HPV = 43.5 × 0.15×0.607= 3.960

OOIP = HPV× 7758× A

OOIP=3.960 × 7758 × 35528.8 = 1,091 MM, STB

IOIP =OOIP/FVF

Where:

OOIP: is the Original Oil in Place.
A: is the Area in acres (35528.8Acre).
7758: is the number of barrels per feet.
IOIP: is the Initial oil in place (STB).
FVF: Is the Formation Volume Factor equal to (1.15 RB/STB), obtained from the reservoir data summary of (Akakus, 2017).

IOIP **=** *1,091,690,476 ÷ 1.15 =949,29STB*

The original oil in place was estimated to be 1,091, MM stack tank Barrel using equation This is equation to initial oil in place at formation volume factor (F.V.F) of (1.15 RB/STB) calculated using equation . The recovery factor (R) in I –NC186 Oil field is (32 %) in I –NC186 field The Recoverable oil is using equation

*Oil recoverable = IOIP * RF*

Where:

IOIP: Is initial oil in place (STB).

RF: Is recovery factor, considered as (32 %).

Oil recoverable = 949296066.3* 0.32 = 303.77MM STB

Summary and Conclusions

- *Thickness the Upper Mamuniyat in study area about from 33 to 182 feet.*
- *The Mamuniyat reservoir is main target and has the best reservoir characteristics with an average porosity ranging between (13%) and (22%) .*
- *The Net-pay thickness ranges between 5.5 feet and 137 feet .*
- *The water saturation values were fair to good hydrocarbon saturation as good reservoir in I –NC186 Oil field in all of studied wells with average water saturation 39.3%.*
- *The oil in place about 1,091,69MMSTB and OIL recovery about 303, 77 STB.*
- *No more well will be to drill in the north or to Eastern part in area due to thickness could be very thin or absent also the reservoir quality is very bad quality reservoir (shaly bed).*

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Integration of Petrophysical and Sedimentological analysis of Aouinet Ouenine Formation, in South Wafa Field (NC169a), Ghadames Basin, Libya.

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Abstract

Geophysical and Wireline log analysis of the Middle Devonian Aouinet Ouenine F3 Sandston Member (main reservoir), in the south part of Wafa Field-NC169a (NW Libya), have been carried out on seven wells (A12,A13, A40, A41, A50, A51 & A55), in order to better understand the reservoir potential and its distribution in this region. Two cores data from these boreholes also used in this investigation. The integration of the 3D seismic results and petrophysics results from both wire line logs and core data; enable better understanding of F3-sand quality and distribution in the south part region of the Wafa gas and Oil field.The results revealed that the reservoir has lateral changes in terms of lithology and thickness, the F3 sand mapped with confident by using the seismic attribute volume in conjunction with the seismic interpretation stack volume, the lithology change from sandstone to shaly sand (pinching out) toward the south indicating bad reservoir quality interm of properties (porosity & permeability) due to increase of the shale volume and thinning of the sand part, and on the other hand better reservoir quality in term of properties and sand thickness toward North part of the study area.

Introduction

Wafa Field-NC169a is located in Block NC169a, close to the Libyan-Algerian border at the south western part of Ghadames Basin about 100 Km of Ghadames city, lies between Latitudes (28° 40' and 29° 00')-North and Longitudes (17° 21' and 18° 00') -East. The study area is presented by different land forms as sand and gravel plains, also sabkha and small sand dunes.

The first discovery well , D1-52, was drilled back in 1964, it is only in 1991 that the Wafa Field was discovered by well A1-NC169 that successfully tested hydrocarbons in the Middle Devonian sandstones (Aouinet Ouenine Formation).

main aims of this study is to evaluate the reservoir quality of Middle Devonian Aouinet Ouenine F3 Sand Member in Wafa Field-NC169a,which is located in Ghadames Basin from point view of petroleum system, reservoir element , Evaluate the reservoir quality of Aouinet Ouenine (F3Sandston) Member by using seismic interpretation techniques andpetrophysical analysis for selected wells to determine porosity, permeability, Net Pay.

by combined all above help us to understand the variable of reservoir quality of Aouinet Ouenine B' F3SandstonMember in Wafa Field-NC169a.

Method of study is the petrophysical analysis by using (7) wells including Electric logs (Gamma Ray, Sonic, Neutron, Density, Spontaneous potential, Resistivity ... etc.). The study uses a wide variety of technique, Petrel platform is powerful software for generate structure map, thickness map well interpretation, well to well correlation, identified stratigraphic sequences, facies, geological interpretation, Techlog platform one of the best software uses for determine the petrophysical properties such as porosity, permeability, water saturation, net pay and net to gross ratio, by combined all of them identified the reservoir quality.

