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BUILDING A RESERVOIR STATIC MODEL OF THE LOWER SAFA MEMBER AT EL-OBAIYED FIELD, NORTH WESTERN DESERT, EGYPT

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بناء نموذج خزاني ساكن لعضو الصفا السفلى في حقل الابيض، شمال الصحراء الغربية، مصر

الخلاصة: استخدمت الأساليب الجيوفيزيائية المتكاملة، ممثلة بتفسير الانعكاس السيزمي، والسجلات السلكية، وتحليل البيانات الأساسية، للكشف عن الخصائص الهيكلية والطبقية، وكذلك تقدير الخصائص البتروفيزيائية التي تهدف إلى إنشاء نموذج ساكن للخزان، لتقييم إمكانات الهيدروكربونات في حقل العبيد، الصحراء الغربية الشمالية، مصر الذى يقع في الجهة الغربية من حوض مطروح في منطقة الدراسة.

تم جمع نتائج التفسيرات المذكورة لبناء نموذج ساكن للخزان. يمكن أن تدعم الكشف عن الأماكن المناسبة لإنتاج الهيدروكربونات. والنموذج الساكن هو أداة تمثيلية للخصائص البتروفيزيائية والهيكلية للخزان.

ويمكن استنتاج أن خزان الصفا السفلي النموذجي هو مصيدة هيكلية متشابكة ومصدعة وذات معلم طبقى. وينقسم هذا الخزان إلى عدة وحدات تتألف من الرمال والصخور الحجرية مع زيادة سماكة ناحية الشمال. كما لوحظ ارتفاع المسامية الفعالة وقيم النفاذية للرمل، في حين تقلصت هذه الخصائص فى الطفال.

ABSTRACT: *Integrated geophysical methods, represented by seismic reflection interpretation, wireline logs and analysis of results of core data, were used for the detection of the structural and stratigraphic features, as well as the estimation of the petrophysical properties aiming at the establishment of a reservoir static model, for evaluation of the hydrocarbon potentiality at El-Obaiyed Field, North Western Desert, Egypt. Obaiyed Field lies at the western flank of Matruh basin in this study area.*

The results of the above-mentioned interpretationswere collected to build the reservoir static model. Such as Static model can support the detection of suitable places for hydrocarbon production. Static model is a representative tool by which facies, petrophysical properties and structurecan be visualized.

It can be concluded that, The Lower Safa static model reservoir is a combined trap formed from faulted anticline structural trap with pinching out stratigraphic feature. This reservoir is subdivided into several units composed of sand and shale intercalations increasing thickness northwards. Higher effective porosity and permeability values are noticed for the sand, while lower values are found for the shale.

INTRODUCTION

El-Obaiyed field is approximately 65km southwest of Matruh, 50 km south of the Mediterranean coast and about 400 km^2surface area (Figure 1). This study is concerned with the Jurassic gas reservoir of the Khatatba Formation at a depth of 4000 m.

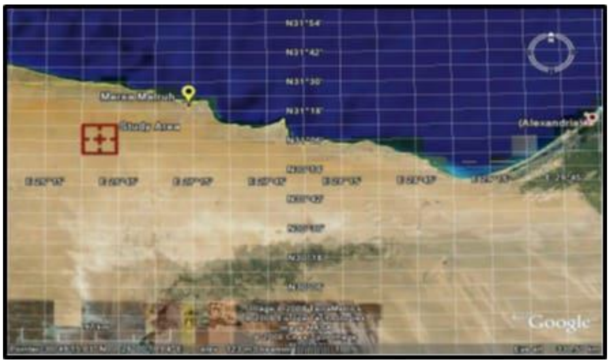

Fig. (1): Location of Obaiyed Field study area.

Said (1962) and EGPC (1984) divided Egypt into four structural divisions; unstable shelf, Hinge zone, the Nubian/Arabian cratons eastward andstable shelf. El-Obaiyed field is situated in the unstable shelf. Consequently, the dominant structural style comprises rifts and compression of Syrian arc system.

Khatatba Formation is divided into four members: Zahra, Upper Safa, Kabrite and Lower Safa (Said1962). Ghanima et al (2015)said that Upper Safa is considered as a source rock of Lower Safa gas reservoir, while Kabrite is a seal rock, Lower Safa reservoir composed of sandstone and shale intercalations.

The main objective of this study is to estimate the Lower Safa reservoir parameters in terms of faices change detection and petrophysical parameters distribution. To achieve this objective, Seismic interpretation, wireline logs evaluation and core data analysis have been achieved.

1. Seismic Interpretation

The available data are twenty 2D seismic lines and check shots of four wells D-13, D-17, OBA-SA and JB 16-3. These data were used for structural and stratigraphic interpretations of the tops of The Khatatba, Kabrite, Lower Safa and Paleozoic (Shifah) members.

Seismic sections should be tied to the available wells in a step of well-to-seismic tie, using Petrel 2013 computer software for horizon picking of The Lower Safa reservoir through manualtracking, looping technique, reflection characters, and correlation of individual pulses and sequence of reflections and their spaces. Then, the fault picking was carried out on the sections to draw fault polygons on the 2D map, to perform the fault detection criteria,according to Dobrin and Savit (1988).

The interpreted seismic sections (Figures 2, 3, 4 and 5) show that,the horizons oftheJurassic rock units (Khatatba, Kabrite, Lower Safa and Paleozoic)are affected bythe Pre-Cambrian fold pattern acting on the Egyptian basement, following by atension force in the NW-SE direction producing a series of step-like faults NE-SW direction. Then, theJurassic members suffered froma compressionalforce of Syrian arc system that affected on the throws of those faults and let them be in the range of 0-50 m.

The tectonic events have been controlled the structural style of El Obaiyed field, that can be expressed as faulted fold and/or planner fault system with mutually horst and graben blocks.

The results of picking of all the interpreted seismic sectionsare focused on The Lower Safa Member, yielding its two-way time structure map. Itshould be transformed to depth structure map by usingthe average velocity on its top to transform it from time domain, into depth domain as shown in the depth structure map (Figure 6).

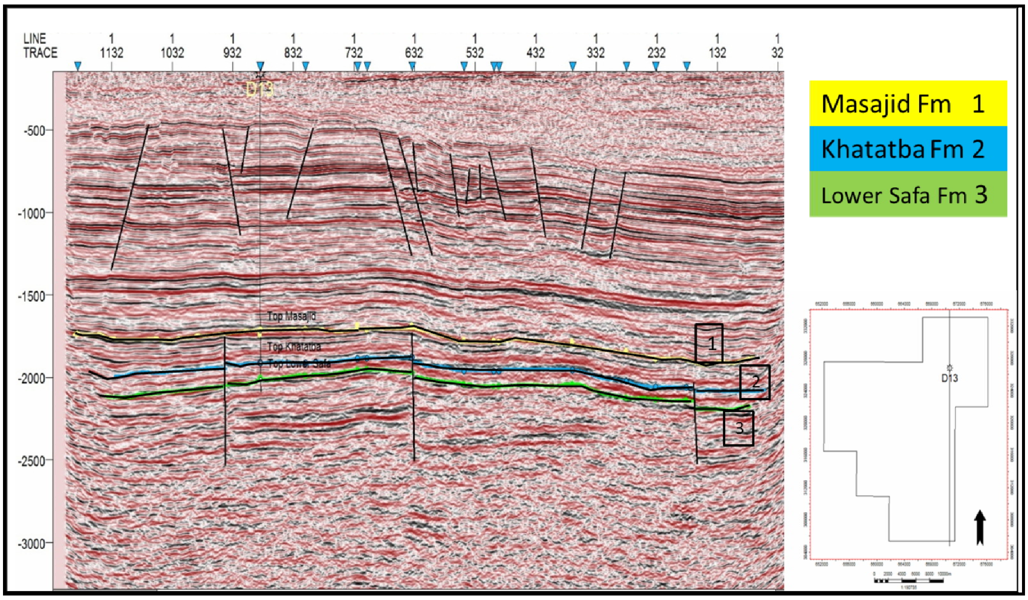

Fig. (2): Interpreted inline seismic section (D-13).

