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Modelling of Reservoirs in Awe-Field, Eastern Niger Delta, Nigeria

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Abstract:*Reservoir modelling has been used to predict reservoir performance and gain understanding of reservoir uniqueness in "AWE FIELD" Eastern Niger Delta.A qualitative and quantitative approach was adopted to characterise and model the hydrocarbon bearing sands in the study area. Deviation/survey data, 3D seismic volume, wireline logs for five wells and checkshot data were used for this study. Reservoir zone G and I were delineated and correlated across the 5 wells using reservoir modelling software. The deterministic model adopted distributed the rock properties (structural, petrophysical and facie data) into a 3D grid using Sequential Gaussian Simulation and Sequential Gaussian Indicator algorithm. From this study three major faults were identified across reservoirs G and I. Well point petrophysical values were computed and compared with the deterministically modelled results. Reservoirs G and I have average thickness of 661ft and 558ft, net-to-gross of 78% and 75%, porosity of 29% and 26%, water saturation of 50% and 43%, permeability of 262.5mD and 77.06mD respectively. Well point petrophysical values for reservoir G show similarity when compared with deterministic value while, well point derived petrophysical value for reservoir I shows similarity in net-to-gross, porosity, and water saturation but dissimilarity in permeability. This difference in permeability value between the well point petrophysics and deterministic petrophysics shows that the deterministic value is more reliable. Based on Rider's classification reservoir G has very good porosity and very good permeability while reservoir I has a very good porosity and a good permeability. The delineated reservoirs are oil bearing and have a STOIIP (Stock tank oil initially in place) of 156MMSTB and 127MMSTB respectively. These values are satisfactory for economic production of the reservoirs. The environment of deposition of the reservoirs-based log motifs are interpreted as distributary channel fill and shoreface. The results of the porosity and permeability of Awe Field are in range of those reported in the Niger Delta. The STOIIP for reservoir G is higher than I because of higher shale intervals in reservoir I. Reservoir I is a shoreface deposit. The shorefacedepositcontains high shale contentthat could act as baffles to flow as seen in the 3D models of the lithofacies, porosity and permeability.*

Key Words*: Deterministic model, Sequential Gaussian Indicator algorithm, porosity, permeability, distributary channel fill, Shoreface, Niger Delta, well point value.*

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I. Introduction

After hydrocarbon has been discovered in a field, additional studies are carried out to evaluate the reservoir, to understand the reservoir heterogeneity, delineate the extent of the reservoir in three dimensions and estimate the volume of fluid in the reservoir to know the best development model the reservoir management team will adopt for maximum and efficient reservoir fluid recovery. It is widely recognized that reservoir characteristics such as: structures, lithofacies heterogeneity, spatial variability of porosity and permeability control the reservoir performance, development strategies and the returns on investment in the reservoir (Ailin et al, 2014). Reservoir modelling involves construction of a computer model of the petroleum reservoir to improve the reservoir estimate and predict the reservoir production.The process begins with describing various reservoir characteristics such as geologic, petrophysics, geochemical and engineering properties, using all available data to provide reliable reservoir models for accurate reservoir production and performance prediction as well as economic and safe decision making in determining the viability of the reservoir (s) under study (Jong-Se Lim, 2005) To comprehensively understand the reservoir uniqueness, it is important to adopt qualitative and quantitative approach. The 3D reservoir model is a geomodel of the reservoir's spatial representation of the reservoir properties capturing key heterogeneity of the reservoir. Models are not precise representation of the real world but merely a computer-aided design showing property distribution of the reservoir characteristics which, helps in the prediction of the reservoir's future outcome. Reservoir models also help toidentify the best and safest drilling, completion and recovery option for a reservoir as well as the most economic, efficient, and effective field development plan for that reservoir.

To build a geologic reservoir model, the reservoir must be described/characterized using all available data obtained from well -points such as well directional/survey, well logs, drill cuttings, core, pressure point, geochemical and paleontology. All these data are taken and logged against depth at the wellsite. Well logs are very important in reservoir characterization and are vital source of quantitative data on porosity, permeability and fluid saturation. It is also useful in correlation and constructing both structural and stratigraphic cross-sections. Well log shapes are good indicators of reservoir depositional environment whereas Seismic data can contribute to the geometric description of reservoir structure and stratigraphy by meaningful interpretation of the data (Selley 1978). Seismic interpretation is useful for structural and stratigraphic analysis however, the primary objective is to prepare contour maps (Emujakporue et al., 2012).To characterize and develop models of the reservoir properties in the field, the study integrates seismic interpretation, rock petrophysical properties and their distribution to provide reservoir models for predicting the reservoir volumetric. The reservoirs in the Awe Field will be subdivided based on stratigraphic features and depositional environment.

The aim of this research is to characterize and carry out 3D static modelling of AWE Field Eastern Niger Delta Nigeria. The objectives are as followscorrelate the reservoir across the five wells, delineate the hydrocarbon bearing reservoir, map major faults within the field, compute the petrophysical parameters such as porosity, permeability net-to-gross ratio and water saturation using the deterministic approach. Compare the well point petrophysical values with deterministically modelled results. In addition to, inferring the depositional environment from well-log motif and relate the quality of the reservoirs to its environment of deposition. Creating a 3D static petrophysical and facies model and evaluate the reservoir hydrocarbon volume. The study area is located within the south-eastern part of the coastal swamp depo belt region of Niger Delta (Figure 1). The geology of the Niger Delta is well established, the stratigraphic and structural framework and petroleum geology (Doust and Omatsola, 1989, 1990; Reijers, 1996; Kulke, 1995; Ekweozor and Daukoru, 1994; Evamyet al, 1978). See Figure 2.0