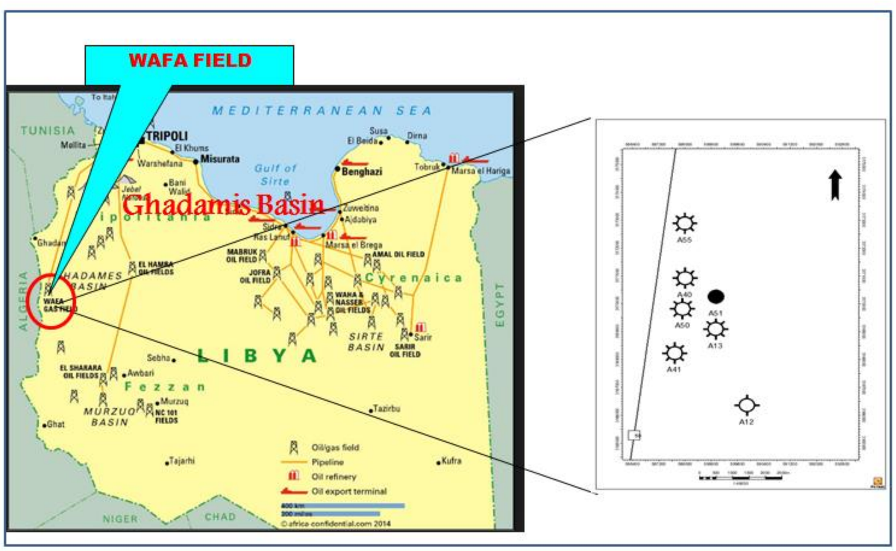

Figure (1) location map of Ghadames Basin and study area.

Ghadames Basin Overview.

The Ghadames Basin (1) is a large intracratonic basin on the North African Platform, formed during early Palaeozoic time. It covers an area of 350,000 km² over parts of Libya, Algeria and Tunisia, and contains up to 6000m of Palaeozoic and Mesozoic sediments. The Palaeozoic sections separated from the overlying Mesozoic deposits by a major regional unconformity of Hercynian (Permian-Carboniferous) age. The erosion pattern and topography developed on this unconformity has a major control on petroleum systems within the basin (Echikh 1998), affecting the preservation of Palaeozoic hydrocarbons, communication between source and higher reservoirs, and patterns of long-distance migration within the Triassic reservoir. The Ghadames Basin was affected by Caledonian Orogeny during Cambrian to lower Devonian, which produced Al Gargaf arch on the basin. The northern part of the basin was uplifted during Hercynian folding (lower Devonian to lower Triassic, (Buroelet 1960).

Stratigraphy of Ghadames Basin

The sedimentary section of the Basin ranges in age from Paleozoic to Cenozoic. It attains a maximum thickness of 6000 meter and consists of sandstone, shale, siltstone and local limestone, Its fill consists of shallow marine to continental sediments Two main potential source rocks are present in the Paleozoic sediments of the Ghadames Basin: the basal shaly member of the Tanezzuft Formation (Lower Silurian)and the Aouinet Ouenine formation (Late Devonian).

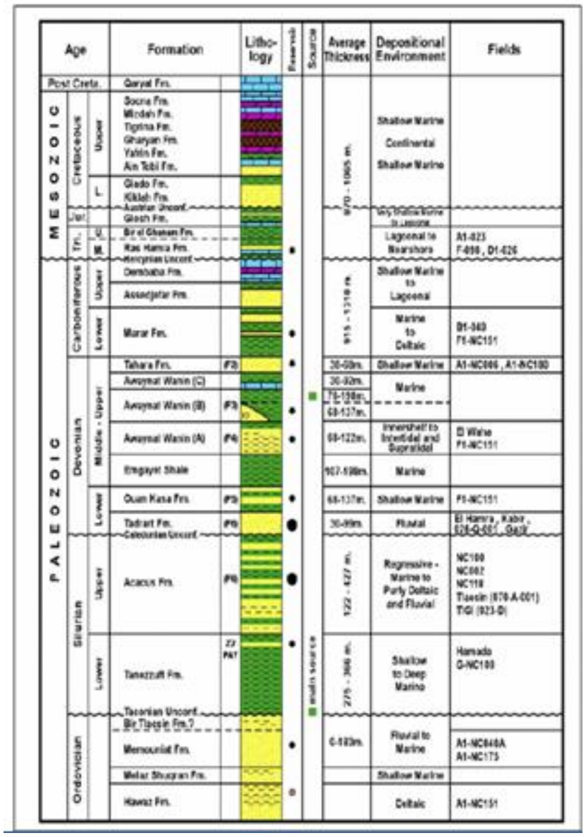

Figure (2) Stratigraphic Column of Wafa Field (Mellitah. 2017).

