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Volumetric Assessment through 3D Geostatic Model for Abu Roash "G" Reservoir in Amana Field-East Abu Gharadig Basin-Western Desert-Egypt

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Abstract

The main objective of constructing a geostatic model is to determine the 3-D geometry of the reservoir rock and assess its hydrocarbon volumetrics. To achieve this goal, the Amana oil field is taken as a real example. An integrated methodological approach was applied starting with data collection and quality control and then followed by interpretation of the available geological, geophysical and petrophysical data. The field area is located in the most eastern trough of the Abu Gharadig basin in the East Bahariya Concession in the Western Desert of Egypt. The source rock in this area is the Upper Jurassic Khatatba Formation that was deposited in a continental to inner-middle shelf environment. The reservoir rock is Abu Roash "G" sand, one of the seven lithologic members of the Abu Roash Formation.

Interpretation of seismic data together with well logs revealed the presence of a horst block, acting as a good structural trap, meanwhile the Abu Roash "F" carbonate and Abu Roash "G" shale are the seal rocks. Well data have shown that the reservoir rock in the Amana field is the Abu Roash "G" Member, which comprises three sand lithologic zones; namely the upper, meddle and lower zones. Of these zones, the middle one is the most attractive and has the best reservoir quality. The shale content in this sand is 8% compared to 13% and 26% in the upper and lower zones. In addition, the net to gross thickness ratio is less than 18%, more than 35%, and about 10% in the upper, middle, and lower zones, respectively.

Data analysis also indicates that the upper and lower zones are appreciably water wet. However, the middle sand zone appears to be prospective. The net pay thickness in this zone varies between 10 and 32 ft, porosity 19-22%, water saturation 18-40% and average permeability 40 md. Based on the geostatic model of the Amana field reservoir, it is concluded that this area is a positive prospect in the most eastern part of the Abu Gharadig basin. The volume of oil (STOLIIP) in Amana reservoir is calculated as 10 million barrels, with an initial recoverable oil of 1.4 million barrels.

Keywords: Geostatic model; Petrophysics; Seismic interpretation; Western desert abu gharadig basin; Egypt

Introduction

Abu Gharadig basin is considered the most petroliferous basin in Western Desert as far as hydrocarbon production and potential. It is a deep E-W trending asymmetric graben, has dimensions of 300 km E-W and 60 km N-S, with an area of about 17500 km^2, and basement at depths over 10 km. Its structure has been recognized as a major rift basin in which there are numerous localized highs that in NE-SW oriented plunging anticlines that are believed to be fault-controlled folding [1]. The northern margin of this basin is marked by a major border fault zone which up-throws the basement to about 10,000 feet forming Sharib-Sheiba ridge, and the southern boundary is called Sitra platform [2]. Amana oil field is located in the most eastern trough of the Abu Gharadig basin (Figure 1), exactly in East Bahariya concession that exists in Mubarak sub-basin.

Tectonic framework and structural settings

Abu Gharadig Basin may have begun life as a pull-apart basin between two right-lateral wrench faults, its development began during the Jurassic and Cretaceous and the tectonic activity reached a peak during the Upper Cretaceous to Eocene interval [3]. It is subdivided into three structural units from east to west; Mubarak sub-basin, Abu Gharadig basin and Qattara depression including Mubarak High, Abu Gharadig Anticline and Mid basin Arch (Figure 2).

Litho-stratigraphy

The study area is related to the unstable shelf which covers the northern belt of Egypt, which is characterized by a thick stratigraphic succession that ranges, in age, from Pre-Cambrian Basement to Holocene time, varying in lithology (Figure 3). Abu Roash Formation is characterized by a cyclic alteration of deltaic flood plain sandstones, coastal sandstones and shales, and shallow marine shales and limestones [4]. The formation has been divided into seven units (members) "A" to "G". Units "B", "D" and "F" are mainly carbonates, units "A", "C", "E" and "G" contains variable amounts of detrital materials [5]. Abu Roash "G" shale acts as a very good top and lateral seal while Abu Roash "F" carbonate acts as a lateral seal, especially in the central part Amana field , where the major fault throw exceeds 300 ft. The pay sand zone in Amana field is involved within Abu Roash "G" Mbr. which is composed mainly of marine shale intercalated by carbonate streaks, with three cycles of sand facies considered as the main reservoirs in Abu Gharadig basin, and named (from top to base) as Upper sand zone, Middle sand zone and Lower sand zone) (Figure 4).

Methodology and Workflow

In order to perform a reliable 3D Geostatic Model, it is necessary to quality control and manages all types of the data, starting from seismic

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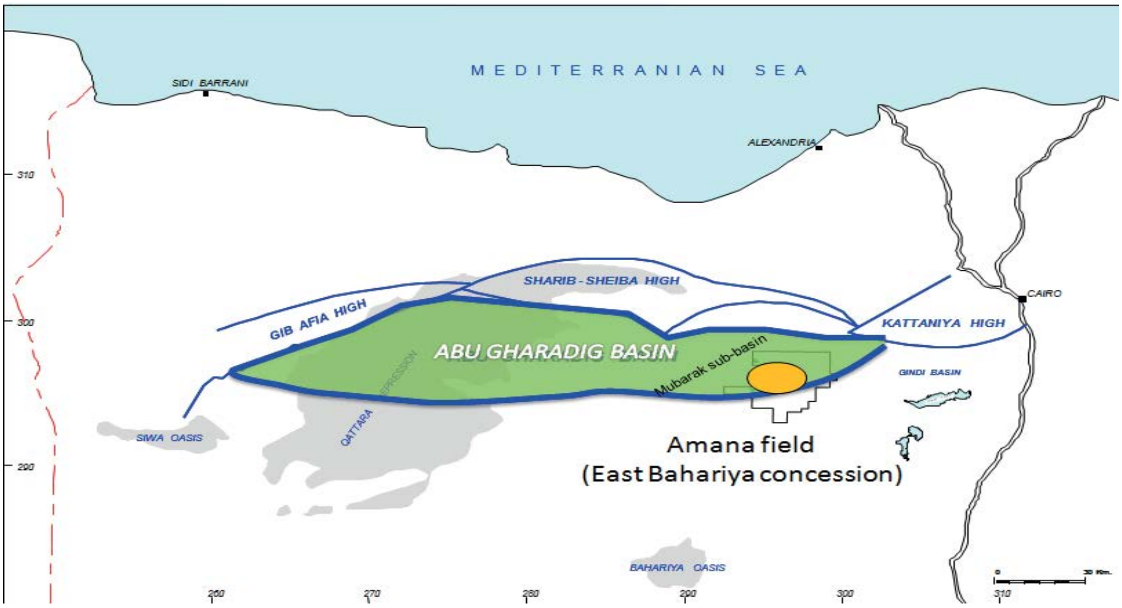

Figure 1: Location map of Amana field relative to Abu Gharadig basin.

