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Reservoir Evaluation of Abu Roash Formation by Using Well Log Data at East of Beni-Zouf Area, Egypt

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Abstract: The new concept for oil exploration in Egypt in the last few years is to go to the Upper Egypt, where it is considered as a promising area .The area of study is located to the east of Beni-souf,Egypt where six wells are located(EBS-7X ,EBS-8X, EBS-6X, EBS-4X, EBS-3X,and EBS-2X). Abu Roash Formation is considered as target for oil exploration and production, especially the Abu Roash (G) Member at Western Desert of Egypt. The available open-hole well log data used in the analysis of Abu Roash Formation are in the form of resistivity logs (deep and shallow), porosity tools (sonic, density and neutron) and the gamma-ray log to determine the petrophysical parameters. The petrophysical parameters (total porosity, effective porosity, shale volume, and hydrocarbon and movable hydrocarbon saturations) are represented in the form of iso-parametric maps. This analysis of the considered studied rock unit in the area of study illustrates that, the reservoir quality increases toward the western part of Abu Roash (G) Member for the study area.

Key words: Reservoir, Abu Roash formation, well log data, Egypt.

INTRODUCTION

Abu Roash Formation is considered as a target for oil exploration in Western Desert and is subdivided into seven members termed informally A, B, C, D, E, F and G Members A, B, D and F are mainly composed of calcareous rock, with argillaceous intercalation. Members C,E and G are made-up of calcareous rock with arenaceous interbeds, Fig. (2). Many of the steps are followed to calculate the petrophysical parameters, such as Vsh,porosity,Sw and hydrocarbon saturation for the formation,and to Abu Roash (G) member where it is considered as a pay zone and a target for oil exploration.

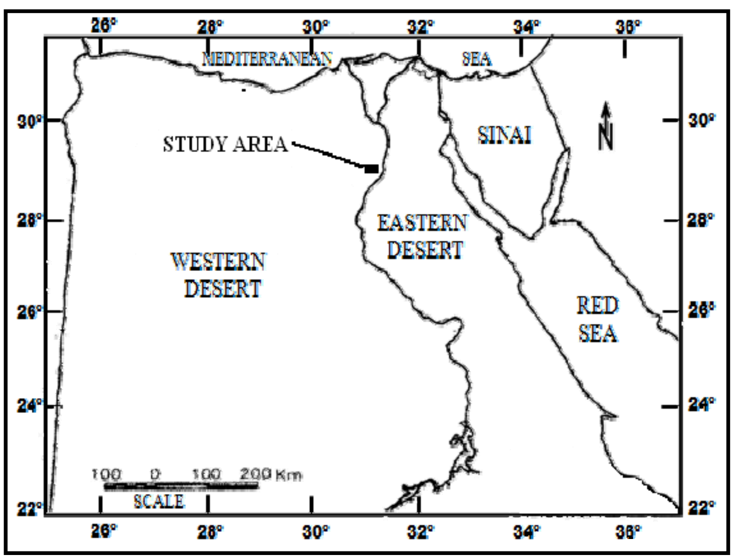

Fig. 1: Location map of the study area.

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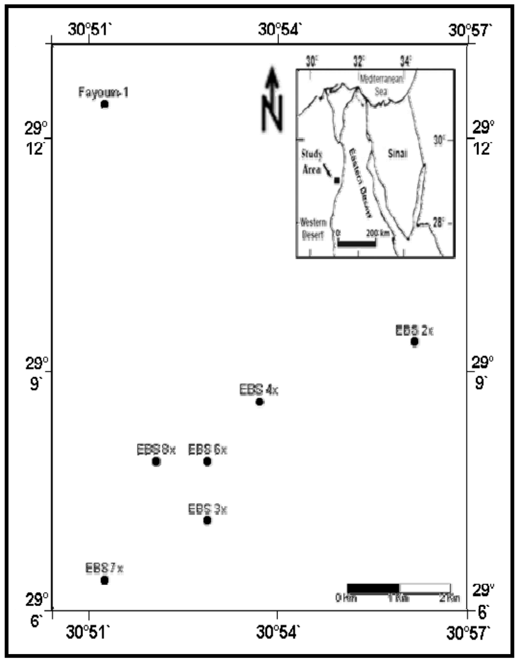

Fig. 2: Well location map of the study area.