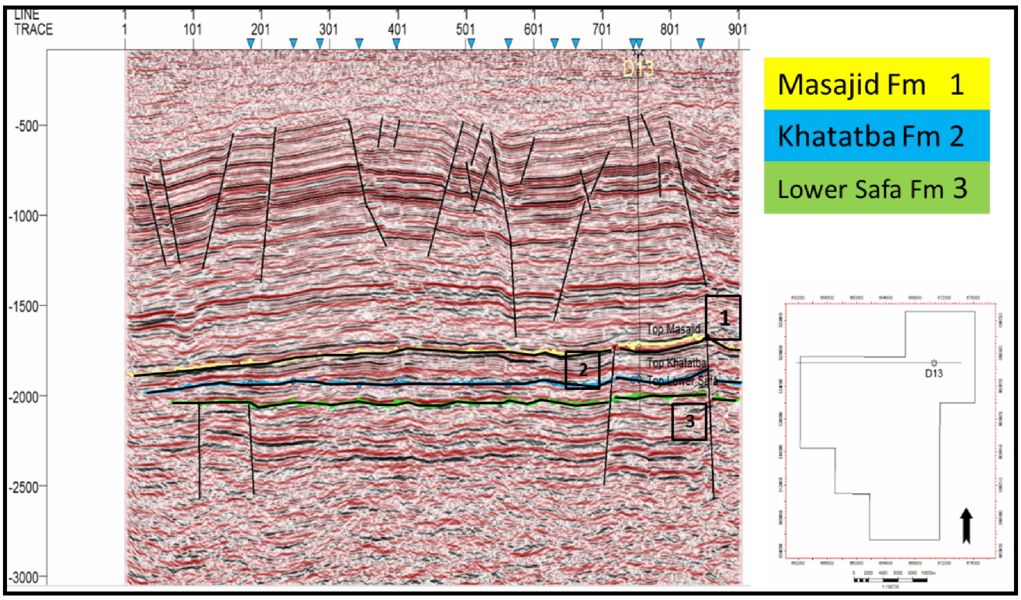

Fig. (3): Interpretedcrosslineseismic section(D-13).

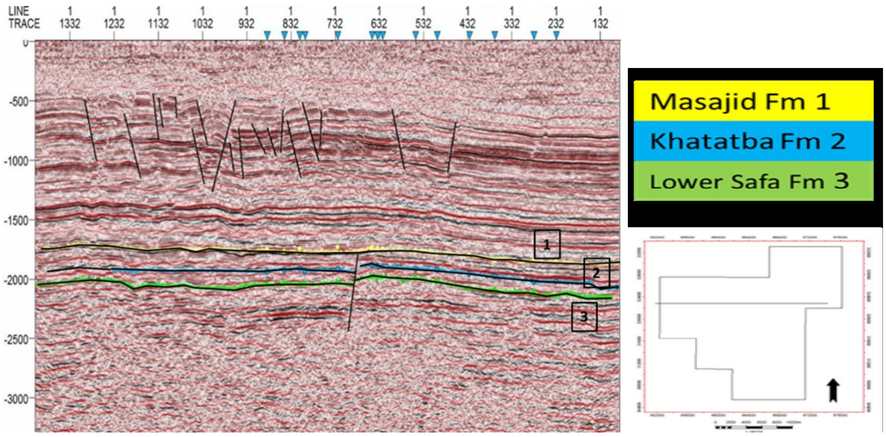

Fig. (4): Interpretedinlineseismic section (2500).

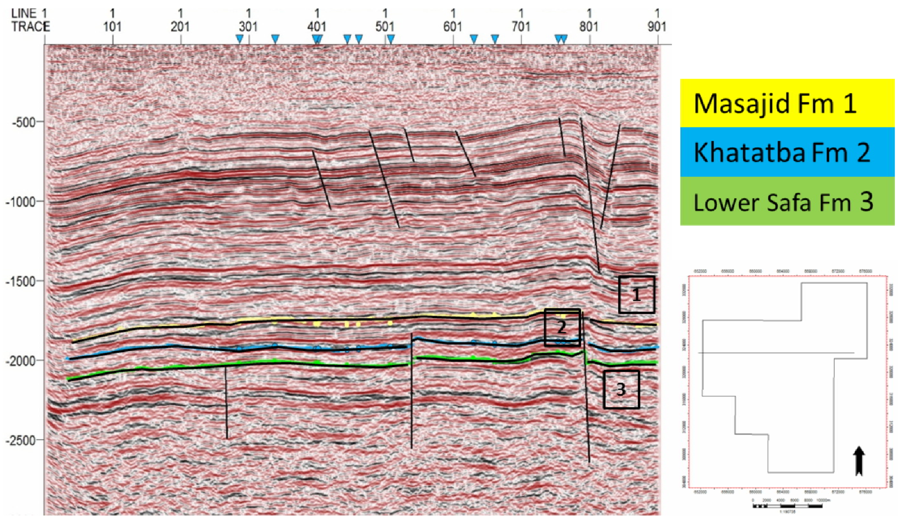

Fig. (5): Interpretedcrosslineseismic section (1800).

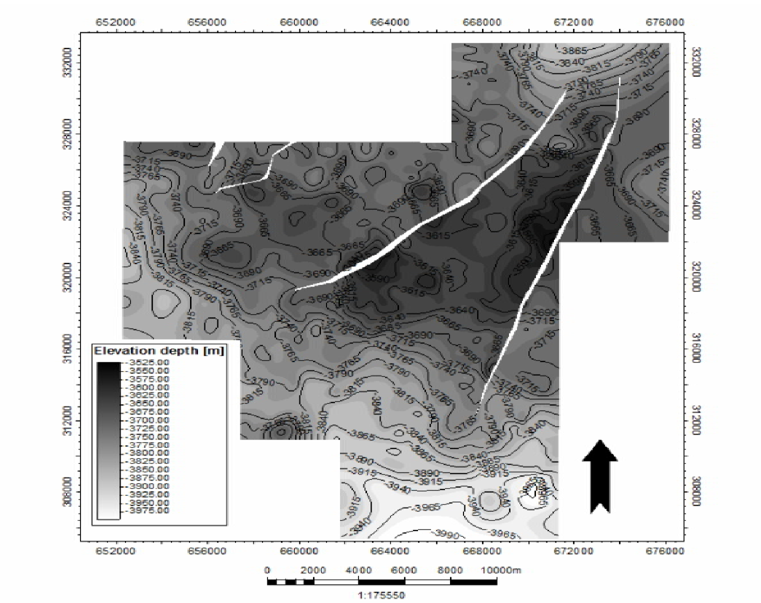

Fig. (6): Depth structure map of Lower Safa reservoir.

Depth structuralmap of the Lower Safa membershows the structural highs and lows anomalies,forming mutually occurring horst and graben structures, separated by fault polygons. These structural styles represented inmajorstep-like faults F1, F2, F3 and F4 (arranged by order from east to west), where F1, F3 and F4 throw eastward, while F2 throws westward. In addition,a faulted fold anticlinal trending in theNE-SW direction is present,dissectedby a number of normal faults oriented in the NE-SW direction.

2. Wireline Log Evaluation:

Tens of wells that have a triple compo (TQ) and Quadra compo (QC) penetrate El-Obaiyed field. Wireline logs analysis gives information about The Lower Safa lithology description, petrophysicalparameters calculationand facies prediction.

1. Lithology description:

The wireline responses depend on rock properties, by which the lithology of formations and zonation could be known. The lithology of Lower Safamember in all the studies wells were investigated, using loggingcross plots (including the neutron porosity-density cross plot andthe neutron porosity- GR cross plot). Figures (7 and 8) show that Lower Safa member is mainly composed of sandstone with shale interbeds, where sandstone layers has low Gamma Ray (GR) and low neutron log response.

Based on the available log data, the Lower safa lithologycould be divided into three units A-B, C and D. Where unit D is composed of pure sand stone, unit C is composed of shale and unit A-B is shaly sand. It is clearly that, the Lower Safa sand units that containing gas saturation have lower density from sand of water saturation, figure (7) show gas effect on the neutron – density cross plot.

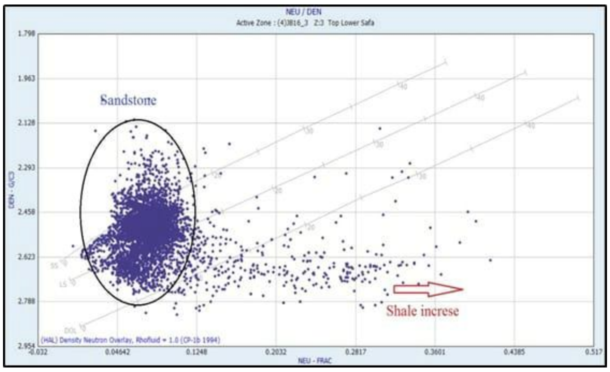

Fig. (7): lithology identification with neutron - density cross plot of the Lower Safa member.

2. Porosity and water saturation calculation

Units A-B and D are characterized by low GR response and high resistivity, while unit C has high GR response and low resistivity. Shale volume calculation is carried out with a single indicator technique(GR method) and double indicatorstechnique (Neutron-Density). Figure (9) shows Porosity and water saturation calculations, are carried out by using Density **-** Neutron combination and Archie’s method.The Lower Safa units show a high percentage of porosity, except unit C, and show that,the water saturation increases at depth of 3870 m.

