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Impact of Reservoir Characteristics and 3D Seismic Analysis for the Bahariya Reservoir at AES-E3 Field, Alam El-Shawish East, North Western Desert, Egypt

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Abstract

The Bahariya Formation is considered as a crucial hydrocarbon reservoir in AES-E3 on the East Alam El-Shawish Field, North Western Desert of Egypt. This work aims to illustrate the impact of Petrophysical characteristics and subsurface features on Bahariya reservoir development through the integration of petrophysical analysis and seismic interpretation. The seismic interpretation displays Bahariya reservoir structure as a series of normal faults separating the area into deferent segments represented by two to three-way dip closure which considered as the main structures in the East Alam El-Shawish field. Petrel and Tech Log software was used for analysis and mapping the five well logs, to provide the lithology and fluid saturations for Bahariya reservoir. Also, the effect of geological features in the development of the area study was clarified. East Alam El-Shawish area has excessive porosity and hydrocarbon saturation values because of the massive fracturing resulting from faulting supported by high structural position, porosity, high percentage of hydrocarbon saturation and both low shale content and water saturation. This helps and encourages drilling lots of development and appraisal wells in north east, south east and central parts at the area of study to increase oil production. Consequently, the integration between the petro-physical characteristics and geological structures will be helpful for the development and increasing productivity of the study area.

Keywords: Well logging analysis, reservoir characterization, the Bahariya Formation, East Alam ElShawish field, the North Western Desert

1. Introduction

Clarified the reservoir quality is considered as an important method for integrated petrophysical properties which leads to and optimizes the field development **[1, 2]** . So, reservoir characterization refers to evaluation all properties of reservoir such as permeability (K), porosity (Φ), Net pay thickness and fluid saturation.

The current study aims to evaluate reservoir quality and quantity for the Bahariya reservoir potentiality which considered as one of the main oil reservoir producers at East Alam El-Shawish field, North Western Desert, Egypt which located between latitudes 29^o 40’ N and 29^o 43’N and longitudes 28^o 21’ E and 28^o 24’ E as shown in Figure (1). The area of study is a part of Abu Gharadig Basin as shown in Figure (2). Exploration, Development and production in Abu Gharadig Basin involve advanced techniques and technologies to extract hydrocarbons efficiently and sustainably. Additionally, the basin’s geological characteristics continue to attract interest from international energy companies seeking investment opportunities in Egypt’s oil and gas sector.

The work objectives include the next points: 1) determination of depth and thicknesses the Ba-

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hariya reservoir, 2) definition of the structural features affected the area of study, 3) identification of the hydrocarbon-bearing horizon using the available well logs, 4) definition of the parameters of the Bahariya reservoir describing hydrocarbon intervals from logging data to highlight the best development and appraisal areas.

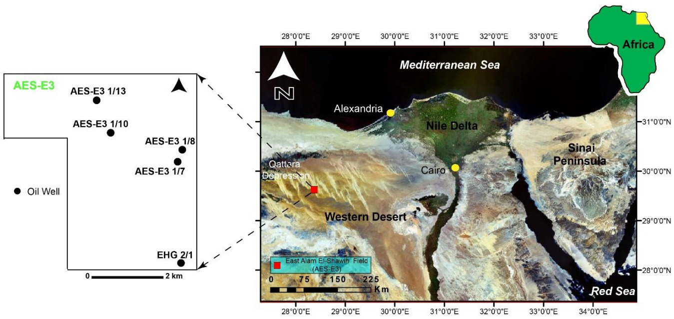

Figure 1: The location map of AES-E3 field, East Alam El-Shawih

1.1. *Geology of the Western Desert*

The Western Desert of Egypt is a vast region covering approximately 700,000 square kilometers, which accounts for nearly two-thirds of the entire area of Egypt. It extends approximately 1000 km from the Mediterranean shoreline in the north to the Sudanese border in the south. From east to west, it stretches between 600 to 800 kilometers from the Nile valley to the Libyan border. The main topographic features of the Western Desert include large plateaus sloping seaward, closed depressions often referred to as oases, and extensive sand dunes. These features collectively create a diverse and dynamic landscape characteristic of desert environments [1–3]

The Abu Gharadig Basin is an important geological feature located in Egypt. It's primarily known for its significant oil and natural gas reserves. The basin covers a considerable area in the Western Desert of Egypt, which has been extensively explored and developed for hydrocarbon extraction.The basin has been a focal point for the Egyptian oil and gas industry, with various exploration and production activities ongoing in the region. Its strategic significance lies in its contribution to Egypt's energy sector, providing substantial reserves that contribute to the country's domestic energy needs and exports. [4, 5]

The Abu Gharadig Basin is characterized by a complex geological structure typical of many sedimentary basins. The basin contains various structural features such as faults, folds, and anticlines, which play crucial roles in hydrocarbon accumulation and migration. These structural elements result from tectonic forces acting on the Earth's crust over time. The tectonic history of the region has influenced the formation and evolution of the Abu Gharadig Basin. It may have experienced periods of extension, compression, and uplift, leading to the creation of structural highs and lows within the basin [5, 6] .

It's important to note that the Western Desert has experienced multiple tectonic episodes, including rifting during the Mesozoic era and subsequent extensional tectonics during the Cenozoic era. The Abu Gharadig Basin is a typical half-graben, a geological structure formed by extensional tectonic forces that cause the Earth's crust to stretch and thin. This results in the creation of linear horsts (uplifted blocks) and depressions (down-dropped blocks) within the basin, Fig.4. The basin flanks exhibit a complex fault system, including normal faults and inverted strike-slip faults. Strike-slip faults are characterized by horizontal movement along the fault plane, and when they become inverted, they resulting in compression rather than extension, leading to the formation of thrust faults and folds. This complexity gives rise to asymmetrical depressions, horsts (uplifted blocks), and buried linear inversion folds [7–9] .