MATERIALS AND METHODS

Shale Determination:

A-Gamma-Ray Method:

Gamma-ray log is one of the best tools used for identifying and determining the shale volume. This is principally due to its sensitive response for the radioactive materials, which normally concentrated in the shaly rocks. The following equation is used to determine the Gamma-ray index (Dresser Atlas, 1983):

$$IGR = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

Where:

IGR is the Gamma-ray index.
GR_{log} is the Gamma-ray reading for each zone.
GR_{min} and GR_{max} are the minimum Gamma-ray value for (clean sand or carbonate) and the maximum Gamma-ray value (shale), respectively.

Then, the shale volume for each zone can be calculated from the Gamma-ray index, by either of the following formulae *(Dresser Atlas, 1979):*

A-Older Rocks (Paleozoic and Mesozoic) Consolidated:

$$V_{sh} = 0.33\ [2^{(2*IGR)} - 1.0] = \chi \quad (2)$$

B - Younger Rocks (Tertiary), Unconsolidated:

$$V_{sh} = 0.083\ [2^{(3.7*IGR)} - 1.0] = \chi \quad (3)$$

Accordingly, the first formula was applied for Abu Roash Formation in the present work.

B - Neutron Method:

It can be used for determining the shale volume in case of high clay content and low effective porosities, from the formula:

$$V_{sh} \le \frac{(\varphi_N)_{log}}{(\varphi_N)_{sh}} = \chi \tag{4}$$

Where:

$(\varphi_N)_{log}$ is the neutron log reading for each studied zone , and
$(\varphi_N)_{sh}$ is the neutron log reading in front of a shale zone.

C – Resistivity Method:

It can be utilized to calculate the shale volume in case of high clay content and low (R_t) values, from the relation:

$$V_{sh} \le \frac{R_{sh}}{R_{t\,log}} \tag{5}$$

If this ratio is more than (0.5) (i.e., $0.5 \le V_{sh} \le 1$) then:

$$V_{sh} \le (R_{sh} / R_t) = \chi \tag{6}$$

If this ratio is less than (0.5) (i.e., $V_{sh} \le 0.5$) then:

$$V_{sh} \le \left[\frac{R_{sh}}{R_{t\,log}} - \frac{R_{cl} - R_{t\,log}}{R_{cl} - R_{sh}} \right]^{1/B} = \chi \tag{7}$$

Where:

R_{sh} is the resistivity log reading of a shale zone.
R_{cl} is the resistivity log reading of a clay zone.
$R_{t\,log}$ is the resistivity log reading for each zone and
B is a constant, ranging in value between 1 and 2.

Correction of Shale Volume:

The values of (χ) obtained previously must be corrected by valid formulae to obtain the optimum shale values usable in the log interpretation. The first formula is :

$$V_{sh} = 1.7 - \sqrt{3.38 - (\chi + 0.7)^2} \quad \text{(Clavier } et\ al.\text{, 1971)} \tag{8}$$

The second formula is:

$$V_{sh} = \frac{0.5\chi}{1.5 - \chi} \quad \text{(Steiber, 1973)} \tag{9}$$

The usual approach for deciding which of the resulted shale volumes to use is to find the minimum values of the results. The minima have to be chosen, because most of the errors for any method tend to increase the apparent shale volume. Then, the different zones were classified into clean, shaly and shale zones, depending on the following bases:

- If $V_{sh} < 10$ % This means clean zone.
- If V_{sh} is from 10 to 35 % This means shaly zone.
- If $V_{sh} > 35$ % This means shale zone.

Shale Distribution Map of Abu Roash Formation:

Fig. (4) shows the shale distribution map for Abu Roash Formation, where it reveals gradual increase toward the northern eastern direction, while the minimum values are observed at the southwestern direction.

