	5	0	8.08

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