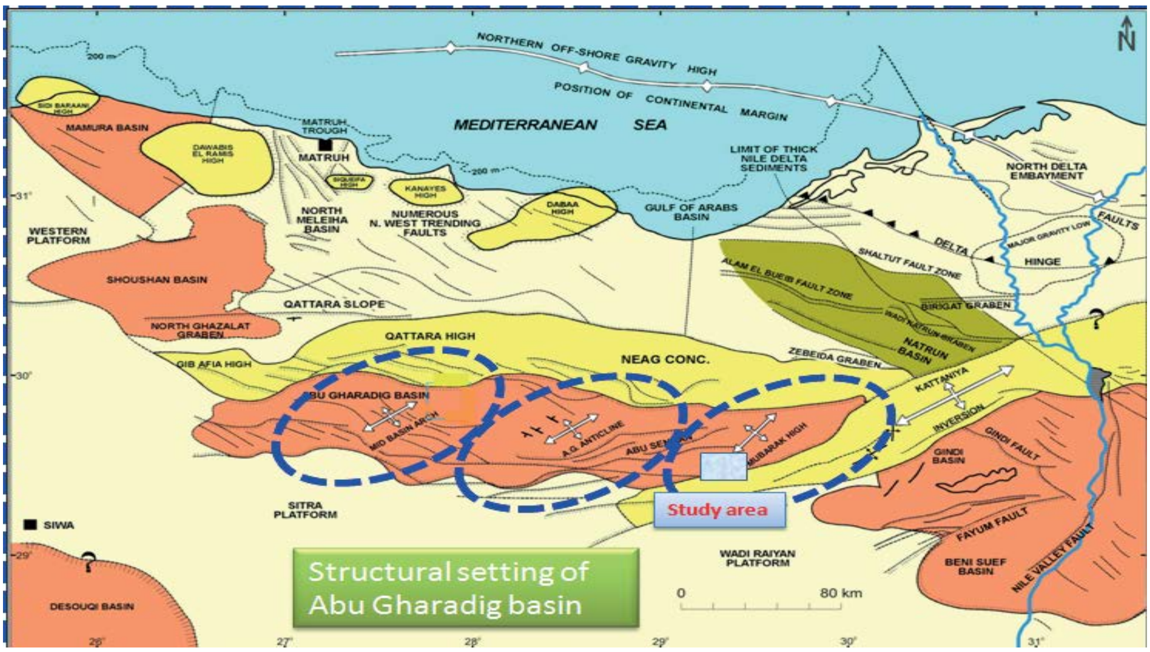

Figure 2: The main structural divisions of Abu Gharadig basin, modified after (Bayoumi, 1996).

data, well logs and well test results. Conducting the Model is starting through seismic data to be interpreted explaining the areal extent of the interpreted surfaces and the regime of the faults running in the area, and then suppose the horizontal gridding in which the model spreads the values, with determination of the trends of the modeled area. After that, a high light should be focused on the reservoir bed by Zoning stage, frequently, the tying with well data and well correlation should be processed to help in facies modeling layering the reservoir bed for more accuracy. The facies and petrophysical properties are distributed (i.e. interpolated and extrapolated) to assign a value for each cell in volume calculation stage as shown in Figure 5.

Data collection and quality control

In order to acquire a reliable 3D geostatic model, it is necessary to use all available data related to the study area. The data should be quality checked, and environmental corrected, in addition to removing the spikes or any unreliable readings. Almost all seismic data are enhanced and qualified for interpretation after passing through the stage of processing. Some complicated corrections should have been conducted on the well logs to be suitable for log analysis. These corrections are varied in certainty levels and have various types of mechanism. The most common log corrections that have been run are:

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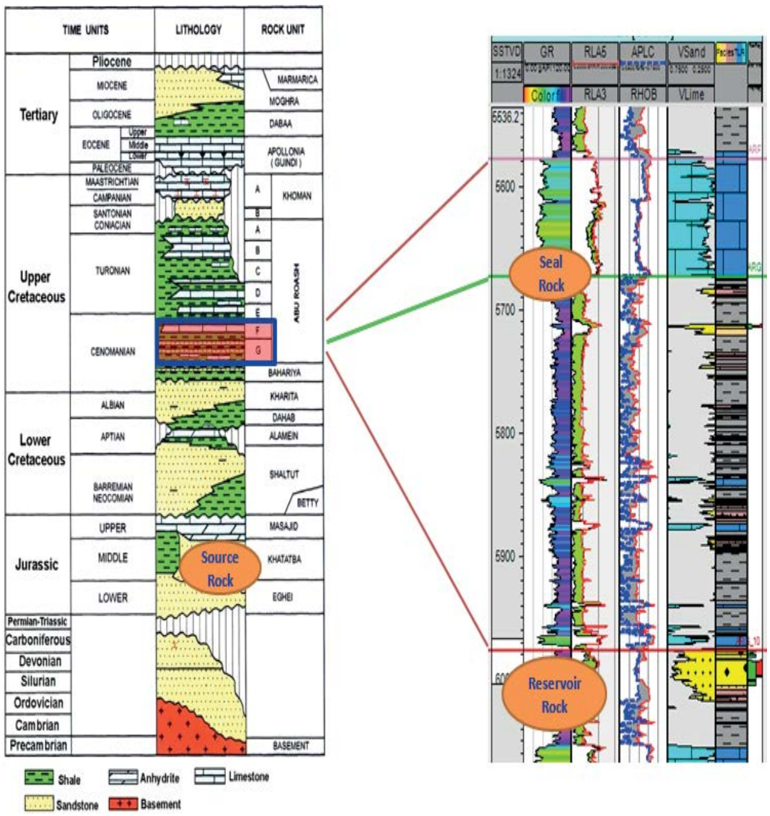

Figure 3: Generalized lithostartigraphic column in Abu Gharadig basin with high light on reservoir and seal beds in Amana field [14].

