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RESERVOIR EVALUATION OF BAHARIYA FORMATION IN TUT OIL FIELD, NORTH WESTERN DESERT, EGYPT

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ABSTRACT: Tut Oil Field is located in the northwestern part of the Western Desert, Egypt. This work aims to study the subsurface and reservoir characteristics to evaluate the hydrocarbon potential of Bahariya Formation based on subsurface data available from open-hole well log records of nine wells distributed in the area of study. The subsurface geologic setting, in terms of determining the stratigraphic and structural settings, is gained through the construction of different aligned stratigraphic and structural cross sections, isopach and lithofacies maps. The petrophysical evaluation, in terms of determining the petrophysical characteristics; net pay thickness, effective porosity ($\emptyset_{eff}$), shale content (V_{sh}), water saturation (S_w) and hydrocarbon saturation (S_h), is acquired through quantitative computer processed interpretation. The petrophysical characteristics are illustrated laterally in the form of iso-parametric maps and vertically in the form of litho-saturation cross-plots. According to subsurface study and petrophysical evaluation the most productive area is located in central and southern parts of Tut field.

Keywords: Tut Field, Subsurface study, Petrophysical evaluation, Hydrocarbon saturation

1. INTRODUCTION

Tut oil Field is located 4-5 km north and northwest of Salam Field at the northern edge of the major Safir-Salam-Tut ridge at Khalda concession in the northwestern part of the Western Desert. This area is a part of the Western Desert which is considered as one of the most prolific petroleum province in Egypt for its location inside Shushan basin. It lies between Latitudes 30° 44' 40" and 30° 46' N and Longitudes 26° 57' 20" and 26° 59' 20" E as shown in Fig.1.

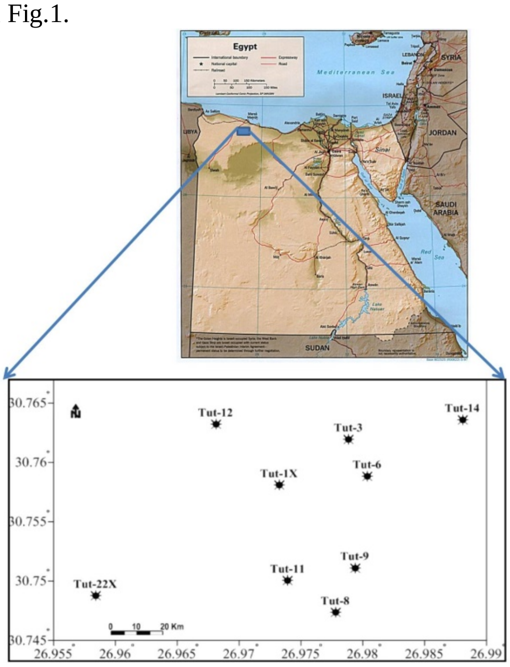

Fig.1 Location map showing the investigated wells.

The subsurface geologic setting of the northern part of Western Desert has been investigated by many researchers as shown in; [1-18].

1.1 Subsurface Stratigraphy

The stratigraphic section of North Western Desert (including Shushan Basin) ranges in age from Paleozoic to Tertiary as shown in Fig. 2.

The term Bahariya Formation was firstly published in [19], the type locality is in Gebel El Dist, Bahariya Oasis. Bahariya-1 well is the type locality for the subsurface Bahariya Formation as reported by [1].

The Bahariya Formation deposited conformably on top of the Albian Kharita Formation and is located stratigraphically below the Cenomanian-Turonian Abu Roash Formation. The contact between the Abu Roash and the Bahariya Formation is easily recognized by the abrupt change from clastic to a carbonate facies. The age of the Bahariya Formation is Cenomanian [5].

The Bahariya Formation in the Khalda Concession has been informally subdivided into upper and lower units as shown in; [20-22].

Wehr et al, [21] documented the lower Bahariya Formation to be a relatively sand rich succession of fine to medium-grained sandstone and mudstone that indicate deposition in an estuarine to shallow-marine environment with strong tidal influence and has been recognized as the primary reservoir unit in the Khalda Concession. The upper Bahariya Formation was described as a relatively sand poor succession deposited in a relatively low-energy, restricted marine setting and recognized as a secondary producer in the Khalda Concession.

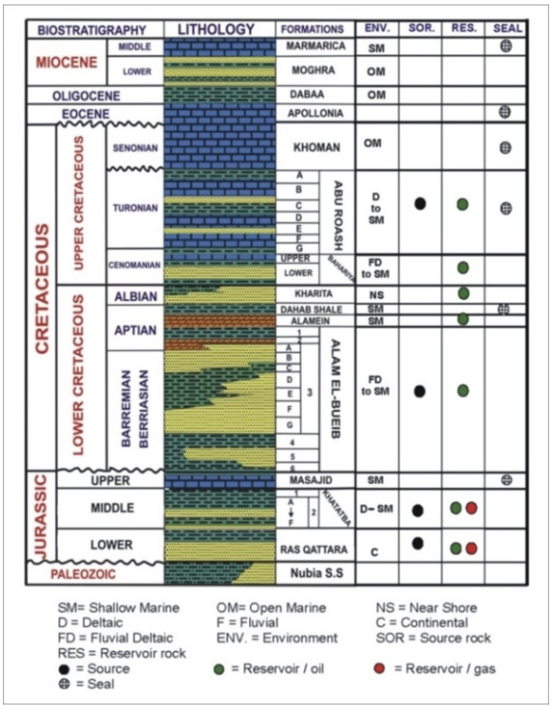

Fig.2 Regional stratigraphic section, North Western Desert including Shushan Basin, Egypt (compiled from [15]).