1a 1b

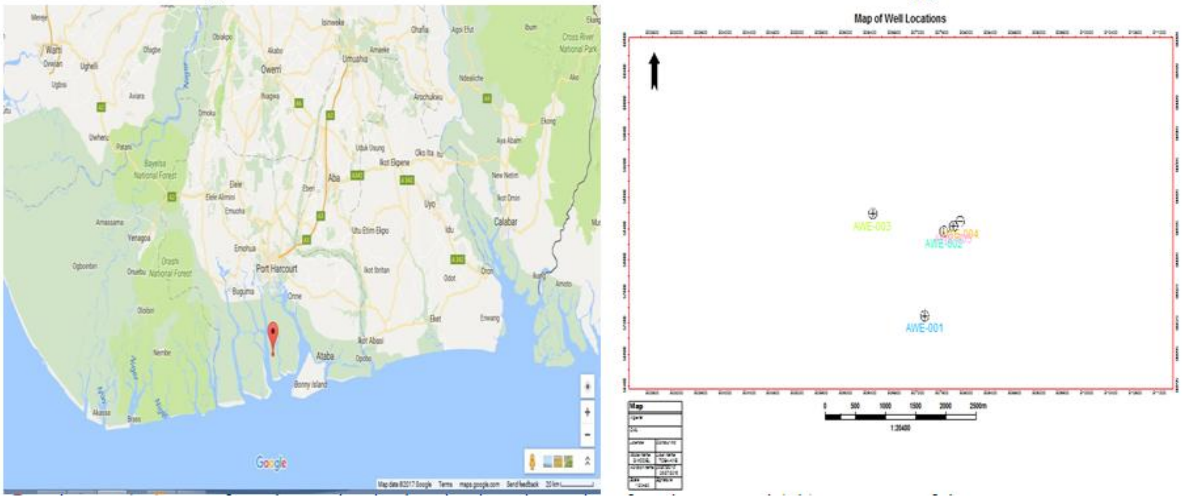
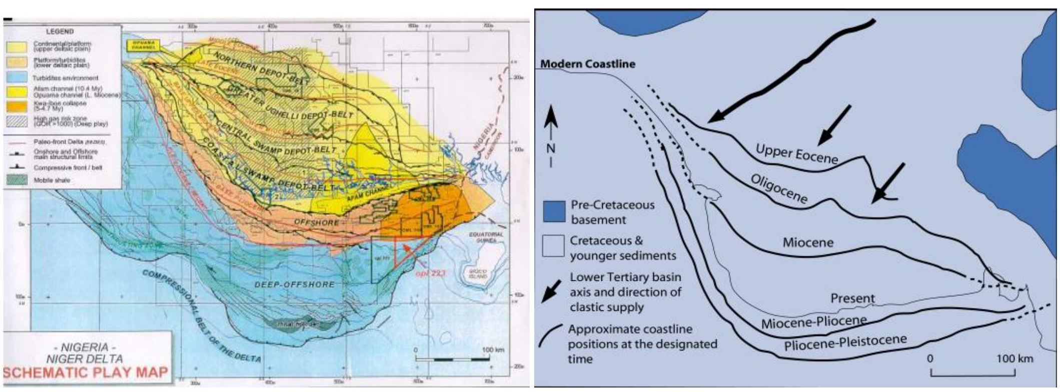


Figure 1(1a)Map of southern Nigeria showing location point of study area and (1b) Base map of the study area with well-locations



(2a) (2b)

Figure 2(2a) Map of Niger Delta showing the depobelts(2b) Cartoon showing how the coastline of the Niger Delta has prograded since 35Ma. (USGS, The Niger Delta Province).

II. Materials And Methods

Materials

Proprietary data used for this research was obtained from an IOC in Nigeria and the data provided include 3D seismic data, well log data for 5wells, deviation/survey data and checkshot data

Methods

The work flow diagram illustrates the methodology applied in this research (Figure 3). Quantitativepetrophysical analysis and evaluation was carried out on the five wells to determine the Net-to-Gross (NTG), Porosity (ϕ), Water saturation ($S_{w)}$, and Permeability (K) from the well logs. The results are displayed in log format for better interpretation. See Figure3. The formula upon which the software computes the petrophysical parameters are shown below.

1. Effective Porosity

$$\phi_{eff} = \phi_D - (V_{sh} \times \phi_{Dsh}) \quad (1.0)$$

Where:

ϕ_{eff} = Effective porosity

ϕ_D = Total porosity

V_{sh} = Shale volume

ϕ_{Dsh} = Shale porosity from density log

$$GR_i = (GR_{log} - GR_{min}) - GR_{min}) / (GR_{max} - GR_{min}) \quad (2.1)$$

$$V_{sh} = 0.083 \times (2^{(3.7 \times GRi)} - 1) \quad (2.2)$$

Where: GRi = Gamma ray index,

GR_{log}= Gamma ray log reading,

GR_{min} = Minimum Gamma ray log reading, which signifies clean sand and GR_{max}= Maximum Gamma ray log reading, which signifies 100% shale. Both equations calculate the volume of shale but equation 3.2 is the corrected one.