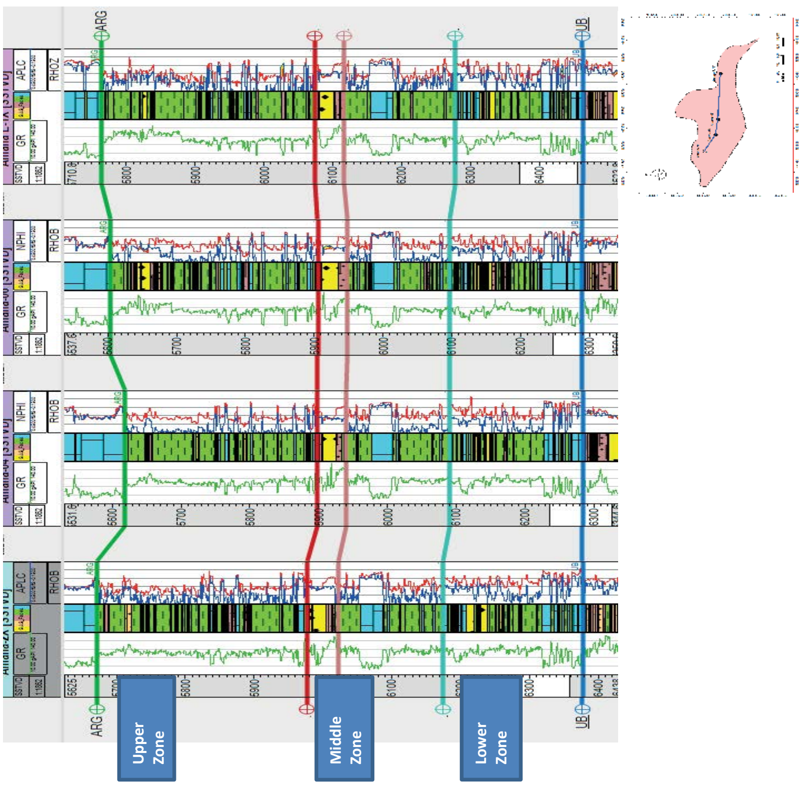

Figure 4: Stratigraphic correlation for Abu Roash "G" Member through Amana wells with key map.

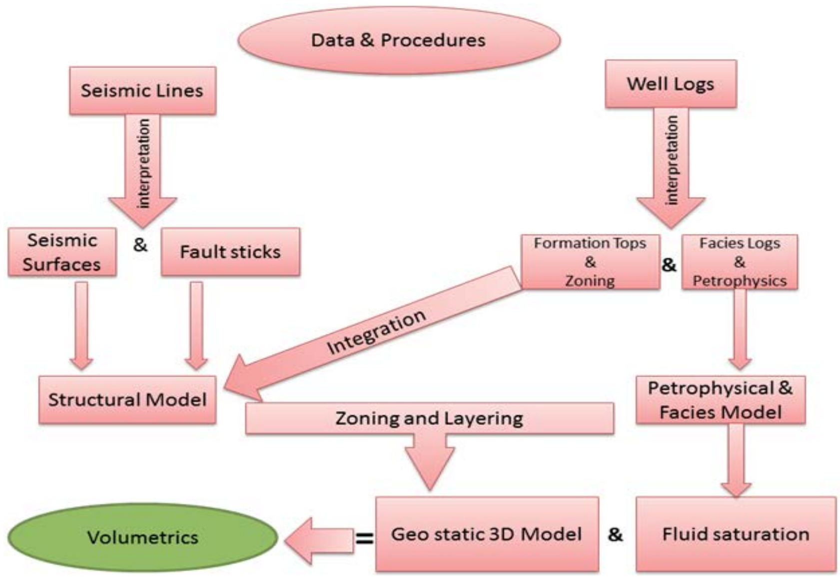

Figure 5: A sketch illustrating Model construction work flow.

Temperature and pressure effect removal.

Mud weight, salinity and mud resistivity calibration.

Gamma Ray log corrections for mineral and organic matter effect, borehole washout, and mud weight.

Resistivity logs' corrections for mud salinity, borehole size, and mud resistivity.

Neutron, Density and sonic logs' corrections for borehole size, drilling fluids and formation fluids, mud cake thickness.

Well log analysis

In order to conduct the 3D geostatic model, it is necessary to analyze the well logs to obtain the most interesting properties needed for spatial distribution. After the logging acquisition has been done, petrophysicist will start the correction and the quality control on the data, and then will interpret and evaluate the logs resulting in a traditional petrophysical evaluation. This petrophysical evaluation is the most reliable stage in the static reservoir study, since it generates a series of vertical profiles, for each well in the reservoir, describing the main properties of the reservoir pore system [6], such as Vshale, porosity, fluid saturation, estimated permeability from logs, and net to gross ratio.

Shale volume

The estimation of the volume of shale and clay minerals within the reservoir interval has an essential impact on the effective porosity [7]. In this study gamma Ray logs (wireline or LWD) are the main indicator for determining the volume of shale for Abu Roash "G" reservoir. And it was found that the middle zone is considered a clean sand zone with average volume of shale less than 8%, and it is clearly recommended to use Archie's equation in determining water saturation for this zone while the upper zone has an average volume of shale more than 13% and the lower zone shows 23% average volume of shale (Figure 6).

Total porosity

Determination of porosity can generally be considered the least complex stage in the petrophysical interpretation but the most important one because it defines the quantity of the hydrocarbons present in the reservoir [8]. The most frequently used methods in determining porosity are those based on the interpretation of well logs. Actually, none of the logging tools measure porosity directly, but the interpretation is carried out by indirect measurements [6], even neutron technique, which detects the hydrogen resides in the pore spaces (as a function of water and/or hydrocarbon), and the logging unit used this hydrogen index in order to simply deduce the formation porosity, thus the total porosity can be directly read from the neutron display.

Effective porosity

Not all the fluid presented in the rock is movable, because of the existence of isolated pores (not connected together) and wettability, thus during determining porosity, it should be the effective one regardless the immobile fluid. The effective porosity is determined clearly by using total porosity and volume of shale from this formula:

$$\Phi_{eff} = \Phi_{total} * (1\text{-}Vsh)$$

Abu Roash "G" Mbr. has a wide variation in effective porosity, especially among its three zones, where the Upper zone has an average effective porosity of 11%, Middle zone has 21% and the Lower zone displays about 14% Φ_{eff}. (Figure 6).