1.2 Subsurface Structure

The structure in North Western Desert focusing on the Shushan Basin, consists mainly of parallel, elongated, titled fault blocks, that is, horst and half-graben structures, with associated erosion of the upthrown blocks, [24] and [7]. The structure of Tut field at the Bahariya level is faulted anticlinal trap [25].

2. MATERIALS AND METHODS

Depending on the usage of the available open-hole well log records represented by electric, radioactivity and sonic logs in the form of composite well logs (Resistivity, Caliper, SP, GR, Density, Neutron, and Sonic logs of nine wells distributed in the area of study. The subsurface geologic setting is gained through the construction of stratigraphic and structural cross sections, isopach maps and lithofacies maps. The petrophysical evaluation is gained through the computer processed interpretation that passes through the quantitative interpretation technique. The petrophysical characteristics are illustrated laterally (in the form of iso-parametric maps) and vertically (in the form of litho-saturation cross-plots). This study mainly depends on the use of computer software programs, such as Interactive Petrophysics version 3.6 software program ® Schlumberger, 2010, and other petroleum-related geological software programs such as Surfer 13 and Corel Draw 12.

3. RESULTS AND DISCUSSIONS

3.1. Subsurface Evaluation

Isopach maps of Upper and Lower Bahariya Formations have been constructed using the thickness of Bahariya Formations in studied wells as summarized in Table 1.

Table 1: The thickness of evaluated Bahariya Formation in studied wells (in feet).

Well number / Formation	Tut-1X	Tut-3	Tut-6	Tut-8	Tut-9	Tut-11	Tut-12	Tut-14	Tut-22X
Upper Bahariya	152	158	157	160	156	163	166	157	161
Lower Bahariya	665	665	589	718	734	708	654	670	680
Bahariya	817	823	746	878	890	871	820	827	841

Isopach map of Upper Bahariya Formation, Fig. 3a, shows an increment in thickness toward the northwestern direction of the study area reaching maximum thickness at Tut-12 well with 166 feet and decreases toward central and eastern directions reaching its minimum thickness at Tut-1X well with 152 feet; and isopach map of Lower Bahariya Formation, Fig. 3b, shows an increase in thickness toward the southern direction of the study area reaching maximum thickness at Tut-9 well with 734 feet and decreases toward eastern part reaching its minimum thickness at Tut-6 well with 589 feet. These isopach maps illustrate the variation in thickness of Bahariya Formations may be due to the uplifting followed by erosion at this Formation. Moreover, these reflect one main depocenter locates around Tut-9 well.

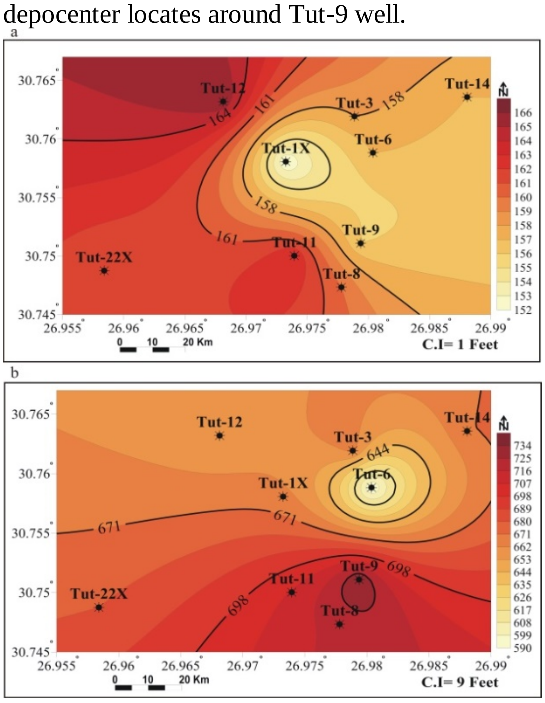

Fig.3 Isopach map of; a) Upper Bahariya Formation t and b) Lower Bahariya Formation.

Lithofacies maps show the distribution of different types of rock attributes occurring within a designated geologic unit, [23]. The lithologic thickness of Bahariya Formation in studied wells is summarized in Table 2.

Table 2: The lithological thickness of Bahariya Formation in studied wells (in feet).

Formation (Well number)	Ratios	Tut-1X	Tut-3	Tut-6	Tut-8	Tut-9	Tut-11	Tut-12	Tut-14	Tut-22X
Upper Bahariya	Sandstone	8.9	1.94	9.5	41.2	23.7	47.3	42.3	0	34.4
	Shale	113.5	141.3	96.5	100.6	101	91.1	119.6	138.4	84.5
	Sand/Shale	0.08	0.014	0.099	0.41	0.23	0.52	0.35	0	0.41
	Clastic	122.4	143.3	105.1	141.8	124.7	138.4	161.9	138.4	118.9
	Non clastic	29.7	14.75	51	18.2	31.3	24.6	4.1	18.6	42.1
	Clastic/non -clastic	4.12	9.7	2.1	7.8	4	5.63	39.5	7.44	2.8
Lower Bahariya	Sandstone	172.41	448.4	370.5	446.6	316.4	474.6	398.3	514.6	447.3
	Shale	457.6	188.3	151.1	235.1	395.2	205	240.7	124.2	169
	Sand/Shale	0.38	2.38	2.45	1.9	0.8	2.3	1.65	4.14	2.65
	Clastic	630.01	636.7	521.6	681.7	711.6	679.6	639	638.8	616.3
	Non clastic	34.84	28.3	67.4	36.3	22.4	28.4	15	31.2	63.7
	Clastic/non -clastic	18.08	22.5	7.74	18.8	31.8	24	42.6	20.5	9.7

Isolith maps were constructed to show thickness variation in the single rock type to interpret the environmental conditions during the deposition of sediments and to explain the geological history of this time. Sandstone and clastic isolith maps of Upper Bahariya and lower Bahariya Formations as shown in (Figs. 4 and 5).