Lithostratigraphy of study area

Locally F3 sandstone reservoir is mainly respected to the area between Alrar and Wafa fields and the surrounding areas. The F3 sandstone can be found in some discovered field in the Algerian areas adjacent to the eastern border. Farther North adjacent to western border of Libya . Regionally F3 sandstone and F4 sands are part of Awaynat Wanin A are Givetian to Frasnian of the middle to upper Devonian. The Awaynat Wanin B is Frasnian and the overlying Awaynat Wanin "C" is Famenian of Late Devonian works as a seal for the lower reservoirs. The F3 sandstone is the most important local reservoir sandstone in the area and vicinity of Alrar/Wafa fields. It may represent regressive sequence but it is not widely developed as a reservoir unit in Algerian Libya Ghadames basin. The lithology for F3 sandstone Aouinet-Ouenine "B" is composed mainly of sandstone interfered with minor amount of Shale, there for a cross plot chart made to illustrate the relationship between bulk density and porosity which used to determine the lithology of the studied reservoir. The accumulation of most points was found around the sandstone through these relationships *between GR versus depth showed the reservoir consist mainly of pure sandstone and there are also found a low amount of shale in the lower and the most upper parts as shown in Figures (3). These figures clearly define the boundaries of sandstone through each well of the F3 sandstone reservoir.*

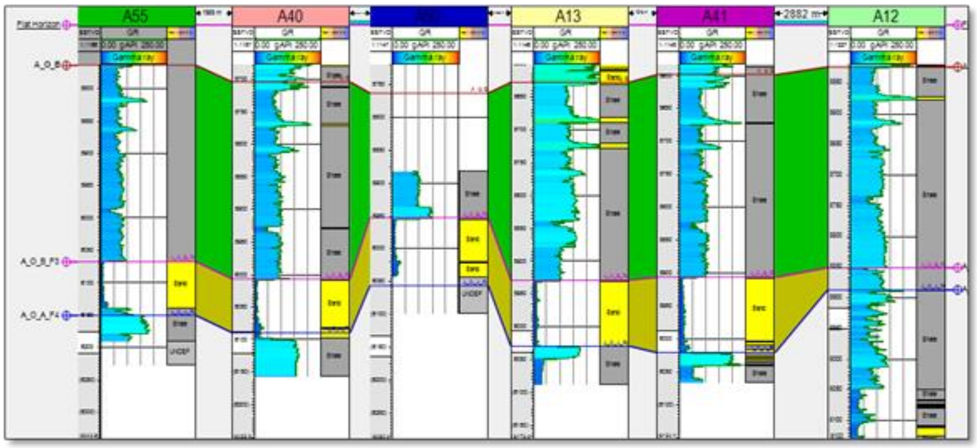

Figure (3) Wells available for this study used to show the relationship between GR logs responses versus depth through wells in south Wafa field,

F3 reservoir sandstone was developed as a regressive sequence due to a drop in sea level, also the main reservoir sandstone unit in Algerian fields such as Alrar and other fields in the area in the vicinity area of Alrar Gas field. The F3 sandstone is very thin or absents in the southern part of the study area and extends to the eastern area of Wafa field with defined line limit identified seismic and drilling ,its extends to the Northern area Wafa field outside of Concession NC 169 into Concession 26 demonstrated by well G1-26 where the F3 reservoir sandstone is clearly present but below the Gas/Water. The structural cross-section Figure (4) shows the F3 reservoir limits between the Northern portion and the southern portion of Wafa

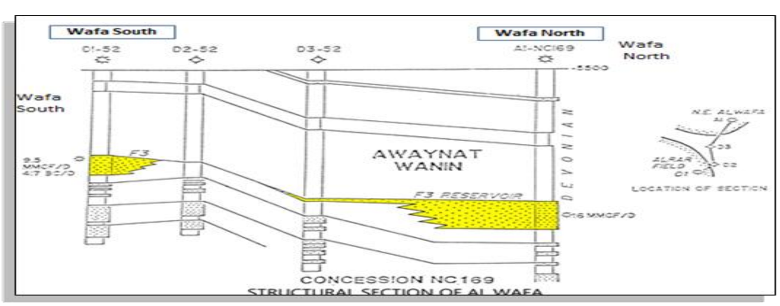

Figure (4) Structural cross-section from N-S Wafa field

The F3 sandstone is interpreted as localized shallow marine sand beds that pinch-out and pass into equivalent shaly facies (Mellitah, ,2016). These sandstone body shape generally is elongated towards the North-South direction with up structure towards the east and southeast of Wafa areas (Mellitah, 2016). This large body of these marine F3 sandstone reservoir bodies in the area of south-east Libya is of Stratigraphic trap in nature Figure (5) and extends north-south along most of the length of the concession NC169 also extends east into Alrar Gas/Oil field of Algeria.