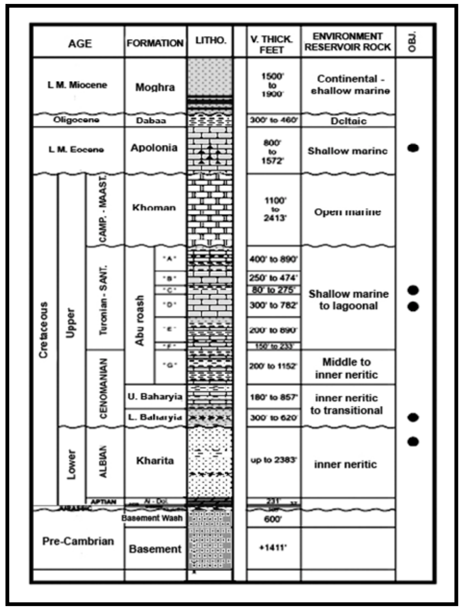

Fig. 3: lithostratigraphic column of the study area.

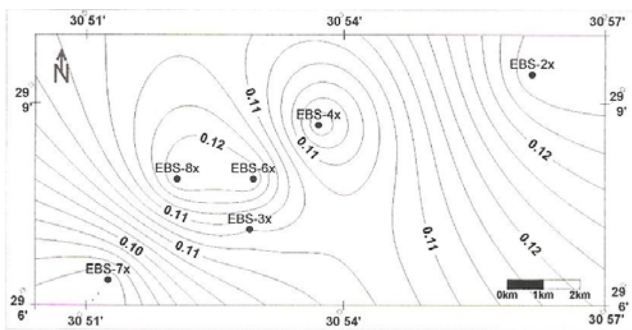

Fig. 4: Shale Distribution of Abu Roash Formation for the study area.

Shale Distribution Map of Abu Roash (G) Member:

The shale distribution map of Abu Roash (G) Member Fig. (10) exhibits a general low at the central part of the area, that changes northeastwardly and northwestwardly to give higher values at ABS-2X and EBS-6x wells.

Determination of Types Of Porosities:

Total Porosity (φ_t):

A - Sonic log:

The porosity can be diversified according to its presence in clean or shaly zones. The determination of either of these porosities can be explained as follows:

In Clean Zones:

The determination of the sonic porosity in the shale free formations depends on ***Wyllie et al., (1958)*** formula as follows:

$$\varphi_S = \frac{\Delta T_{log} - \Delta T_{ma}}{\Delta T_f - \Delta T_{ma}} \quad (10)$$

If the compaction factor is considered incase of shale occurrence, then:

$$\varphi_S = \left[\frac{\Delta T_{log} - \Delta T_{ma}}{\Delta T_f - \Delta T_{ma}}\right] * \frac{1}{CP} \quad \text{and} \tag{11}$$

$$CP = \frac{\Delta T_{sh} * C}{100} \tag{12}$$

Where:

ΔT_{log} is the reading of the evaluated zone on the sonic log in μ sec / ft.
ΔT_{ma} is the sonic transit time of the matrix material.
ΔT_f is the sonic transit time of the fluid; it is about 188 μ sec/ft. for saline water.
CP is an empirical correction (compaction) factor.
ΔT_{sh} is the sonic transit time of the shale and
C is a constant normally equals 1.0 (***Hilchie, 1978***).

In Shaly Zones:
The sonic porosity is determined in the shaly formation (***Dresser Atlas, 1979***) from the formula:

$$\varphi_S = \left[\frac{\Delta T_{log} - \Delta T_{ma}}{\Delta T_f - \Delta T_{ma}} * \frac{1}{CP}\right] - V_{sh}\left[\frac{\Delta T_{sh} - \Delta T_{ma}}{\Delta T_f - \Delta T_{ma}}\right] \tag{13}$$

B - Density Log:

It is one of the best tools for determining the formation porosity, due to the minor influence of argillaceous matter, if present, in its response. In clean and shaly zones, the porosity derived from density log can be determined as follows:

In Clean Zones:

The porosities obtained from the density log (φ_D) are calculated (***Wyllie, 1963***) from the relation:

$$\varphi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \tag{14}$$

Where:

ρ_b is the formation bulk density,
ρ_f is the fluid density (equals 1.1 for saline mud) and
ρ_{ma} is the matrix density, as calculated from the formula :

$$\rho_{ma} = \frac{\rho_{silic} + \rho_{carb}}{2} \tag{15}$$

Where:
ρ_{silic} is the density of sandstone zone and
ρ_{carb} is the density of carbonate zone.