The generalized stratigraphic column of the northern Western Desert encompasses a thick succession of sedimentary layer Fig 3, spanning from Mesozoic to Quaternary deposits. Despite some local variations, the total thickness of the sedimentary sequence tends to increase progressively towards the north and northeast. In the southern regions, the sedimentary sequence may be around 6000 feet thick, whereas along the coastal areas, it can reach approximately 25,000 feet in thickness. Several Research discussed the structural setting of the northern Western Desert and many authors [10–13]

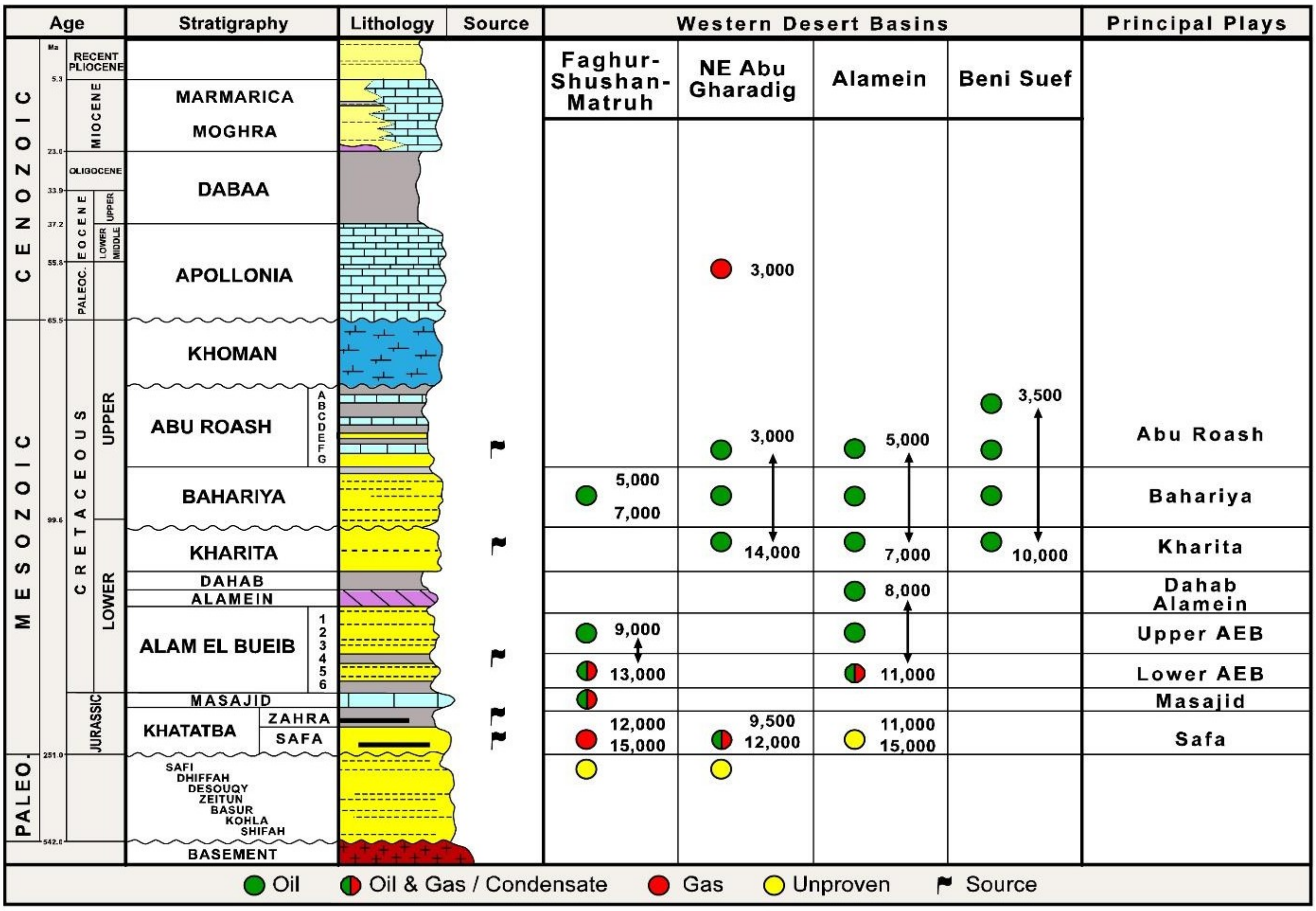

Figure 2: Showing the litho-stratigraphic column of the northern Western Desert of Egypt indicating different rock units in the area illustrating their relationship and positions (Abdel-Fattah et al., 2018)

2. Materials and Methods

The data are based on logging of five wells are: EHG (2-1,1-1) AES-E3 1-(8, 10,13) and twenty seismic lines have been analyzed and mapped using the Petrel and Tech Log software to determine the lithology and fluid saturations for Bahariya reservoir.

The available seismic data include base map for AES-E3 field which illustrates the locations of twenty depth seismic lines (thirteen seismic lines covering the area of study in North-South direction and seven seismic lines overlay the area of study in East-West direction) (Fig. 5).