Water saturation

The porous system of a reservoir rock is filled fluids, typically water and hydrocarbons with percent depending upon the chemical and physical properties of the rock and the fluids as well as the interaction between rock and fluid (rock wettability). The water saturation influences not only the volume of hydrocarbons, but also the productivity of the wells. For the purposes of reservoir studies, water saturation is mainly predicted on the basis of log interpretation for open holes using the famous Archie equation for clean formation [9].

$$Sw = \sqrt{\frac{F*Rw}{Rt}}$$

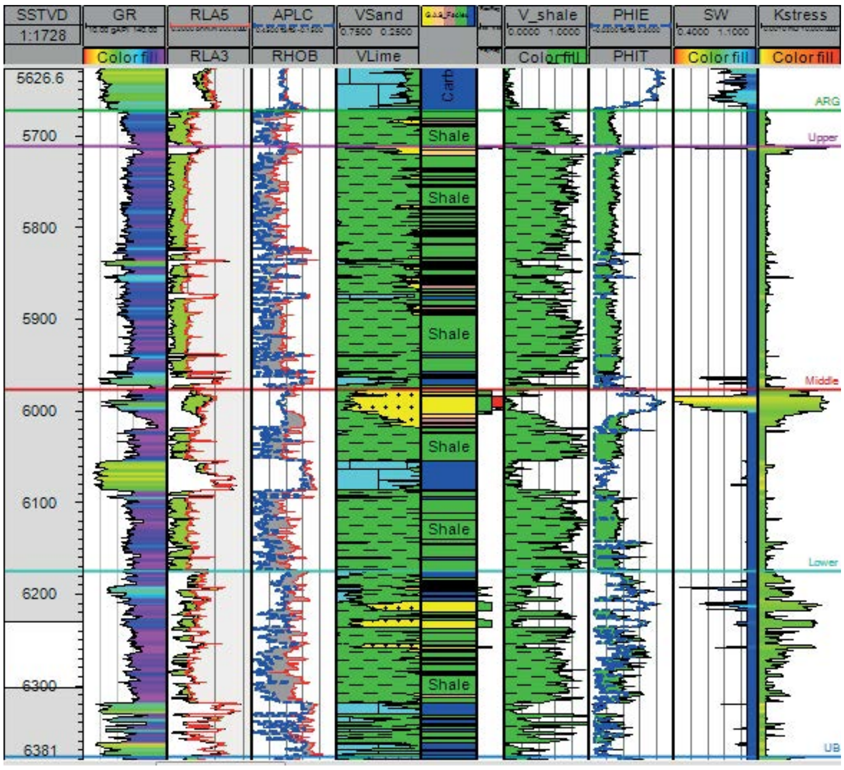

Figure 6: Log interpretation in Amana field.

Where: **Sw** ..... is water Saturation

Rw ..... is Formation water resistivity

Rt ...... is true resistivity

F...... is the formation resistivity factor

Calculating water saturation for Abu Roash "G" Mbr. has indicated that the whole member is a water bearing zone S_w is more than 90%, even the Upper and Lower Zones, except the Middle zone which is subsequently considered as a hydrocarbon bearing zone with average water saturation of 30% (Figure 6).

Permeability

The productivity of the wells and reservoir ability to feed drainage areas are the function of the permeability which is the most difficult parameter to be determined because of the extreme spatial variability among wells. The measurement of permeability derives from Darcy's law in case of available core data, but if the core data is absent, it will be estimated from the well logs by Timur equation [10].

Timur permeability: Timur permeability is given by equation

$$K = \left(\frac{100 * \Phi e^{2.25}}{Swirr} \right)^2$$

Estimation of permeability for Abu Roash "G" Mbr. showed that the permeability average of the Middle zone is about 100 mD and more, while all the rest of the member is ranging from 1 to 40 mD (Table 1).

Net to gross ratio (N/G)

For more detailed description of reservoir, the gross and net thickness should be calculated. Some geologists depended on the porosity cut-off to distinguish between the gross and net thickness, and others are depending on permeability cut-off, but a more rigorous approach to net thickness determination is on the basis of a detailed analysis of the rock properties [11,12]. The net to gross is a relation compiling the gross thickness and net thickness in one function obtained from dividing the net thickness by the gross thickness as a decimal fraction or percentage. The N/G ratio was calculated for the three zones in Abu Roash "G" Mbr. as shown in the figure below, illustrating that the N/G ratio increasing in the Middle zone in the central part of the study area (Figure 7).

Structural modeling

Structural model is the initial point of the reservoir model construction. It is considered as the backbone of the reservoir model. The structural model for the reservoir is basically conducted through two major procedures; mapping the structural geometry of the top of reservoir, and defining the set of faults running through the reservoir. These two procedures are ideally performed through the stage of seismic interpretation, where this stage involves two modules of interpretation; Horizon interpretation which is acquired on the horizons of interest, and Fault interpretation for the faults affect the reservoir [13,14]. In Horizon interpretation, all seismic lines and section used for covering all the area of interest, while in Fault interpretation, the cross lines (the lines that are perpendicular to the major fault trend) should be selected at the first in order to clearly pick the faults with their real throw and trend. Interpretation of the seismic lines in Amana field explains the structural setting affected the reservoir and formed the hydrocarbon trap in the area. As shown in the figure below, Amana oil field displays a horst block that is considered a good structural trap for accumulating the hydrocarbon in it.

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Well Name	Total Porosity	V _ Shale	Eff. Porosity	Water Saturation	Net Pay	Estimated Permeability
	Φt (%)	(%)	Φeff (%)	Sw (%)	(Ft)	K (mD)
Amana-1X						
Middle zone	24	8-Feb	22	18	32`	100 - 250
Lower zone	15	20 - 33	14	52	wet	0.5 - 4
Amana-2						
Middle zone	22	8-Jun	22	28	28`	110 - 150
Lower zone	20	23-Oct	16	50	wet	20 - 30
Amana E-1X						
Middle zone	23	7-Apr	| 21	30	20`	100 - 300
Lower zone	21	20 - 30	| 17	55	wet	Feb-40
Amana-3						
Middle zone	22	16-Jan	19	41	10`	50 - 150
Lower zone	19	20-Dec	15	90	wet	30 - 50

Table 1: Average petrophysical properties for Abu Roash "G" Reservoir in Amana Field.

