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Integrated Reservoir Characterization Studies of Bahariya Formation in the Meleiha-NE Oil Field, North Western Desert, Egypt

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Abstract. The first objective of this paper is to do seismic interpretation of thirty four 3D seismic sections for identifying the structural traps, and the second is to use the well log data to determine the reservoir characteristics and fluid contents.

The seismic interpretation covered eight steps, namely; reflectors identification, picking and correlation of reflectors, fault location, closing loops, velocity analysis, digitization, time to depth conversion, constructing geo-seismic cross-sections and construction of the isochronous and structural contour maps. The seismic interpretation reflects the outstanding role of faulting and folding on the top of Bahariya Formation in the studied area.

The high values of core porosity indicate that the Bahariya Formation belongs to the high quality reservoir. The low correlation coefficients of some porosity relations reflect the influence of porosity heterogeneity in the studied wells.

The well log analysis procedures are performed in five phases; Digitizing, data gathering, environmental corrections, multi-well normalization and formation evaluation tasks. The well log interpretation used to determine the properties and fluid contents of Bahariya reservoir indicates its high values of porosity, that consider it as a high quality reservoir.

The fluid contents of Bahariya Formation are illustrated in three forms; distribution maps, litho-saturation cross-plots and models. The fluid contents distribution maps reflect a general increase of hydrocarbon at the northwestern and southeast parts of the study area at NE-1x well and NE-14 well, respectively. The fluid content litho-saturation cross-plots show that, Bahariya Formation consists of sandstone, shale, limestone, and the effective porosity is filled by fluids which are; water, irreducible hydrocarbon and/or movable hydrocarbon. These fluids have widely vertical distribution in each well. Litho-saturation cross-plots ensure that, the southeastern part of the study area is the best place to produce oil. The reservoir fluid contents 3D models show that, the hydrocarbon saturation concentrate in the northwestern and southeastern parts of the study area and oil in place is controlled by the structural traps.

Introduction

The study area (Meleiha NE oil field) lies in the northern part of the Western Desert. The Western Desert has numerous oil potentialities and may soon jump as a great oil province. Many promising areas are still waiting for detailed examination; one of these is Meleiha NE oil field, located in Meleiha concession, 6 km northeast of Meleiha Field and 60 km south of Matruh Town (Fig. 1).

The general structural and stratigraphical aspects of the Western Desert have been the subject of many studies, such as; Amin (1961), Said (1962 and 1990), Norton (1967), Eloui and Abdine (1972), Deibis (1978), Parker (1982), Barakat (1982), Meshref (1982 and 1990), Awad (1985) and others. The reservoir characteristics of Meleiha oil field have been studied by many authors, such as; Abdel Samad *et al.* (2005), Compobasso *et al.* (2005) and Ismail *et al.* (2005).

The generalized stratigraphic column of the northern Western Desert is thick and includes most of the sedimentary succession from Pre-Cambrian basement complex to Recent (Fig. 2). The total thickness, despite some anomalies, increases progressively to the north and northeast from about 6000 ft in the South and reaches about 25,000 ft in the coastal area.

The main producing horizon in Meleiha concession is Bahariya Formation; the type locality of which is situated in Gebel El-Dist, Bahariya Oasis, where its base is not exposed (Said, 1962). Norton (1967) designated the lower part in the nearby Bahariya –1 well. The section is made up of fine to very fine-grained sandstone with shale interbeds. Pyrite and glauconite are common. Thin limestone beds are common in the northwest that occur irregularly and are not easily correlatable within the different wells.

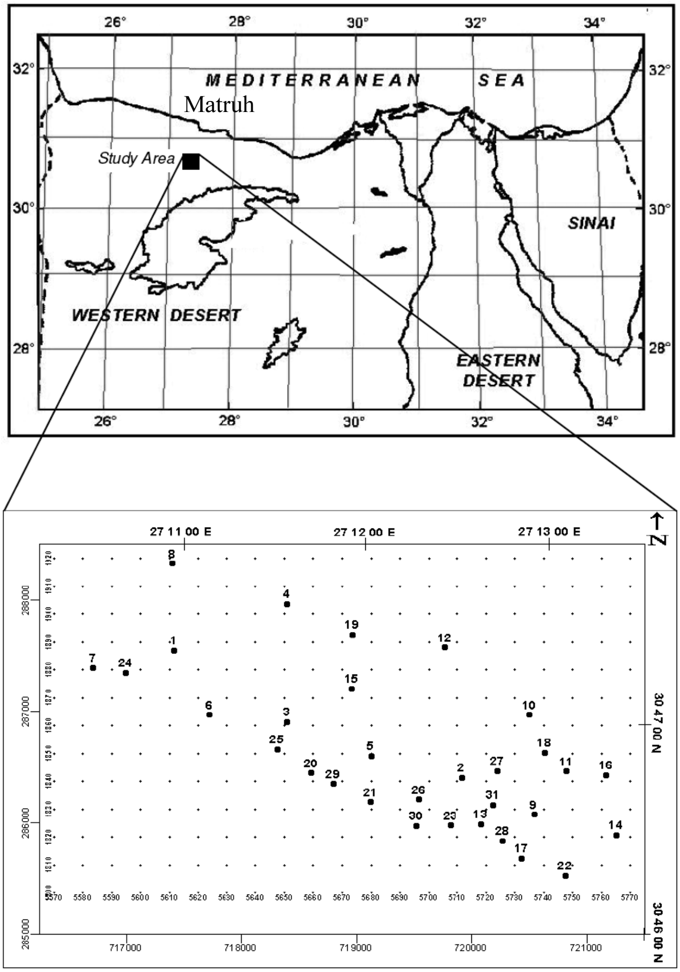


Fig. 1. Location map of Meleiha-NE area, north Western Desert, Egypt.

Throughout the Western Desert, the Bahariya Formation conformably rests on the Kharita Formation. The Bahariya Formation is thick (more than 1000 ft), the thickest section is in El Ramis -1 well (1580 ft) and it is Early Cenomanian at the type locality. Lithological and paleontological evidences suggest that most of the formation was deposited on a wide extensive shallow marine shelf.