The available well logs are gamma ray, neutron, caliper, sonic, resistivity and composite logs (Petrosannan Company). In addition, twenty depth seismic lines and seismic lines base map. To obtain the study goal, the next procedures were performed to the data availability: picking structural features, horizons and depth contour maps, and stratigraphic correlation. The remarked tops of reservoir in the wells were linked to depth seismic sections to identify and map the horizon. The data of formation tops were optimized for the well-to-seismic tie pay zone and represented on the intersected seismic lines. The reflections on both cross-line and in-line depth seismic sections through the area for horizon identification and depth structure map creation [14–16]. Based at the well to seismic tie the horizon to interpret have been selected withinside the seismic data. The fundamental interest turned into centered over the reservoir intervals, where in 4 horizons have been decided on to interpret. The selected four horizons for interpretation are Top Abu Roash"C', Top

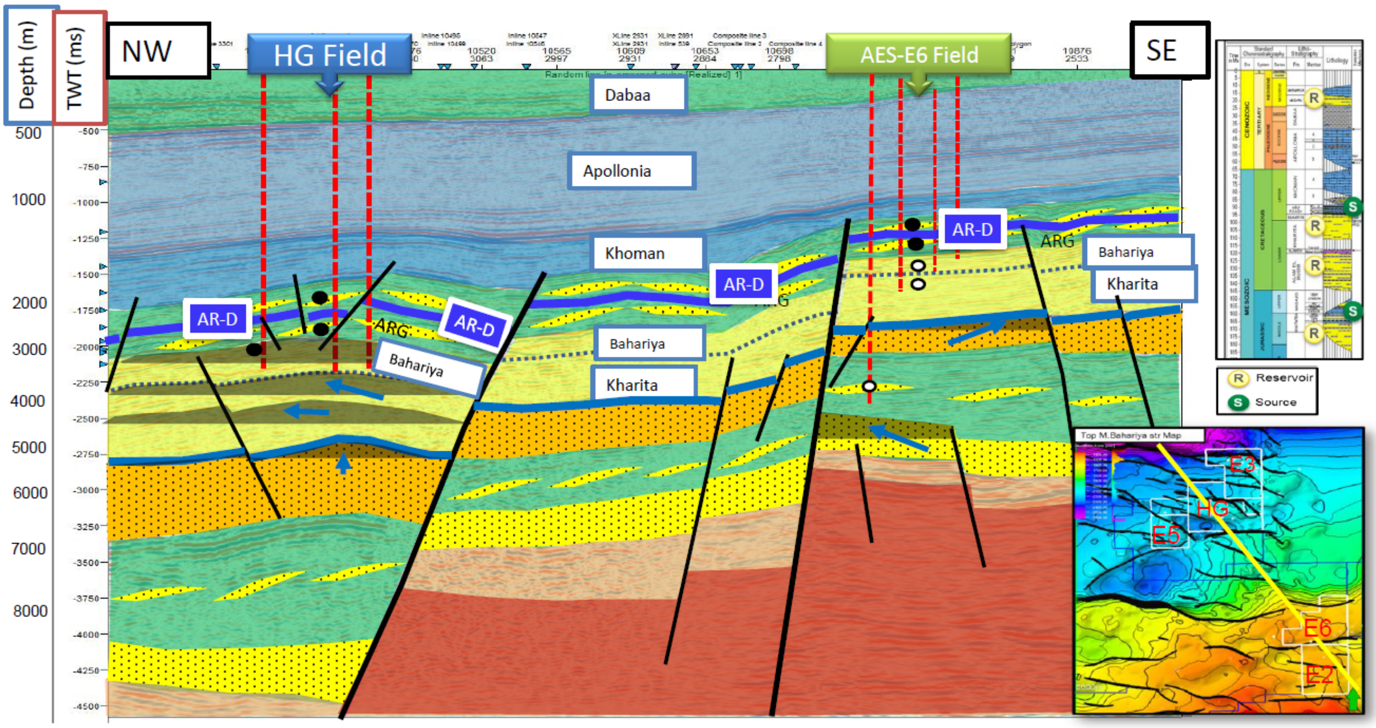

Figure 3: Showing the litho-stratigraphic column of the northern WesternDesert of Egypt indicating different rock units inthe area illustrating their relationship and positions (Abdel-Fattah et al.,2018)

Abu Roash"E", Top Abu Roash"G" and Bahariya. Top Abu Roash"C", Top Abu Roash"E", Top Abu Roash"G" and the Bahariya have been selected to work as structural framework to define the geometry of reservoir.

The lithology determination and interpretation of lithology for the Bahariya reservoir defined by using the logging data. The evaluation of well logging data has been performed by using techlog software. The reservoir parameters of the Bahariya Formation from well logging data refer to or include the total and effective porosity, total thickness, shale volume, water saturation, net to gross, net sand thickness, hydrocarbon saturation and net pay thickness. [17–20]

The Bahariya reservoir can be estimated by examining the petrophysical parameters vertical distribution due to well logging analysis results. For all stratigraphic units, rock properties vary similarly from one part of the basin to another, but the rate of variability depends on several factors such as adjacent basins, water and climate chemistry etc. Changes in sedimentation patterns within the commonly associated stratigraphic units reflect both tectonic framework and environmental differences.

Petrophysical parameters and vertical distribution of lithology are displayed as a form in litho-saturation Cross plot which is responsible for the formation analysis that gives lithology (vertical distribution of the rocks) [21, 22], porosity (total and effective porosity) and fluids. The diagram also shows the bore hole log package from left to right (measured depth, bit size-caliper, gamma ray, volume of shale, resistivity, density-neutron, reservoir flag, pay flag, effective porosity, water saturation, lithology, formation name) shown in Table (1). The Bahariya upper isn't complete in AES-E1 1-10 &AES-E1 1-13 due to stop drilling, the Bahariya middle wasn't drilled in AES-E1 1-10 & AES-E1 1-13. The Bahariya lower wasn't drilled in AES-E1 1-(10, 13) wells.

