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Integratred Characterization Of Desouqy Reservoir Rock In Faghur – Siwa Basin, Western-Desert, Egypt

Abd-El-Gawad*, E. A., M. Fathy*, Abd-El-Dayem, Kh.**

* Geology Department, Faculty of Science, Al-Azhar University
**Egyptian General Petroleum Corporation.

Abstract

The main aim of this study is to evaluate the reservoir rock in Faghur-Siwa basin through the subsurface geological studies. These were achieved to illustrate thickness variation, lithofacies changes and structural elements affecting the area. The evaluation of the different reservoir parameters characterizing the pay zone from well log data was accomplished to spot lighting on the promising locations for other further exploration.

1. Introduction

The area under study deals with Faghur - Siwa basin oil field. It lies between Latitudes 25°00', 30°00' N and Longitudes 25°00' – 27°00' E (Fig.1). Faghur-Siwa basin is a north-south oriented Paleozoic basin covered wide stretches in the north western reaches of the Western Desert and can be considered as a northern extension of Libya's Kufra Paleozoic basin. The Faghur-Siwa basin represents continental sag, craton interior basin, contains thick Paleogoic sequences, ranging from Cambro-Ordovician to Carboniferous. Hydrocarbon source potential is suggested by some authors within limestones and shales of Carboniferous and Devonian. Recent discoveries in the Umbaraka area to the east are adjacent to, and probably charged from, updipping Paleozoic potential sources in the Faghur-Siwa basin **(Schlumberger, 1995)**.

2. Stratigraphic Framework of the Western Desert

The 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).

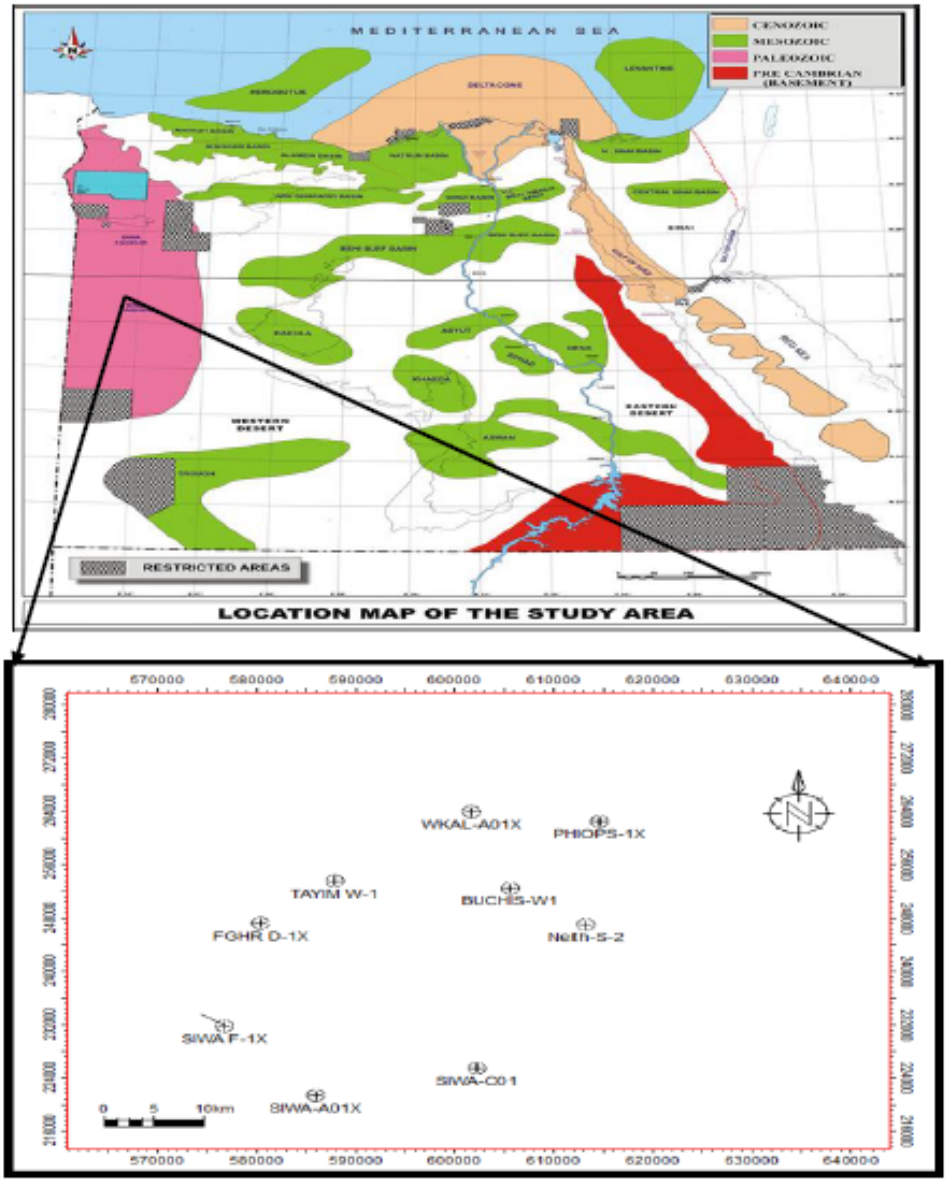

Fig. (1): Location map of the study area showing the location of the drilled wells in Faghur - Siwa Basin, North Western Desert, Egypt.