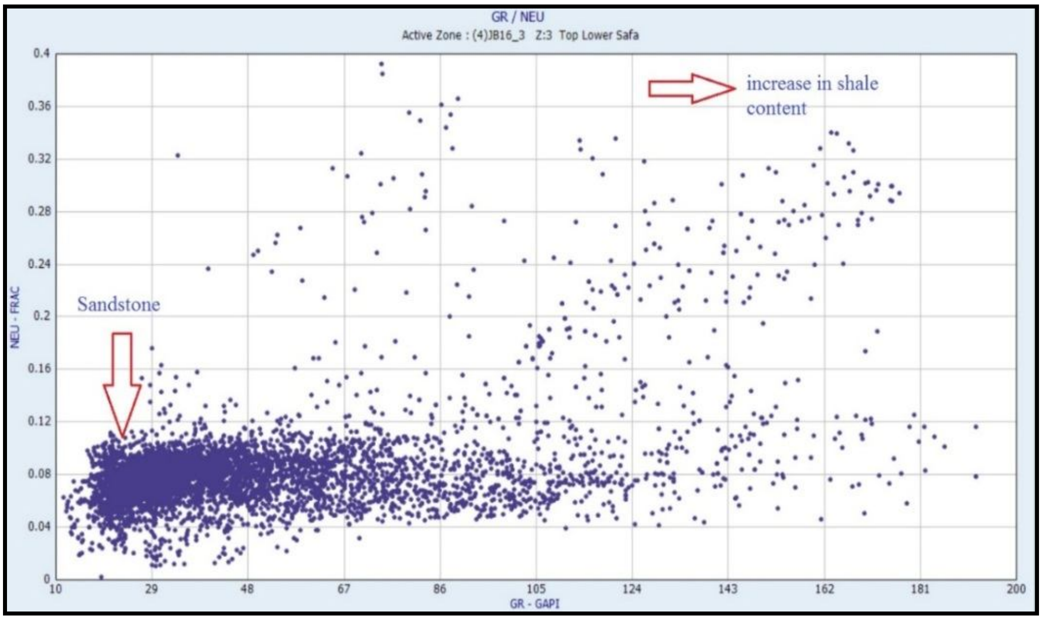

Fig. (8): Lithology identification with neutron porosity- GR cross plot of the Lower Safa member.

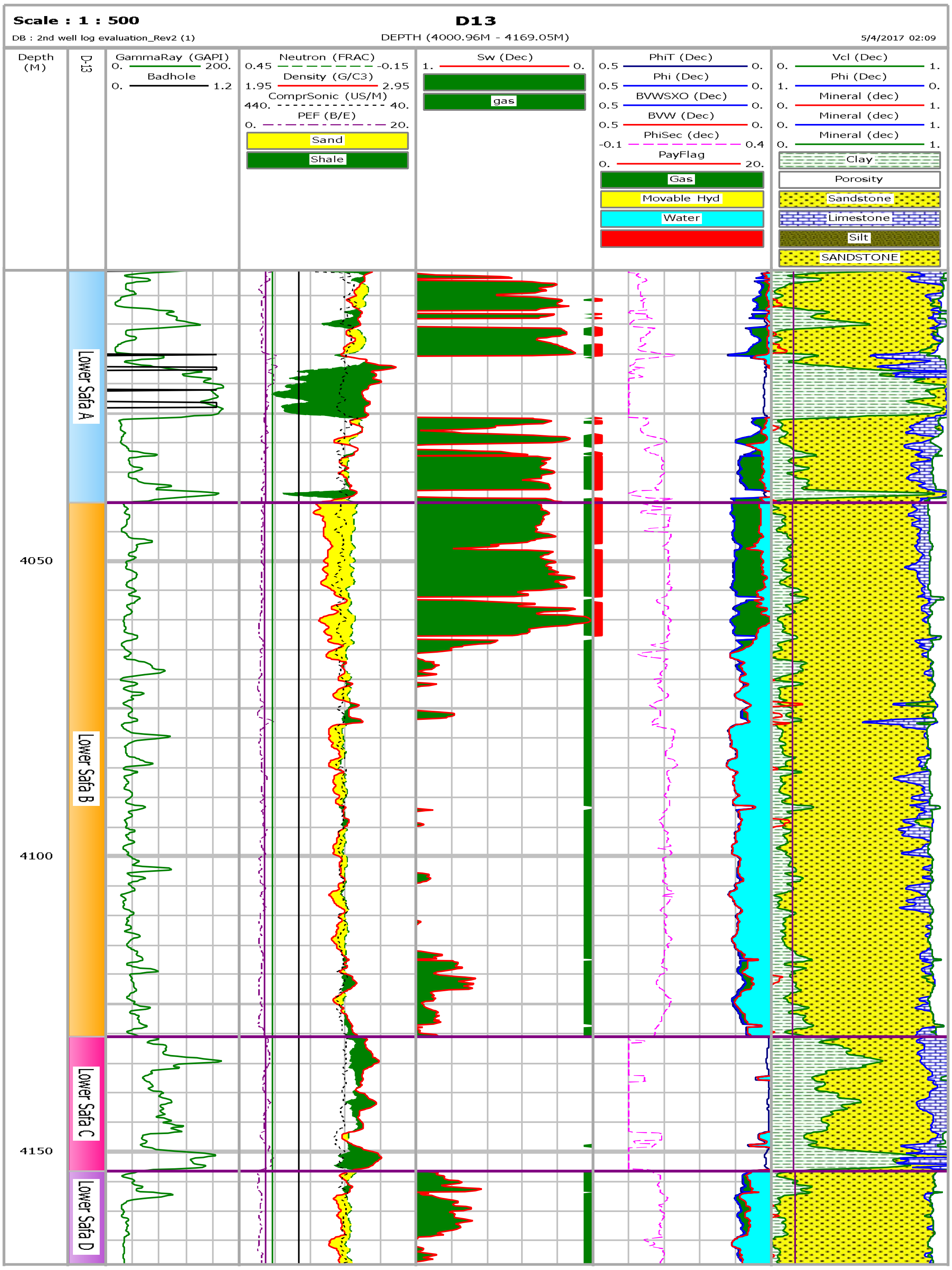

Fig. (9): Litho-saturation cross plot of D-13 well.

Figure (10) shows an Isochore thickness map of the Lower Safa member that thins toward the southwest and thickens toward the northeast.

This study divided the Lower Safa interval into an upper pay representing (unit A-B) and a lower pay representing (unitD). Figures (11, 12 and 13) show Property maps of the Lower Safapaysare carried out to show properties lateral distribution such as thenet-pay maps, gas saturation maps and porosity maps.

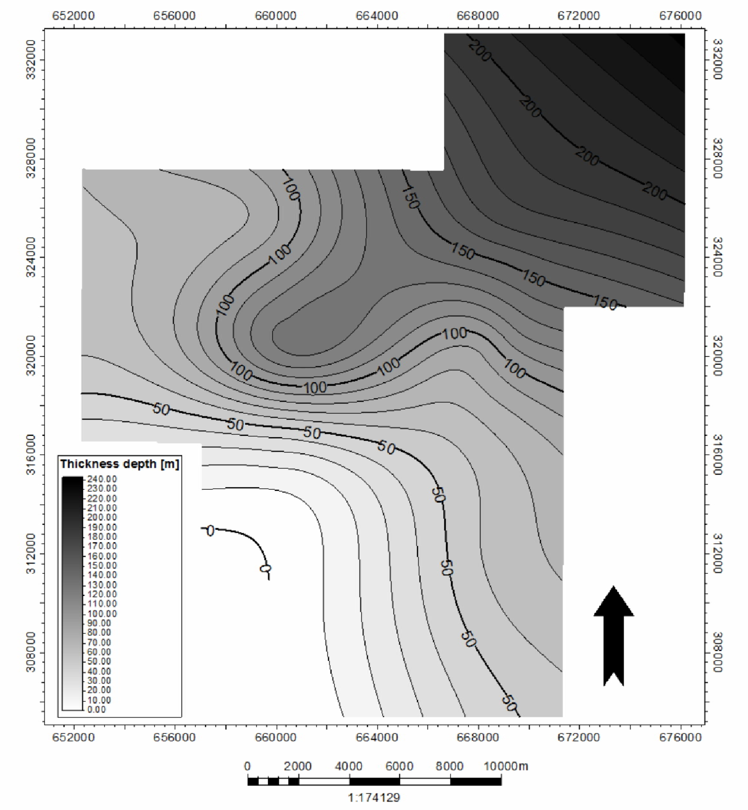

Fig. (10): Isochore thickness map of Lower Safa reservoir.

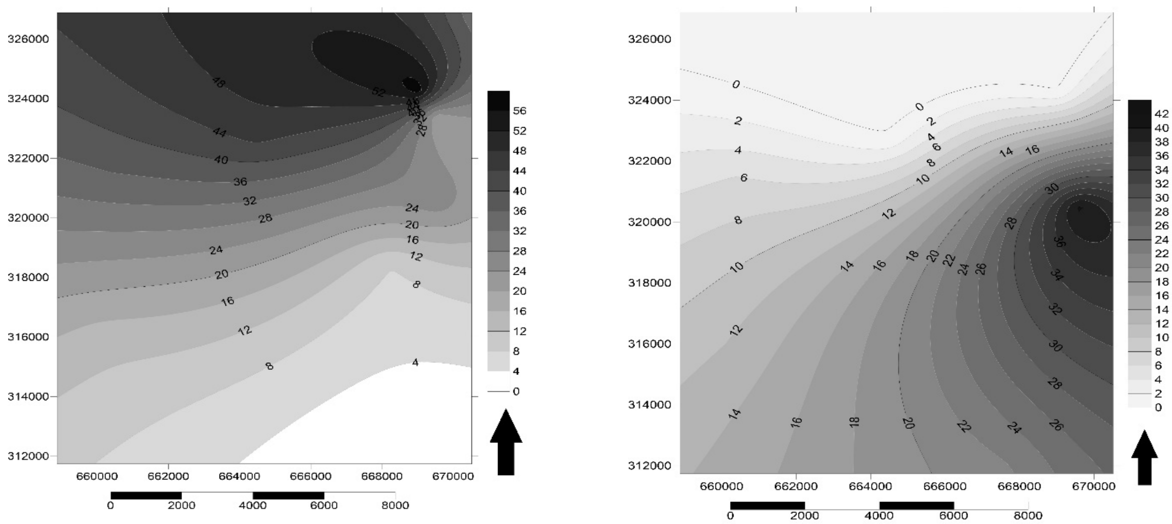

Fig. (11): net-pay map of the upper pay (left one) and the lower pay (right one).