2. Permeability

$$K = (250 \times \phi_{eff}^3 / S_{wirr})^2 \text{ [Tixerequation]} \quad (3.0)$$

Where:

K = Permeability

ϕ_{eff}=Effective porosity

S_{wirr}= Irreducible Water Saturation

3. Water Saturation

$$S_w = 0.082 / \phi \text{ (Udegbunam and Ndukwe, 1988)} \quad (4.0)$$

Where:

S_w= Water saturation

ϕ = Effective porosity

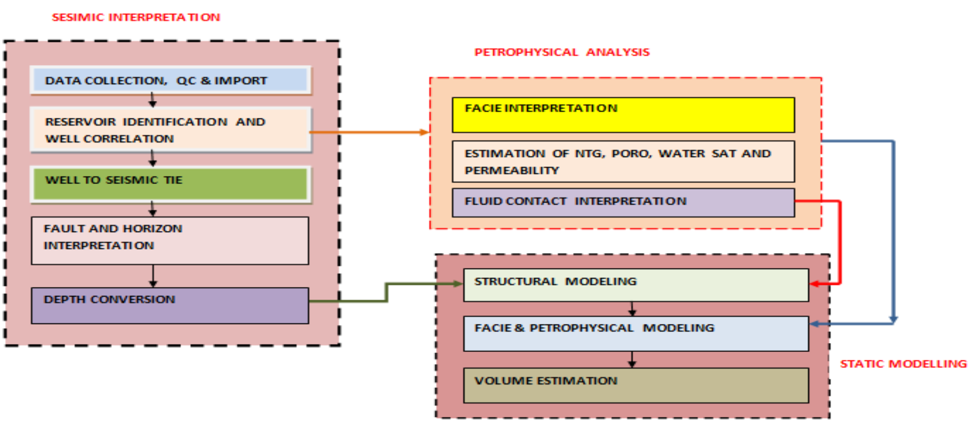


Figure 3 Methodological approach for this reseach.

Hydrocarbon types in the reservoir are correlated using Resistivity and Neutron/Density log to differentiate between fluid types and infer their contacts. The neutron log was used to delineate the oil-water contact when combined with the bulk density log. For reservoir sand containing both oil and gas, the neutron reading is higher in the oil zone than the gas zone. Neutron and density logs are placed in a single log track in such a way that both logs overlay in water bearing formation. In oil bearing sand, neutron porosity log and density log over lay each other, showing minor positive separations and maintaining almost similar reading with the water bearing reservoir sand. Where there is gas in the reservoir sand, neutron porosity log deflects to the right, showing a decrease in neutron porosity while the bulk density log deflects to the left, giving a negative separation which is known as "balloon shape/structure".

Seismic Interpretation

In well-to-seismic tie, theCheckshot data for well 1, 3 and 4were used to compute velocity required and seismic reflection coefficient used in create the synthetic seismogram. This is important in identifying the origin of the seismic reflection seen on the seismic section. The synthetic seismogram was tied to the seismic volume and used to pick the right event (reservoir tops).

Fault and horizon mapping

Faults typical of Niger Delta structure were mapped. Fault mapping on the seismic section was based on delineation of fault planes, reflection discontinuity at fault planes, vertical reflection displacement and abrupt termination and change in pattern of events across the fault (i.e. synthetic or antithetic faults). Horizons of the interested well tops where picked on the seismic using the time equivalent from of the reservoir well tops from Checkshot data. Two horizons where picked, horizon G and horizon I which, represent the tops of the delineated reservoir in "AWE" field.

Seismic time and depth surface maps

Time maps for the two horizons of interest, horizon G and I, were created and then converted to depth map using velocity model (Table 3). The velocity model converts the two-way time (TWT) map into the depth map with the equation: $V_0 + K^*Z$. Where V_0 is the Velocity of the mapped horizon, K is the constant at which the velocity changes and Z is the depth obtained.

3D Static Modelling

The 3D seismic data was used to generate horizon, polygon and grid data as framework for the 3D model. Deterministic model approach was adopted in the distribution of the rock properties (petrophysical and facies data) into a 3D grid using Sequential Gaussian Simulation and SequentialIndicator Simulation Algorithm respectively. The result for the various petrophysical analysis such as net-to-gross (NTG), effective porosity (ϕ), permeability (K) in mD, and water saturation (S_w) were used to used to estimate the volume of oil in the reservoir (Table 7). Equation 3.5 shows the formula used in computing the reservoir volumetrics – stock tank oil initially in place (STOIIP).

$$\textbf{STOIIP} = (7758 \times A \times H \times \phi \times NTG \times S_h) / Boi \qquad (3.5)$$

Where:
Boi = initial oil formation volume factor
A x H = Gross rock volume

III. Results And Discussion

The results of the research are presented are in Figures 4 to 15 and Tables 1 to10. Five wells used in this research is presented in Figure 5.0. Information on the reservoir top and base depth which are important data for geosteering and well placement (Tables 1 and 2). The results of the reservoir fluid type and contact with contact depth at 10950ft, 9750ft, 9750ft, 9750ft, and 9750ft for Awe 1, Awe 2, Awe 3, Awe 4 and Awe 5 are in SSTVD (Figure 6.0). the result of the well-to-seismic tie shows a good tie between the synthetic seismogram and the seismic inline, seismic fault and horizons mapping (Figures 7- 11). Reservoir time map and the depth structural map produced from the time map is presented in Figure9 -10). The velocity model in Table 3 was used in converting the time map to depth structural map. The petrophysical values obtained for both reservoirs include 3D models of reservoirs structural, fluid contact, porosity, permeability and facies(See Figure 11 to 15).