The total thickness, despite some anomalies, increases progressively to the north and northeast from about 6000 ft. in the southern reaches to about 25,000 ft. along the coastal area. The sedimentary section of the Western Desert ranges from Lower Paleozoic to Resent. According to **Said (1990)** four major sedimentary cycles occurred with comparable maximum southward transgression during the

Carboniferous, Upper Jurassic, Middle and Late Cretaceous and Pliocene ages' times. Also, maximum north word regressive phases occurred during Permo- Triassic and Early Jurassic and continued in the Early Cretaceous and again in the Late Eocene to Oligocene with final phase in the Late Miocene time.

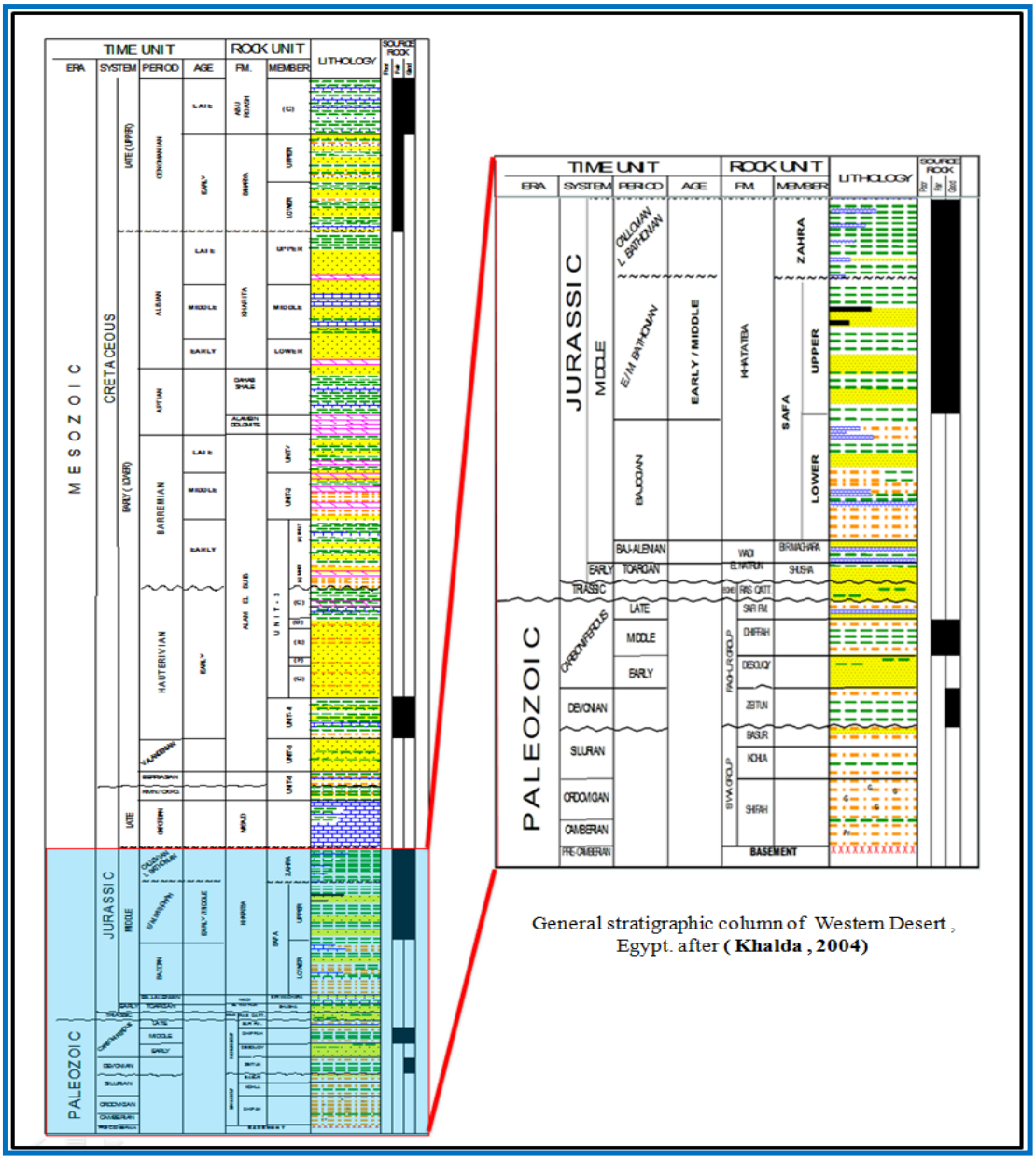

Fig. (2): Generalized stratigraphic column of the North Western Desert, **(Khalda, 2004)**