In Shaly Zones:

The following formula (***Dresser Atlas, 1979***) is used for determining the total porosity in the shaly formations:

$$\varphi_D = \left[\frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}\right] - V_{sh}\left[\frac{\rho_{ma} - \rho_{sh}}{\rho_{ma} - \rho_f}\right] \tag{16}$$

Where:

ρ_{sh} is the shale zone density.

Neutron Log:
In Clean Zones:

Neutron logs directly give the porosity values (φ_{CNL}) in the clean zones.

In Shaly Zones:

In the shaly zones, neutron porosity can be corrected for the effect of the implied shales. The corrected porosity, as derived from the neutron log, can be thus manipulated according to ***Allen's equation (1965)*** as follows:

$$\varphi_{NC} = \varphi_{N\,log} - V_{sh} * \varphi_{N\,sh} \tag{17}$$

Where:

φ_{NC} is the neutron porosity corrected for shaliness effect,
$\varphi_{N\,sh}$ is the neutron porosity of a shale zone and
$\varphi_{N\,log}$ is the reading of neutron porosity from the log.

For clean and shaly zones, the values of porosity obtained from sonic, density and neutron logs are termed φ_S, φ_D and φ_N, respectively. It must be noticed that, the values of φ_N and φ_D represent the total porosities (primary + secondary), while the values of φ_S represent the primary porosities, in case of shaly and carbonate rocks.

Effective Porosities (φ_e):

This type of porosities depends largely on the degree of connection between the rock pores with each other forming channels, to facilitate the path of fluids through the lithologic contents. There are two ways to calculate the effective porosities:

The former is the general equation:

$$\varphi_{e1} = \varphi_t * (1 - V_{sh}) \tag{18}$$

The latter is the empirical formula:

$$\varphi_{e2} = \frac{2\varphi_{NC} + 7\varphi_{DC}}{9} \tag{19}$$

Where:

φ_{NC} is the neutron porosity corrected for shaliness effect and
φ_{DC} is the density porosity corrected for shaliness effect.

The corrected neutron and density porosities are calculated (***Schlumberger, 1972***) from the equations:

$$\varphi_{NC} = \varphi_N - \left[\frac{\varphi_{N\,sh}}{0.45}\right] * 0.30 * V_{sh} \tag{20}$$

$$\varphi_{DC} = \varphi_D - \left[\frac{\varphi_{D\,sh}}{0.45}\right] * 0.13 * V_{sh} \tag{21}$$

Where:

$\varphi_{N\,sh}$ is the neutron porosity of a shale zone and
$\varphi_{D\,sh}$ is the density porosity of a shale zone.

Effective Porosity Distribution Map of Abu Roash Formation:

Generally, the effective porosity distribution of Abu Roash Formation decreases gradually from from the north toward the north eastern ward (Fig. 5), in which the minimum porosity value (8%) is represented at EBS-4X well, till reaches its maximum value (19%) toward the southwest direction.

Effective Porosity Distribution Map of Abu Roash (G) Member:

Generally, the effective porosity distribution of Abu Roash (G) Member increases gradually toward the southeast and southwest (Fig. 11), in which the minimum porosity value (2%) is represented at EBS-4X well, while reaches its maximum value (22%) toward southwest direction at EBS-7X WELL.

Determination of Water Saturations:

Total Water Saturation:

Extensive studies by ***Simandoux (1963)*** on artificial media composed of sand and shale have suggested that, the resistivity can be expressed by the relation:

$$\frac{1}{R_t} = \frac{\varphi^2 S_w^n}{aR_w(1-V_{sh})} + \frac{V_{sh}S_w}{2R_{sh}} \tag{22}$$

In using this equation, R_{sh} is taken equal to the resistivity of the adjacent shale beds and V_{sh} is the shale fraction. In recent years, there are equations that have gained the widest acceptance in the evaluation of water saturation in shaly sands. These equations have the general form:

$$S_w = \frac{\dfrac{-V_{sh}}{R_{sh}} + \sqrt{\left[\dfrac{V_{sh}}{R_{sh}}\right]^2 + \left[\dfrac{4\varphi^2}{aR_w \cdot R_t(1-V_{sh})}\right]}}{\dfrac{2\varphi^2}{aR_w(1-V_{sh})}} \tag{23}$$

This is the water saturation equation, in case of total shale model.

Flushed Zone of Water Saturation (S_{xo}):

The estimation of S_{xo} is essential for the definition of the residual hydrocarbon saturation (S_{hr}) in clean and shaly zones.