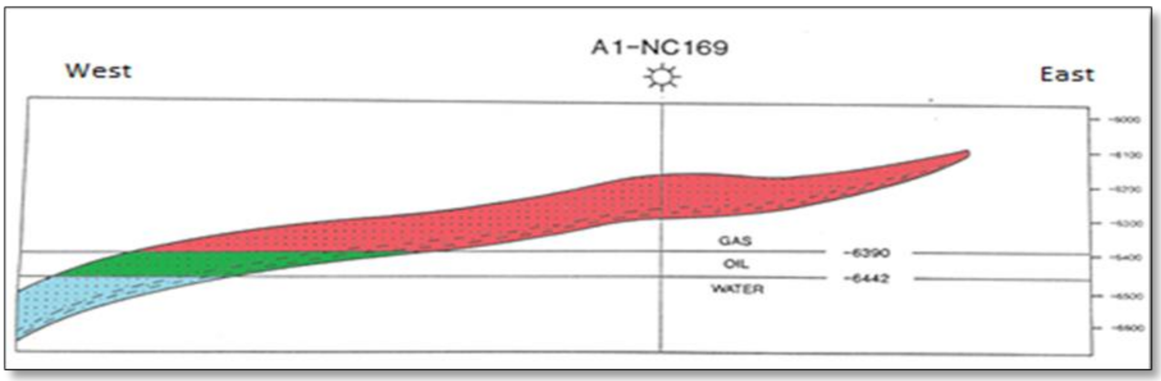

Figure (5) Sketch of Wafa Field Stratigraphic trap extending from the east of Algeria to west Libya.

Sedimentological Facies

The general description of Lithofacies from top to bottom For the available Electric logs and Core for this study:

- *Cross laminated massive sandstone of coarse-grained, cross-laminated to massive sandstone.*
- *Sandstone of fine-grained & well-cemented sandstone.*
- *Draped Sandstone of thin sandstone beds with mudstone drapes.*
- *Sandstone of alternating with horizons of laminated heavily burrowed sandstone.*
- *Units of bioturbated shale & sandstone.*
- *Fine Sandstone with carbonate shell fragments & calcareous cement.*
- *Thinly Lenticular beds of Sandstone & Shale.*
- *Thinly Laminated Shale.*

Four main facies association were identified on cores analysis:
***Facies Association A** : It consists of two facies: Massive medium grained sandstones – high quality reservoir Sands A1 massive medium grained sandstones with carbonaceous*

fragments and rare clay chips A2 large/medium scale medium grained cross bedded sandstones.

Facies Association B *:It consists of Medium to fine grained sandstones – high to low reservoir quality sands Four facies belong to this association:*

B1 medium/small scale medium to fine grained cross bedded sandstones;

B2 parallel laminated fine grained sandstones;

B3 structure less fine grained sandstones with occasionally carbonaceous fragments;

B4 structure less fine grained bioturbated sandstones.

Facies Association C *It consists of one single facies characterized by Fine and bioturbated sandstones – poor quality reservoir Sands*

Facies Association D *It is characterized by thin bioturbated Thin fine/very fine bioturbated sandstones alternated with shale. The sand/shale ratio is usually less than 1*

Figure (6) the main sedimentary facies in South Wafa Field

The overall genetic process was interpreted to be related to gravity flows loosing energy and developing more and more relatively deeper and outer facies from Facies association A to D. In particular the association A and B may be related to high density turbidities currents or fluvial floods; C and D to low density turbidities currents strongly affected by bioturbations. The general feeling is that all the gravity flows coming from the Tihemboka element deposited the bulk of their load in the Algerian sector and that they divided in at least two branches giving origin respectively to the Wafa North and Wafa South The shaling out of the *system occurs seawards concomitant with a thickness reduction of the sedimentary wedge due to its external geometry and to a decreasing of the sedimentary load. Well A12-NC169a is a clear evidence of this depositional model; the Palynological analysis carried out on the upper shaly unit of this well allowed to consider this shaly unit as the lateral equivalent of F3 sandstone.*

The Wafa sandstone body can be used as a sedimentological model in nearby areas to explore for the F3 east of the Wafa field. The Wafa sandstone body generally has a coarsening upward grain size profile possibly produced by seaward progradation.