EGPC (1992) classified subsurface lithostratigraphic column of the north Western Desert into five cycles from base to top as follows:

- A cycle of clastic facies dominates the oldest sedimentary rocks and includes the entire Paleozoic and Lower Jurassic formations.
- A carbonate section of middle and Upper Jurassic formations.
- A cycle of clastics comprises the Lower Cretaceous up to the Upper Cretaceous (Early Cenomanian).
- From Upper Cenomanian and Upper to the Middle Eocene, carbonate deposits are again distributed throughout northern Western Desert.
- The upper most clastic depositional cycle includes the Upper Eocene-Oligocene, Miocene and younger section.

3. Methodology

The studied oil field will be investigated using available data in nine representative wells, for the purpose of evaluation the Desouqy reservoir .These wells are: (Phiops-1X, Faghur D-1X, Siwa A-1X, Siwa C-1X, Siwa F-1X, Wkal A-1X, Buchis W-1X, Tayim W-1X, Neith S-2) (Fig. 1).

4. Petrophysical analysis

4.1 M-N Cross-plot:

Lithology interpretation with neutron, density, and sonic logs is facilitated by the use of M-N plots. This plot was first introduced by **Bruke et al., (1969)**. It combines the data of all three porosity logs to provide the lithology-dependent quantities, M and N, which are essentially independent of primary porosity. Therefore a cross-plot of these two quantities makes lithology characteristics be more apparent.

M and N are defined as:

$$M = (\Delta t_f - \Delta t) / (\rho b - \rho b_f) \times 0.01 \quad \textbf{(1)}$$

$$N = (\phi_{nf} - \phi n) / (\rho b - \rho b_f) \quad \textbf{(2)}$$

Where;

$\Delta t_{f:}$ Interval transit time of the mud fluid. Δt: Sonic log reading.

$\phi_{nf:}$ Neutron of mud fluid. ϕ_n: Neutron log reading.

ρb_f : Density of mud fluid. ρb : Density of mud fluid.

Quartz, limestone and dolomite are the three standard minerals composing the rock units. The tabulated values of M are plotted vs. N to generate the M-N plot used for mineral identifications. The place to which the plotted points are directed depends on the different amount of matrix components they contain. If it is monomineral, it will fall very close or exactly coincide on the corresponding standard points. If it has binary mixture, it will fall on the line connecting the two corresponding points. But if it has a mixture of three minerals, it will plot within the triangle formed by connecting the three respective single-mineral points.

The effect of secondary porosity, shaliness, and gas-filled porosity will shift the position of the points with respect to their true lithology, and can even cause the M-N points to plot outside the triangular area defined by the primary mineral constituents. The displacement of the plotted points upward indicates secondary porosity while the effect of gas may shift the points to upwards on the right. No unique shale point exits on the M-N plot because shales tend to vary in their characteristics. Mostly, shale effect will be situated below the line that joins the silica and anhydrite points **(Bigelow, 1995)**.

Some distortion of scattered points have been recognized on M-N graphs in that may be due to the presence of radioactive elements and organic matters which cases some deflections on sonic readings which affect the M-N graphs and make such these distortions **(Schlumberger 1972).** Figure (3) show the mineralogical composition of **Desouqy** reservoir. The major of the plotted points are scattered to fill the space between sandstone and

limestone points but tend to be near to sandstone point more than limestone one. This may indicates the presence of mixed sandstone and limestone lithology. The effect of secondary porosity appears in shifting of some points upwards. 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 average value is about 42%. Also the effect of gas appears in shifting the scattered points in the upright corner of the diagram.