The flushed zone water saturation is determined for both as follows:

Clean Zones:

It is calculated using Archie's equation (1942) as follows:

$$S_{xo} = \left[\frac{a}{\Phi^m} \times \frac{R_{mf}}{R_{xo}}\right]^{1/n} \tag{24}$$

Shaly Zones:

It is determined in the shaly zones, utilizing the Saraband's equation as follows:

$$\frac{1}{\sqrt{R_{xo}}} = \left[\frac{V_{sh}^{(1-V_{sh}/2)}}{\sqrt{R_{sh}}} + \frac{\Phi^{m/2}}{\sqrt{aR_{mf}}}\right] \times S_{xo}^{n/2} \tag{25}$$

Water Saturation Distribution Map of Abu Roash Formation:

(Fig. 6) shows that, the water proportion attains its maximum value of 37% at EBS-7X well and the minimum value of 22% at EBS-2X well localities.

Types of Hydrocarbon Saturations:

Since water saturation is the natural result of the previous calculations, it is often reported by the log analyst as one of “the answers”. However, the amount of oil or gas, not water, is wanted. This information can be derived from the following equations:

Total Hydrocarbon Saturation:

$$S_h = 1 - S_w \tag{25}$$

- Residual Hydrocarbon Saturation:

$$S_{hr} = 1 - S_{xo} \tag{26}$$

Movable Hydrocarbon Saturation:

$$S_{hm} = S_h - S_{hr} \tag{27}$$

Where:
S_{hr} is the residual hydrocarbon saturation in the invad zone and
S_{hm} is the movable hydrocarbon saturation.

The water saturation (reducible and irreducible) and hydrocarbon saturation (movable and residual) are illustrated in the iso-parametric maps given later.

Total Hydrocarbon Distribution Maps of Abu Roash Formation:

The total hydrocarbon saturation map (Fig. 7) reveals its maximum value of 78% at EBS-2X well and the minimum value of 63% at EBS-7X and EBS-3X wells, with a general trend of increase towards the northeastern direction in the opposite direction of the water saturation trend for the study area. The residual hydrocarbon is generally smaller than the movable one that increases gradually towards the southern direction (Fig. 9). Figure (8) reflects that, the movable hydrocarbon increases toward the northern direction at EBS-8X well.

Hydrocarbon Movable Distribution Maps of Abu Roash (G) Member:

The hydrocarbon movable saturation map (Fig. 12) reveals its maximum value of 65% at EBS-8X well and the minimum value of 63% at EBS-7X well, with a general trend of increase towards the northeastern direction.

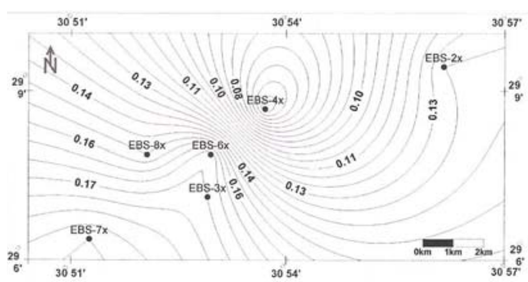

Fig. 5: Effective Porosity Distribution Map of Abu Roash Formation for the Stury Area.

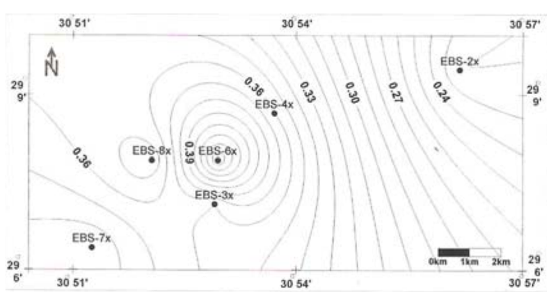

Fig. 6: Water Saturation map of Abu Roash Formation for the Study Area.

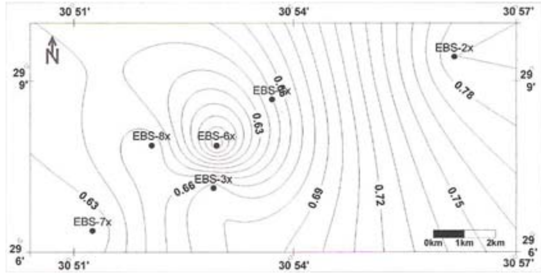

Fig. 7: Hydrocarbon saturation Map of Abu Roash Formation for the Study Area.