Figure (7) well core description in well A120NC169a

Figure (7). A-12 well core description is very fine to fine-grained, strongly laminated or bioturbated, common scour and oxidation, flat pebble conglomerates, large vertical burrows, shell beds, clay drapes, thin lenticular bedding. Deposited as back barrier sandy to mixed tidal flats, lagoons, wash over fans; non-reservoir due to fine grain size, cementation, biogenic clay

The environment of deposition of F3 sandstone main reservoir of South Wafa field current study suggested being Barrier Island Figures (8).

Figure (8). Suggested depositional model of Wafa field by this study

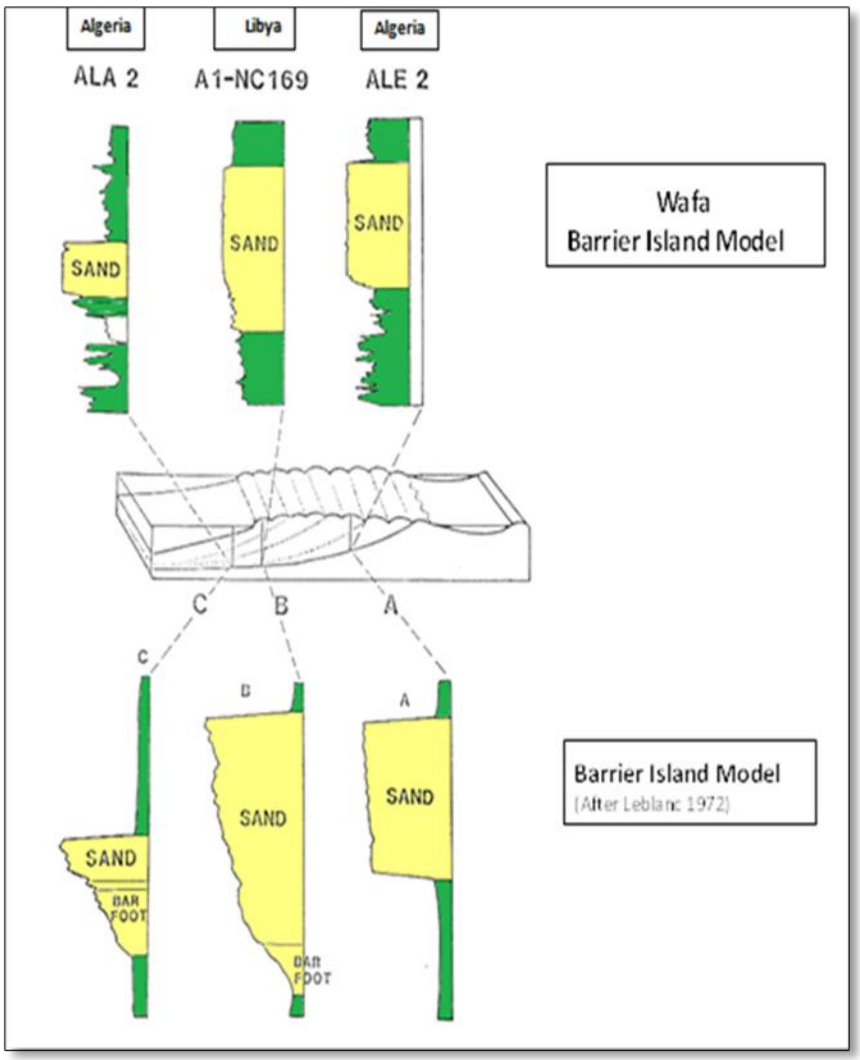

Figure (9). Barrier Island Model after Leblanc 1972 in relation to Wafa depositional Model

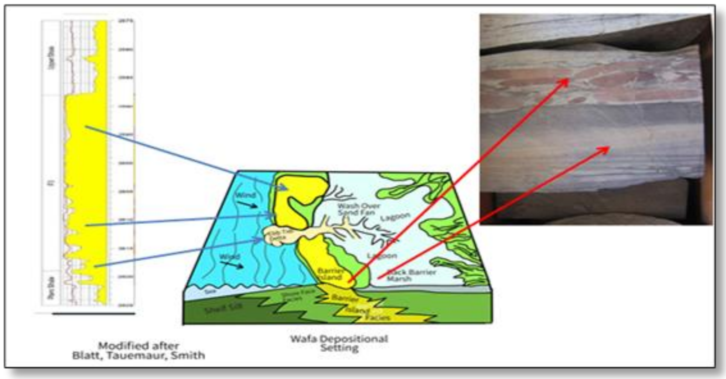

Figure (10). Wafa depositional model Barrier Island related drilled to well log & core available for this study

Geophysical & Petrophysical Analysis and Building 3d Module

In this thesis F3 sand member was mapped by using 3D seismic cube with good quality as shown (Figure 11) covered Wafa Field and generated Depth structure map for Top F3 sand along the south Wafa Field Figure (11) The results combined with the petrophysical to understand the depositional environment and there distribution, thickness of F3 sand in the south Wafa Field .