Well-to-seismic tie seen (Figure 7) has a good match, this helped to check quality of the reservoir horizon picked by comparing seismic time data and well - depth data. Nine faults were delineated from the seismic lines, which are typical of the Niger Delta - normal growth fault, rollover, collapse crest, and antithetic faults were recognized by reflection discontinuity, displacement and abrupt termination and change in pattern of events. Rollover structure occur in west area of both reservoirs while the southern part is characterized by collapse crest (Figure. 8) The seismic, reveals the structural complexity in both reservoirs - mainly rollover anticline. From the structural map (Figure. 10), reservoir G is bounded by two major faults and reservoir I shows more folding than the G counterpart due to the presence of shale - the synthetic fault and antithetic faults in this field trend in NW-SW and NE-SW direction respectively. These structural styles contribute to hydrocarbon accumulation and entrapment - the hydrocarbon is believed to be trapped in the faulted anticline (Figure 11).The correlation gives the lateral extent and continuity of the reservoir across the five wells (Figure5). Two reservoirs (G and I) where delineated,reservoir G is predominantly sandy with minor intercalation of shale while reservoir I isshalysand with higher shale and shaleysandinterbeds (Figure 15). The reservoir top and base depths for the five wells were penetrated at different depths in Awe 1, Awe2 Awe 3, Awe 4 and Awe 5. Average thickness of the shallow reservoir, G is 660.8ft (SSTVD), with an average NTG 78%, porosity of 29%, permeability of 262.5mD and water saturation of 50% (Table 6).These values show similarity with values obtained at well point (Table 4 - 6).With these values, the reservoir has a very good porosity and a very good permeability (Rider (1986) qualitative description of reservoir quality) see Tables 7 and 8. The reservoirshave no oil-water-contact but an oil-down-to (Figure6). Reservoir I have average NTGof 75%, porosity of 26%, permeability of 77.1mD and water saturation of 43% (Table 7).The well point values for this reservoir show similarity in net-to-gross, porosity, and water saturation but the permeability is dissimilar when compared with deterministic value. The reservoir has a very good porosity and a good permeability based on Rider (1986) qualitative description of reservoir quality (Table 5 and 6). The reservoir shows oil-water-contact at depth 10950ft (SSTVD) in Awe 1 and 9750ft (SSTVD)in the other wells. (Figure 7). By comparing the two reservoir petrophysical values, reservoir G has the best hydrocarbon potential (Tables 4 – 9).

The 3D structural model reveals the highs and lows present the area, three wells (Awe 2, Awe 4 and Awe 5) are placed in the low angle anticline trough of the reservoir sand body G and the two reservoirs are purely oil-bearing (Figure. 11 - 15). The reservoir G does not have an oil-water-contact (OWC) but an oil-down-to (ODT) because the oil zone is separated from the water zone by shale interval. Reservoir I show oil-water-contact (OWC) and the model reveals that the reservoir contains more water compared to reservoir G (Figure 12). G and less than 100mD for I (Figure 13 - 14). When compared with reservoir G, Reservoir I generally have low porosity distribution because of the influence lithofacies distribution has on it (Figure 15). Awe1 and Awe3 is located within the orange colour portion of the model; this correspond to the highest porosity level of the field. Highest permeability (red colour) is observed in G while low permeability is observed in I. Environment of deposition plays a key role in reservoir characterization as well as in reservoir quality/performance prediction across field. Different reservoir sand bodies deposited in different depositional environments are characterized by different sand shape/geometry, size and heterogeneity. The depositional environment of the reservoirs has been inferred from of well logs using standard shape of GR-log (Figure 4). Clastic sedimentary facies mostly display characteristic vertical profiles in which grain size fines upward, coarsens upward, or remains constant. Determination of such these vertical variations in grain size from GR-log is extremely valuable in the diagnosis of depositional environment. See Figure 4.0. Lithological model shows only two facies (sand and shaleysand) with sand predominately present in reservoir G while reservoir I shows three main lithofacies distribution (Figure 15, Table 10)

IV. Conclusion

The Awe field has satisfactory porosity and permeability values. By comparing the two reservoir petrophysical values, reservoir G which is distributary channel has the best hydrocarbon potential than reservoir I which is a shorefacedeposit.The difference between average petrophysical well point value and the deterministic modelled petrophysical value shows that reservoir modelling is the preferred way of distributing reservoir properties across a field with few wells in other to predict reservoir performance and plan for future well with limited data.

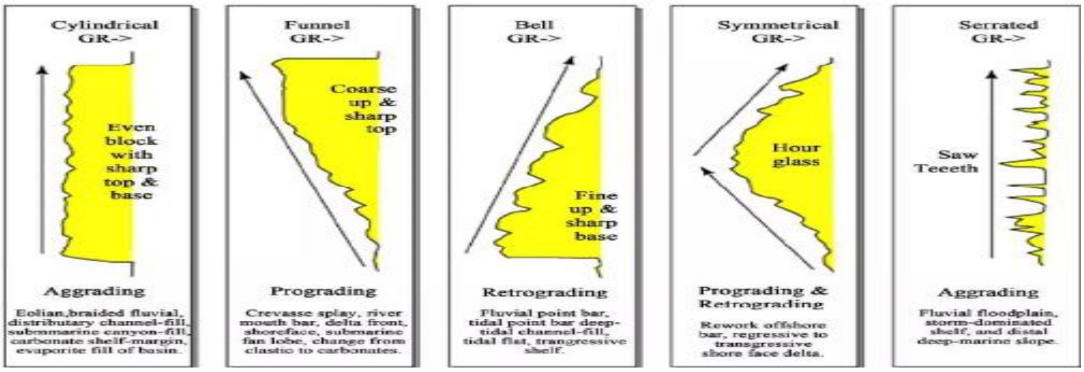


Figure 4 GR Log response for different environments - shows how vertical grain size profile of sandstone used to interpret facies.

Table 1: Reservoir G top, base and thickness

Reservoir G

Well Name	Top Ft	Base Ft	Thickness Ft
Awe 1	6714.12	7267.61	553.49
Awe 2	6497.9	7184.4	686.5
Awe 3	6507.09	7241.51	734.42
Awe 4	6424.18	7085.07	660.89
Awe 5	6454.97	7123.85	668.88
Average	6519.65	7180.49	660.84

Table 2: Reservoir I top, base and thickness

Well Name	Top Ft	Base Ft	Thickness Ft
Awe 1	10588.51	11342.71	754.2
Awe 2	9362.11	9872.14	510.03
Awe 3	9456.07	9805.48	349.41
Awe 4	9290.8	9972.34	681.54
Awe 5	9334.93	9828.82	493.89
Average	9606.48	10164.29	557.81