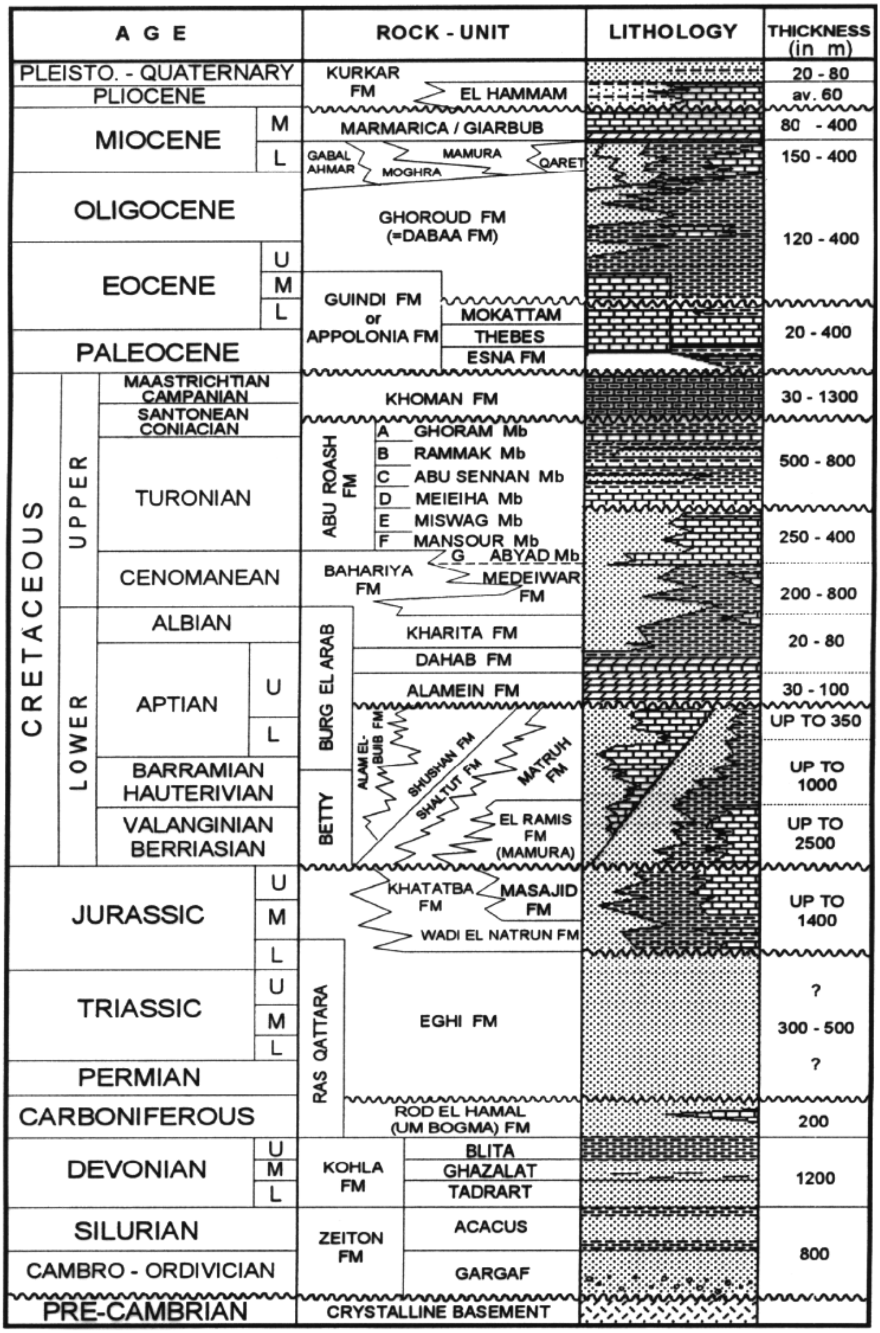


Fig. 2. Generalized Litho-stratigraphic column of the north Western Desert, (Schlumberger, 1984 and 1995).

The available data are represented by 34 survey lines of reflection seismic sections, which traversed the study area in northeast-southwest and northwest-southeast directions. The total length of these lines is about 127.5 km. These seismic data were used to delineate the detailed structural features affecting Bahariya section. Additionally; logging data of 23 wells of Bahariya Formation in Meleiha NE oil field were used to evaluate hydrocarbon potentialitiy. The used data are obtained and licensed from Agiba Petroleum Company.

Seismic Analysis

Generally, seismic analysis is undertaken in three main steps; acquisition, processing and interpretation. The main objective of seismic data acquisition is to obtain accurate travel time measurements from energy sources to receivers while, the objective of seismic processing is to improve the quality of the data and to present it in a form that is convenient for geological interpretation. The seismic interpretation includes eight steps; reflectors identification, picking and correlation of reflectors, fault location, closing loops, velocity analysis, digitization, time to depth conversion, constructing geo-seismic cross-sections and construction of the isochronous and structural contour maps. Identification of reflectors starts picking by inspecting seismic sections passing through boreholes. Due to the low reflectivity of Bahariya Formation top, it is picked in reference to the top of Abu Roash G Member (It overlies the top of Bahariya by 10 msec.). The top of Bahariya Formation on the seismic section is shown in (Fig. 3 a) by yellow colour. The Bahariya horizon is picked along all seismic grids by correlating the seismic events, tying their times and closing their loops (Fig. 3b).

The picked time values and the locations of fault segments are posted on the shot point location map of the study area, in order to construct an isochronous reflection map on top of Baharyia Formation (Fig. 4 a and b). This map shows the structural elements characterizing the studied formation top in terms of two-way times. The conversion of this map into depth map is carried out using the estimated average velocity in well log data.

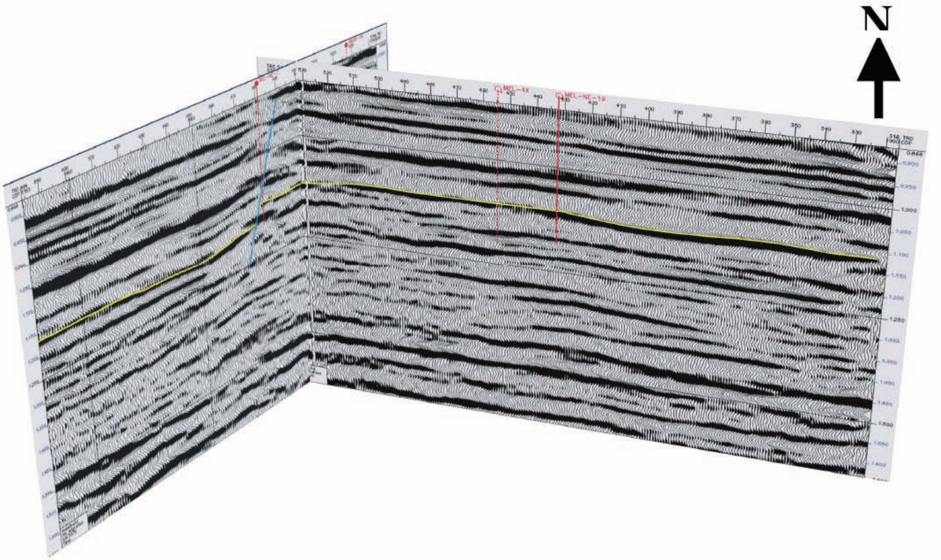


Fig. (3-a) Correlation process by tying Bahariya Formation on seismic sections.

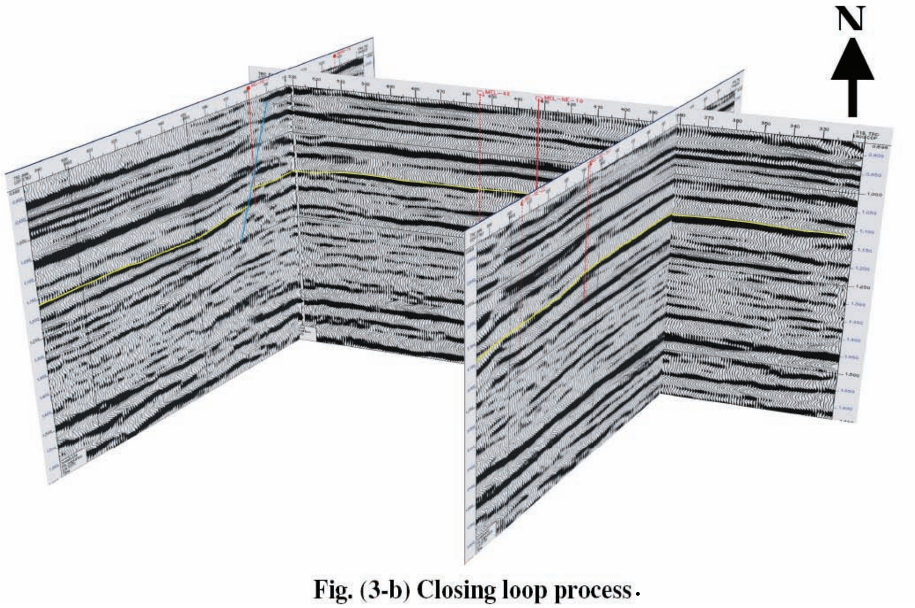


Fig. (3-b) Closing loop process.

Fig. 3. Correlation process and picking structure features on top of Bahariya Formation, Meleiha-NE oil field, north Western Desert, Egypt.

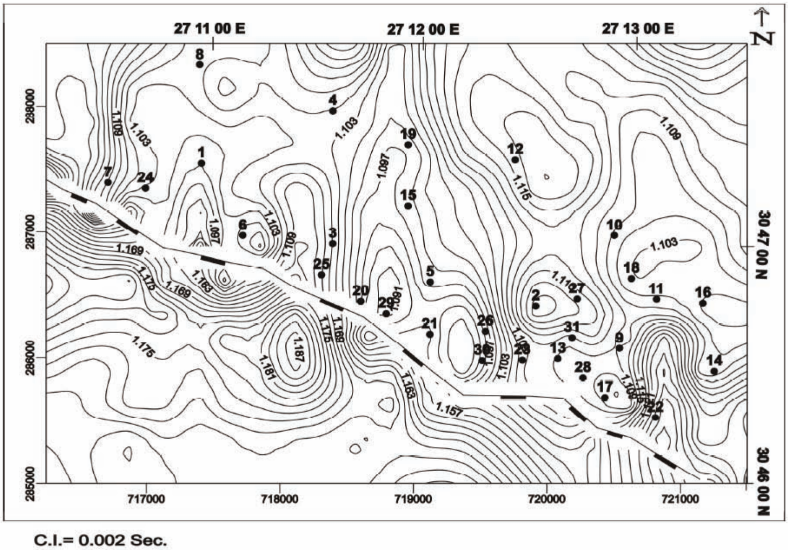


Fig. (4-a) Isochronous map on top of Bahariya Formation.