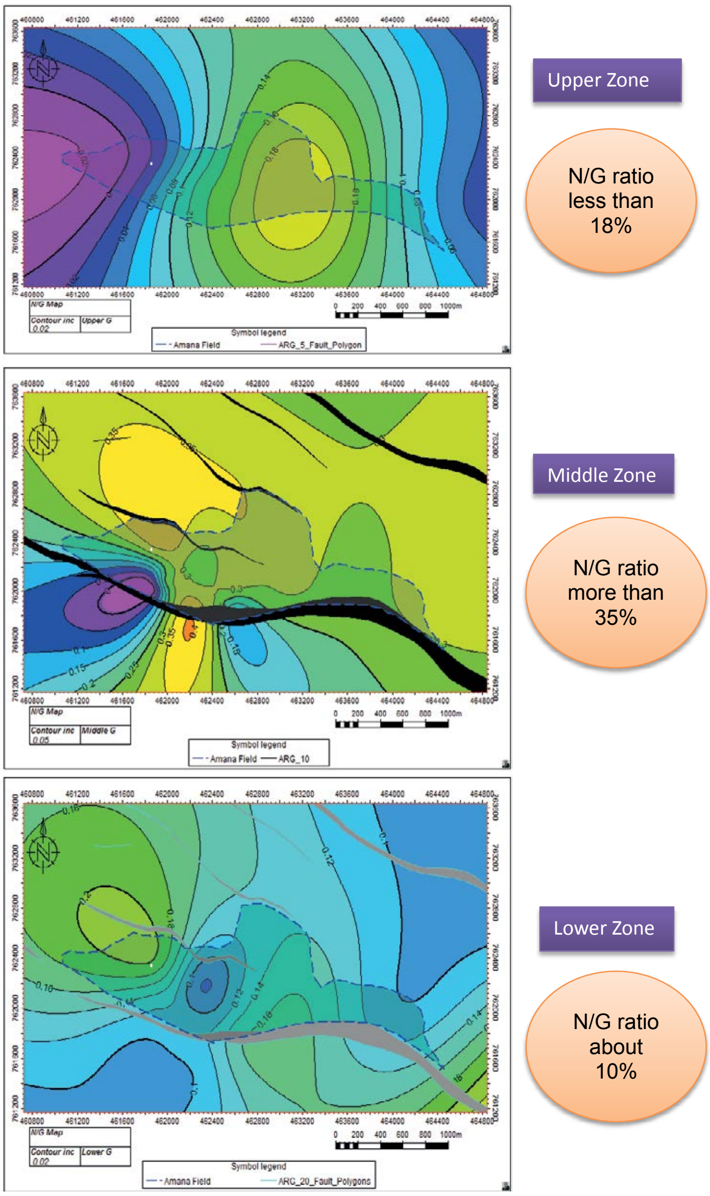

Figure 7: N/G map for the three zones of Abu Roash "G" Reservoir.

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The direct results for seismic interpretation are summarized in the lateral explanation of the fault system affecting the reservoir as shown in Figure 8, in which the tectonic setting shows a flower structure that indicates a wrench fault system resulting in a horst structure, and mapping the structural geometry of the top of reservoir that displays NW-SE trending normal faults as shown in Figure 9.

The structural model of the reservoir is the result of compiling the output of Horizon interpretation and Fault interpretation, thus the indirect results for seismic interpretation are the basic inputs for constructing structural model, such as fault sticks (*the fault interpretation in lateral view*), also defined as sets of line data that represent the fault plane, and seismic surfaces (*the horizon interpretation*), so that an interpretation has been carried out on Abu Roash "F" "G" and Upper Bahariya surfaces (Figure 10).

The structural model is carried out through four steps as follow.

Fault model: This step converts the fault sticks (*the output from seismic interpretation*) into key Pillars which are easily editable in 3D grid. This step is considered as a fine tuning for the faults to be more fitting in the structural model as the key Pillars connecting two faults, are used for extending a short one, making cross faults, or dividing one to two faults (Figure 11).

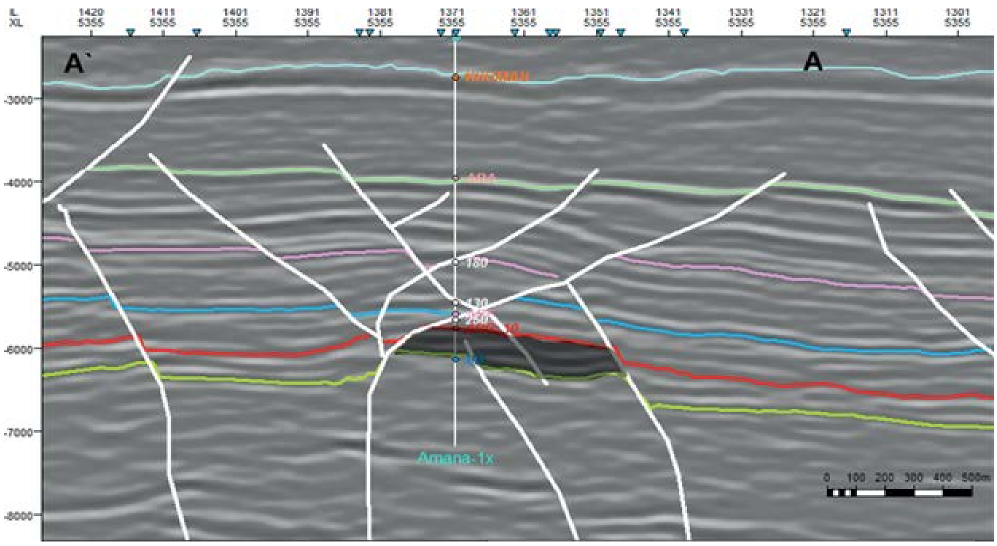

Figure 8: A Seismic X-line showing the structural setting in Amana block.

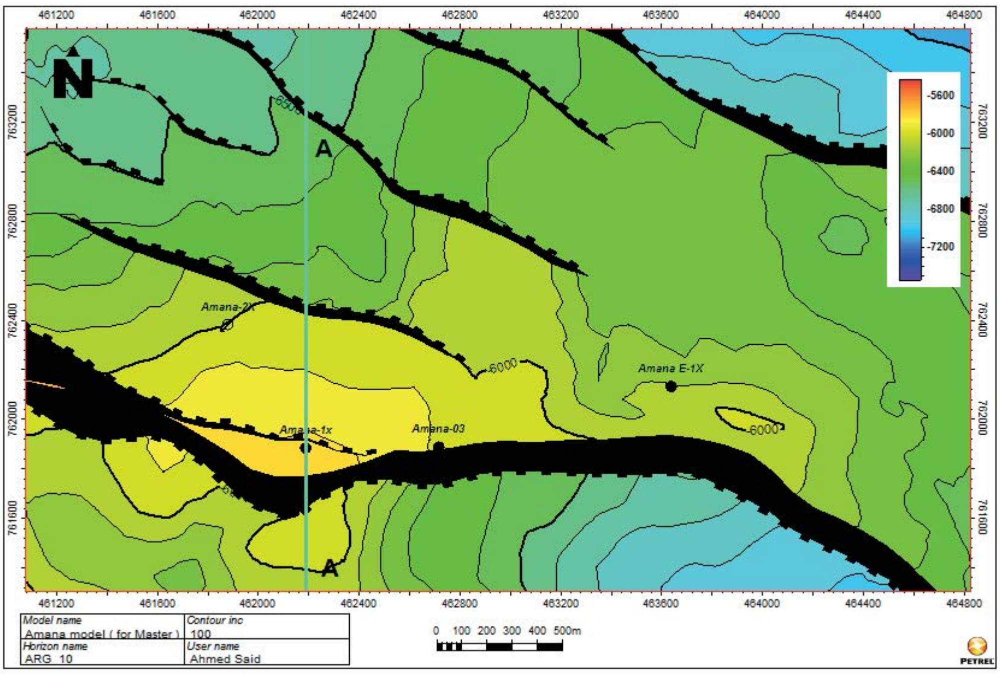

Figure 9: Structural map on top Abu Roash "G" Middle reservoir in Amana field.