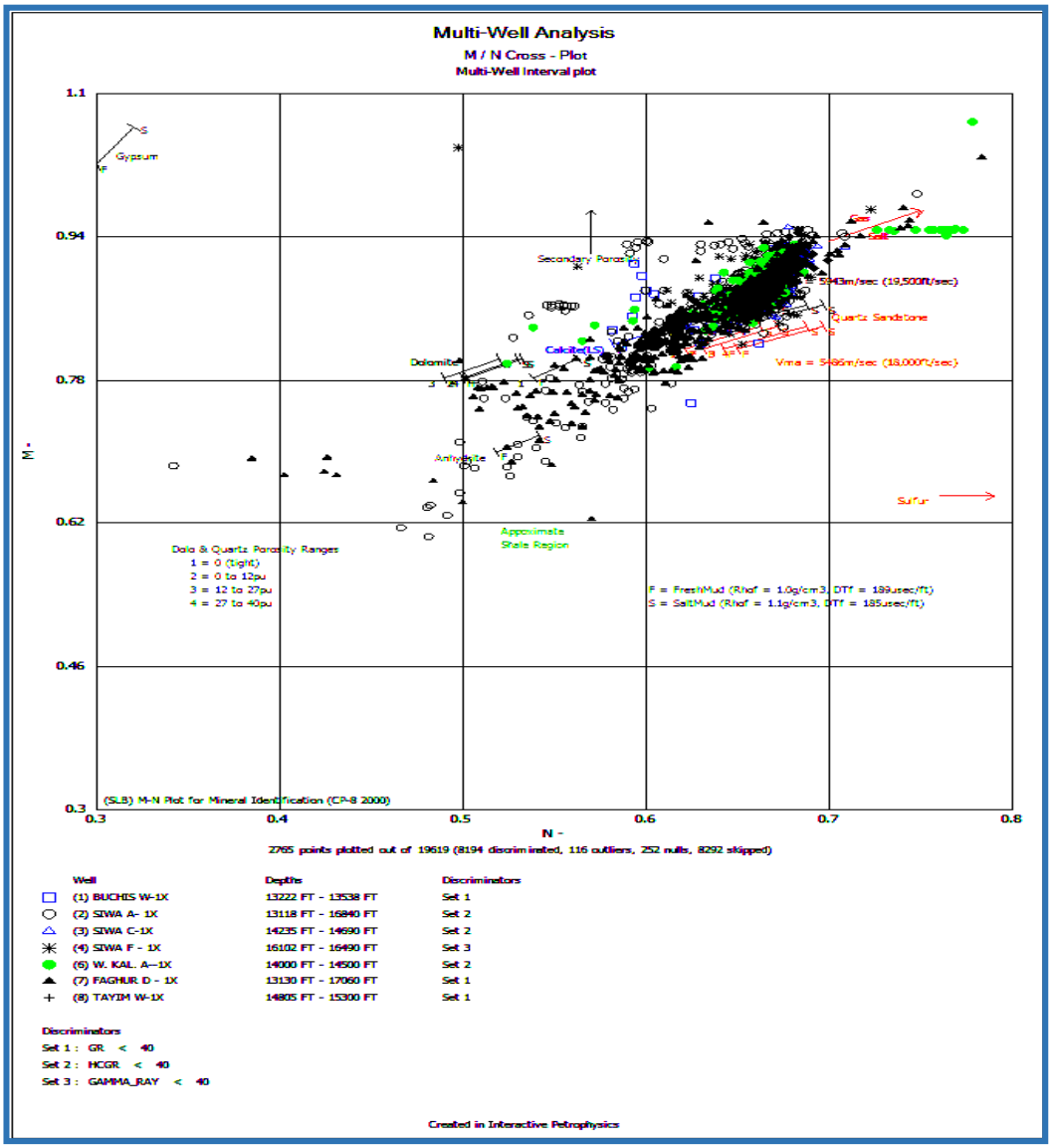

Fig. (3): M-N cross-plot of Desouqy reservoir, in Faghur- Siwa Basin.

4.2 Dia Porosity Cross-plot:

Figure (4) shows the neutron-density cross-plot of **Desouqy** reservoir, the reservoir rocks scattered in sandstone area with slight change toward the limestone area in wells FAGHUR D-1X and TAYIM W-1X, the porosity ranges from 3 to 14%, the maximum recorded in the southwest and the central part directions where BUCHIS W-1X well is present, while the minimum recorded porosity in FAGHUR D-1X and TAYIM W-1X wells in the northeast directions.