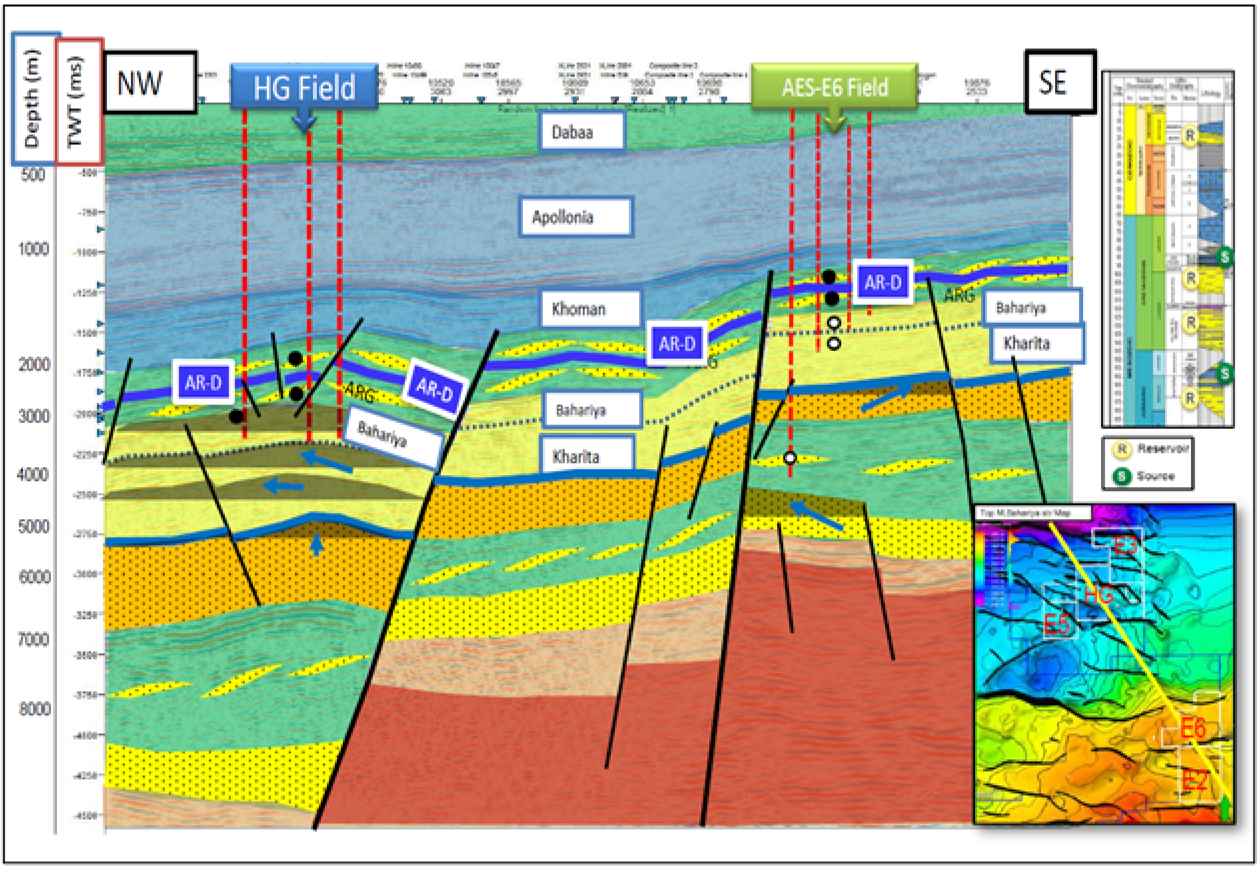

Figure 4: A regional geoseismiccross-section from NW to SE direction through all petrosannan fieldsillustrates all reservoirs shallower in the south and deeper in the northdirection due to set of parallel normal faults divided the area into several fault-blocks, Petrosannan internal report, (GPC conference 2022).

3. Results and Discussion

3.1. Seismic interpretation

Interpretation of seismic lines number (1,7,13) passing through AES-E3 field from north to south, this line showing several normal faults (F1, F2, F3 &F4) in E-W directions. Faults are clear in the N-S seismic lines than the E-W lines where faults trending nearly EW as in Figures (6-9).

The top of the Bahariya depth structural contour map (Fig. 10) showing four closures (B1, B2, B3 & B4), depth values increase at the north west and south west parts of the study area, recording the maximum value -3870m at these parts of the area (structurally low) on the other hand the depth of top of the Bahariya decrease at the north east and central parts of the study area (around F2 and F4 faults) and the south east part, recording minimum depth 2970m in this part of the study area (structurally high). According to that, we can notice that the basin mainly in the north west and south west parts of the study area mean while the depths increase at these parts which is structurally low. The area is dissected by four normal faults which are oriented in the East -West and North West-South East directions.

3.2. Well Correlation:

The composite logs for borehole data were used to perform the correlation line chart in the direction (A-A') as shown in Figure (7) to define the subsurface geological features. The intention of correlation chart is to comply with the adjustments in lithologic characters or any break within the depositional continuity and geologic structures. It defines the equivalency of stratigraphic units and shows the variation in thickness as in stratigraphical correlation. The well logging correlation results deliver the five wells in the study area for the Bahariya reservoir which are shown in Figures (8-10)