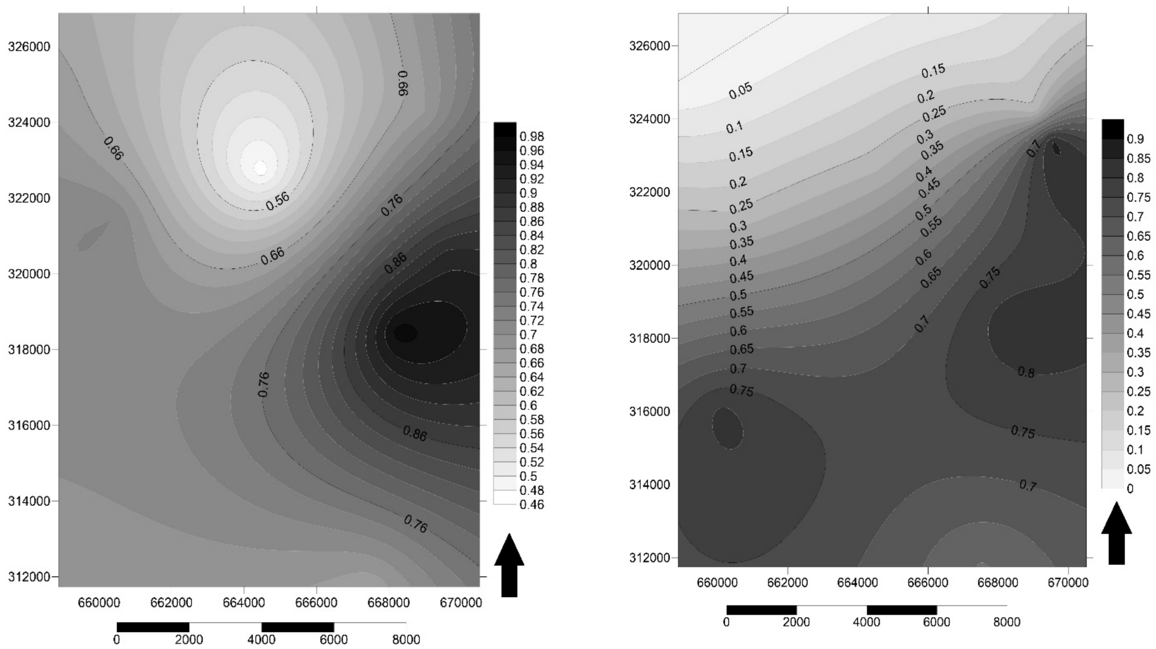

Fig. (12): gas saturation map of the upper pay (left one) and the lower pay (right one).

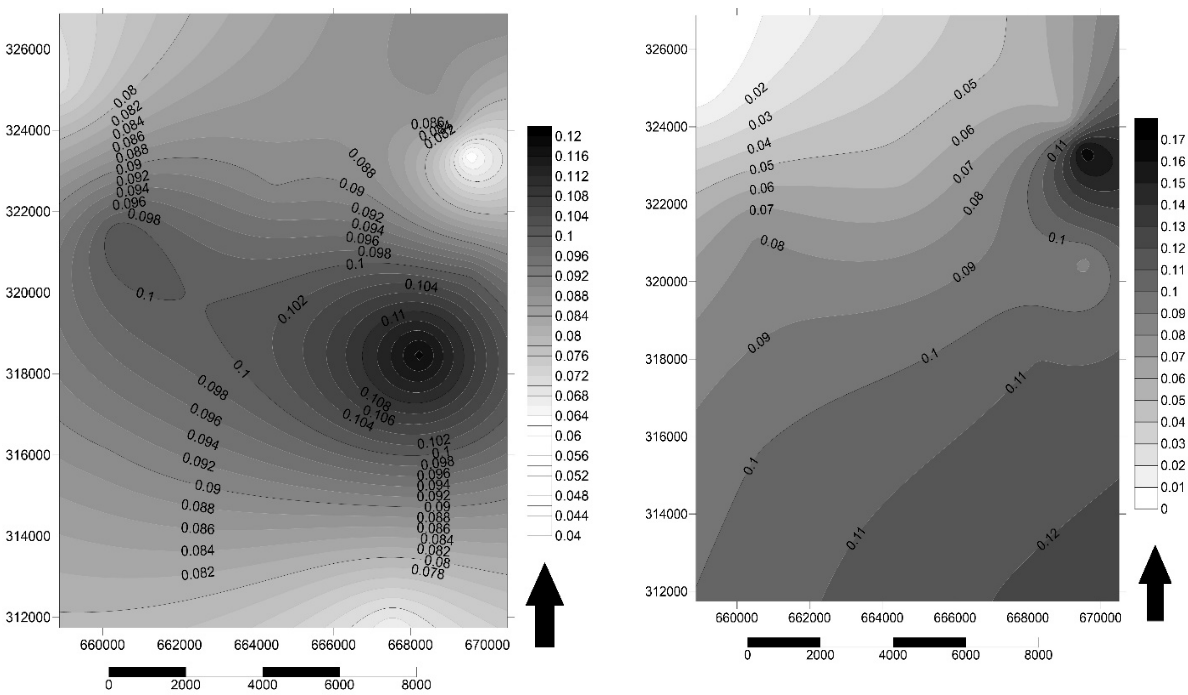

Fig. (13): Porosity map of the upper pay (left one) and the lower pay (right one).

The previous figures ofProperty maps showthat theupper pay is pinched out toward the southern direction.Toward the northern,the upper pay facies changes to be shaly.Itcan be concluded that, the best location of porosity located in the central part of the field and ranged from 0.04 to 0.12, as shown in figure (13) map, and net pay of the upper pay increasesnorthward.The lower pay is dominant all over the field with porosity ranged from 0.04 to 0.17,but dipping toward the north.Therefore, the lower payis expected to lies below the gas water contact. Consequently, the net pay of the lower pay will increase toward the southeast (figure 11).

3. Core data Analysis:

This study was used the conventional core analysis results to detect the reservoir rock typing for permeability prediction by using hydraulic flow unit concept. Figure (14) shows the relation between log permeability on y-axis versus porosity on x-axis, the relation shows a scatter plot with a directly proportion trend.

Amaefule, (1993) said that, pore geometry varies with lithofacies variation. Depositional factors and diagenesis process will control on the pore geometry distribution. Amaefule (1993) derived a mathematical equation to calculate the rock quality, based on the modified Kozeny Carmen theory.

For any hydraulic unit, figure (15) shows a log-log plot of a Reservoir QualityIndex (RQI), versus a"Normalized Porosity will yield a straight line with a unit slope. The intercept of the unitslope line with $\emptyset z$ = one, designated as theFlow Zone Indicator(FZI), which is a parameter for each hydraulic unit, based on the porosity and permeability datameasured on core samples.

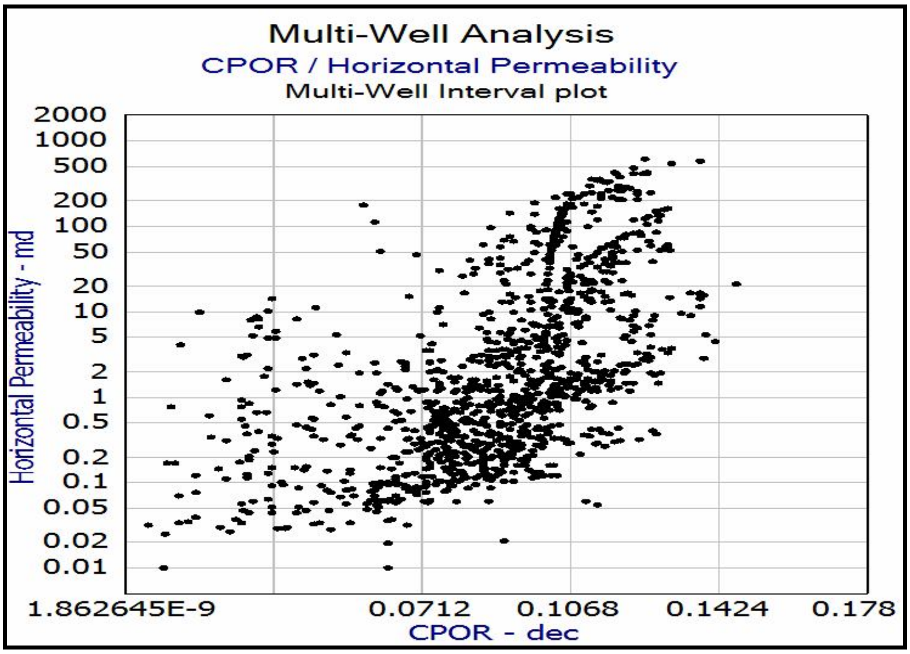

Fig. (14): porosity versus permeability relationship.