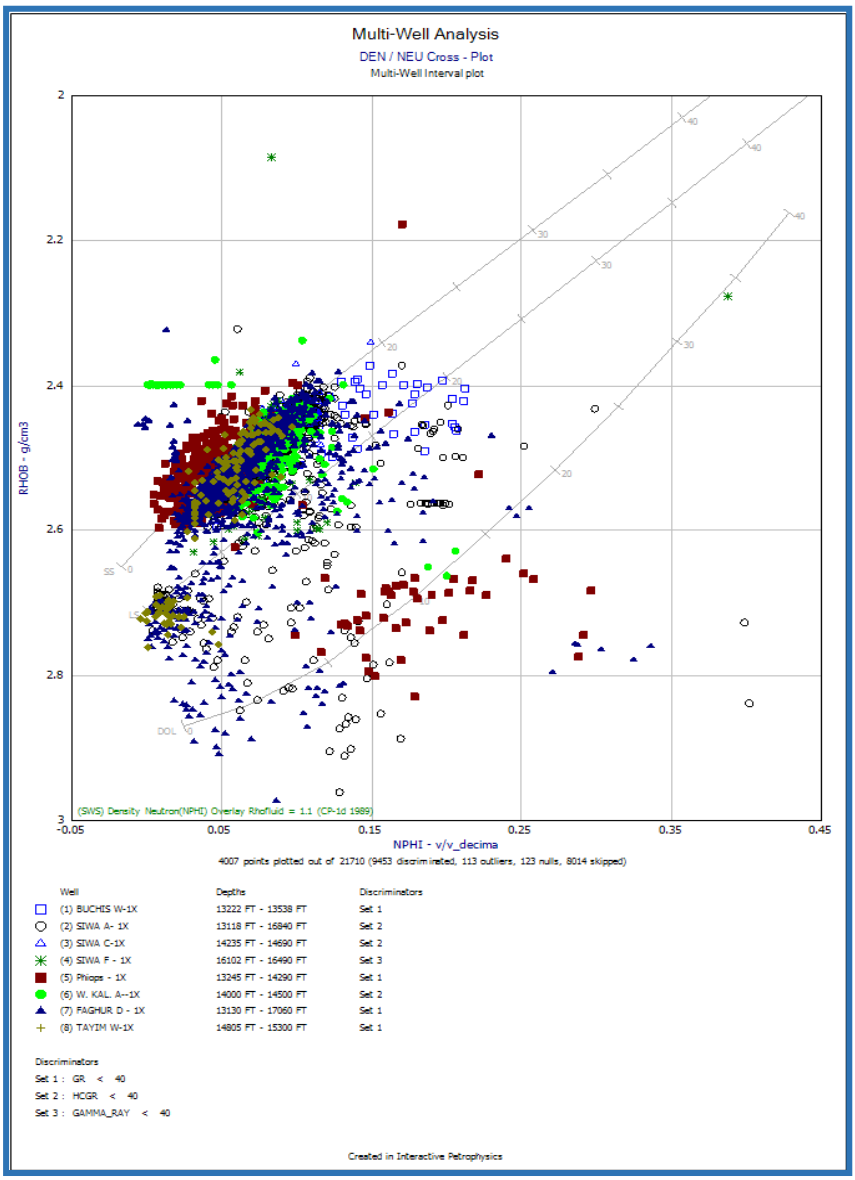

Fig. (4) Density neutron cross-plot of **Desouqy** reservoir, in Faghur- Siwa Basin.

4.3 Reservoir pressure measurement:

The repeat formation tester (RFT) is an open hole logs used for measuring vertical pressure distribution in a reservoir, the technique of point-by-point evaluation of reservoir pressure is used to determine pressure profiles, fluid density, fluid contacts, differential depletion and reservoir intercommunication. RFT is a device capable of providing an estimate of formation permeability through the interpretation of pretest pressure data record during drawdown and build up (**Stewart and Wittmann, 1979**). Reservoir pressure is necessary to have knowledge of the driving mechanisms that control the behavior of fluids within reservoirs.

Cole (1969) suggested that a depletion-drive reservoir can be identified by reservoir pressure: The reservoir pressure declines rapidly and continuously. This reservoir pressure behavior is attributed to the fact that no extraneous fluids or gas caps are available to provide a replacement of the gas and oil withdrawals.

Cole (1969) and Clark (1969) presented a comprehensive review of the reservoir pressure characteristic trend associated with gas-cap-drive reservoirs. The reservoir pressure falls slowly and continuously pressure tends to be maintained at a higher level than in a depletion drive reservoir. The degree of pressure maintenance depends upon the volume of gas in the gas cap compared to the oil volume.

Cole (1969) presented the following discussion on the reservoir pressure characteristic that can be used for identification of the water-driving mechanism. The reservoir pressure decline is usually very gradual. The reason for the small decline in reservoir pressure is that oil and gas withdrawals from the reservoir are replaced almost volume for volume by water encroaching into the oil zone.

Cole (1969) stated that reservoir operating largely under a gravity drainage producing mechanism are characterized by variable rates of pressure decline, depending principally upon the amount of gas conservation.

Besides the measurement of formation pressure, The RFT has found many applications in the field of reservoirs.