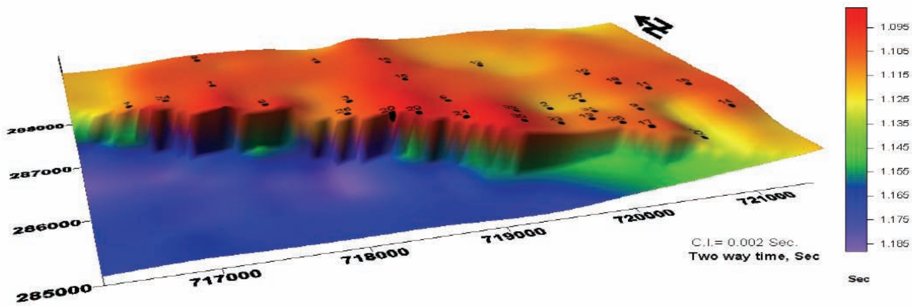
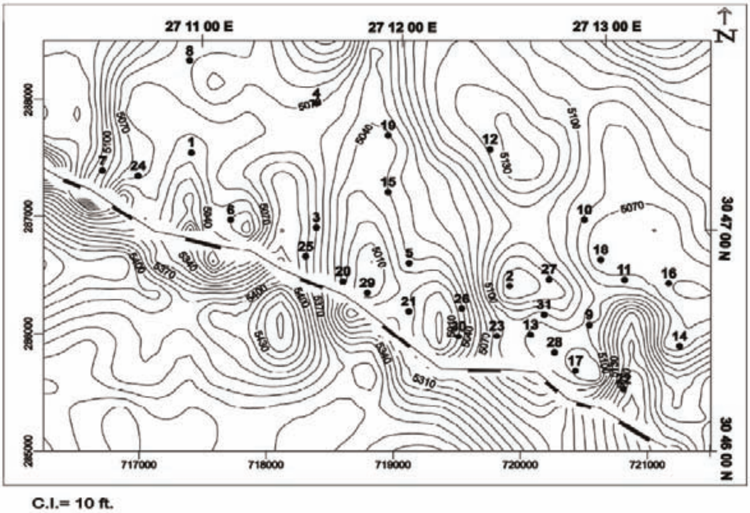


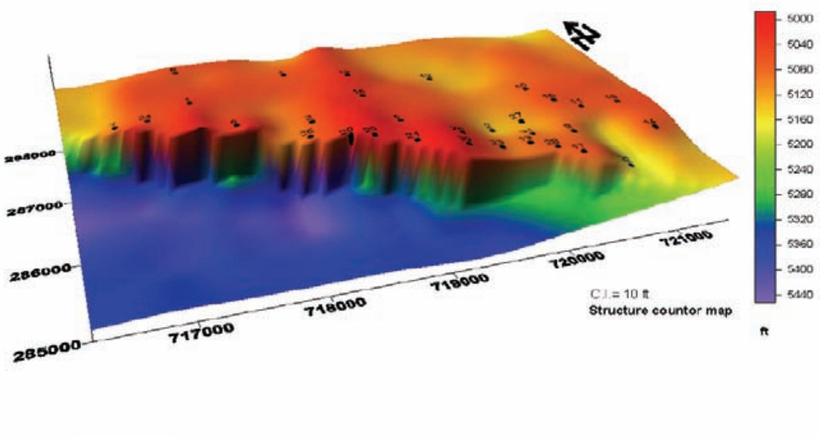
Fig. (4-b) 3-D model of reflection time on top of Bahariya Formation.

Fig. 4. Isochronous map and 3D model on top of Bahariya Formation, Meleiha-NE oil field, north Western Desert, Egypt.

The isochronous map and average velocity are both used to convert the reflection time to depths, and construction of a structure contour map (Fig. 5 a and b). This map shows the structural elements in terms of depth rather than time. It shows that, the general dipping in the southern part of the area is steeper than that in the northern part. The faulting and folding play a prominent role in the definition of the structural setting on formation tops. Only one normal fault has WNW-ESE trend with several minor syn-forms and anti-forms in series on each side of the fault (hanging and footing walls) around the fault plane. Their axes lie perpendicular to the strike of the fault with which they are associated. The highest relief (5010 ft) is located at the central part of the up-thrown part.



(a) Structure contour map on top of Bahariya Formation



(b) 3-D model of structure on top of Bahariya Formation

Fig. 5. Structure contour map and 3D model on top of Bahariya Formation, Meleiha-NE oil field, north Western Desert, Egypt.

Core Analysis

In hydrocarbon reservoirs, the void spaces are available for the accumulation and storage of oil, gas and water. Porosity is a dimensionless quantity expressed either as decimal fraction or as a percentage. Porosity can be expressed in a mathematical form as;

$$\phi = \frac{Vb - Vgr}{Vb} = \frac{Vp}{Vb} = \frac{Vp}{Vp + Vgr}$$

Where; ϕ = porosity (fraction),

Vb = bulk volume of the reservoir rock,

Vgr = grain volume, and

Vp = pore volume.

Levorsen, (1967) classified the reservoir porosity into five categories, namely negligible (0-5%), poor (5-10%), fair (10-15%), good (15-20%) and very good (20-25%).

Three core reports of Bahariya Formation in NE-2X, NE-5 and NE-16 wells are used in this paper. 67 core samples from NE-2x well, 152 core samples from NE-5 well and 70 core samples from NE-16 well.

Statistical Analysis of Porosity Data

From the available porosity data, it can be observed that the helium porosity of Bahariya Formation in NE-2X, NE-5 and NE-16 wells varies from 7.7 to 29%, 2.4 to 30.6% and 3 to 27.1%, respectively. The fluid summation porosity ranges from 7.5 to 33.3%, 1.7 to 31.1 and 2.8 to 29.7% in the same wells, respectively.

The high values of porosity (more than porosity cut off 10%) indicate that the Bahariya Formation belongs to the high quality reservoir.

Relationships between Measured Porosities

Relationships were made between helium and fluid summation porosities. These relations always show positive trends which mean that the increase of helium porosity is associated with increase in fluid summation porosity.

The linear regression equations and correlation coefficients are given in Table 1 and are shown in (Fig. 6 a, b and c).

Table 1. Relationships between measured porosities in NE-2X, NE-5 and NE-16 wells.

Well name	Linear regression equation	Correlation Coefficient	Figure
NE-2X	$\varphi_s = 0.705\varphi_h + 8.2667$	r = 0.54	(6-a)
NE-5	$\varphi_s = 0.9013\varphi_h + 2.2702$	r = 0.88	(6-b)
NE-16	$\varphi_s = 0.9169\varphi_h + 1.963$	r = 0.87	(6-c)

The low correlation coefficient in NE-2X well reflects the influence of porosity heterogeneity in this well compared with other wells.

Well Log Interpretation

The results of well log interpretation using the PETCOM 1997 program for Bahariya Formation in Meleiha NE oil field are illustrated in three forms. These forms are; a) distribution maps, b) litho-saturation cross-plots, and c) models.

a) Reservoir Distribution Maps

The total thickness distribution map of the Bahariya Formation (Fig. 7a) shows that the thickness increases toward the southeast and northwest, while it decreases toward the north, northeast and southwest directions. The Bahariya Formation has a maximum thickness of 534.5 ft at NE-1 well in the middle of the northwest part and a minimum thickness of 270.5 ft at NE-28 well in the middle of the southeast part. Similarly, sand thickness distribution map shows sand thickness increase toward southeast and northwest directions (Fig. 7 b).

Figure (7 c) shows the total porosity distribution, which increases at the center of the northwestern part and toward the southeast to reach 0.29 at NE-14 well, while it decreases toward the north and south to reach 0.25 at NE-17 well. The effective porosity map (Fig. 7 d) shows that it increases toward the northwest and southeast, and decreases toward the south. The maximum value (0.2) is shown at NE-24 well, while the minimum value (0.12) is shown at NE-21 well.