Sandstone isolith map of; Upper Bahariya Formation, Fig. 4a, shows an increase in the thickness of sandstone toward the southern part of the study area reaching maximum thickness at Tut-11 well with 47.3 feet and decreases toward northeastern part and completely disappeared at Tut-14 well and, the sandstone isolith map of Lower Bahariya Formation, Fig. 4b, shows an increase in the thickness of sandstone toward the southern and the northeastern parts of the study area reaching maximum thickness at Tut-14 well with 514.6 feet and decreases toward central part reaching its minimum thickness at Tut-1X well with 172.4 feet.

Clastic isolith map Upper Bahariya Formation, Fig. 5a, shows that the thickness of clastic increases toward the northern part of the study area reaching maximum thickness at Tut-12 well with 161.9 feet, while it decreases toward eastern part reaching the lowest value at Tut-6 well with 105.1 feet and Lower Bahariya Formation, Fig. 5b shows that the thickness of clastic increases toward the southern part of the study area reaching maximum thickness at Tut-9 well with 711.6 feet, while it decreases toward eastern and central parts reaching the lowest value at Tut-6 well with 521.6 feet.

Isolith maps indicate that the shoreline is located at northern part and extends to southern part during Upper Bahariya deposition and southern part during Lower Bahariya deposition.

Sand/shale ratio and clastic/non-clastic maps of Upper Bahariya and Lower Formations have been constructed as shown in (Figs. 6 and 7).

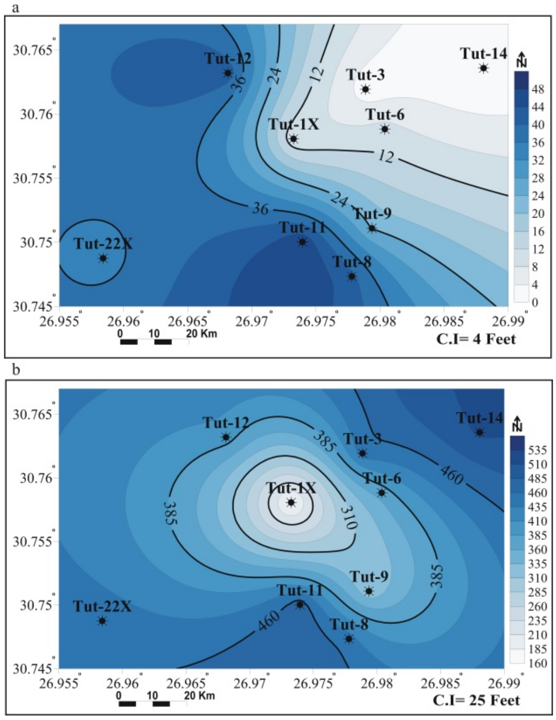

Fig.4 Sandstone isolith map of; a) Upper Bahariya Formation and b) Lower Bahariya Formation.

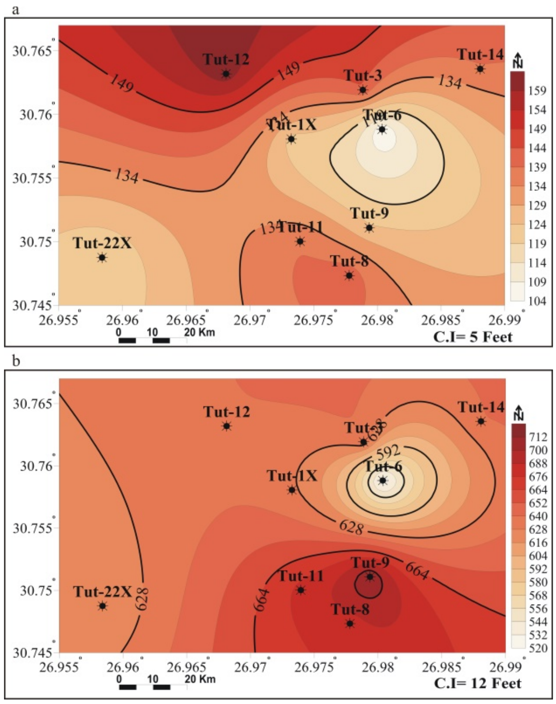

Fig.5 Clastic isolith map of; a) Upper Bahariya Formation and b) Lower Bahariya Formation.

Sand/shale ratio map of Upper Bahariya Formation, Fig. 6a, indicates that the sand/shale ratio increases toward the southern part of the study area reaching maximum ratio at Tut-11 well and decreases toward the northeastern part reaching its minimum ratio at Tut-3 well, while it completely disappeared at Tut-14 well, and in Lower

Bahariya Formation, Fig. 6b, indicates that the sand/shale ratio increases toward the northeastern part of the study area reaching maximum ratio at Tut-14 well and decreases toward the central part reaching its minimum ratio at Tut-1X well.