1) In exploration wells in unproductive fields, it is known that formation pressures must conform to gravity-capillary equilibrium established over geologic times. Thus the conduct of the RFT survey and the interpretation of the data are governed by the constraint that the formation pressure lie on straight line fluid gradients. The main objective of the testing is to delineate these gradients (water, oil and gas) and their intersections.

2) In development wells, either partial depletion or possible water injection may already affect the observed formation pressures. Thus the new development well is used as an observation location at which the current state of the reservoir can be measured on a vertically distributed basis.

A plot of formation pressure against depth can give valuable information of the reservoir, and it gives an indication of the nature of formation fluids (gas, oil, or water) as well as the position of the interfaces between different phases (gas-oil contact, oil-water contact) **(Stewart and wittmann, 1979).** It should be noted that the intercept of the pressure gradients, corresponding for instance to oil and water, is representative of the so-called free water level, it may thus be somewhat below the 100% water level, as indicated by logs, due to capillary pressure effects.

Figures (5 and 6) The RFT data of Desouqy reservoir shows that the water gradient (0.5 psi/ft.) in Faghur deep-1x. Also RFT data indicates a probable oil water contact at 13865 ft. TVDSS. The reservoir pressure decline of Desouqy is usually very gradual, so it is considered as active water drive reservoir.

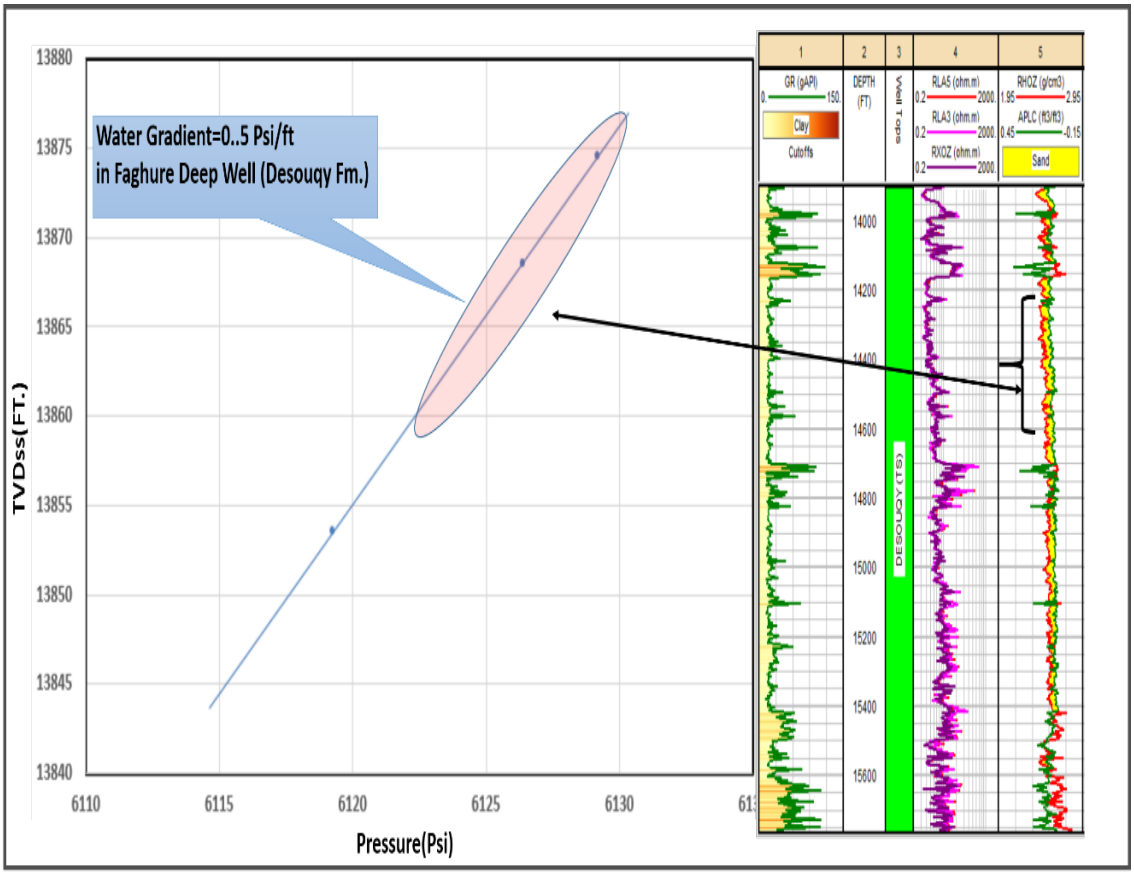

Fig. (5) Analysis of Desouqy reservoir pressure data (RFT), in Faghur deep well.