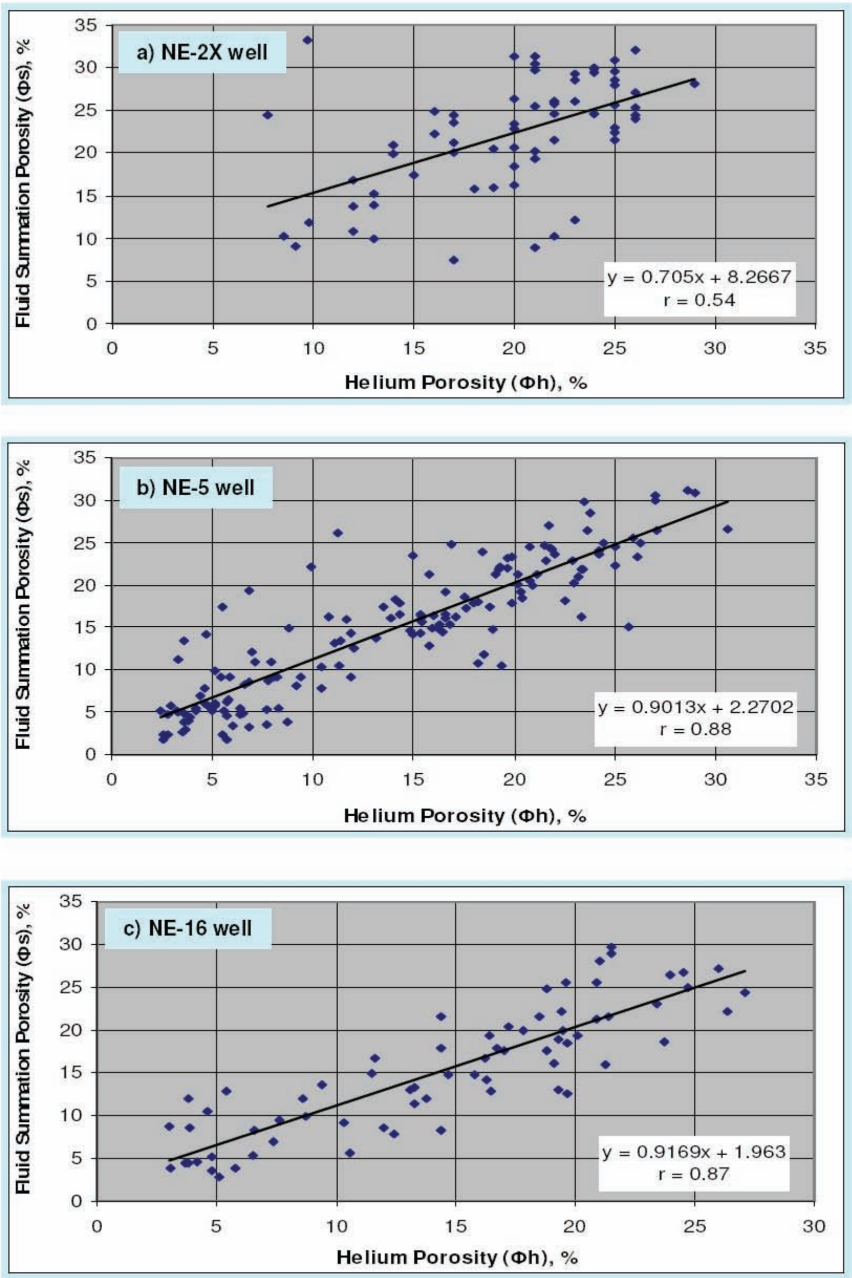


Fig. 6. Relationships between helium and fluid summation porosities of Bahariya Formation In NE-2X, NE-5 and NE-16 wells, of Bahariya Formation, Meleiha-NE oil field.

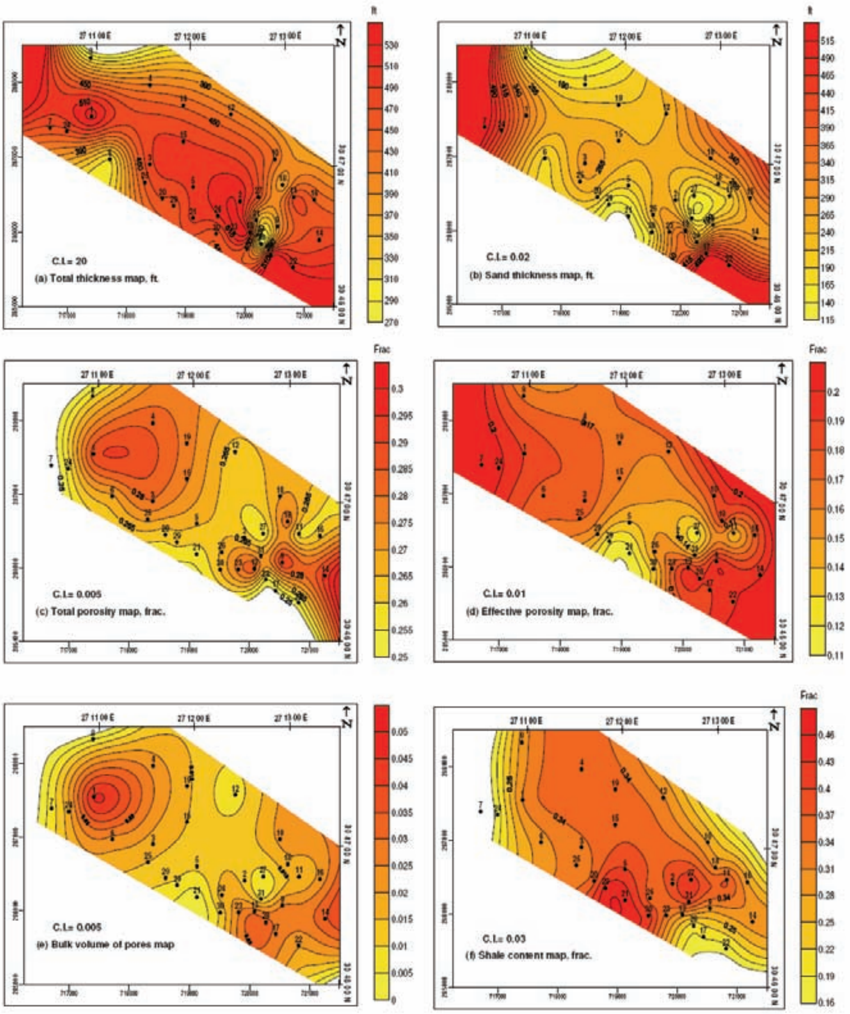


Fig. 7. Reservoir distribution maps of Bahariya Formation in Meleiha-NE oil field, north Western Desert, Egypt.

The bulk pore volume distribution map (Fig. 7e) shows that it increases in the vicinity of NE-1X well, while it decreases toward the southern central part of the field. The maximum value was detected at NE-1X well, while the minimum value is recorded at NE-21 well. Shale isolith distribution map of Bahariya Formation (Fig.7 f) shows that the shale content increases toward the south, while it decreases toward the northwest, northeastern and southeastern parts of the field. The maximum value (0.452) was detected at NE-21 well, while the minimum value (0.173) occurs at NE-24 well.

The water saturation map (Fig. 8 a) shows an increase toward the northwest and south part around NE-27 well while it decreases toward the east and around NE-1X well. The maximum value (0.72) is recorded at NE-27 well, while the minimum value (0.49) is found at NE-1X well. The hydrocarbon, irreducible hydrocarbon and movable hydrocarbon saturation distribution maps (Fig. 8 b, 8 c and 8 d) show general increases at the center of the northwestern part around the NE-1X well and the eastern part. The maximum value of the movable hydrocarbon (about 0.46) was exhibited at NE-1X well and the minimum one (0.27) was encountered at NE-27 well. The highest values of movable hydrocarbons were confined to the high values of the effective and total porosities.

Reservoir potential represents the final target of reservoir evaluation through the integration of geological and petrophysical data. In the present study, net pay and oil in place indicator maps have been constructed to evaluate the reservoir potential. The net-pay thickness distribution map (Fig. 8e) shows that it increases at the central part of northwest area around NE-1X well and decreases gradually toward the south and central of the area. The minimum net-pay thickness (10 ft) is recorded at NE-21 well, while the maximum (203 ft) occurs at NE-1X well. The oil-in-place indicator distribution map (Fig. 8 f) indicates that, it increases around NE-1X and toward the east close to NE-17 and NE-14 wells and decreases toward the south. The maximum and minimum values were detected at NE-1X and NE-21 wells, respectively.

b) Litho-Saturation Cross-plots of Bahariya Formation in Meleiha NE Oil Field

The Bahariya Formation can be evaluated through studying the vertical distribution of petrophysical parameters based on the results of well log analysis. In all stratigraphic units, the rock characteristics change is in the same manner from one part to another of the basin, while the rate of variation depends on some factors such as the adjacent basin, chemistry of the water and climate *etc.* The changing patterns of sedimentation within a generally related stratigraphic unit reflect difference in both tectonic framework and depositional environment. The vertical distribution of petrophysical parameters and lithology is presented in the form of litho-saturation crossplots. It consists of one track including the vertical distribution of the rock types (lithology) and fluids in effective porosity. Also the other diagram represents the total percentage of the rocks and fluids. This evaluation of reservoir potential can be used as a reliable basis to make the decision to either complete or abandon the well. It is also useful to isolate zones for possible future testing.