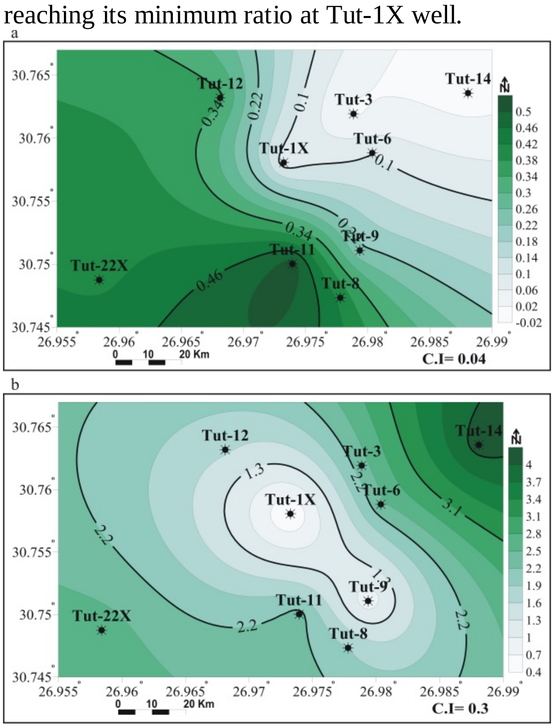

Fig.6 Sand/shale ratio map of; a) Upper Bahariya Formation, and b) Lower Bahariya Formation.

Clastic/non-clastic ratio map of Upper Bahariya Formation, Fig. 7a, indicates that the clastic/non-clastic ratio increases toward the northwestern part of the study area reaching maximum ratio at Tut-12 well and decreases toward the other parts of the study area reaching its minimum ratio at Tut-6 well, and in Lower Bahariya Formation, Fig. 7b, which shows that the clastic/non-clastic ratio increases toward the northwestern part of the study area reaching maximum ratio at Tut-12 well and decreases toward the southwestern and eastern parts reaching its minimum ratio at Tut-6 well.

Sand/shale ratio and clastic/non-clastic maps indicate that the depositional environment is deeper to east direction.

To have a complete and detailed image about the stratigraphical and structural features at the study area, four cross sections are constructed in different directions to interpret the stratigraphy and structures of the subsurface succession at the study area, Fig. 8.

The constructed stratigraphic cross sections, Fig. 9. illustrate that, Upper Bahariya Formation is composed of argillaceous and/or calcareous sandstone and siltstone intercalation with shale and limestone, where it was deposited in environment changes from fluvio-marine to relatively deep marine environment within neritic environment in eastern part while the Lower Bahariya Formation is composed of sandstone and shale interbedded with limestone where it was deposited in environment changes from fluvio-marine to shallow marine environment in eastern and southwestern parts. The output of studying the stratigraphic cross section is matching with [20-22] and [25].

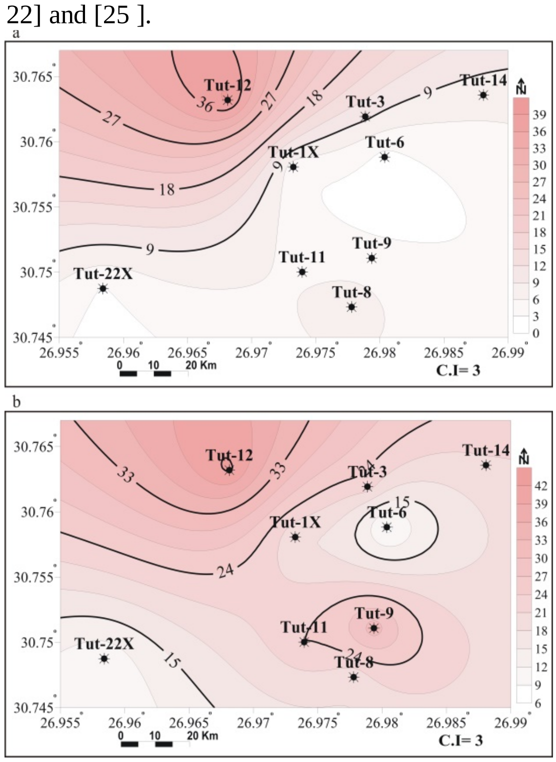

Fig.7 Clastic/non-clastic ratio map of; a) Upper Bahariya Formation, and b) Lower Bahariya Formation.

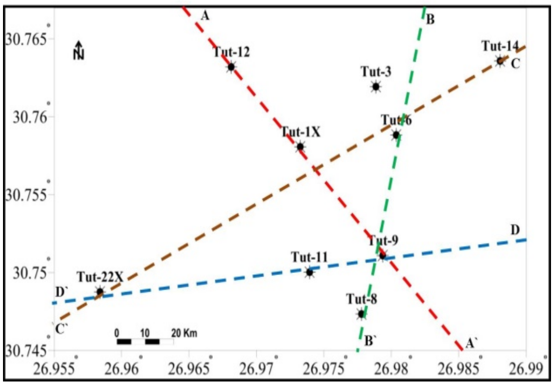

Fig.8 Base map shows drilled wells location and cross section profiles of the study area.

Also, we highlighted the subsurface structural patterns of the study area, for this purpose geologic structural cross sections are constructed with respect to sea level datum. These sections, Fig. 10, are tentatively illustrating that, there are many normal faults affected on the formations and forming horst blocks in some areas. These faults may form good structural traps in Tut field.