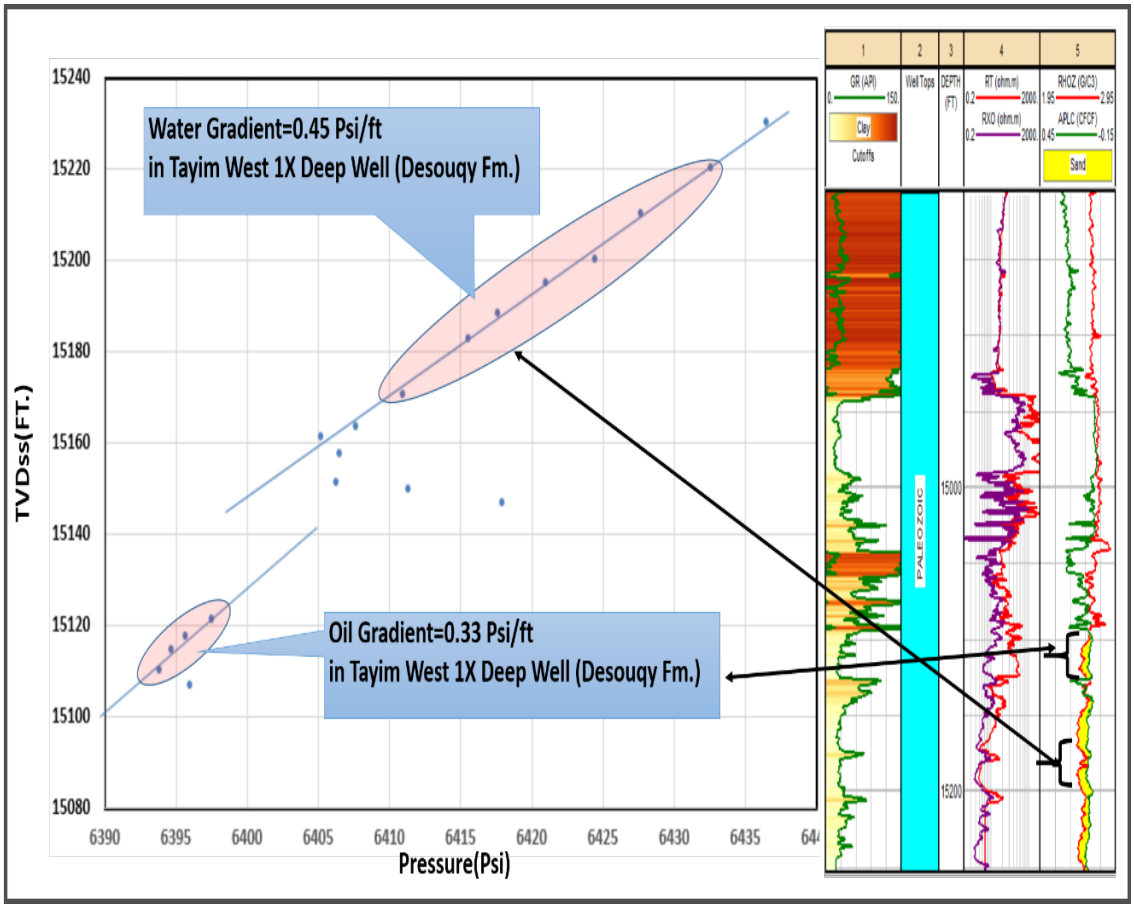

Fig. (6) Analysis of Desouqy reservoir pressure data (RFT), in Tayim west1x well.

4.4 Lateral Variation of Petrophysical Characteristics of Desouqy Reservoir

4.4.1 Shale volume

The shale volume distribution map for Desouqy reservoir shows that it increases toward the west and the south directions; which related to the facies distribution where it affected by the transgression system tract (TST); it reaches the maximum value (7%) at SIWA C-1X and BUCHIS W-1X wells, while the porosity decreases in the west direction.

The Shale volume decreases towards the northeast and the central part to reach (4%) as a minimum value at NEITH S-2, TAYIM W-1X wells; due to low stand system tract (LST) (Fig. 7).

4.4.2 Net pay

The net pay distribution map shows an increasing toward the northeast and the central part directions. It reaches the maximum value (47ft) at PHIOPS-1X and TAYIM W-1X wells while it shows observed decreasing toward the west and the south directions to reach zero value SIWA A-1X, SIWA C-1X, and BUCHIS W-1X wells as illustrated in (Fig. 8), where the water saturation and the shale volume increase in the northwest and southeast directions.

4.4.3 Effective porosity

The effective porosity distribution map for Desouqy reservoir in On the other hand, the porosity decreases towards the west direction to reach (0%) as a minimum value at Neithe-2 and PHIOPS-1X wells (Fig.9). Cross-section is showing the effective porosity ranges between (4- 10%) at trend NNE-SSW.