Table 3: Velocity model

	A	B	C	D	E	F	G	H	I
1	Velocity model	Velocity model							
2	User name	TOBA							
3	Project	"AWE" FIELD PROJECT.pet							
4	Date	Friday, 22-07 2016 10:36:00							
5	From:	TWT [ms]							
6	To:	Z [ft]							
7	XY:	[m]							
8									
9	Surface G	Well	X-value	Y-value	Z-value	Horizon after	Diff after	Corrected?	Information
10		AWE-002	507625.4	58374.5	-6435.95	-6435.95	-0.00	Yes	
11		AWE-001	507309.1	57299.3	-6657.85	-6657.85	0.00	Yes	
12		AWE-005	507783.4	58440.3	-6402.03	-6402.03	0.00	Yes	
13		AWE-003	506447.6	58601.1	-6459.01	-6459.00	-0.00	Yes	
14		AWE-004	507896.2	58499.2	-6377.86	-6377.86	-0.00	Yes	
15									
16	Surface I	Well	X-value	Y-value	Z-value	Horizon after	Diff after	Corrected?	Information
17		AWE-002	507625.4	58374.5	-9313.65	-9313.65	-0.00	Yes	
18		AWE-001	507309.1	57299.3	-10535.14	-10535.14	-0.00	Yes	
19		AWE-005	507783.4	58440.3	-9280.91	-9280.91	0.00	Yes	
20		AWE-003	506447.6	58601.1	-9409.65	-9409.65	-0.00	Yes	
21		AWE-004	507896.2	58499.2	-9241.74	-9241.74	-0.00	Yes	