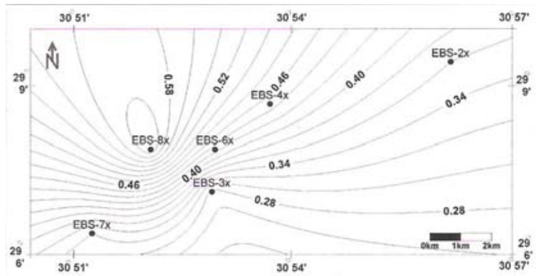

Fig. 8: Movable Hydrocarbon Saturation Map of Abu Roash Formation for the Study Area.

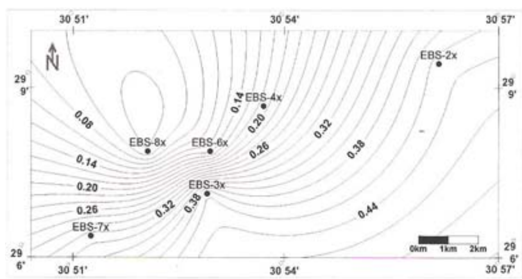

Fig. 9: Residual Hydrocarbon Saturation Map of Abu Roash Formation for the Study Area.

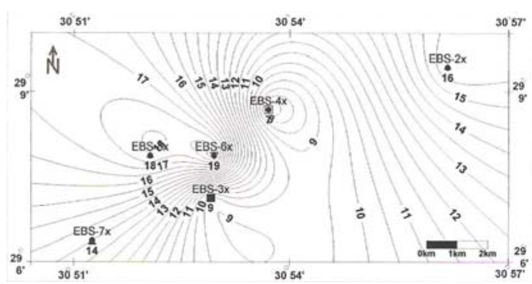

Fig. 10: Shale Distribution of Abu Roash Formation g Member.

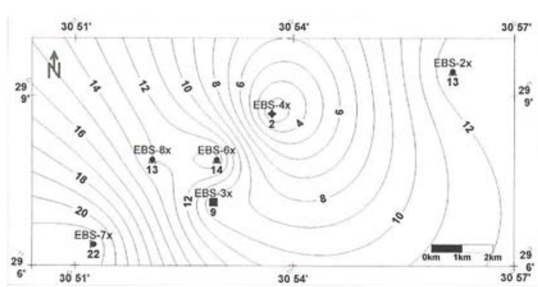

Fig. 11: Effective Porosity Distribution Map of Abu Roash Formation G Member.

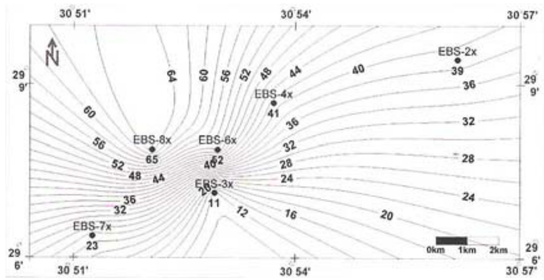

Fig. 12: Movable Hydrocarbon Saturaton Map of Abu Roash Formation G Member.

RESULTLS AND CONCLUSIONS

The available open-hole well log data used in the analysis of Abu Roash Formation are in the form of resistivity logs (deep and shallow), porosity tools (sonic, density and neutron) and the gamma-ray log. The petrophysical parameters (total porosity, effective porosity, shale volume, hydrocarbon and movable hydrocarbon saturations) are represented in the form of iso-parametric maps. This analysis of the studied rock unit in the area of study illustrates that, the reservoir quality increases toward the western direction of Abu Roash (G) Member for the study area. From the accurate calculation of water saturation, it can obtain the accurate amount of hydrocarbons(movable and residual hydrocarbons) can be determined in the reservoir, where the movable hydrocarbon shows a gradual increase toward the west and northwest at EBS-8X well, while it exhibits a gradual decrease toward the south direction, where EBS-7X well is located. From the abovementioned, it can be deduced that, the eastern part of the study area is promising for oil exploration and production.

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