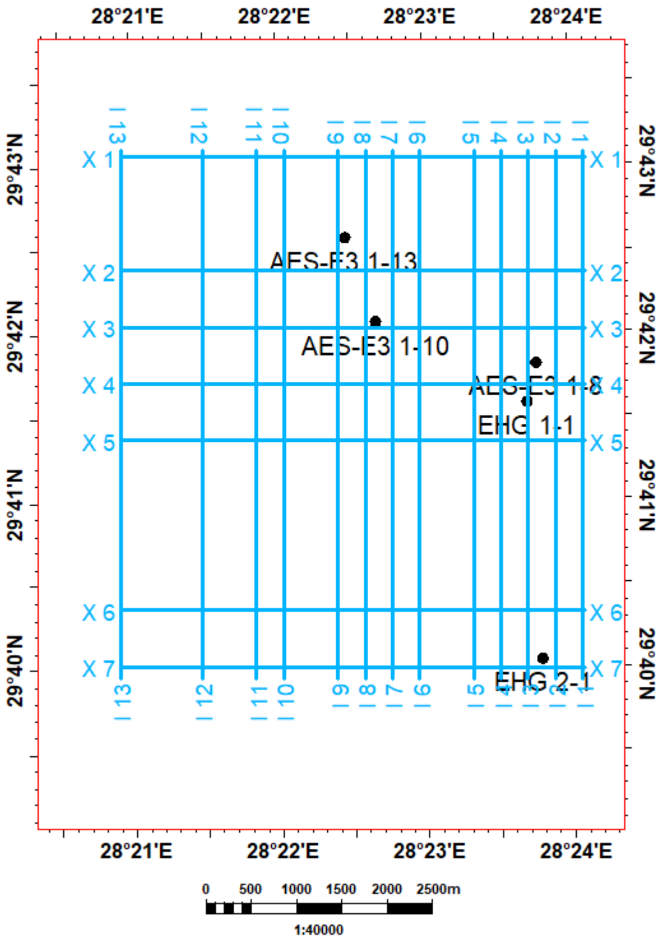

Figure 5: Base map showing the twenty seismic lines (thirteen N-S-oriented seismic lines and seven E-W-oriented seismic lines, AES-E3 field.

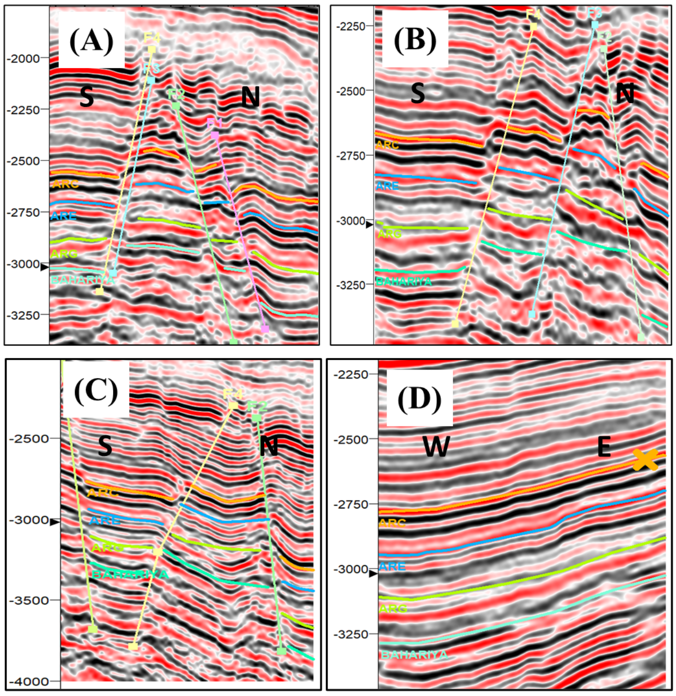

Figure 6: (A) Seismic line (1) showing N-S-oriented; (B) Seismic line (7) showing N-S-oriented; (C) Seismic line (13) showing N-S-oriented; (D) Seismic X line (9) showing E-W-oriented

The Bahariya Formation was classified to three zones (Bahariya upper, Bahariya middle and Bahariya lower) as a result of deep correlation between the studied wells: -

• Clear limestone body (good marker) between the Bahariya upper and middle zones

• Clear and clean sandstone body (good marker) between the Bahariya middle and lower zones

The difference in reservoir pressures between the Bahariya (upper, middle and lower) zones.

3.3. *Petro-physical and Lithological Results*

As a result of testing results for the wells in the field, the cut-off of net pay for the Bahariya reservoir considered as hydrocarbon bearing if shale volume less than 30% and effective porosity greater than 8%, and the saturation of water inside the zone is less than 60%

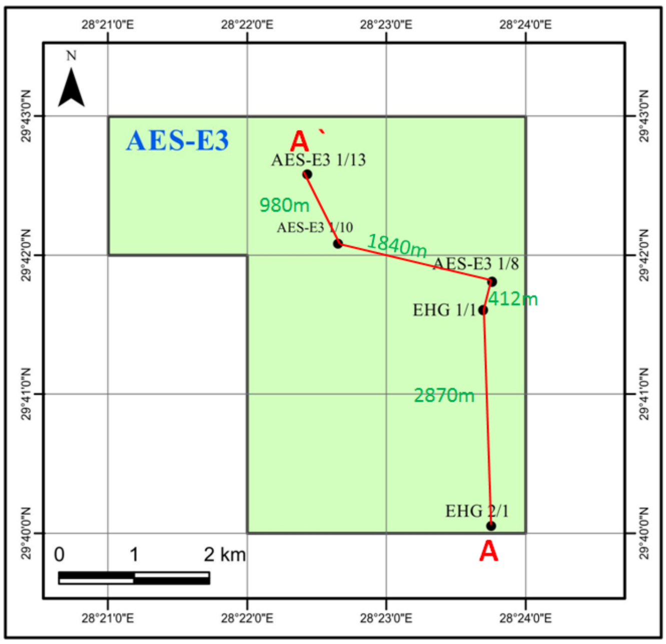

Figure 7: Location map showing the correlation direction (A-A') through EHG (2-1,1-1) and AES-E3 1-(8,10,13)

Table 1: Well log analysis of the Bahariya (upper, middle and lower) in AES-E3 field.