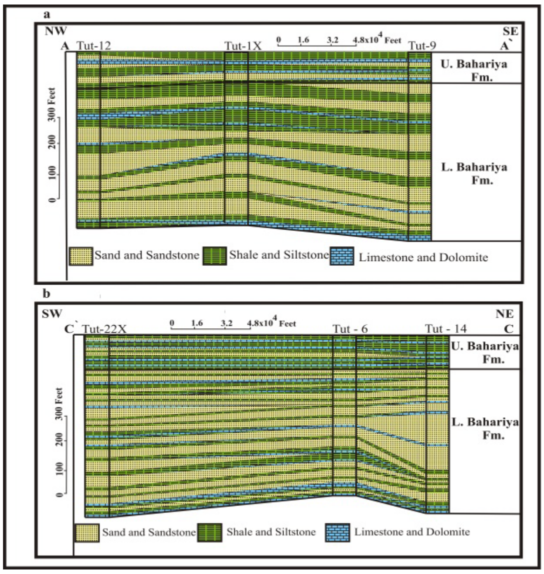

Fig.9 Examples of the stratigraphic cross sections; a) cross section A-A` extends along NW-SE direction and b) cross section C-C` extends along NE-SW direction.

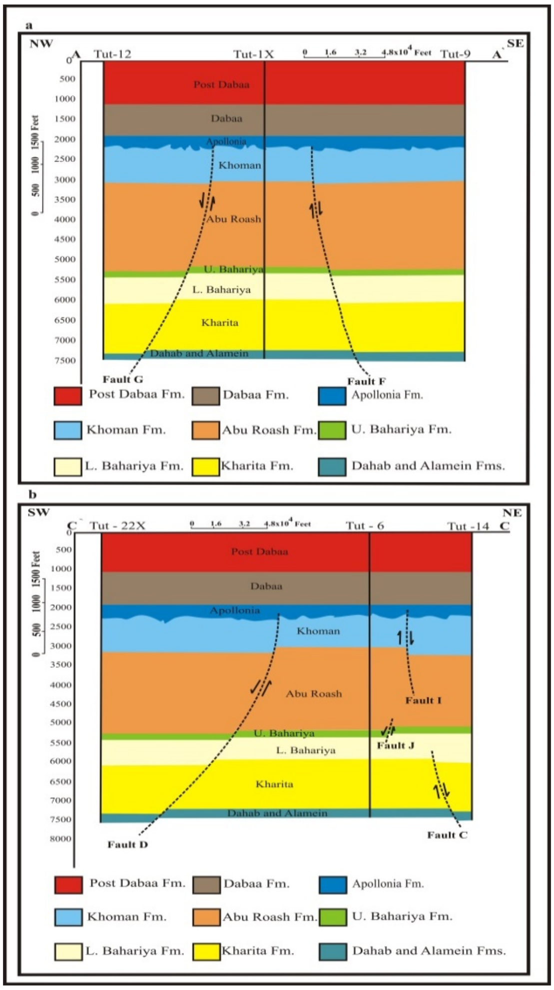

Fig.10 Examples of the structural cross sections; a) cross section A-A` extends along NW-SE direction and b) cross section C-C` extends along NE-SW direction.

3.2. Petrophysical Evaluation

The petrophysical characteristics and lithology are presented vertically in the form of litho-saturation crossplots, laterally in the form of iso-parametric maps and lithological crossplots.

The litho-saturation crossplots are constructed for illustration the gross character of the petrophysical parameters, in terms of lithology fraction and fluid saturation throughout the wells in the vertical direction as shown in Fig. 11. The average petrophysical parameters are tabulated in Table 3 by using these cutoffs: effective porosity is 12% for Upper Bahariya and Lower Bahariya Formations, volume of shale is 50% for both formations and water saturation is 70% for Upper Bahariya Formation and 55% for Lower Bahariya Formation. These plots show that the average effective porosity within reservoir ranges from 13% in Tut-14 to 19% in Tut-6 for Upper Bahariya Formation and from 17% in Tut-12 to 21% in Tut-8 for Lower Bahariya Formation and, the average volume of shale within reservoir ranges from 19% in Tut-22X to 35% in Tut-1X for Upper Bahariya Formation and from 15% in Tut-22X to 29% in Tut-14 for Lower Bahariya Formation and the average water saturation within reservoir ranges from 63% in Tut-8 to 98% in Tut-14 for Upper Bahariya Formation and from 76% in Tut-9 to 93% in Tut-22X for Lower Bahariya Formation while the average water saturation within pay zones ranges from 49% in Tut-8 to 64% in Tut-11 for Upper Bahariya Formation and from 35% in Tut-11 to 48% in Tut-3 for Lower Bahariya Formation in the study area.

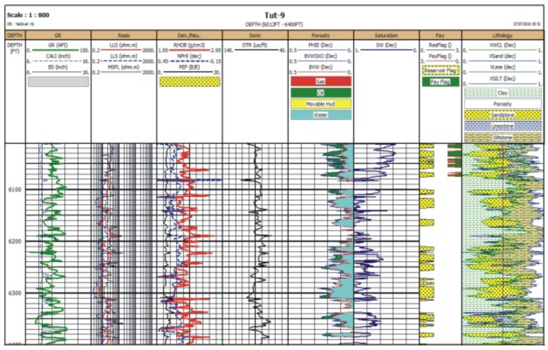

Fig.11 Part of the litho-saturation crossplot in Tut-9 well.