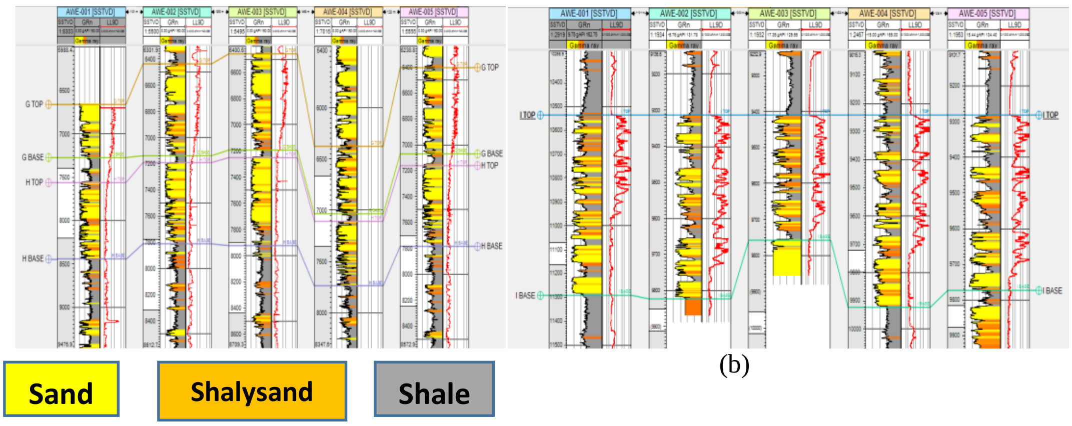


Figure 5: Well correlation panel

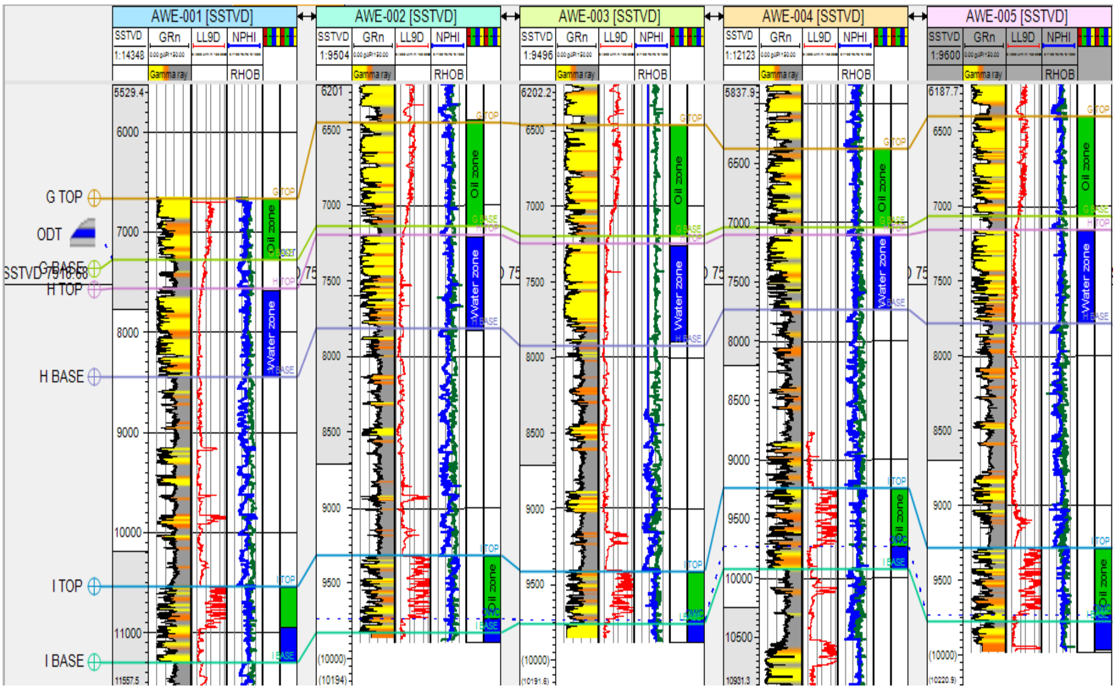


Figure 6: Hydrocarbon fluid contact

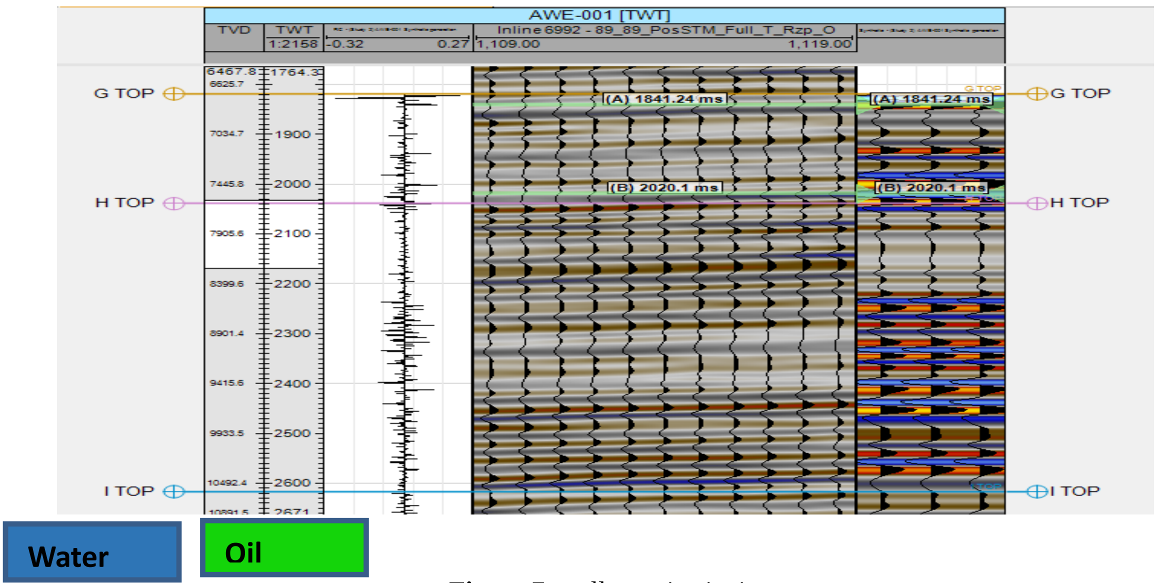


Figure 7: well-to-seismic tie

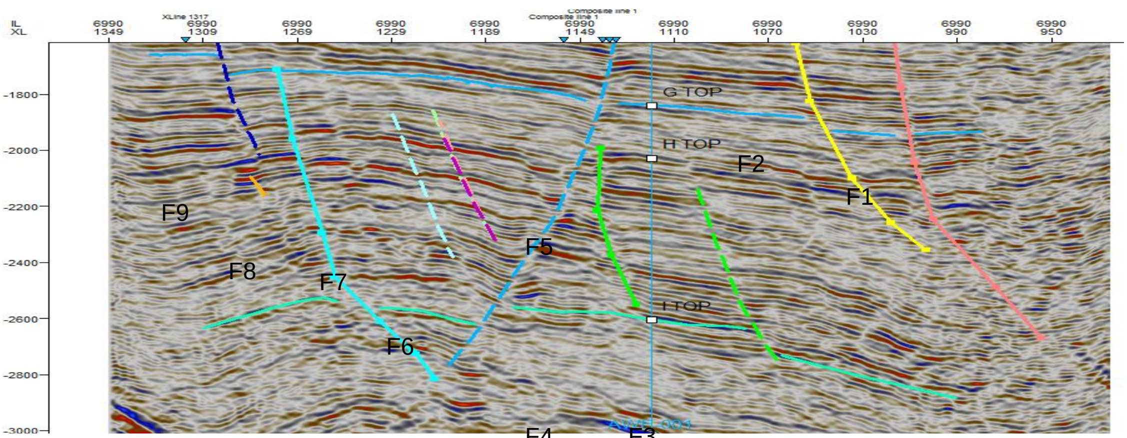
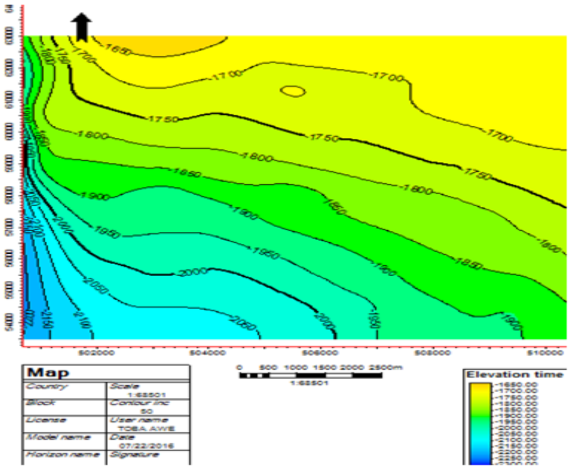
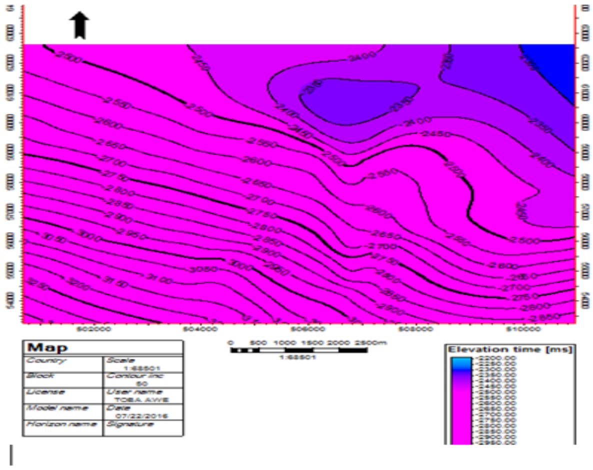