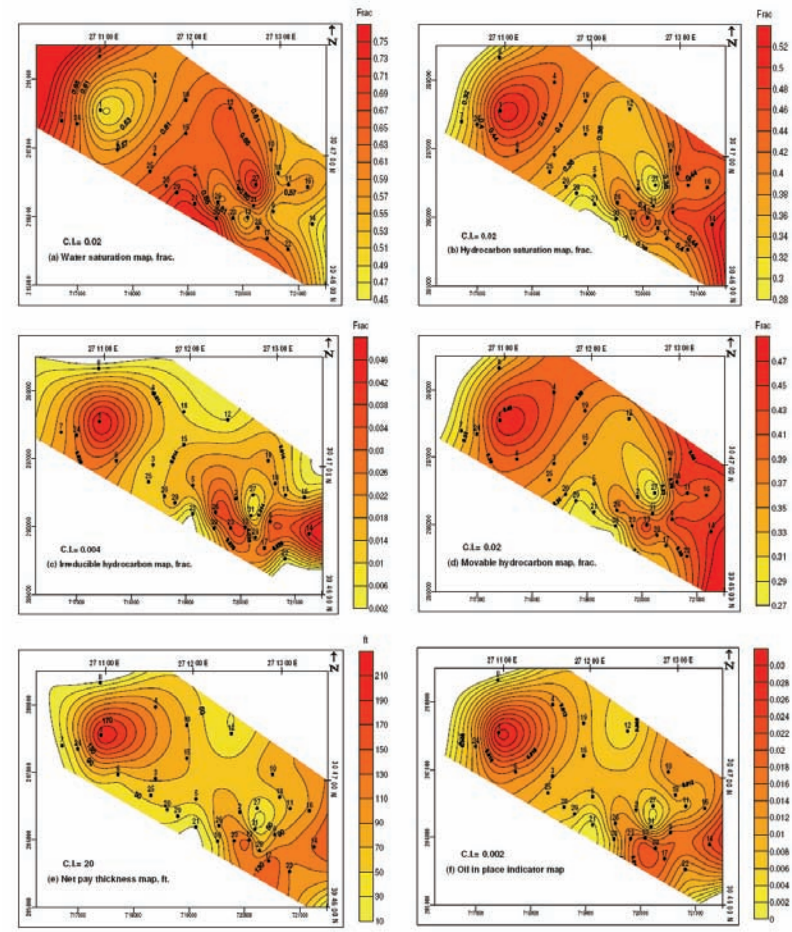


Fig. 8. Reservoir fluid distribution maps of Bahariya Formation in Meleiha-NE oil field, north Western Desert, Egypt.

The Bahariya litho-saturation cross-plots of selected Meleiha-NE wells on what basis, are shown in (Fig. 9). They illustrate that, the Bahariya Formation consists of sandstone, shale and limestone and the effective porosities are filled by fluids. Sandstone and shale are the most important components of this formation. Sandstone is inversely proportional with shale in most zones. Fluids of this formation are water, irreducible, and movable hydrocarbons. Water saturation is the main fluid spreads in Bahariya Formation where, it has a widely vertical distribution. On the other hand, irreducible hydrocarbon has a minor vertical distribution all over the studied wells. It could be shown at few zones in few wells. Movable hydrocarbon is the important parameter in each well; has a vertical wide distribution in most of the studied wells. It increases mostly at the top and middle of the wells. From Fig. 9, it can be concluded that, the sandstone percentages increase, the shale percentages decrease and the limestone percentages decrease toward the southeastern part of the studied area. This may reflect that, the direction of the shoreline in the study area was most likely towards the southeast direction during Bahariya deposition. The effective porosity increases, the irreducible hydrocarbon saturation decreases and the movable hydrocarbon increases toward the southeastern part. Hence, it might be considered that the southeastern part of the study area is most likely the favorable place to produce oil.

c) Reservoir Fluids Models

Rock work 2004 software (RockWare Earth Science & GIS Software, 2004) was used to draw solid modeling, where, X represents the East direction, Y represents the north direction, and Z represents the thickness of Bahariya Formation.

Once, the dimensions of the area are known, the program divides it into 3-dimensional cells or voxels (Fig. 10). Each voxel is defined by its corner points or node and each node is assigned the appropriate X, Y, and Z location coordinates according to its relative placement within the area. A fourth variable, G represents the fluid content parameter.

Several methods are offered to perform the 3-dimensional interpolation of the used data. One of these methods is Inverse Distance Anisotropic. This method assigns a voxel node value based on the weighted average of neighboring data points, either all points or those directionally located, using fixed or variable weighting exponents. Instead of using all available control points for the inverse-distance modeling, the program will look for the closest point in each 90-degree sector around the node. It is useful for modeling drill-hole based data in stratiform deposits.

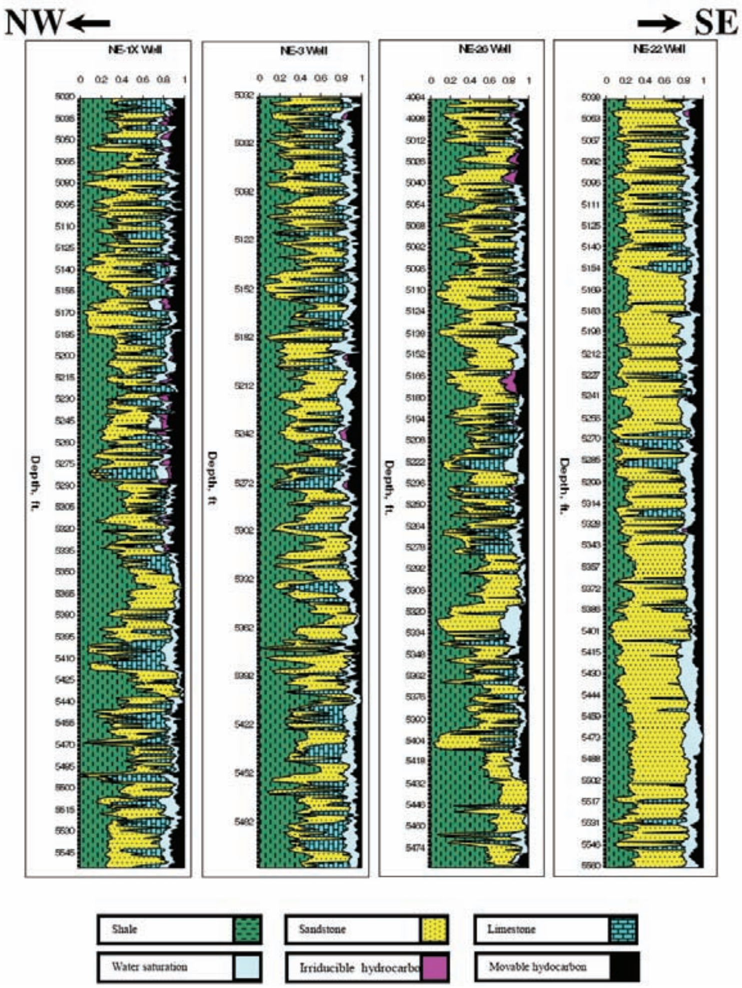


Fig. 9. Litho-saturation cross-plots of Bahariya Formation in NE-1X, NE-3, NE-26 and NE 22 wells, Meleiha-NE oil field, North Western Desert, Egypt.

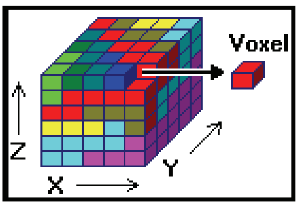


Fig. 10 Represents 3d cells or voxels

The 3D-model of Bahariya reservoir is used to study complex problems associated with water flooding, reservoir heterogeneity and reservoir visualization. The final results of interpolation of the log-derived reservoir parameters are illustrated in three dimensions X, Y and Z where Y-axis is parallel to the north direction. The illustration layout of 3D-model of Bahariya Formation for each parameter is divided into six figures (a, b, c, d, e, and f). The a-figure shows the block model of Bahariya reservoir, while the b-figure shows the Z-planes, at seven planes, showing the lateral variation in the X and Y-directions. The c, d, e, and f figures show cutoffs and percentages of the studied petrophysical parameter.

The models illustrated in (Fig. 11), show that the effective porosity increases in the northern, northwestern and southeastern parts of the studied area. Figures (11c, d, e and f) show that 92.8 %, 59.73 % 21 % and 3.21 % of the original model represent more than 10 %, 15 %, 20 % and 25 % of effective porosity, respectively.