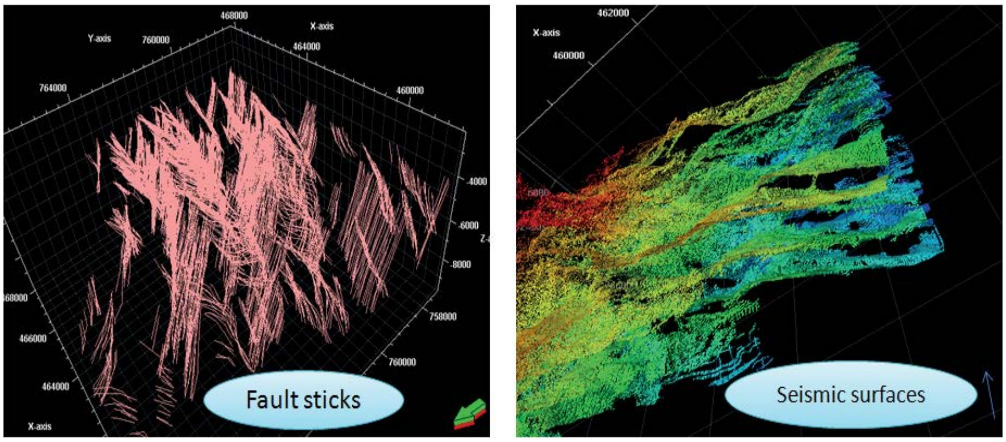

Figure 10: Showing seismic data as input for constructing the structural model.

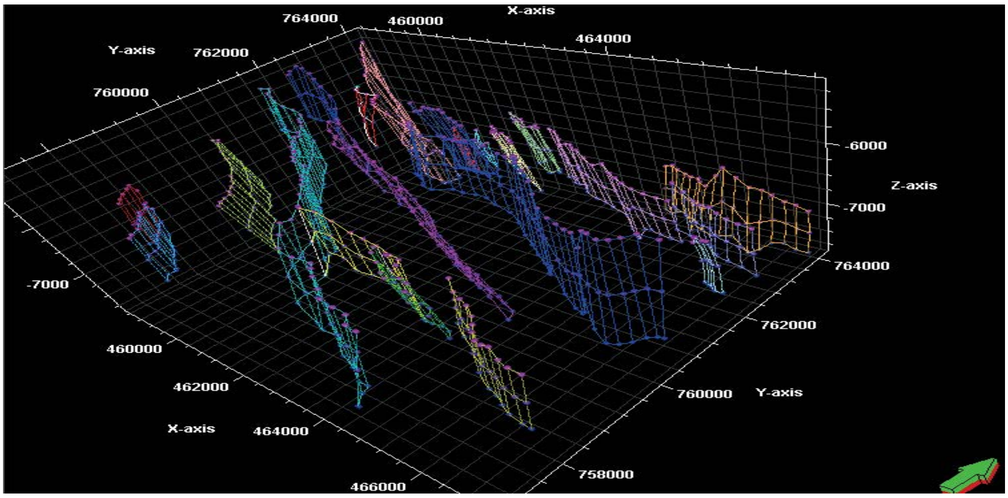

Figure 11: 3D window showing the Key Pillars in fault model step.

Pillar gridding: The construction of the Model is proceeded after that with Pillar Gridding step in which the trending is determined as **I**, **J**, and **K** directions (Figure 12). In this step we build the horizontal gridding of cells in the Model and determine their size which will aid, after that, in volume calculation.

Another important function of Pillar gridding step, is converting the faults in key Pillars into fault surfaces that will be displayed as cell walls in the final static model (Figure 13).

Making horizons: Regarding to the faults, all of them were treated, edited and smoothed in the previous stage, but in this stage we are dealing with the seismic surfaces and 2D grids. This step deals with the seismic surfaces resulted in seismic interpretation and uses them in order to make horizons fitting for constructing the structural model (Figure 14). The resulted horizons from this stage are celled horizons in which each cell takes a value of coordinates (**X** and **Y**) and a value of each property. The resulted horizons should be matched with the formation tops from well data at wells' locations.

The making horizons stage may be considered the final step for structural model, but in most cases, the resulted horizons are for major surfaces only, thus it is recommended to be zoned and detailed.

Zonation and layering: Because only major seismic surfaces can be interpreted, and frequently, just major horizons will be involved in the model, so it is necessary to consider the minor surfaces and sub-zones. By using well tops of formations and sub-zones, it is possible to make sub-zones between the major modeled surfaces for high lightening the pay zone involved within the reservoir bed as shown in Figure 15.

After the zoning process for the reservoir in order to focus on pay zone, the pay zone itself has vertically varied values of the properties, so this pay zone should be subdivided into a number of small layers in to obtain reliable calculations, this process is called layering and had been performed for the middle zone reservoir resulting in ten layers where each one having a reliable value for each property as shown in Figure 16.

Facies and petrophysical modeling: After Make zones stage and Layering, we use the facies log for each well and distribute the facies over all the area of interest among the wells, to predict the lithology in the non-penetrated area, this stage is named facies Modeling and is followed by Petrophysical Modeling in which the Petrophysical parameters are distributed through the pay facies (Figure 17).

Estimating properties for undrilled well locations: The main

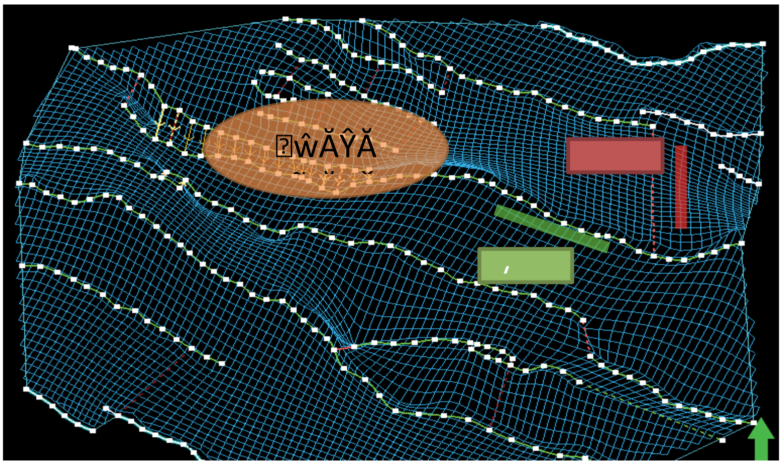

Figure 12: The I and J trends with horizontal Pillar gridding in Amana field.