Well	Zones	Thick. (m)	Net Sand (m)	Net pay (m)	VSh %	PHIT	PHIE %	SW %	Shyd %
	Bahariya upper	83.27	18.50	12.50	0.25	0.15	0.11	0.33	0.67
AES-E3 1-8	Bahariya middle	118.55	35.00	21.00	0.20	0.13	0.10	0.29	0.71
	Bahariya lower	126.26	60.26	0	0.16	0.12	0.10	0.86	0.14
AES-E3 1-10	Bahariya upper	68.69	2.80	0.00	0.41	0.12	0.07	0.84	0.16
AES-E3 1-13	Bahariya upper	45.62	3.40	0.00	0.35	0.11	0.07	0.81	0.19
	Bahariya upper	80.97	7.5	0.00	0.41	0.16	0.09	0.92	0.08
EHG 2-1	Bahariya middle	108.40	22	0.00	0.39	0.10	0.06	0.84	0.16
	Bahariya lower	124.28	21	0.00	0.26	0.10	0.07	0.72	0.28
	Bahariya upper	82.49	15.80	15.8	0.33	0.13	0.08	0.37	0.63
EHG 1-1	Bahariya middle	116.68	21.90	16.70	0.12	0.15	0.13	0.24	0.76
	Bahariya lower	128.47	25.80	0	0.18	0.10	0.08	0.81	0.19

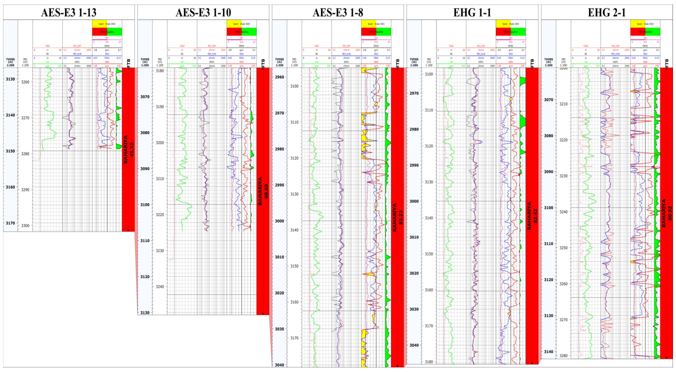

Figure 8: Stratigraphical correlation within EHG (2-1,1-1 and AES-E3 1-(8,10,13) through theBahariya upper

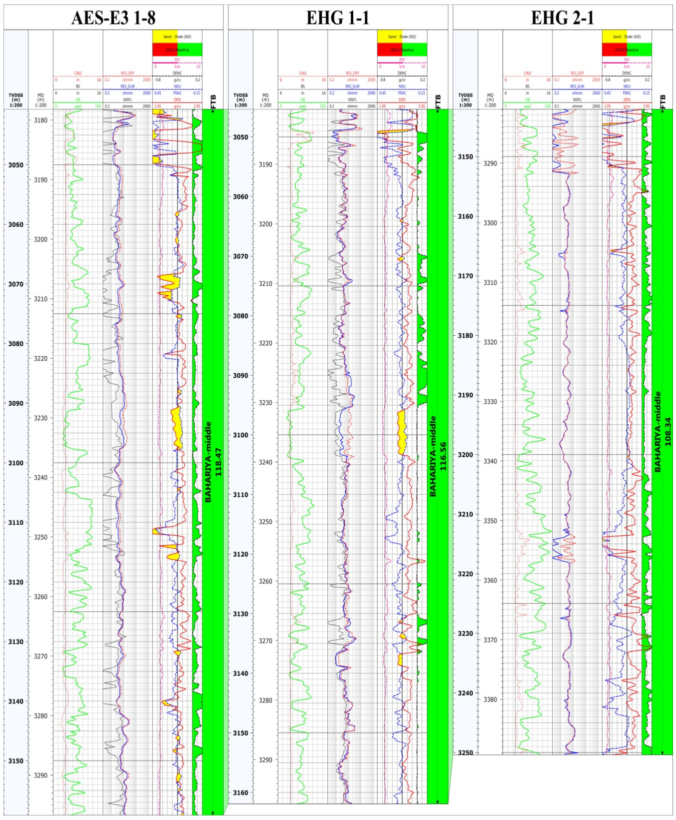

Figure 9: Stratigraphical correlation within EHG (2-1,1-1) and AES-E3 1-8 through the Bahariya middle

3.3.1. *Litho-Saturation cross plots of the Bahariya Upper Zone*

The analysis of the Bahariya upper reservoir in EHG 1-1 well is represented in Figure (11) the analysis reflects that the predominance of shale interbedded with sandstone streaks and thin lamina of limestone. The effective porosity is 8%. The fluid analysis indicates that 15.8m sand net pay with hydrocarbon saturation 63%. So, the potentiality is expected from sandstones zones within the formation

The analysis of of the Bahariya upper reservoir in EHG 2-1 well. It's mainly composed of shale and sandstone. Effective porosity is 9 %. The fluid analysis indicates that 7.5 m sand with water saturation 92%. Therefore, no potentiality is expected from the zones of sandstones

In AES-E1 1-8 well, the Bahariya upper reservoir is composed of an intercalation of shale and limestone thin layers are intercalated while the sand stone are represented by (18.5m) where the fluid analysis indicate that net pay is 12.5 with hydro-