The lateral distribution of hydrocarbon occurrence studied and explained through a number of porosity and saturation gradient maps (iso-parametric maps). These iso-parametric maps constructed to complete the model of hydrocarbon potentialities in the study area, [26].

The petrophysical parameters include; net pay thickness, effective porosity ($\mathbf{\emptyset_{eff}}$%), shale content ($\mathbf{V_{sh}}$%), water saturation ($\mathbf{S_w}$%), and hydrocarbon saturation ($\mathbf{S_h}$%) for Upper Bahariya and Lower Bahariya Formations as shown in (Figs. 12 to 15).

The study of these parameters is very important in judging their lateral variation and the factors controlling them, which may be structural, stratigraphic or both, [27].

Table 3: The average of the petrophysical parameters for reservoirs in Upper Bahariya and Lower Bahariya Formations that obtained from petrophysical evaluation of the study area.

Well No.	Fm	Gross thickness (ft)	Net pay thickness (ft)	Net thickness /Gross thickness	Average effective porosity (Phie) %	Average volume of shale (Vsh) %	Average water saturation (Sw) %	Average hydrocarbon saturation (Sh) %
Tut-8	U. Bahariya	160	8	0.05	18%	21%	63%	37%
	L. Bahariya	718	27	0.038	21%	21%	84%	16%
Tut-3	U. Bahariya	158	13	0.082	18%	22%	70%	30%
	L. Bahariya	665	7	0.011	19%	25%	89%	11%
Tut-22X	U. Bahariya	162	7	0.0432	17%	19%	87%	13%
	L. Bahariya	679	13	0.0191	19%	15%	93%	7%
Tut-1X	U. Bahariya	152	19	0.125	18%	35%	74%	26%
	L. Bahariya	665	67	0.102	17%	22%	77%	23%
Tut-11	U. Bahariya	163	9	0.055	16%	25%	79%	21%
	L. Bahariya	708	19	0.027	19%	26%	81%	19%
Tut-9	U. Bahariya	156	10	0.064	18%	29%	70%	30%
	L. Bahariya	734	36	0.049	19%	18%	76%	24%
Tut-12	U. Bahariya	166	7	0.042	17%	28%	80%	20%
	L. Bahariya	654	14	0.021	17%	28%	89%	11%
Tut-6	U. Bahariya	157	8	0.051	19%	31%	84%	16%
	L. Bahariya	589	37	0.063	17%	24%	76%	24%
Tut-14	U. Bahariya	157	0	0	13%	25%	98%	2%
	L. Bahariya	670	24	0.036	18%	29%	87%	13%

Net pay thickness map of Upper Bahariya Formation, Fig.12a, shows an increase in net pay thickness toward the central part of the study area at Tut-1X and decreased toward the northeastern part and completely disappeared at Tut-14, and Lower Bahariya Formation, Fig.12b, reveals an increase in net pay thickness toward the central part at Tut-1X and decreased toward the northern and southwestern parts of the study area at Tut-3 and Tut-22X.

Effective porosity map of Upper Bahariya Formation, Fig.13a, observed within the range from 13% in Tut-14 to 19% in Tut-6. The highest value of effective porosity is found in the central part of the study area, while the lowest value of effective porosity is found in the northeastern part and Lower Bahariya Formation, Fig.13b, observed within the range of 17% in Tut-12 to 21% in Tut-8. The highest value of effective porosity is found in the southern part of the study area, while the lowest value of effective porosity is found in the northern part.

Shale content map of Upper Bahariya Formation, Fig.14a, illustrates that the shale content ranges from 19% in Tut-22X to 35% in Tut-1X. The shale content decreases toward the southwestern part, while it increases in the central part of the study area, and Lower Bahariya Formation, Fig.14b, shows the shale content ranges from 15% in Tut-22X to 29% in Tut-14. The shale content decreases toward the southwestern part, while it increases in the northern part of the study area.

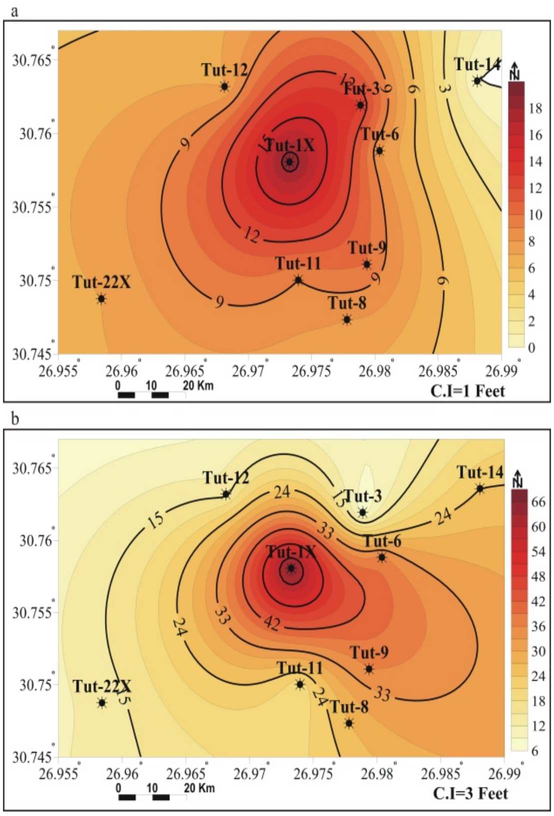

Fig.12 Net pay thickness map of; a) Upper Bahariya Formation, and b) Lower Bahariya Formation.