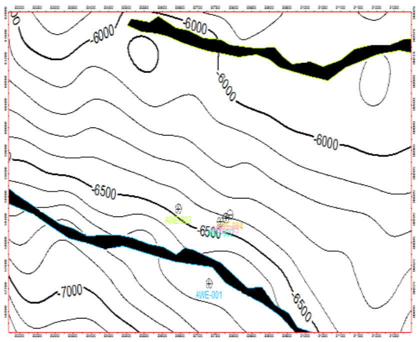
Figure 8. Fault horizon mapping

Figure 9a: Surface G Time map　　　　Figure 9b: Surface G Time map





I DEPTH MAP



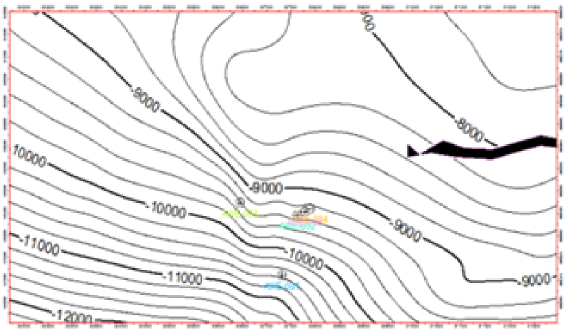
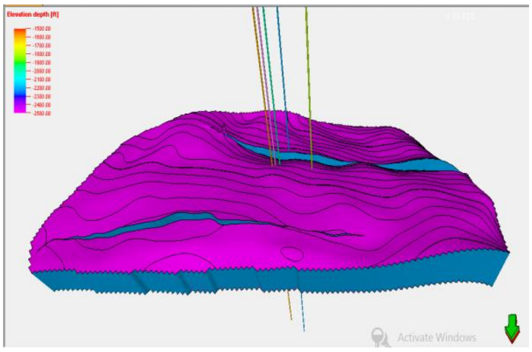


Figure 10a: Surface G Depth Structural MapFigure.10b: Surface I depth Structural map



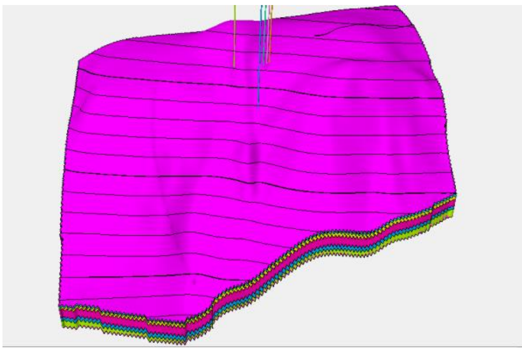
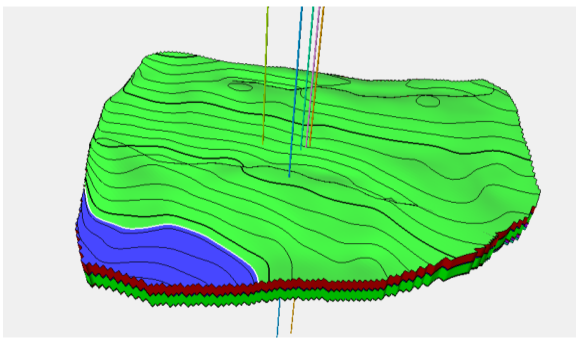


Figure.11a: Structural model of reservoir GFigure.11b: Structural model of reservoir I



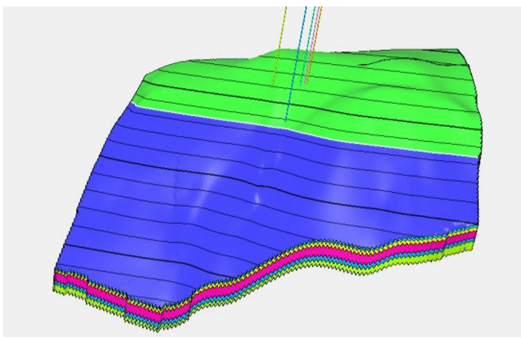


Figure12a: 3D Model of fluid contactfor Reservoir GFigure 12b: 3D Model of fluid contact for Reservoir I

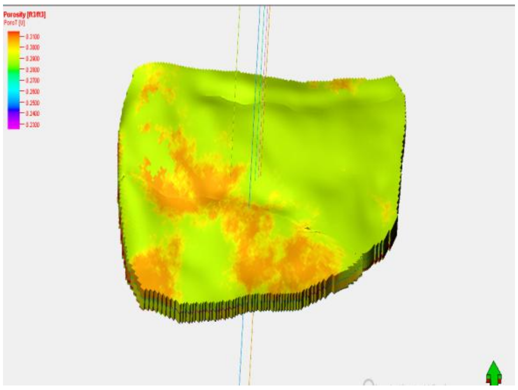
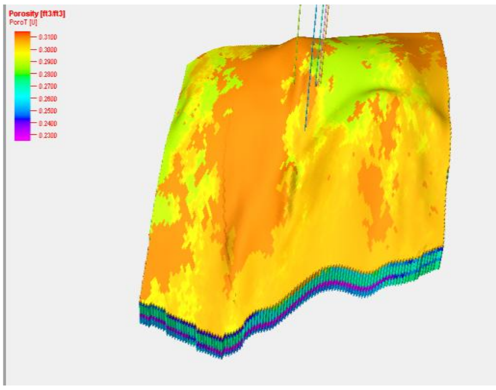



Figure13a: Porosity model for reservoir GFigure13b: Porosity model for reservoir I