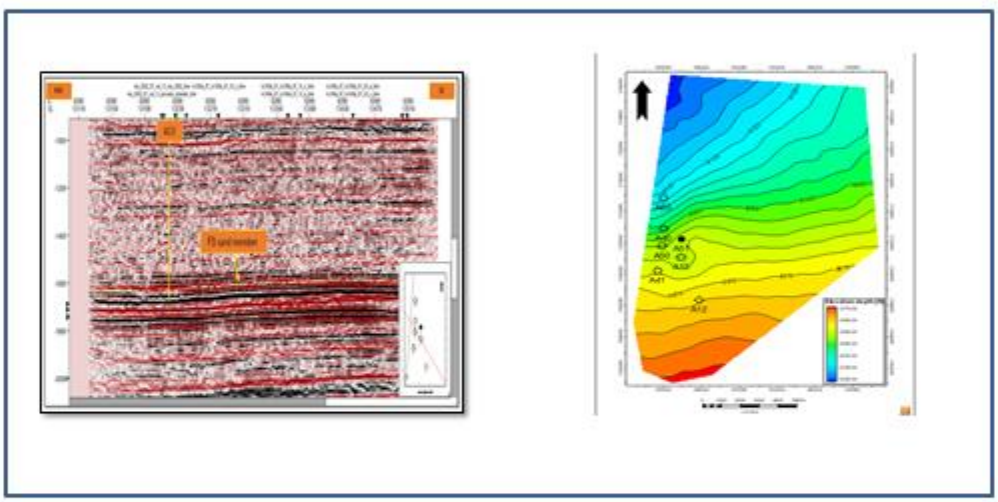

Figure (11) 3D seismic section & Depth Structure map for Aouinet Ouenine F3 Sandston

The Petrophysical Analysis

to determined physical properties in order to evaluate the reservoir quality F3 sandstone Member by determine the properties for seven wells located in south Wafa

Volume Of Shale Determination

The basic method of shale volume determination by using the following indicators:

Gamma Ray Log (GR): *It is common to find radioactive materials associated with clay minerals that constitute shale, it is also common practice to use the relative gamma ray reflection as a shale volume indicator.*

The simplest procedure is to rescale the gamma ray between its minimum and maximum values in one consistent geologic zone including both sandstone and shale. The scale is from ***0%*** *to* ***100%*** *shale.*

*The gamma ray index (**IGR**) is defined as a relationship between gamma ray minimum (**GRmin**) and maximum (**GRmax**). This formula can be written as follows:*

$$IGR = (GR_{log} - GR_{clean}) / (GR_{sh} - GR_{clean})$$

Where:

IGR= the Gamma ray index (**API**). ***GRlog*:** is the Gamma ray reading on the log.
GRclean = the minimum reading on the log. ***GRsh*** :is the maximum reading on the log.

Porosity Determination

All porosity logs of neutron and density logs are used to determine the density porosity (ØD) and the total porosity (ØN-D)) are good indicators of the F3 sandstone reservoir preliminary porosity determination. The density porosity (ØD) was used to determine porosity based on the type of reservoir rock from Equation , while the Total Porosity (Øt or ØN-D) from Equation 2.

Density Porosity formula:

$$ØD = (\rho b_{ma} - \rho b_{log}) / (\rho b_{max} - \rho fl)$$

Where:

•ρb =bulk Density, gm/cc (log). • ρfl =Fluid Density, (equal 1.1 gm/cc). •ρb ma =Matrix Density, equal 2.65 gm/cc (for Sandstone). •ØD =Density Porosity.

Reservoir Parameters: *the parameters that effect and control the porosity are listed below:*

1. *Cementation Factor (**m**).*
2. *Saturation Exponent (**n**).*
3. *Formation Water Resistivity (**Rw**).*
4. *Resistivity of Formation (**LLD**).*
5. *Water Saturation (**Sw**).*

3D Geological Model

Based on workflow application for subsurface interpretation and modeling .Data preparation is the basis for geologic model the data prepare for this 3D-geological model are well heads, well tops, well logs. These data include:

Well head: include the position of each well in 3-dimentions, and the measured depth

Well tops: Markers representing significant points (well picks) along the well path, normally a change in stratigraphy.

Well logs: the data cover porosity and water saturation values along the well path.