The water saturation distribution shown in (Fig. 12) indicates that the maximum value of the water saturation concentrates generally at the northwestern part and also at the middle of the eastern parts. Figures 12 (c, d, e and f) show more than 0.5, 0.6, 0.7 and 0.8 water saturation distribution, respectively. Hydrocarbon saturation concentrates generally, in the southeastern and northwestern parts, as it is shown in Fig. 13. The hydrocarbon saturation with more than 0.5 and 0.6 distribution in the reservoir is shown in (Fig. 13 e and f). The hydrocarbon saturation is high at northwest and southeast areas. It lies on the up-throw and takes the same trend of the normal fault, which passes through the area. Irreducible hydrocarbon distribution is shown in Fig. 14. It reaches its maximum value close to the base in the western part. On the other hand, there are low values displayed generally in the same locations of hydrocarbon saturation.

Finally, Fig. 15 displays the movable hydrocarbon distribution. It has the same trends of hydrocarbon saturation. It reaches the maximum values in northwestern, southeastern and at the center of the model parts. Figures 14 (c, d, e and f) show that more than 0.1, 0.3, 0.4 and 0.5 of movable hydrocarbon are displayed, respectively. So, the Bahariya reservoir model reflects that, its central part in the study area has high movable hydrocarbon.

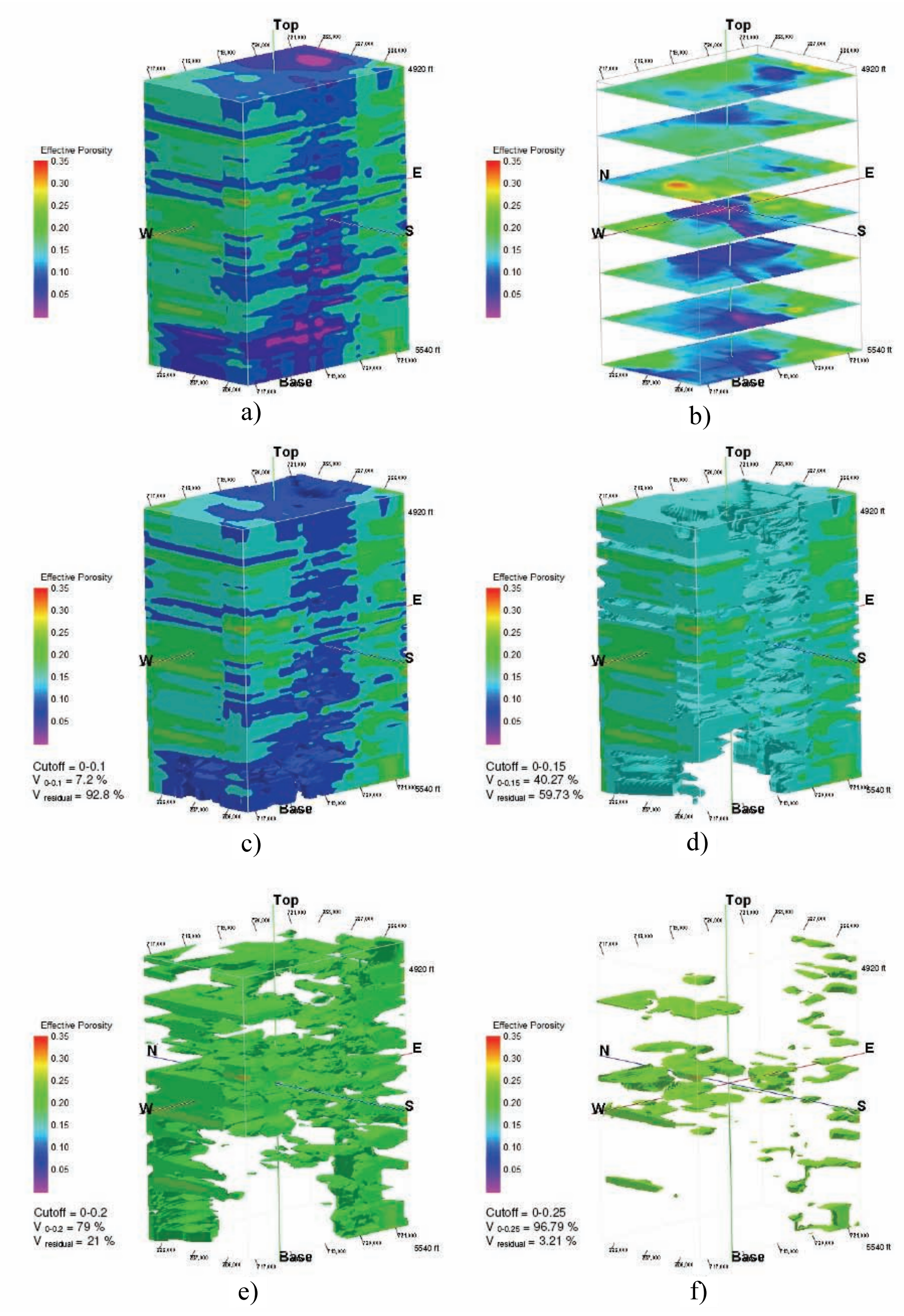


Fig. 11. 3D-modeling, slicing and cutoffs of the effective porosity (Frac.) of Bahariya Formation in Meleiha-NE oil field, North Western Desert, Egypt.

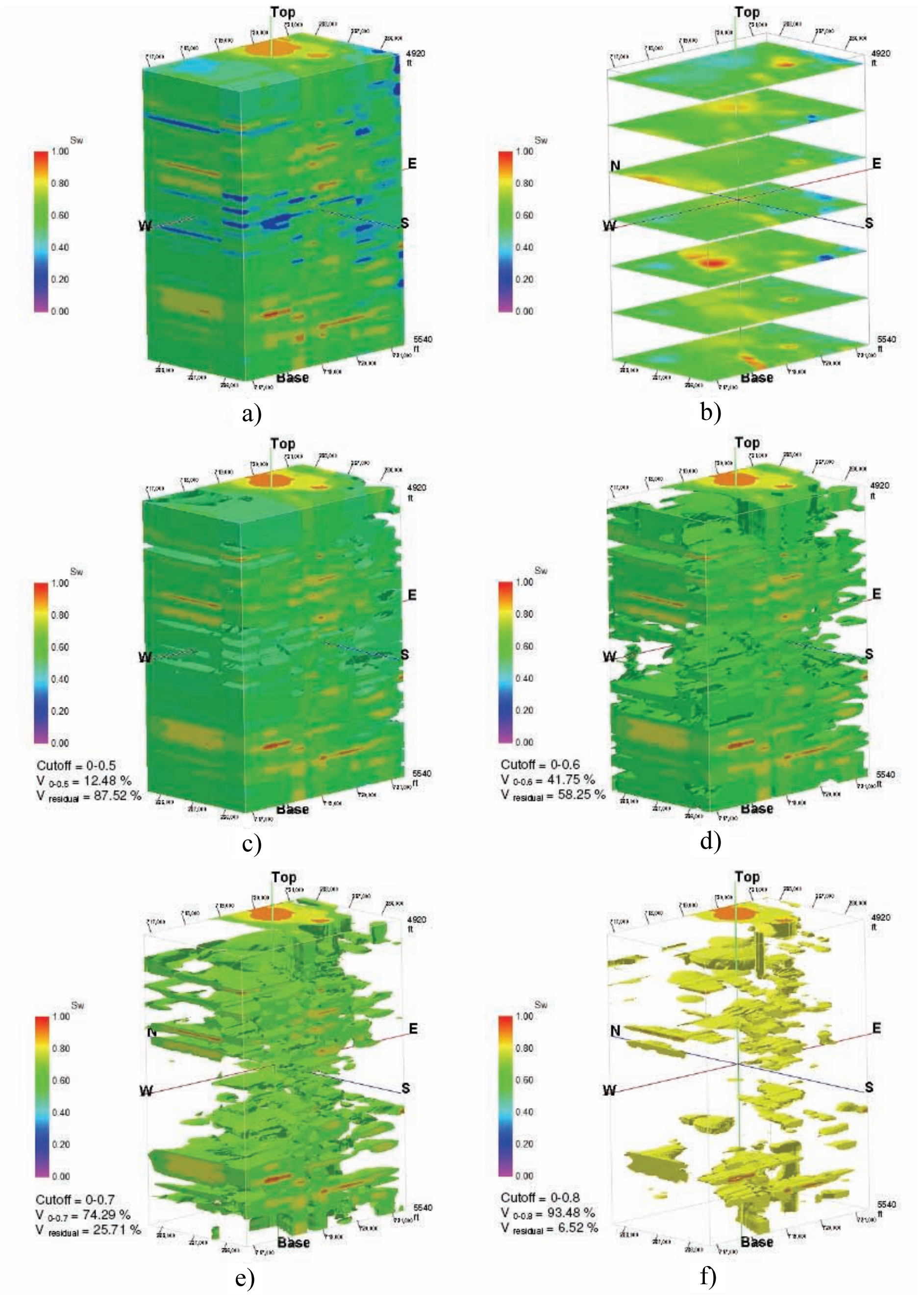


Fig. 12. 3D-modeling, slicing and cutoffs of the water saturation (Frac.) of Bahariya Formation in Meleiha-NE oil field, North Western Desert, Egypt.