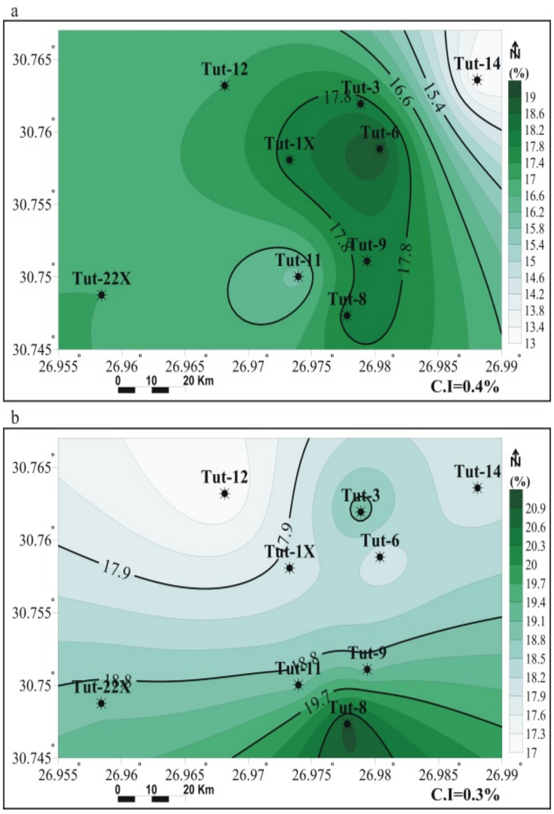

Fig.13 Effective porosity map of; a) Upper Bahariya Formation, and b) Lower Bahariya Formation.

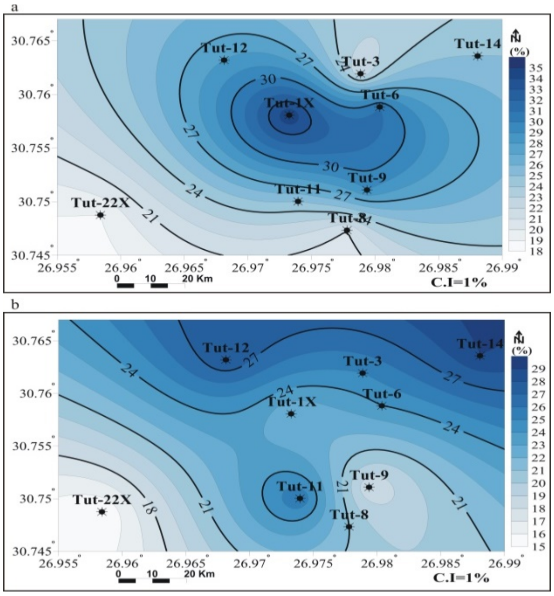

Fig.14 Shale content map of; a) Upper Bahariya Formation, and b) Lower Bahariya Formation.

Water saturation map of Upper Bahariya Formation, Fig.15a, shows that the most water saturation occurrence is observed within the range of 63% in Tut-8 to 98% in Tut-14. The highest water saturation value is found at the northeastern part of the study area while the lowest water saturation value is found at southern and central parts where the hydrocarbon saturation increases, and Lower Bahariya Formation, Fig.15b, reveals that the most water saturation occurrence is observed within the range of 76% in Tut-9 to 93% in Tut-22X. The highest water saturation value is found at the southwestern part of the study area while the lowest water saturation value is found at the central part where the hydrocarbon saturation increases.

The lithologic and mineralogical compositions were identified qualitatively through the utilizing of crossplots which were established by using the different tools such as neutron-density and sonic logs for identifying lithology of formations, [28].

Neutron-density crossplots are commonly used to determine the lithology (using the neutron and density logs) and accurately evaluate the matrix porosity of carbonate rocks. In this case, the bulk density (RHOB) and neutron porosity (NPHI) readings are plotted together, [29].

Neutron-density crossplots of Upper Bahariya and Lower Bahariya formations, as shown in Fig. 16, illustrate that the points are aligned on sandstone line indicate sandstone beds. The effect of gas is observed where some points have moved upwards. The scattered points towards dolomite line are due to shale effect which is clearly confirmed from the litho-saturation cross plots. The points are plotted on the limestone and dolomite lines indicate the presence of carbonate interbeds. The points plotted between sandstone and limestone lines indicate that calcareous cement present. These indicate that Bahariya Formation is composed of sandstone, siltstone and shale interbeded carbonate with argillaceous and/or calcareous cement.

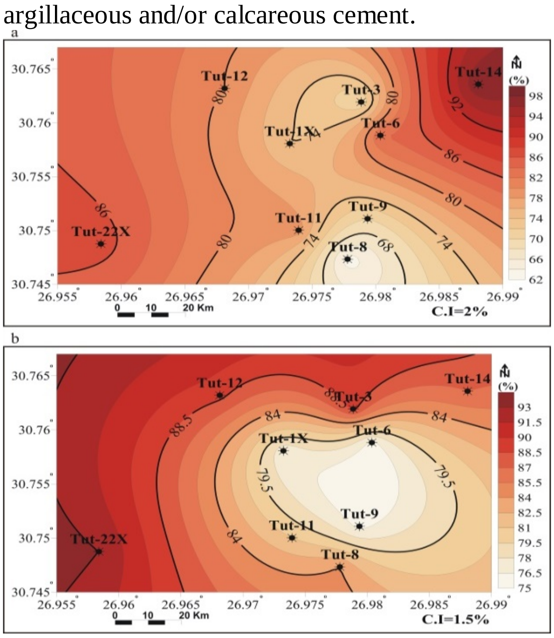

Fig.15 Water saturation map of; a) Upper Bahariya Formation, and b) Lower Bahariya Formation.