Structural Modelling:

A structure contour map is one of the most important tools for three-dimensional structural Interpretation because it represents the full three-dimensional form of map horizon. The mapping techniques to be discussed are equally applicable in surface and subsurface interpretation. 3D Structural maps were built for top of Aouinet Ouenine F3 sandstone reservoir from 3D seismic , represents 3D structural modeling for the Aouinet Ouenine F3 sandstone reservoir units shows that Aouinet Ouenine F3 sandstone reservoir structure is composed of cylindrical anticlinal fold. Structural modeling is to insert the stratigraphic horizons into the pillar grid, honoring the grid increment and the faults. Make horizons process step was used in defining the vertical layering of the 3D grid in Petrel. This present a true 3D approach in the generation of 2D surface, which was gridded in the same process, taking the relationships between the surfaces into account Figure (12) represents horizons of the main units of reservoir

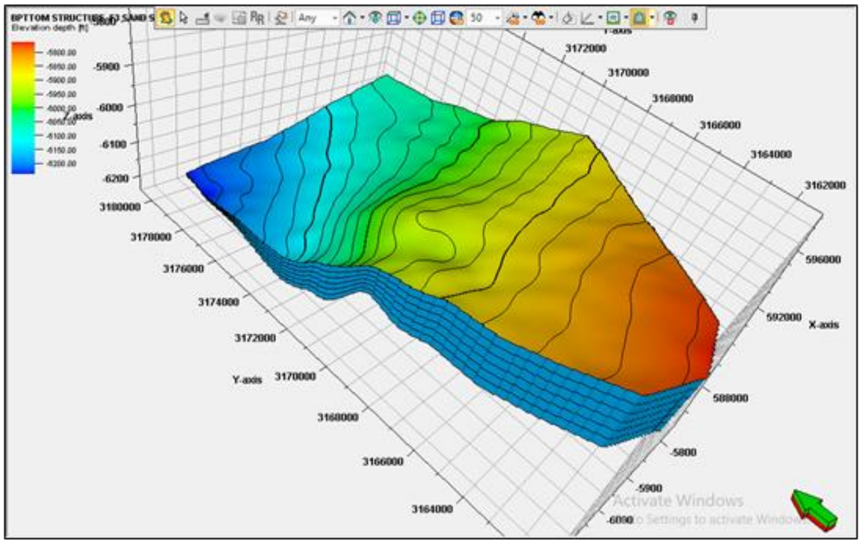

Figure (12) 3D Model of top Aouinet Ouenine F3 sandstone

3-D Geologic model

Geology Modern requires accurate representation of layered volumes. Three-dimensional (3-D) geologic models are increasingly the best method to constrain geology at depth. Each Aouinet Ouenine F3 sandstone reservoir unit in Wafa field has been divided into six layers layers depending on petrophysical properties. The zone consists of six layers in the uppermost of the formation. The Scale up well logs process averages the values to the cells in the 3D grid that are penetrated by the wells. Each cell gets one value per up scaled log. These cells are later used as a starting point for property modeling (Schlumberger, 2017). When modeling petrophysical properties, a 3D grid cell structure is used to represent the volume of the zone. The cell thickness will normally be larger than the sample density for well logs. As a result the well logs must be scaled up to the resolution of the 3D grid before any modeling based on well logs can be done.

Well logs Up scale

This process is also called blocking of well logs there are many statistical methods used to scale up such as (arithmetic, harmonic, and geometric method). The porosity and water saturation values in the current model have been scaled up using the (arithmetic average). Figure (13) shows the scale up of porosity and water saturation for A13 well that is used in the Aouinet Ouenine F3 sandstone reservoir model.

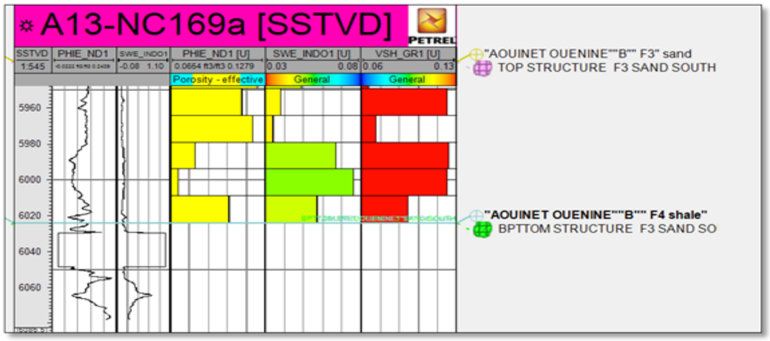

Figure (13) Scale up of porosity and water saturation of F3 sand.

Petrophysical modeling process

Petrophysical property modeling is the process of assigning petrophysical property values (porosity and water saturation) to each cell of the 3D grid. Petrel offers several algorithms for modeling the distribution of petrophysical properties in a reservoir model. Petrophysics model was built using geostatistical methods. Porosity and water saturation models were built depending on the results of porosity and water saturation values which have been corrected and interpreted in the Techlog software. Sequential Gaussian

 The porosity model of the Aouinet Ouenine F3 sandstone reservoir as shown in figure (14) is characterized by high porosity values in all wells in upper part but lower parts of this unit may show porosity decreases to reach 9%. The porosity values in this zone range from (10-12%).