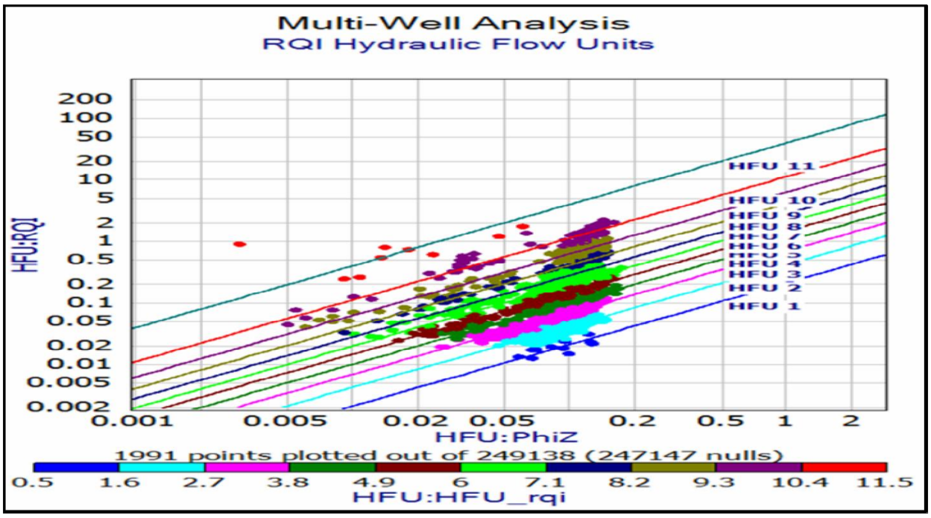

Fig. (15): RQI and normalized porosity cross plot, with respect to HFU.

$$\log RQI = \log \emptyset z + \log FZI \quad (1)$$ Amaefule, (1993)

Where, $\emptyset z$ is the normalized porosity

RQI is the Rock Quality Index = $0.0314 * \sqrt{\frac{K}{\emptyset}}$

FZI is the Flow Zone Indication

To simplify the use of FZI in expressing the reservoir type, FZI can be transformed to a Discrete Rock Type (DRT) by:

$$DRT = Round\ (2 * \ln(FZI) + 10.6) \quad (2)$$

The Lower Safa is a heterogeneous reservoir, due to the diagenesis process represented byClay filling the pore throats and complex depositional environment, represented as estuary environment produce two different types of sands in the Lower Safa member.

Figure (15) shows that, the relation of RQI versus the normalized porosity cross plot can be divided into 11 hydraulic flow units.Each unit could be represented by one equation for permeability prediction (figure 16). Hydraulic flow unit can investigate the heterogenity of the reservoir at core scale,while logs can investigate the heterogenity of reservoir only at the location of the well.

The core report produced by the company is said that, core samples have bioturbation markers of tidal dominated for unit A-B while unit D is clear of markers and refer to fluvial dominant environment. Wahdan, et al, (2013) discussed the results of scanning electron microscopy (SEM), kaolinite is blocky and filling the pore spaces and altered to illite, that has the major effect on reservoir quality. The most effective processes on reservoir quality in the Lower Safa are the kaolinite and illiteprecipitation, feldspar dissolution and quartz cementation.

4. Static model building:

The areal extent of the reservoir, hydrocarbon thickness (pay), porosity and saturation provide the volumetric estimate of the in-place hydrocarbon reserves and constitute the key inputs from seismic, facies and wireline logs to initiate the reservoir static modeling (Niranjan, 2016).

Quality of the static model depends on the quality of facies, wireline logs evaluation and how many input data used for model building. Static model construction aimed at the structural delineation, reservoir management, petrophysical properties distribution, risk reduction and heterogeneity investigation.Three types of models can build the static model of the Lower Safa reservoir (Merletti and Torres-Verdin, 2010):

1. **Structural model**
2. **Facies model**
3. **Petrophysical model**

Structural model:

Structural model is the first step for static model construction. It represents the stress directions affected on the field and resulted faults. The 3D view structural model is the process of integrating the geologic reflection interfaces, such as interpreted horizons and faults (Mitra and Leslie, 2003).The Structural model consists of three steps: Fault Modeling, Pillar Gridding and Making Horizons.

Fault modeling:

This step involves the definition of faults in the geological model that form the basis for the generation of the 3D grid. The faults were obtained from the seismic interpretation study of El-Obaiyed Field.Then loaded into the Petrel software.Faults are considered as the basis of the volume of static model. The Lower Safa suffered from tensionalforce, which produces NE-SW step-likes faults.

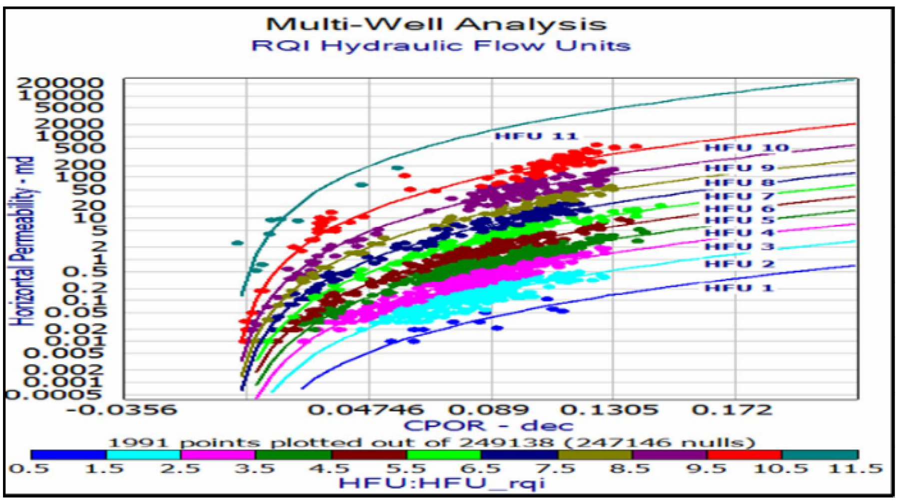

Fig. (16): Porosity-Permeability relation of theLower Safa reservoir with HFU.

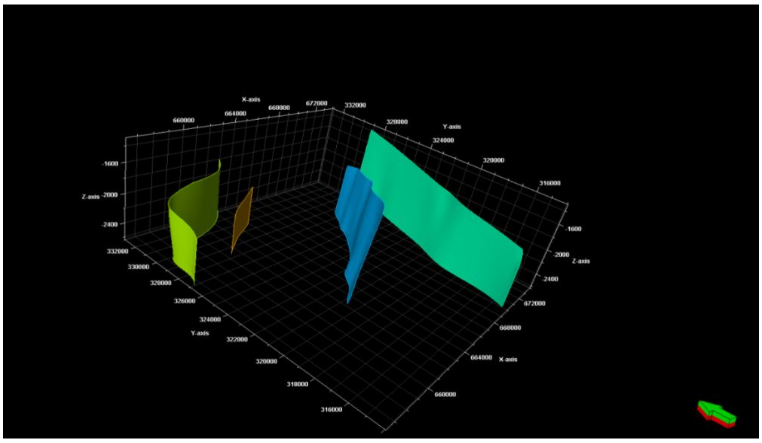

Fig. (17): Fault modeling in a 3D window of the Jurassic Formations.

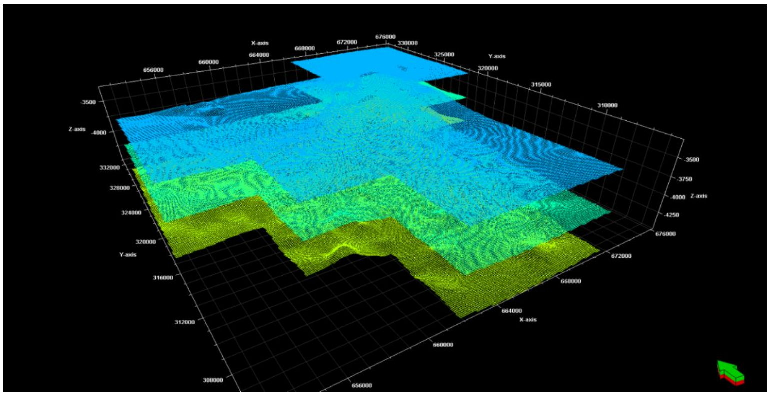

Fig. (18): Skeleton Grid in the 3D view of the Jurassic Formations.