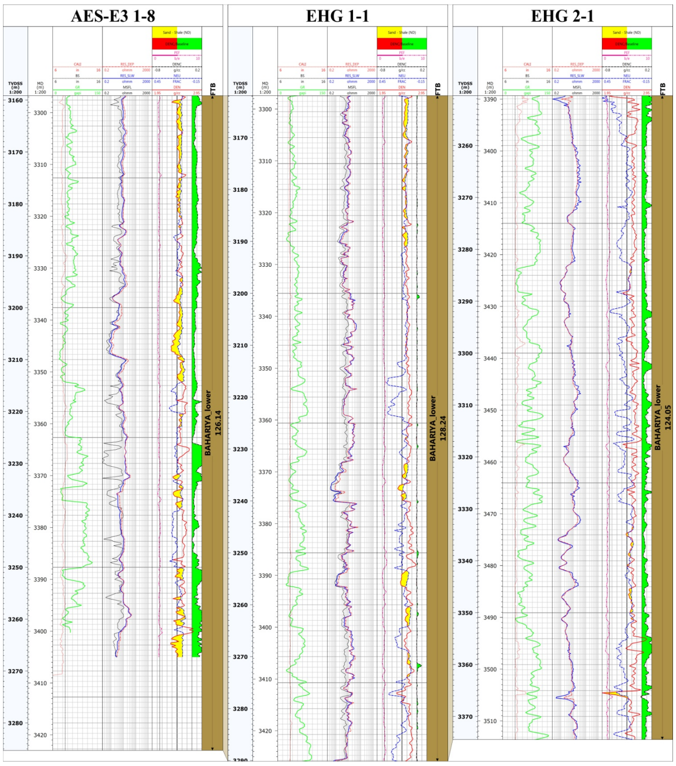

Figure 10: Stratigraphical correlation within EHG (2-1,1-1) and AES-E3 1-8 through the Bahariya lower

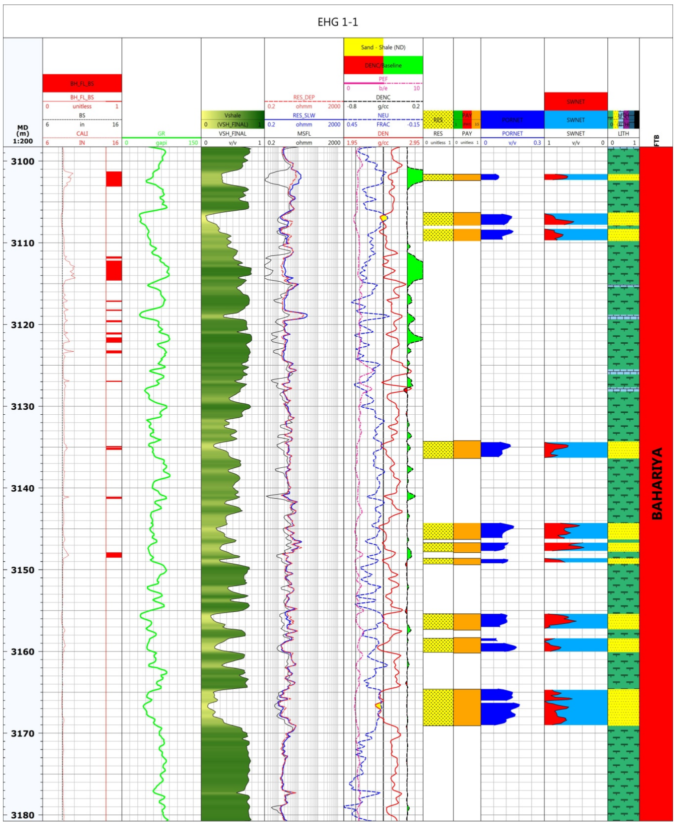

Figure 11: Petrophysical and lithology vertical distribution results for theBahariya Upper reservoir in EHG 1-1 well.

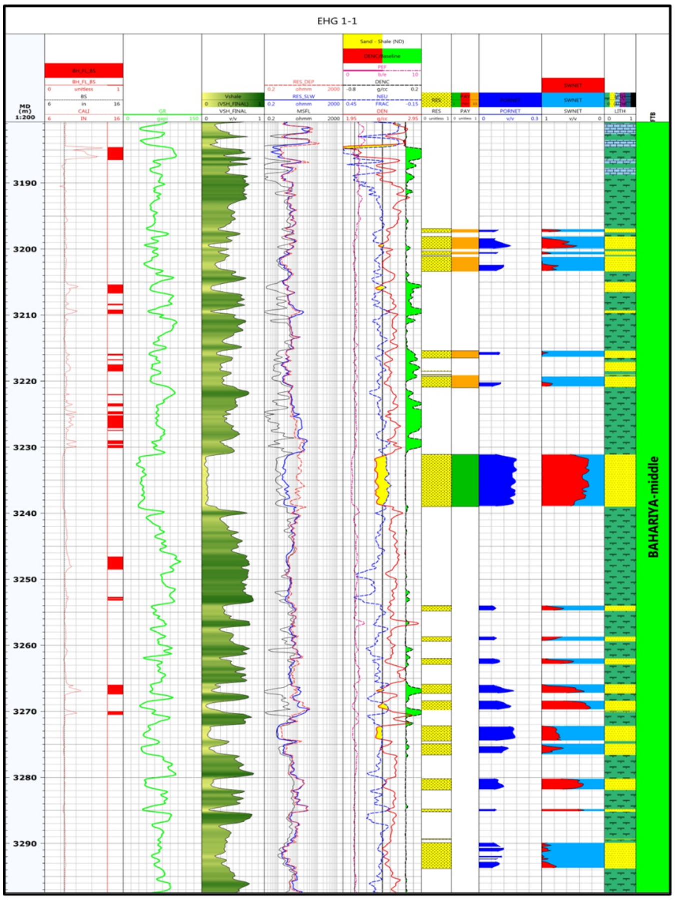

Figure 12: Petrophysical and lithology vertical distribution results for the Bahariya Middle reservoir in EHG 1-1 well.

carbon saturation increasing up to 67%. So, the production is expected from sandstones intervals in the zone.

The analysis of the Bahariya upper reservoir in AES-E1 1-10, it is composed of thin layers of shale and limestone with intercalation of sandstone with water saturation increasing up to 84%. So, no productivity is expected from zones of sand stones in the formation.