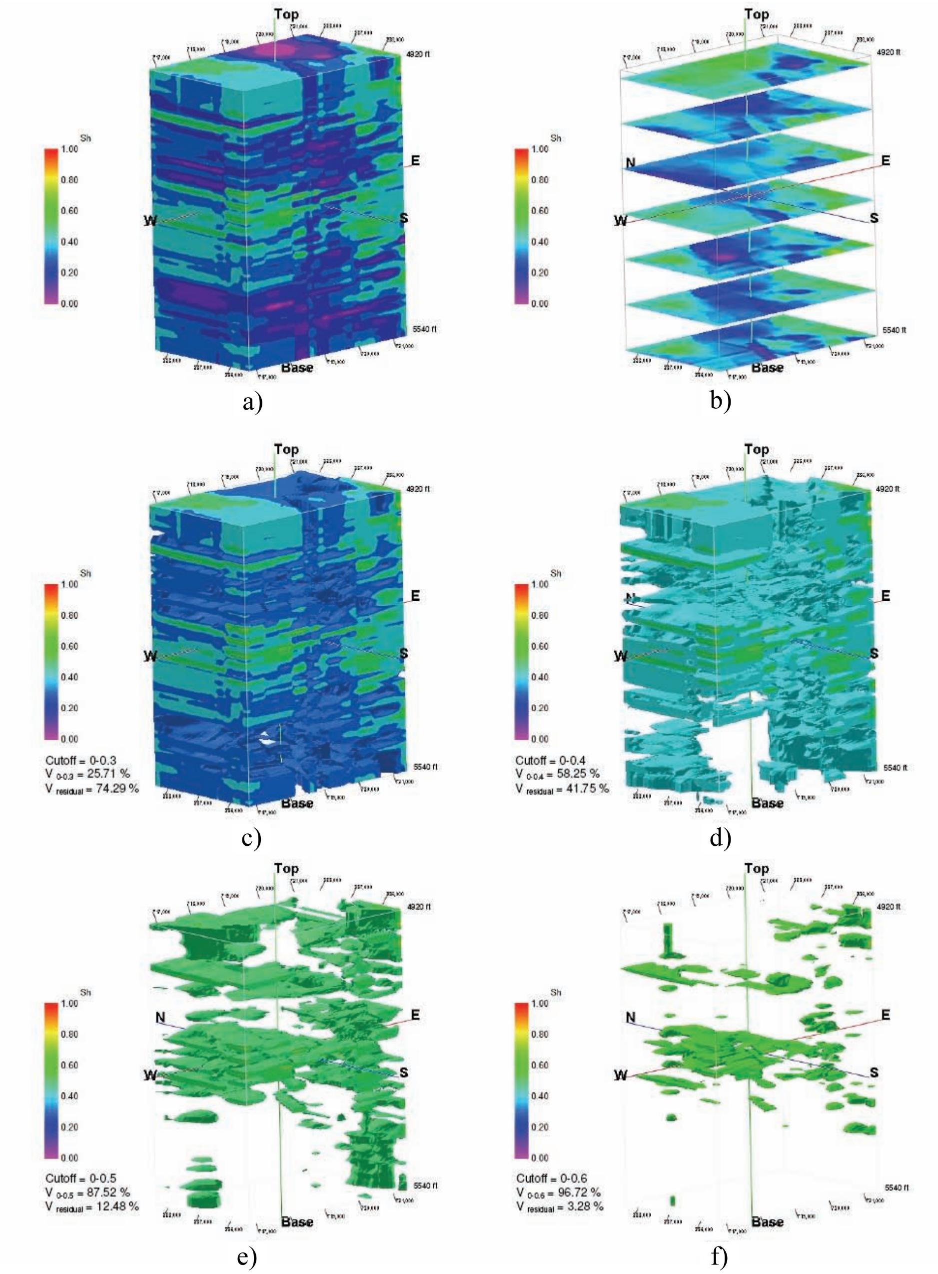


Fig. 13. 3D-modeling, slicing and cutoffs of the hydrocarbon saturation (Frac.) of Bahariya Formation in Meleiha-NE oil field, North Western Desert, Egypt.

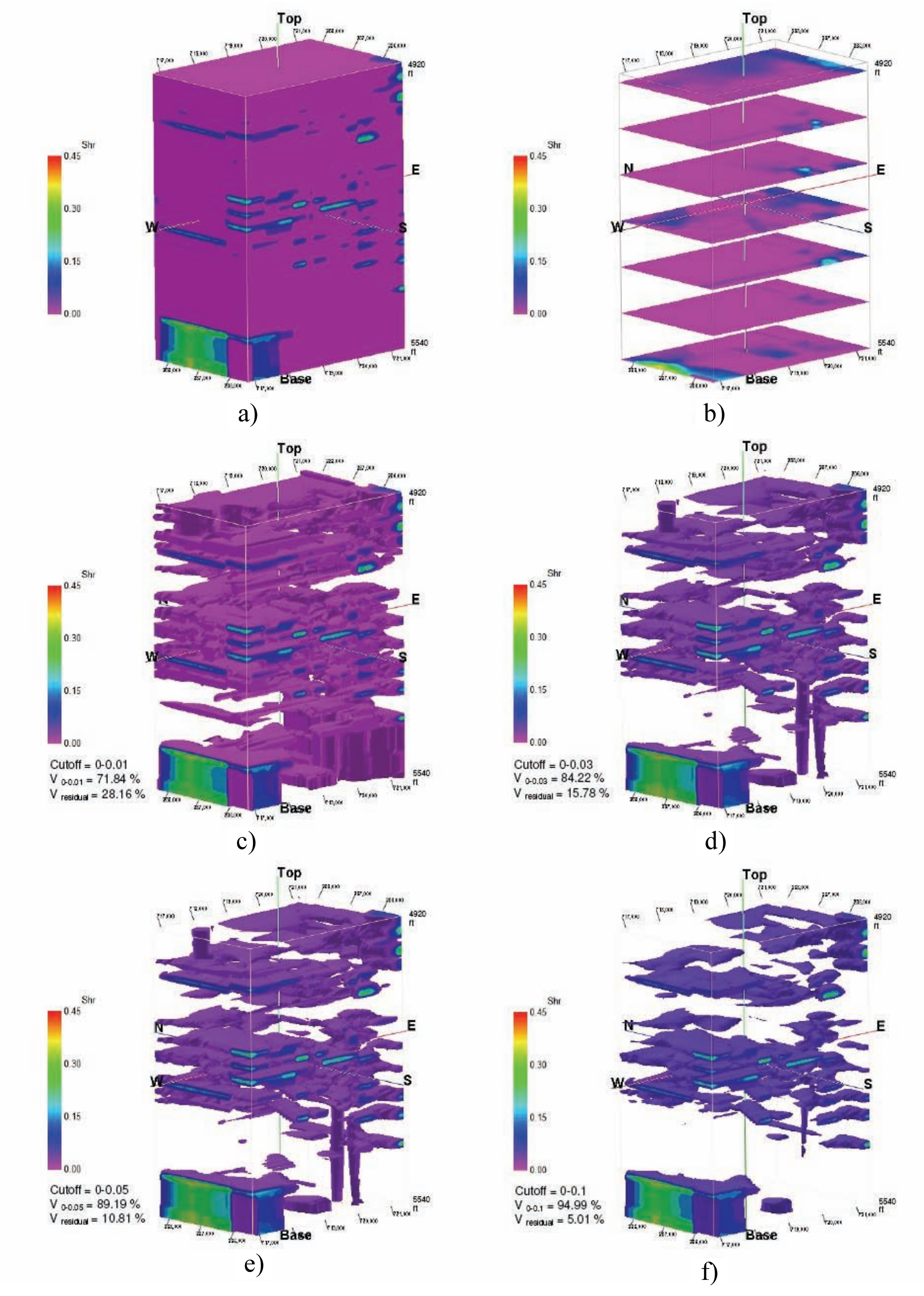


Fig. 14. 3D-modeling, slicing and cutoffs of the irreducible hydrocarbon (Frac.) of Bahariya Formation in Meleiha-NE oil field, North Western Desert, Egypt.