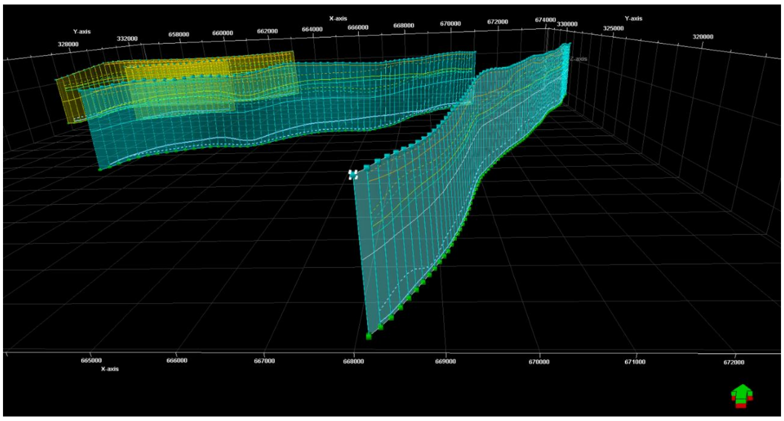

Fig. (19): Faults Pillar cut through the Jurassic Formation in the 3D window.

Figure (17) shows the input faults, which must be converted to fault sticks; these sticks represent the fault surface. It is very important to check faults relationship with each other, due to grid building in the 3D volume. Petrel software grouped a set of sticks to represent one fault and ready to convert to key pillars.

1. Pillar gridding:

This process includes a creation of the 3D skeleton of the structuralmodel. Figure (18) shows that the skeleton is a grid of top, mid and base; this study built a skeleton grid to the Khatatba formation, Lower Safa member and Shifah Formation. In addition, pillars represent the faults and connect corners of grid to adjacent one.

Figure (19) shows Pillars of faults, which makes an easy way to adjust any fault, without going back to the fault interpretation step. It could show the problem, which resulted in faults relationship.

2. Making horizons:

This step is the last step in building a structural model, it includes:

- Make Horizon process: Inserting the surfaces in a 3D grid. This research used thesurfaces of Khatatba, Kabrite, Lower Safa and Shifah rock units.
- Depth Conversion: All of the inputs are insertedin a 3D grid in the time domain, but to tie with well parameters, we need to convert it to depth domain.
- Make Zones: This step is concerned to inserting the isochore maps above or below surfaces. In the Lower Safa, it can be dividedinto three zones Lower Safa A and B in one zone, Lower Safa C and Lower Safa D (figure 20).

Layering: It detects the number of cells in our model; it depends on the heterogeneity of the zone. In this study, 20 layers for units A and B, 5 layers for unit C and 15 layers for unit Dwere used.(Schlumberger Information Solutions, 2007).

Figure 21 (a and b) shows thecross sections passing through a structural model in the direction of N-S direction and E-W direction, with a clear thickening of the units A, B and C, northwards and eastwards, respectively.

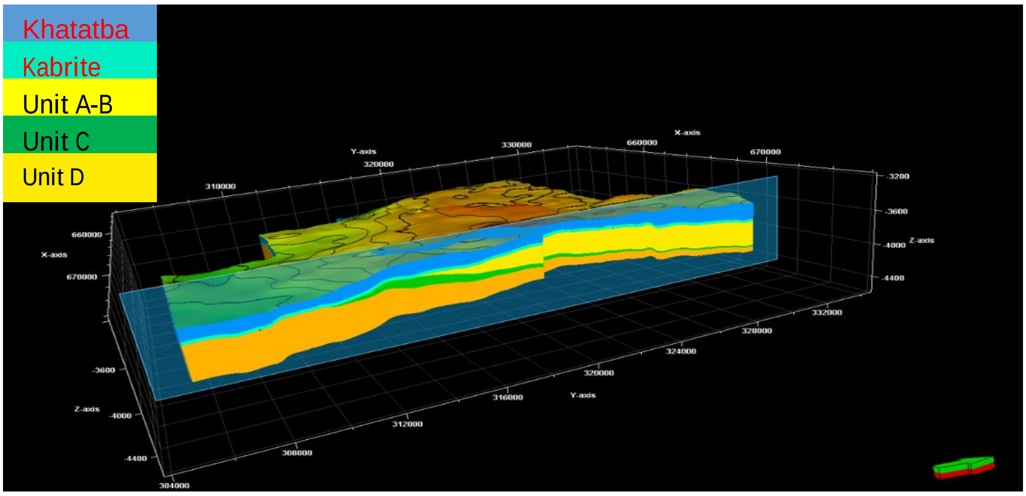

Fig. (20): Lateral and vertical extensions of the Jurassic Formations.

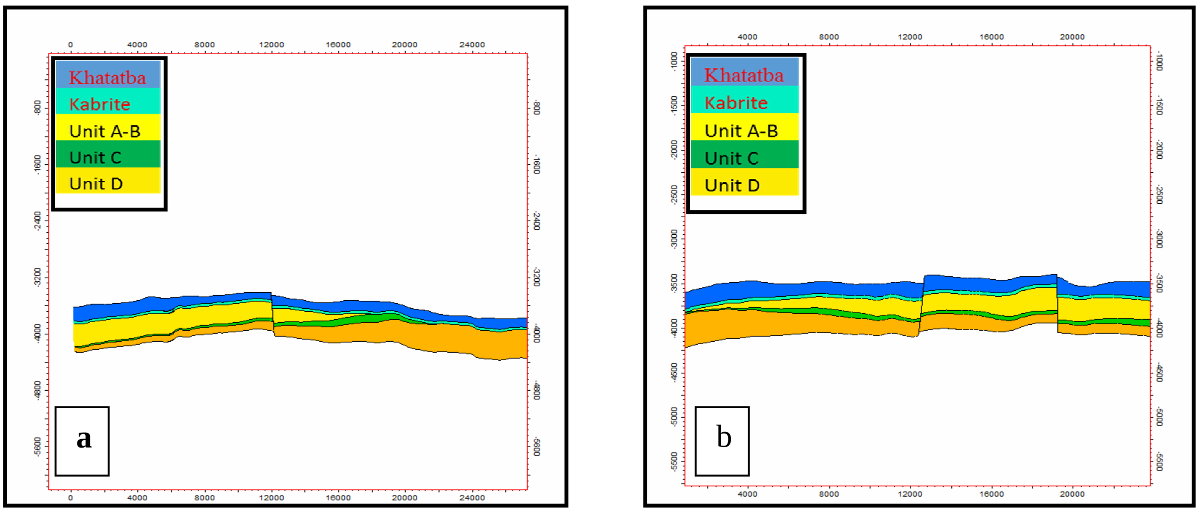

Fig. (21): Cross section of the Jurassic Formations (a) is the north south while (b) is the east-west view.

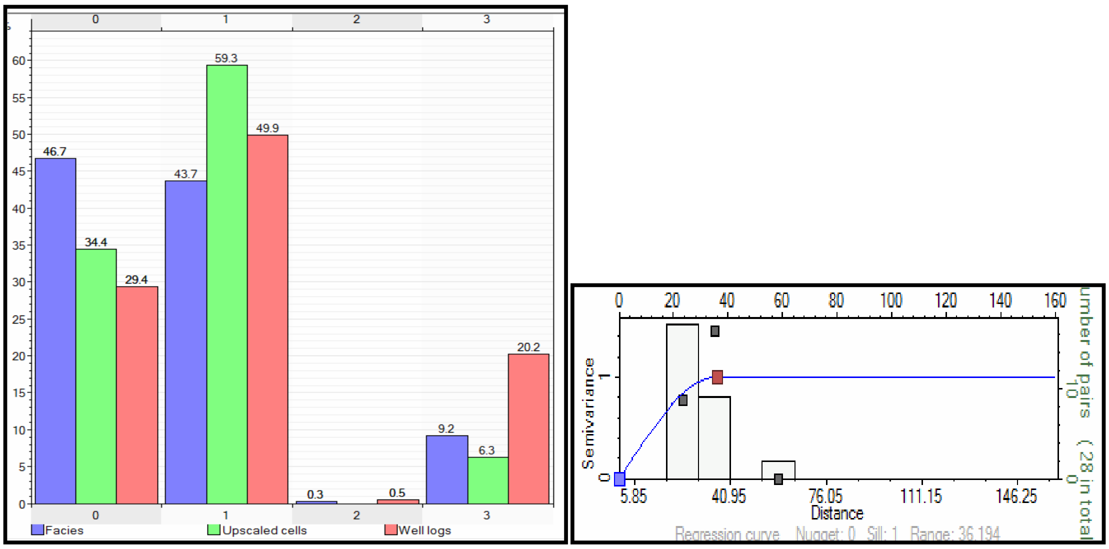

Fig (22): Histogram and Variogram of Facies up-scaling (Code 0 is sand, Code 1 is shale, Code 2 is carbonate and Code 3 is shaly sand).