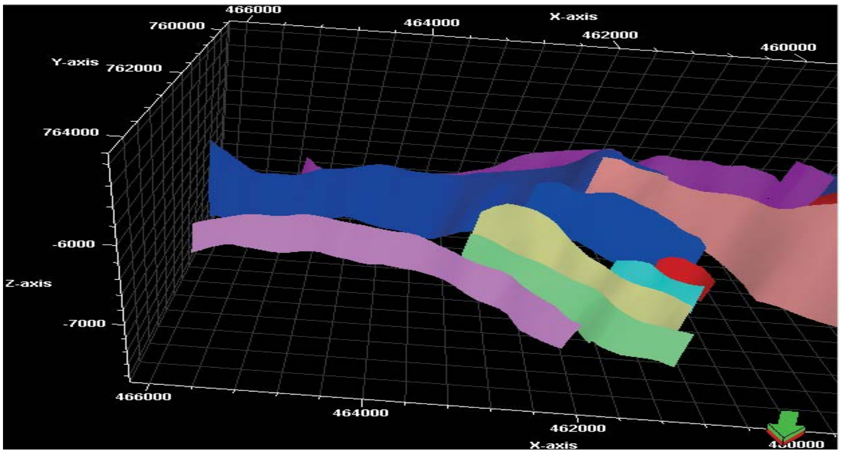

Figure 13: Showing the fault surfaces converted from Key Pillars.

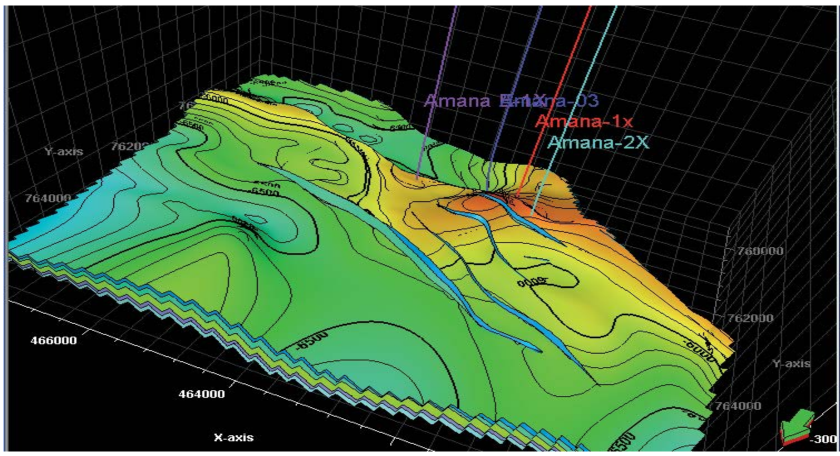

Figure 14: 3D modeled surfaces after making horizons stage.

target behind this work is to estimate facies and Petrophysical properties for the undrilled locations in order to drill new wells for increasing productivity and enhancing the field recovery. Figure 18 shows the area of interest (green area) above the oil water contact where the probability of oil presence is of a value, so it is recommended to drill more wells within the green area lying (far from the blue one), as the Geographic system, between:-

Latitudes: 29°33’20”N and 29°33’48”N

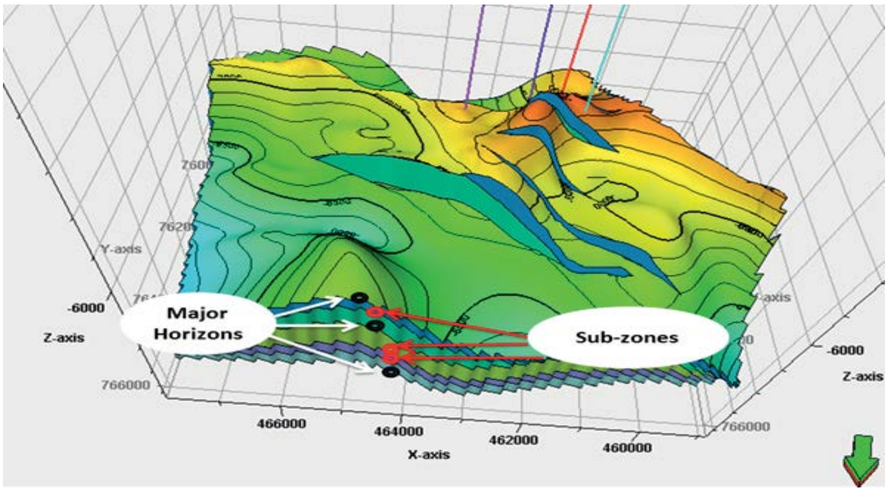

Figure 15: 3D zonation between the major horizons.

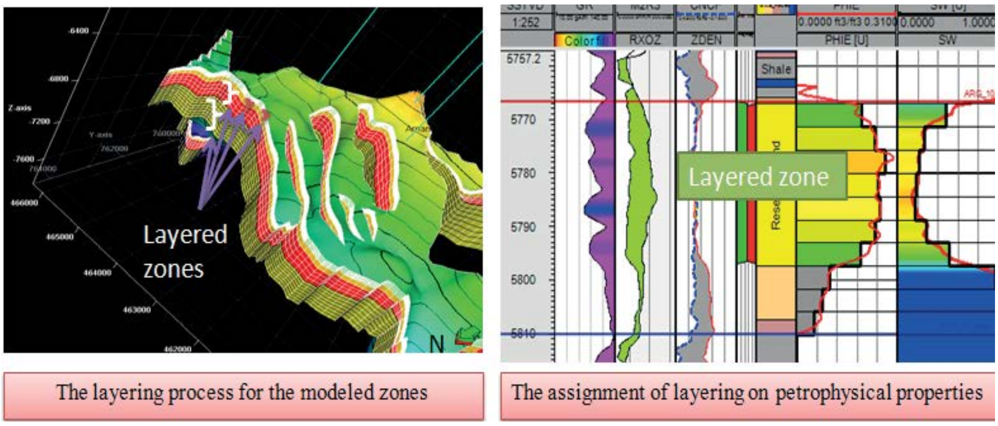

Figure 16: The layering process impact on vertical distribution of the data.

Longitudes: 29°25'17"E and 29°26`01"E

and as the Metric system, it lies between:

X: 462000 m E and 463200 m E

Y: 761800 m N and 762600 m N

Reserves and volumetric calculations: The final step (for completing this work) is volume calculation, where the well logs and seismic surfaces are used indirectly for calculating area, pay thickness, porosity, and fluid saturation in order to determine the OOIP and Reserves. In the 3D Modeling, as a result of facies distribution and calculating Effective Porosity and Water Saturation within the area of interest in the Model, the volume of oil in place could be calculated easily, and by adding the recovery factor, the recoverable reserve is determined.