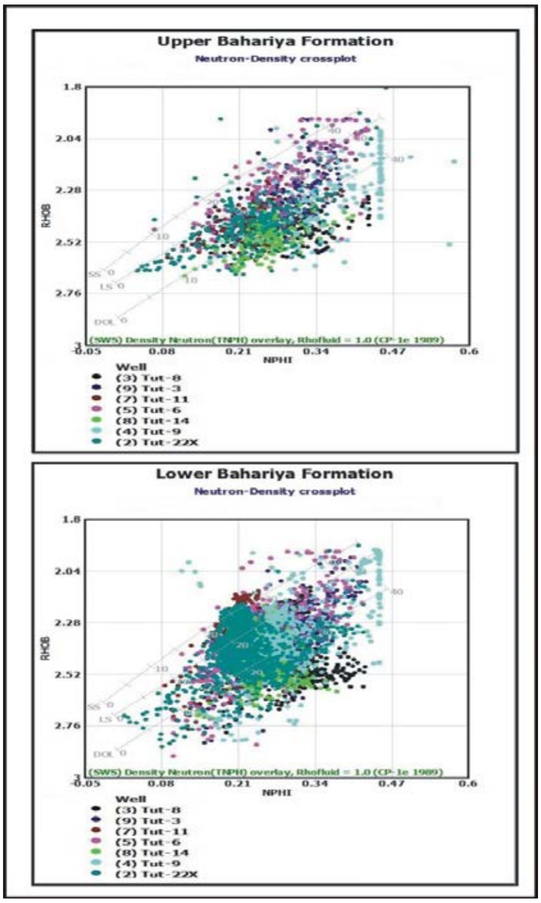

Fig.16 Neutron-density crossplot of Upper and Lower Bahariya Formations in the studied wells.

The three porosity logs combinate to provide the lithology characteristics (M-N crossplot), [30]. M-N crossplots of Upper Bahariya and Lower Bahariya Formations, as shown in Fig.17, illustrate that the major of the plotted points are scattered to fill the space between sandstone and limestone points but tend to be near to sandstone more than limestone. It may indicate the presence of sandstone lithology with amount of limestone. The other distorted points are scattered shifted downwards due to the shale effects and this effect may be the reason of shifting points near the dolomite region as the shale volume percent value is high. The effect of secondary porosity appears in shifting of some points upwards. Also the effect of gas appears in Lower Bahariya Formation in shifting the scattered points in the upright corner of the crossplot.

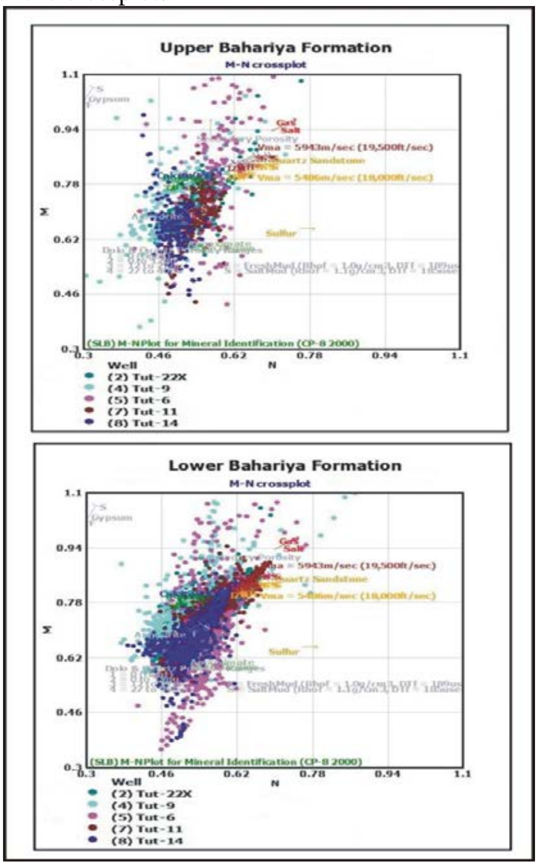

Fig.17 M-N crossplot of Upper and Lower Bahariya Formations in the studied wells.

4. SUMMARY AND CONCLUSIONS

The present work mainly deals with subsurface study and petrophysical characteristics to evaluate the hydrocarbon potentiality of the Bahariya Formation in Tut field, North Western Desert, Egypt.

The subsurface study was achieved by the construction of different aligned stratigraphic and structural cross sections, isopach and lithofacies maps. These studies reflect that Bahariya Formation deposited in environment changes from fluvio-marine to marine environment in eastern part while the carbonate sand shale coincides with the transgression pulse and seem to be deposited in relatively deep marine inner neritic environment. There are many normal faults affected on formations and forming horst blocks in some area. All tops of formations in central part are higher. This means that the central part is more prospective than the other part.

According to the petrophysical evaluation, the central and southern parts of the study area are the most favorable parts for accumulation and production due to increase in net pay thickness and average effective porosity and decrease in water saturation toward these parts of the study area.

As a result of the subsurface study and petrophysical evaluation for this area the most productive area is located in central and southern parts of Tut field. So, for future it is recommended to focus the exploration activities on these areas.

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