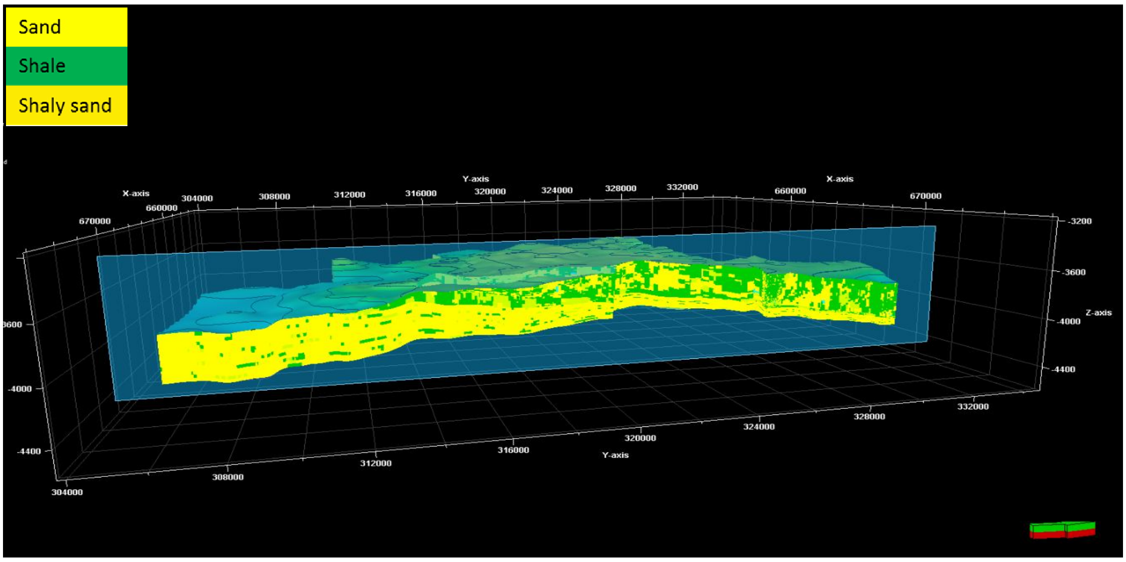

Fig. (23): sand – shale distribution within the Lower safareservoir.

2. Facies model:

Now, our structuralmodel is ready to be linkedto wells, but the wells must be up-scaled firstto represent a value at the intersection point with the grid.

Scale-up Facies log:

Scale-up wells is a process of filling a cell that is penetrated by the well with a value (figure 22), so the well values must be averaged. This step uses thewell data, as input parameters (Walker, R.G, 2006).

Figures (23 and 24) show facies distribution of units of the Lower Safa reservoir, where unit D is mainly composed of pure sandstone, while shale distribution increases upward representing in the shale of unit C and shaly sand of unit A-B.

3. Petrophysical model:

Porosity model

Porosity values distribution has been done by using the sequential Gaussian simulation. Data distribution in the 3D correlation, with variogram and histogram should be done.

Figures (25 and 26) show that units A, B and D are sand rich possess effective porosity values varied from 4 to 15 %. The effective porosity distribution 3D view of the Lower Safa is controlled by facies distribution more specifically, with the sand distribution where the Lower Safa sand is concentrated in the center of our field with the east-west areal extension, and it becamemore shaly in the northeast direction.

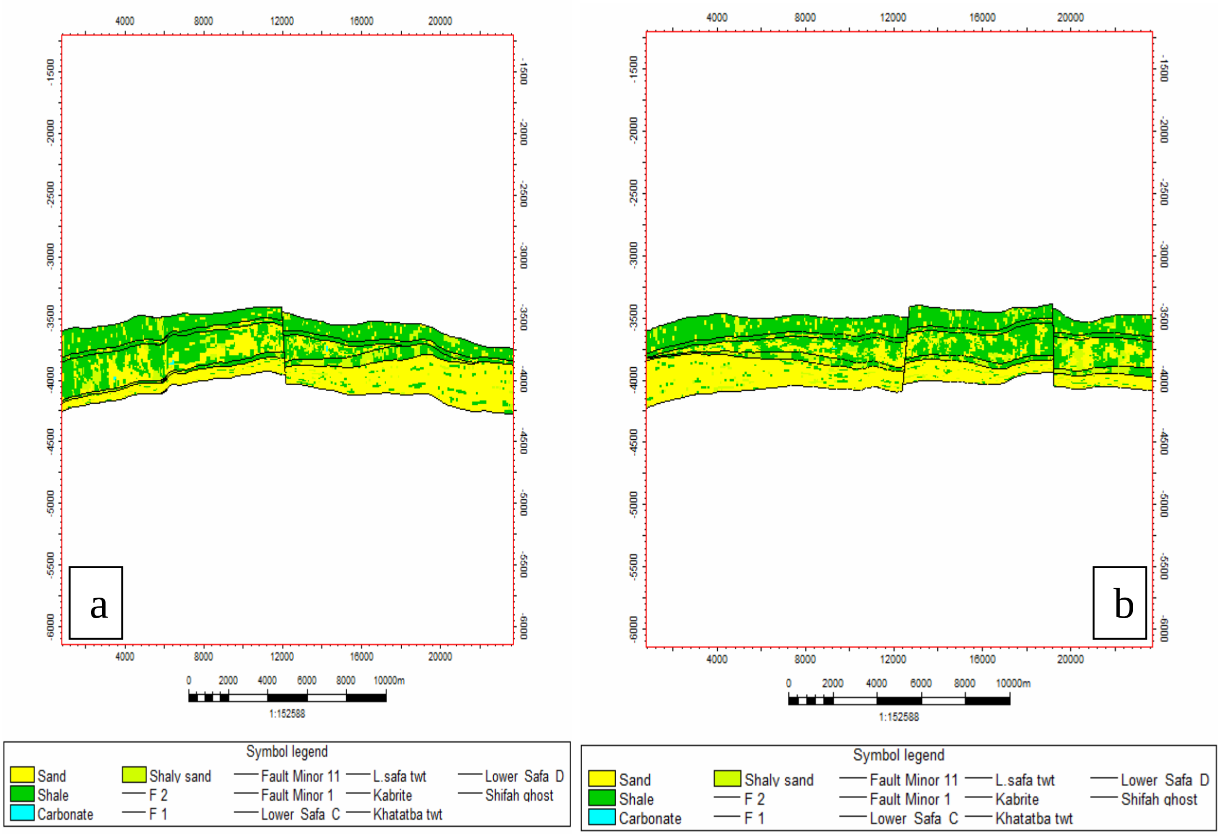

Fig. (24): Facies Cross section of the Jurassic Formations (a) is north-south view, while (b) is east-west view.

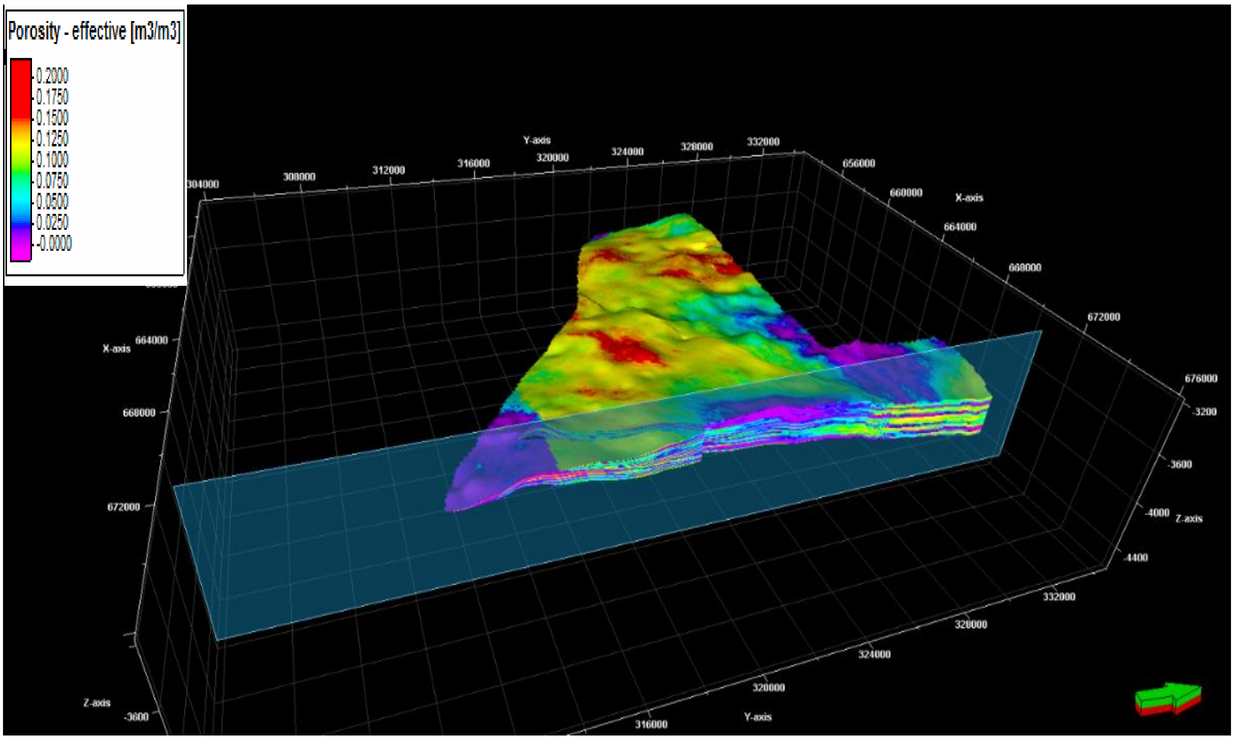

Fig. (25): porosity distribution within the Lower Safa A-B reservoir.