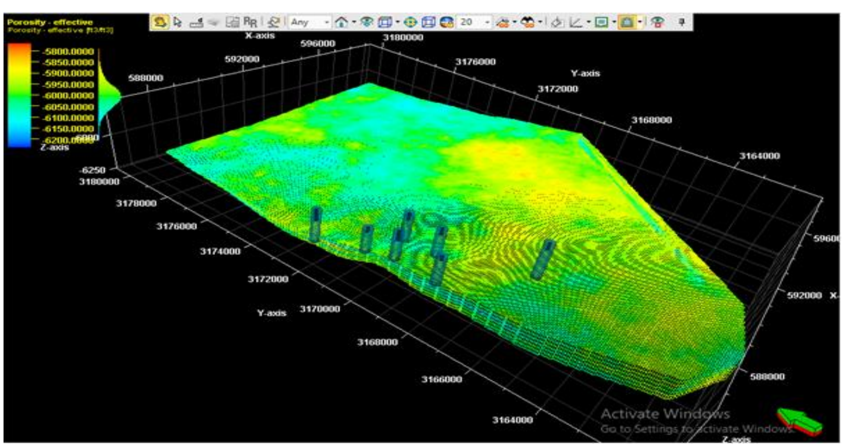

Figure (14) PHIE model for top Aouinet Ouenine F3 sand.

From figure (14) of Water saturation model for zone Aouinet Ouenine F3 sandstone reservoir shows moderate water saturation values that range from (0-10%), but in the south part water saturation values reached to 100%, the zone is represented as having no reservoir unit in the wellA12.

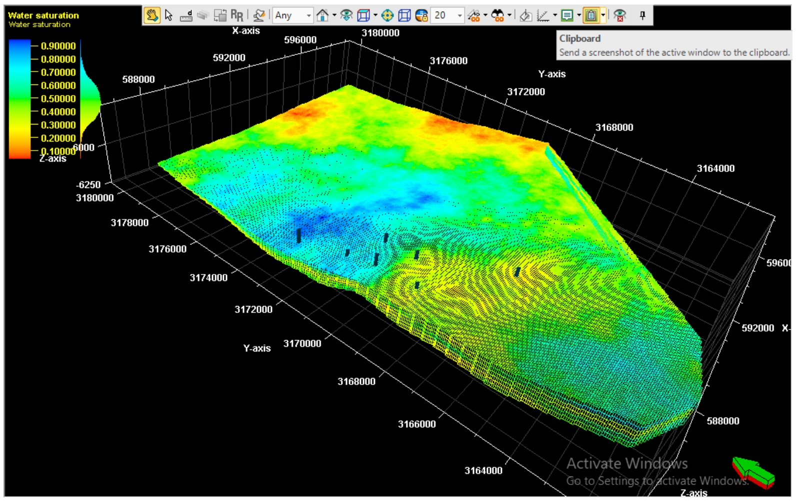

Figure (15) SW model for top Aouinet Ouenine F3 sand.

Conclusions:

The F3 sandstone is main reservoir in the Wafa field which belongs to the Frasnian stage of middle Aouinet-Ouenine Formation of the Devonian age where deposited as transgression sandstone on top of eroded surfaces, thickness decreases towards the southern portion of the study area reaching up to 4 feet (well A12). The lithology of F3 sandstone changes from sandstone to mix of shale and sandstone toward the southern area of Wafa Field probably related to change in sea level fluctuation during the deposition of F3 Sandstone. From our Petrophysical result of the main reservoir F3 sandstone parameters estimated as follows:

The average volume of shale is 2% in North area and 58% in South part where the shale increasing ,The average porosity is 10.5%. The average water saturation is 2.8% in the producing area. The average net pay thickness is 105 ft.

The interpretations of 3 D geology model and Petrophysical model (porosity and water saturation) for F3 sandstone reservoir show that the best location characterized by good *reservoir properties is in the wells located in the north part area gradually these properties decrease toward wells n the southern part area where the non-reservoir and it is mainly shale zone, the volume of shale is higher than 50% and porosity is low*.

Recommendations

1. *We recommend to use 3 D seismic data for undefined the Lithology change and reservoir extend in area as well as reservoir quality also to draw some maps because its more accurate than well data only specially when we attend to make relationship between wells.*
2. *We recommend using more other wells located between wells A12 andA55 to calculate the average porosity of the reservoir, in our study we have just used only 7 wells and the data was not enough.*

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