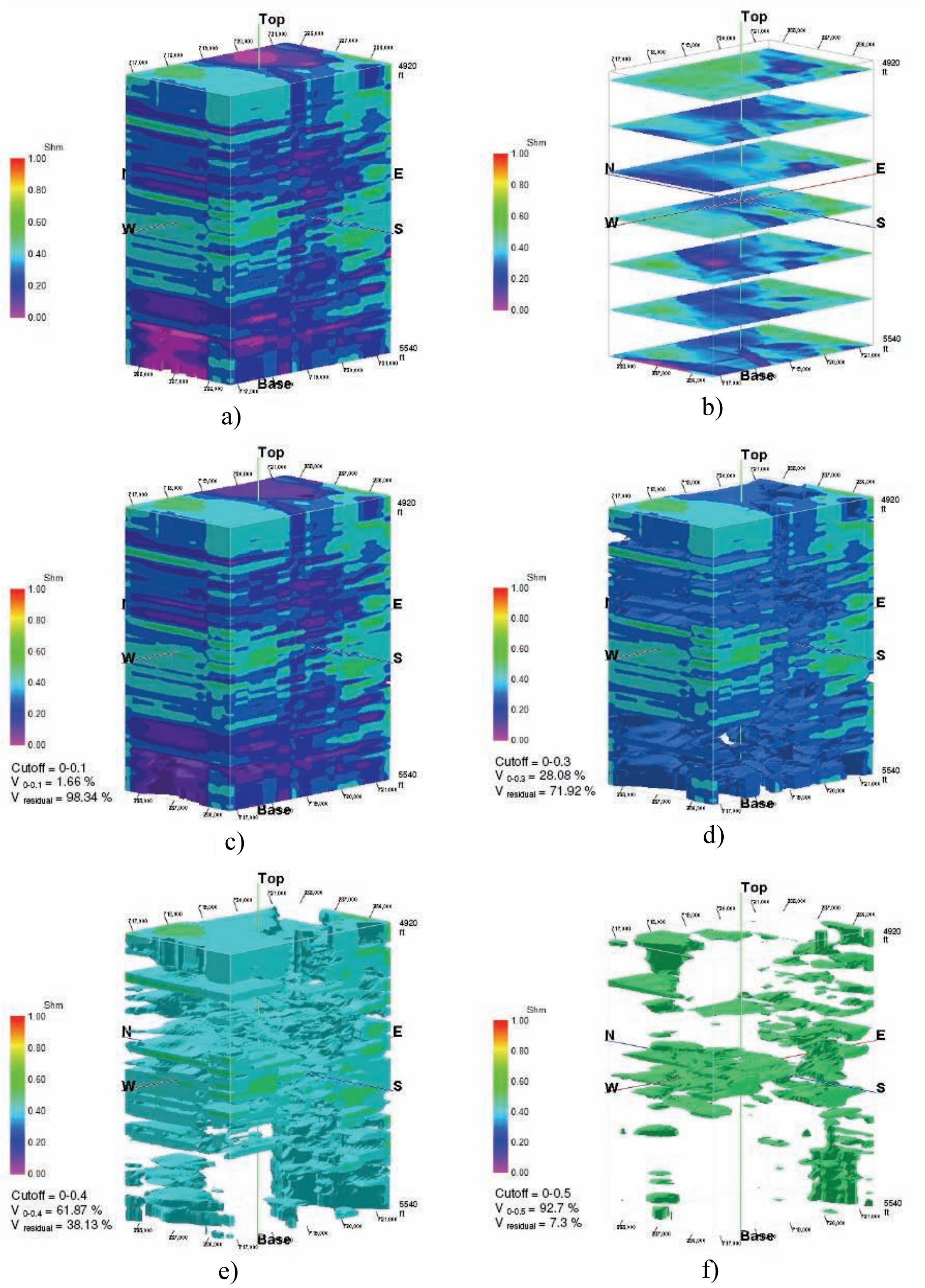


Fig. 15. 3D-modeling, slicing and cutoffs of the movable hydrocarbon (Frac.) of Bahariya Formation in Meleiha-NE oil field, North Western Desert, Egypt.

Conclusions

From the present study, the following conclusions are obtained:

- The general dipping in the southern part of the area is steeper than that in the northern part.
- Faulting and folding play a prominent role in the definition of the structural setting on top of Bahariya Formation.
- Only one normal fault was deduced which has WNW-ESE trend with several minor syn-forms and anti-forms in series on each side of the fault (hanging and footing walls) around the fault plane. Their axes lie perpendicular to the strike of the fault with which they are associated.
- The highest relief (5010 ft, depth) is located at the central part on the up-thrown side of the fault.
- These structural features constitute the main structural traps detected in the top of Bahariya Formation.
- The petrophysical properties of Baharyia Formation reflect the ability of the formation to store and produce oil.
- The hydrocarbon, irreducible hydrocarbon and movable hydrocarbon saturation distribution maps show a general increase at the center of the northwestern part around NE-1X well and the eastern part of the study area.
- The maps of reservoir fluid parameters reveal that the center of the northwestern part of the study area is the most favorable part for oil accumulation and promising for production.
- The Bahariya litho-saturation cross-plots of Meleiha-NE wells illustrate that, lithology of this Formation is represented by sandstone, shale, limestone, with effective porosities are filled by water, irreducible and movable hydrocarbons.
- Movable hydrocarbon is the most important parameter and has a wide vertical distribution in all wells. It increases mostly at the top and middle parts of wells, except few wells where it occurs also at their bottom.

o Hydrocarbon saturation parameter concentrates generally, at the southeastern and northwestern parts.

o The best place to produce oil is located at the southeast part of the study area where the shoreline was located during Bahariya deposition.

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تكامل دراسات خواص خزان متكون بحرية بحقل بترول شمال شرق مليحة – شمال الصحراء الغربية، مصر

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المستخلص. إن أهم خطوة في عملية استكشاف البترول، هي تقييم المصائد البترولية، وتحديد مواصفات ومحتوى الهيدروكربون في الخزان. لذلك كان الهدف الأول من إجراء هذا البحث هو عمل تفسير سيزمي لعدد ٣٤ خطًا سيزميًا ثلاثي الأبعاد، بغرض تحديد المصائد البترولية لمنطقة الدراسة. أما الهدف الثاني فيتمثل في تحليل بيانات تسجيلات الآبار لعدد ٣١ بئرًا، وذلك لتحديد مواصفات الخزان ومحتوى الموائع به.

تمت التحاليل السيزمية على ثمانية خطوات، وهي تحديد الانعكاسات لقمم المتكونات، التقاط ومضاهاة خطوط الانعكاسات لقمم المتكونات، تحديد مواقع الفوالق، قفل الحلقات، تحليل السرعات وتحويل البيانات للصورة الرقمية، تحويل الزمن إلى عمق، بناء قطاعات جيو– سيزمية ثم بناء خرائط كنتورية لتمثيل التراكيب الجيولوجية تحت السطحية. هذا وقد أظهرت التحاليل السيزمية الدور الرئيسي للطي والتصدع في تشكيل السطح العلوي لمتكون بحرية بمنطقة الدراسة.

كما اشتملت خطوات تحليل تسجيلات الآبار على خمس خطوات وهي تحويل تسجيلات الآبار إلى الصورة الرقمية، تجميع البيانات البئرية، عمل التصحيحات البيئية للبيانات، عمل تسوية للبيانات، ثم تقييم لمواصفات الخزان. استخدمت تحاليل تسجيلات الآبار لتحديد خواص ومحتوى موائع خزان بحرية بمنطقة الدراسة. وقد دلت القيم العالية لمسامية الخزان على اعتبار متكون بحرية من الخزانات عالية الكفاءة. هذا وقد تم تمثيل خواص الخزان ومحتوى الموائع لمتكون البحرية في ثلاثة أشكال، وهي خرائط توزيع، رسومات التغير الصخري والمحتوى المائعي، ثم نماذج ثلاثية الأبعاد لتوضيح التغير في هذه الصفات في الأبعاد الثلاثة.

ولقد عكست خرائط توزيع المعاملات البتروفيزيائية زيادة المحتوى الهيدروكربوني للمتكون في منطقة الشمال الغربي والجنوب الشرقي لحقل بترول شمال شرق مليحة، بينما أوضحت رسوم التغير في التركيب الصخري والمحتوى الهيدروكربوني أن متكون بحرية يتكون من سحن صخرية من الحجر الرملي، والطفلة والحجر الجيري، مع المسامية المؤثرة المحتوية على الموائع موزعة بطول الآبار. كما أكدت الرسومات الرأسية للآبار أن اتجاه الجنوب الشرقي لمنطقة الدراسة هو أفضل الأماكن لإنتاج البترول. في حين بينت النماذج ثلاثية الأبعاد للخزان أن الهيدروكربون يتركز في الشمال الغربي والجنوب الشرقي لمنطقة الدراسة.