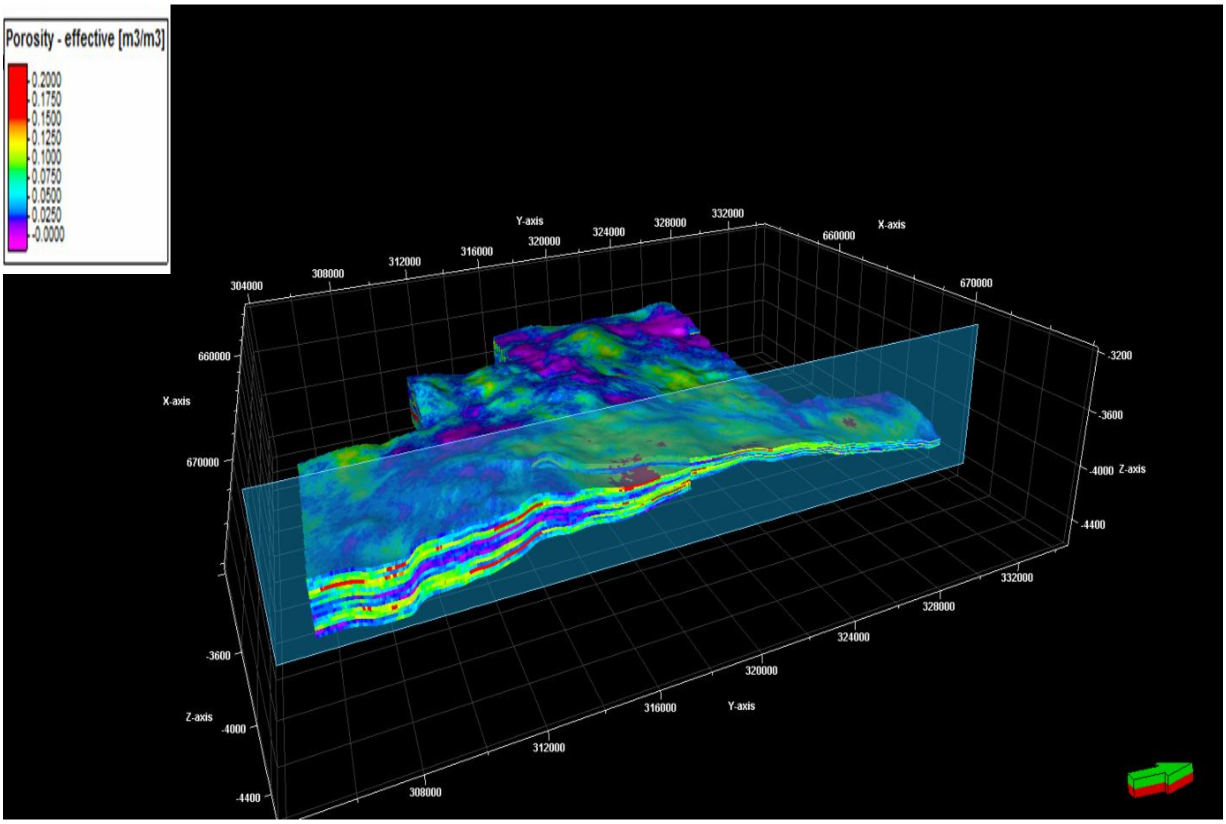

Fig. (26): porosity distribution within the Lower Safa D reservoir.

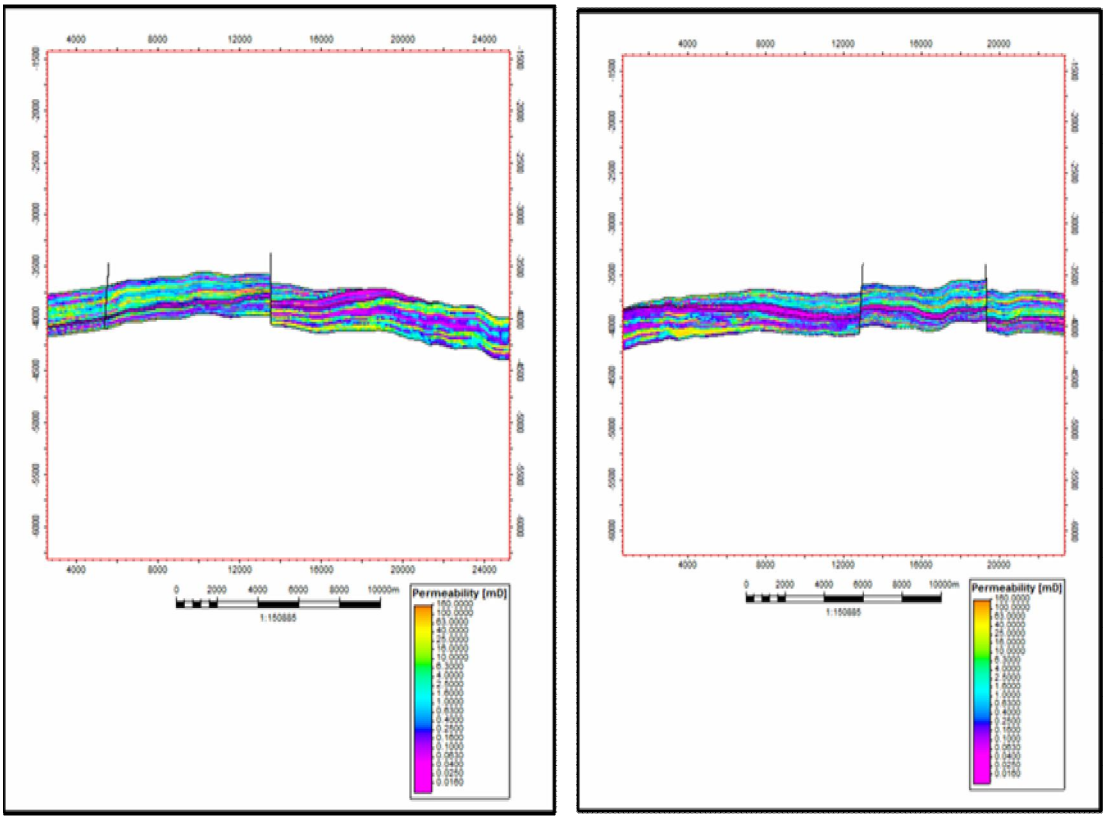

Fig. (27): permeability Cross section of the Jurassic Formations (Left) is the north-south view while (right) is the east-west view.

Permeability model:

Permeability is a function of porosity; we insert the permeability, that is predicted from the hydraulic flow unit technique to the model. Figure (27) shows that the Lower Safa C unit is shale, with low permeability, while the Lower Safa A and B units are higher permeable zones, and the Lower Safa D unit is manifested by very high permeability values. The Lower Safa A, B, C, and D unitsare changed laterally northeastwards from sand to shale and so, their permeability tends to decrease in that direction.

SUMMARY AND CONCLUSIONS

In this paper, the variability of the Lower Safa reservoir was investigated at three different scales. The three scales correspond to seismic interpretation,wireline logs and core-plug scales. Lower Safa reservoir is a member of the Jurassic Formations; it has a wide variability in thickness, facies, and petrophysical parameters.

A consistent reservoir modeling has been developed for the Lower Safa in El-Obaiyed Field, and this geological framework is based on an integrated approach, using seismic interpretation, wireline logs evaluation and core data analysis.

Interpreted seismic sections show that, the Lower Safa has a complex structural pattern. Folding system playsa predominant role in the structural setting definition. A number of step-like faults in the NE-SW direction dissects this fold. Most of these faults are throwing southeastward and northwestward, forming grabens and horsts pattern.

Geological observations obtained from thewireline log evaluation in El-Obaiyed Field, have been used to evaluate the depositional environment and petrophysical characteristics of Lower Safa reservoir. Wireline logs evaluation shows that,the Lower Safa has a thickening northeastward toward the deep center of the basin, and thinning southward and southwestward towards the paleo-high of Matruh basin. This study divided the Lower Safa reservoir into three units are (A-B, C and D). These units composed of sand and shale intercalations. Higher effective porosity and permeability values are noticed for the sand, while lower values are found for the shale.

Conventional core data analysis was used for the Lower Safa heterogeneity investigation and rock typing definition. Hydraulic flow Unit (HFU) technique was used to define the number of rock typingof Lower Safa. HFU shows that, Lower Safa could be composed of 11 units. Core report description provided that, the evaluated wells were drilled into different two types of depositional environments for sands, the first one is thetidal environmental sand, while the second older one is the fluvial-dominated sand.

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