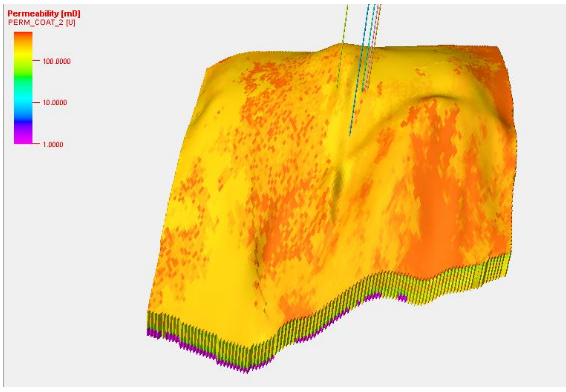
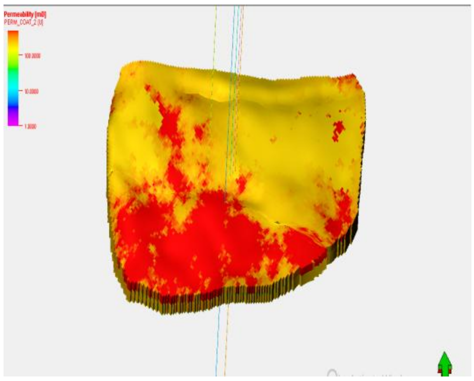
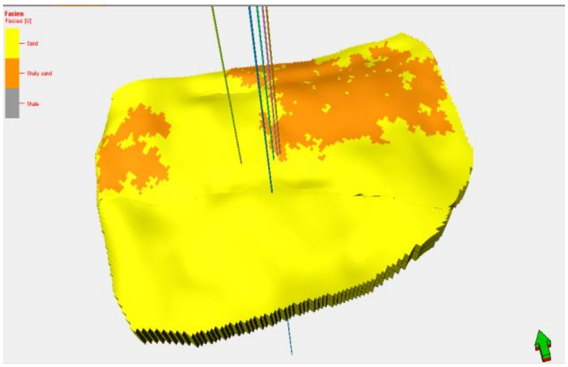
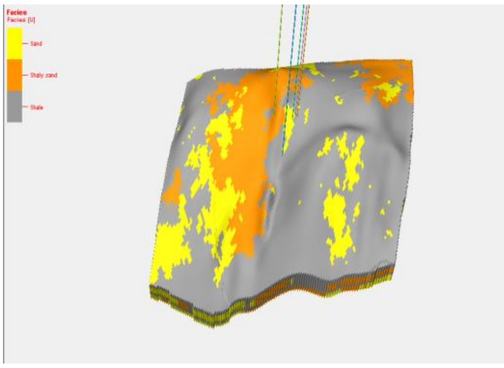



Figure14a: Permeability model for reservoir I
Figure 14b: Permeability model for reservoir G

Sand ShalySand Shale

Figure 15a: Facie model for reservoir I
Figure 15b: Facie model for reservoir G

Legend

Table 4: Reservoir G Well Point Petrophysical Values (NTG – Net to Gross, Poro – Porosity, Perm – Permeability, SWT – Water Saturation).

Well Name	Top	Base	Thickness	NTG	Poro	Perm m.D	SWT
Awe 1	6714.12	7267.61	553.49	0.84	0.3	357.71	0.48
Awe 2	6497.9	7184.4	686.5	0.69	0.29	215.73	0.47
Awe 3	6507.09	7241.51	734.42	0.79	0.3	247	0.48
Awe 4	6424.18	7085.07	660.89	0.71	0.3	229.04	0
Awe 5	6454.97	7123.85	668.88	0.76	0.3	236.97	0.49
Average	6519.65	7180.49	660.84	0.76	0.3	257.29	0.38

Table5: Reservoir I Well Point Petrophysical Values

Well Name	Top	Base	Thickness	NTG	Poro	Perm m.D	SWT
Awe 1	10588.51	11342.71	754.2	0.56	0.26	156.55	0.68
Awe 2	9362.11	9872.14	510.03	0.53	0.27	199.49	0.53
Awe 3	9456.07	9805.48	349.41	0.49	0.28	179.91	0.49
Awe 4	9290.8	9972.34	681.54	0.55	0.27	166.92	0.62
Awe 5	9334.93	9828.82	493.89	0.48	0.26	158.62	0.51
Average	9606.48	10164.29	557.81	0.52	0.27	172.29	0.57

Table 6: Reservoir petrophysical values

	NET-TO-GROSS	POROSITY	WATER SATURATION	PERMEABILITY
SAND G	0.78	0.29	0.5	262.50
SAND I	0.75	0.26	0.43	77.06

Table 7: Qualitative description of porosity value (After Rider, 1986)

Porosity, (ϕ) in %,	Quality Description
0 – 5	Negligible
5 – 10	Poor
10 – 15	Fair
15 – 20	Good
> 20	Very good

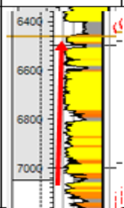
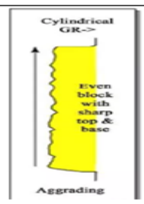
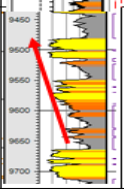
Table 8: Qualitative description of permeability value (After Rider, 1986)

Permeability, K in mD	Quality Description
< 10.5	Poor
11 – 15	Fair
15 – 50	Moderate
50 – 250	Good
250 – 1000	Very Good
> 1000	Excellent

Table 9: Reservoirs volume estimation

	Reservoir Sand G	Reservoir Sand I
Bulk Volume (*10^6 ft^3)	27191	415823
Net Volume (*10^6 ft^3)	27191	239379
Pore Volume (*10^6 RB)	1405	7100
HCPV Oil (*10^6 RB)	422	355
STOIIP (*10^6 STB)	156	127

Table10: **Environment Of Deposition Interpretation**

RESERVOIR SAND	GR LOG SHAPE	DESCRIPTION	INFERRED DEPOSITIONAL ENVIRONMENT	STANDARD GR LOG MOTIF	INFERRED RESERVOIR QUALITY
G		Cylindrical pattern with minor shale intercalation	Distributary channel fill deposit		Fair to excellent depending on the size of the channel
I		Funnel shape, coarsing upward sequence	Shoreface deposit		Fair to Good

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