The area of interest (above the oil water contact) is defined in a function of trap geometry delineated from the top by top seal and from the base by fluid contact as shown in Figure 18.

The net pay thickness is calculated from the well logs, petrophysical properties such as porosity and water saturation are averaged, thus, the application of recoverable reserve equation is achieved as follows [15]:

OOIIP = 7758 * A * H * Φ * So

Where:

OOIIP: Original Oil Initially in Place (reservoir barrel).

7758: conversion from (***acre.ft***) volume to barrel (***bbl***) volume.

A: the areal extent of reservoir (***acre***).

H: the net pay thickness (***feet***).

Φ: Porosity (**%**).

So: Oil saturation (1 - Sw) (**%**).

RR = OOIIP * FVF * RF

where:

RR: Recoverable Oil (stock tank barrel).

FVF: Formation Volume Factor (1/Bo). Bo is reservoir barrel multiplied by stock tank barrel (VR/VS).

RF: Recovery Factor (**%**).

The calculated volume of hydrocarbons in Abu Roash "G" member in Amana Field is displayed in Table 2.

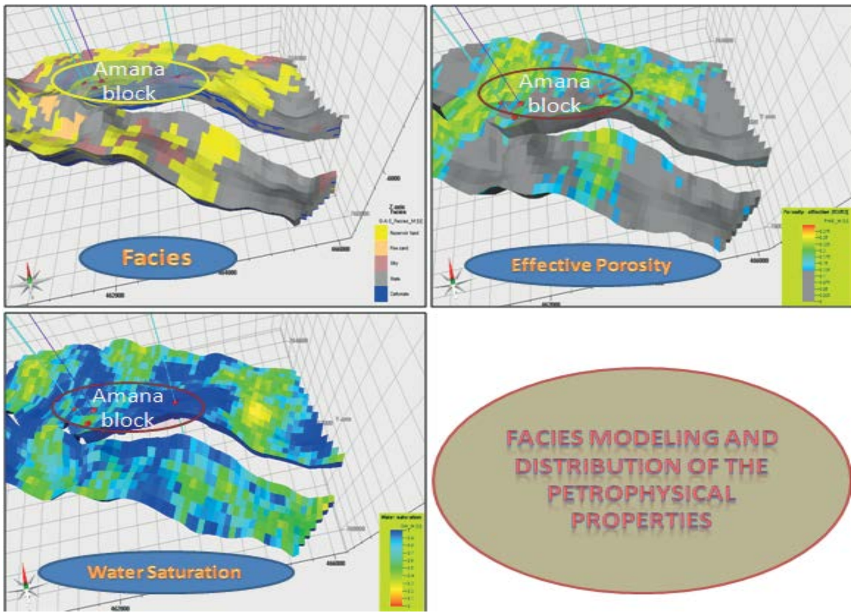

Figure 17: Spatial distribution through Amana block.

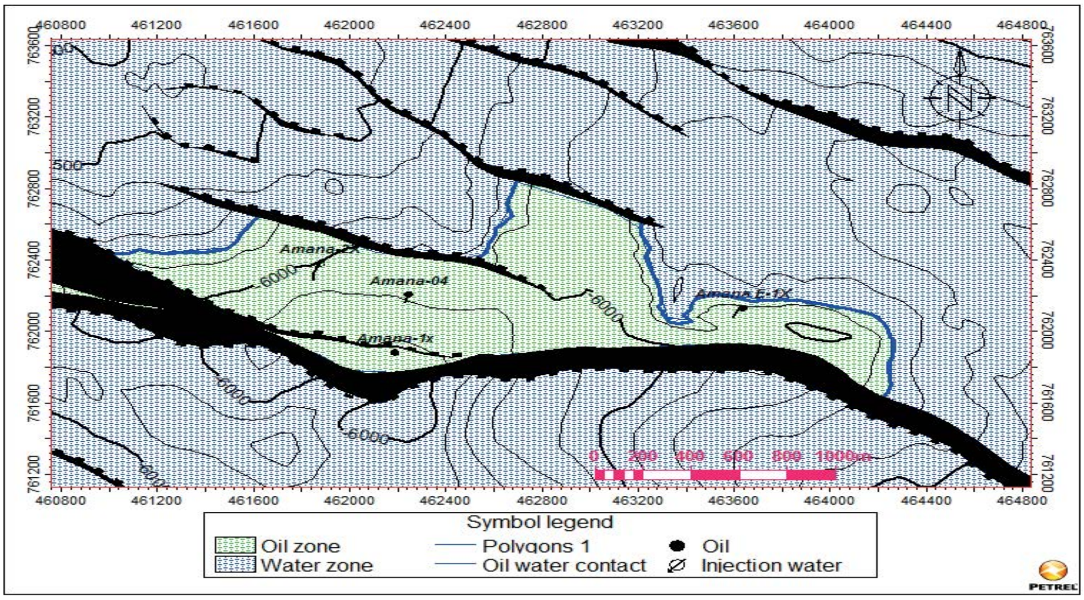

Figure 18: Promise area in Amana block.

Conclusions

The study area (Amana field) represents a positive prospect included in the most eastern part of Abu Gharadig basin where the proven oil that produced from Amana wells proved the presence of petroleum system in the area.

The seismic interpretation for the reservoir horizon and fault system in the area indicated that there is a structural petroleum trap (Horst style) that could be able to accumulate the oil in it.

Well logging interpretation was very useful in order to determine the reservoir and its lithology by constructing the facies log that resulting in the existence of reservoir sandstone in middle zone in Abu Roash "G" Member which shows an average porosity more than 22% and permeability more than 100 mD.

Seismic interpretation integrated with well log analysis, indicats that Abu Roash "G" shales are typical top seal and lateral with Abu Roash "F" carbonate for the present reservoir and explained that the main structural features in Amana field appear to have had their maximum of development during the Late Cretaceous (base Khoman deposition), thus the timing of oil expulsion and primary migration (that had commenced during the Campanian age) relative to the structure trap formation should be favorable.

Case	Net volume[acre.ft]	Pore volume[RB]	HCPV oil[RB]	STOIIP [STB]	Recoverable oil[STB]
Middle Zone	12331	14,513,846	10,159,692	9,152,875	1,372,931

Table 2: The volume calculation results.

The reservoir areal extent and vertical thickness, in addition to, petrophysical properties are recorded in the 3D Model, so the volume of the original oil in place and the recoverable reserves have been easily calculated showing about 10 million barrels STOIIP and 1.3 million barrels initial recoverable oil without former of any stage of EOR(enhancing oil recovery).

3D petrophysical modelling yielded an area of promise in order to increase Amana field productivity, this area lies in the central northern part in the field, so it is recommended to drill more producer wells in this part and drill water injector wells in the most northern edge.

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