The analysis of the Bahariya upper reservoir in AES-E1 1-13. It's characterized by shale and limestone while the sandstone with water saturation is 81%. Therefore, no productivity is expected from the central parts from the formation.

3.3.2. *Litho-Saturation cross plots of the Bahariya Middle Zone*

The analysis of the Bahariya middle reservoir in EHG 1-1 well is represented in Figure (12) the analysis reflects that the predominance of shale in-

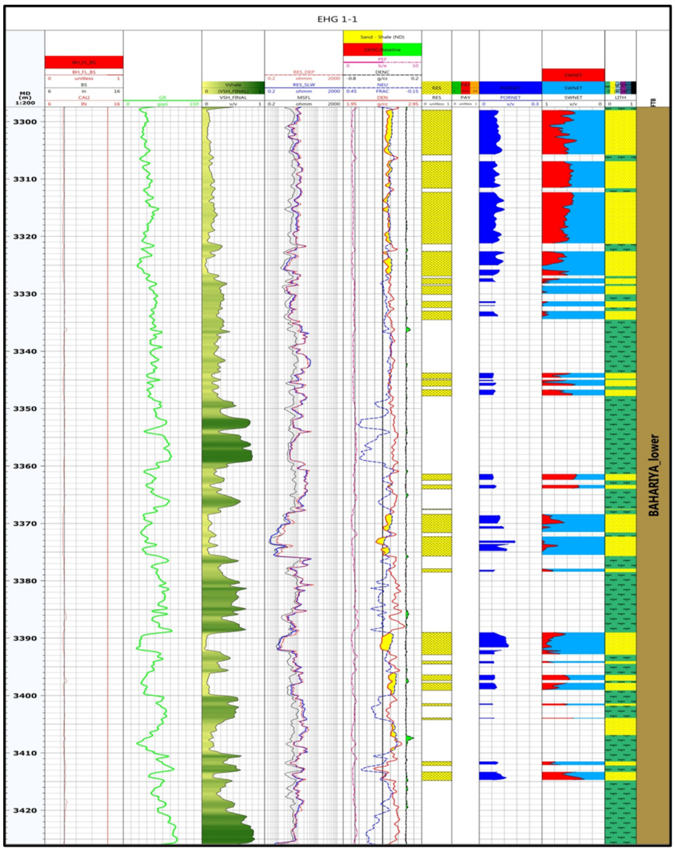

Figure 13: Petrophysical and lithology vertical distribution results for theBahariya Lower reservoir in EHG 1-1 well.

terbedded with sandstone streaks and thin lamina of limestone. The effective porosity is 13 %. The fluid analysis indicates that 16.7 m sand net pay with hydrocarbon saturation 76 %. So, the potentiality is expected from sandstones zones within the formation

The analysis of the Bahariya middle reservoir in EHG 2-1 well. It's mainly composed of shale and sandstone. effective porosity is 10%. The fluid analysis indicates that 22m sand with water saturation 85%. Therefore, no potentiality is expected from the zones of sandstones

In AES-E1 1-8 well the Bahariya middle reservoir is composed of thin layers lamination of limestone and shale are intercalated while the sand stone are represented by (35 m) where the fluid analysis indicate that net pay is 21 with hydrocarbon saturation increasing up to 71%. So, the production is expected from expected from sandstones intervals in the zone.

3.3.3. *Litho-Saturation cross plots of the Bahariya Lower Zone*

The analysis of the Bahariya lower reservoir in EHG 1-1 well is represented in Figure (13) the analysis reflects that the predominance of shale interbedded with sandstone streaks and thin lamina of limestone. The effective porosity is 8%. The fluid analysis indicates that 25.8m sand with water saturation 81 %. Therefore, no potentiality is expected from the zones of sandstones.

The analysis of the Bahariya lower reservoir in EHG 2-1 well. It's mainly composed of shale and sandstone. Which has an effective porosity equals 7%. The fluid analysis indicates that 21m sand with water saturation 72%. Therefore, no potentiality is expected from the sandstone zones.

In AES-E1 1-8 well the Bahariya lower reservoir is composed of thin layers lamination of lime stone and shale are intercalated while the sand stone are represented by (60.2m) with water saturation increasing up to 86%. Therefore, no potentiality is expected from the zones of sandstones.

4. Conclusion

Five well logs EHG (2-1 ,1-1), AES-E3 1-(8,10,13) and twenty depth seismic lines in AES-E3 field at East Alam El-Shawish area have been analyzed and mapped using the Petrel and Tech Log software, to determine the lithology and fluid saturations for the Bahariya reservoirs. Maps from seismic data were used to explain the impact of geological structure on the development of the area. The interpretation of seismic lines clarifies the Bahariya reservoir structures, as shown by seismic sections, create a tilted- fault block dissecting the area into deferent segments. The main structures in AES-E3 field are shown by faulted two - three-way dip closure confined by some of normal faults (horst, graben and half graben). Qualitative interpretation of resistivity, gamma ray, neutron, density logs shows that the Bahariya upper is hydrocarbon saturated in EHG1-1 and AES-E3 1-8 while water saturated at EHG2-1, AES-E3 1-(10, 13). The Bahariya middle is hydrocarbon saturated in EHG1-1 and AES-E3 1-8 while water saturated at EHG2-1. The Bahariya lower are water saturated for all wells.

AES-E3 field has high porosity and hydrocarbon saturation values due to the extensive fracturing caused by normal faults. This was supported by the high structural position, good porosity, low shale content, low water saturation and a high percentage of hydrocarbon saturation. The current outcomes encourage drilling more development and appraisal wells in the central parts and the southeast parts of the study area to enhance productivity in AES-E3 field.

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