4.4.4 Water saturation

The water saturation distribution map for Desouqy reservoir in Faghur- Siwa Basin shows that it increases toward the northwest and the southeast directions, which related to the structural control that formed graben between (Fault “5” & Fault “6”), where it reaches the maximum value (99%) in SIWA A-1X, SIWA F-1X, SIWA C-1X and BUCHIS W-1X wells. While it reaches the minimum value (26 %) toward the northeast and the central part directions in both PHIOPS-1X and TAYIM W-1X wells

(Fig. 10), where the hydrocarbon increases in the northeast and the central part directions.

4.4.5 Hydrocarbon saturation

The movable hydrocarbon saturation map distribution shows an increasing toward the northeast and the central part directions, which related to structural control (Step faults) and facies distribution. It reaches the maximum value (60%) at PHIOPS-1X well. It shows observed decreasing toward the south, east and north directions with minimum value (0%) at SIWA A-1X, SIWA C-1X and SIWA F-1X wells as illustrated in (Fig. 11), where the water saturation decreases in the northeast and the central part directions.

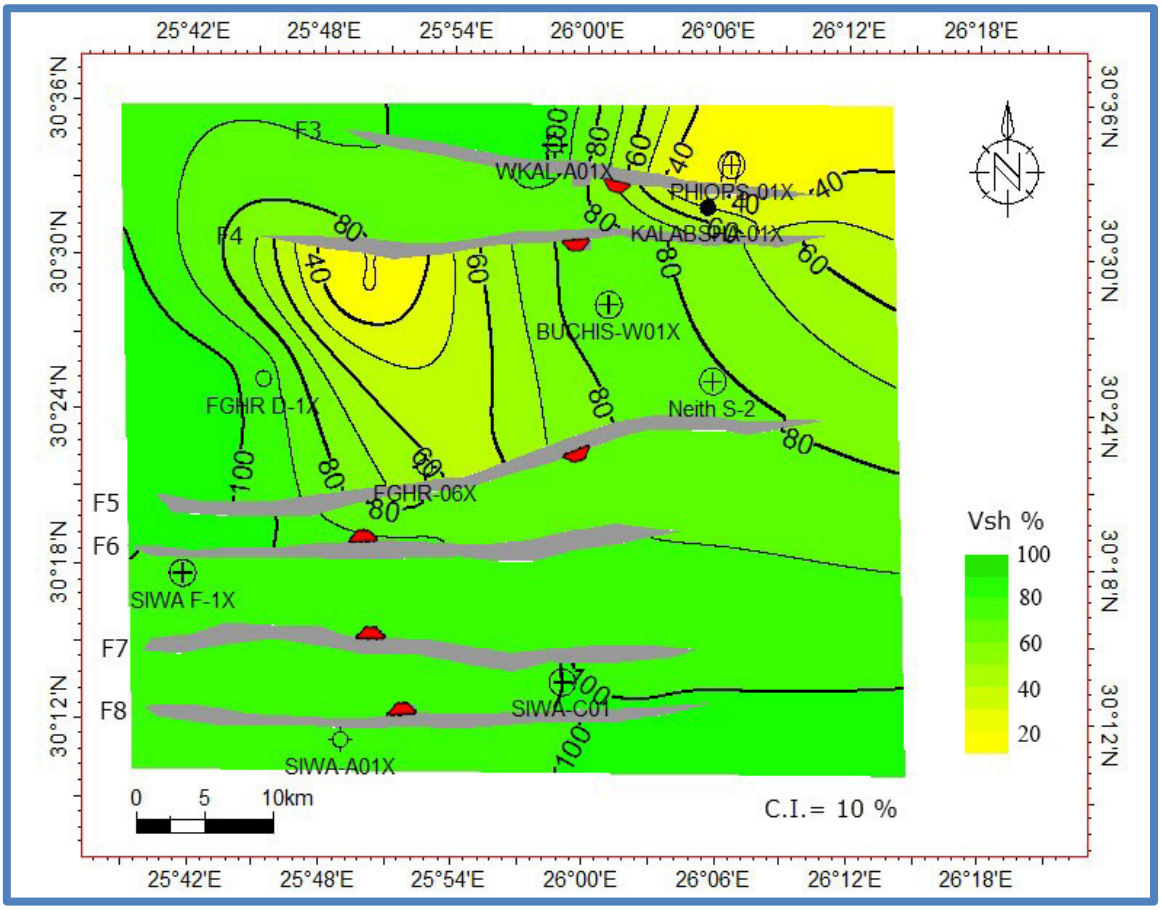

Fig. (7) Shale volume map of **Desouqy** reservoir in Faghur-Siwa Basin.

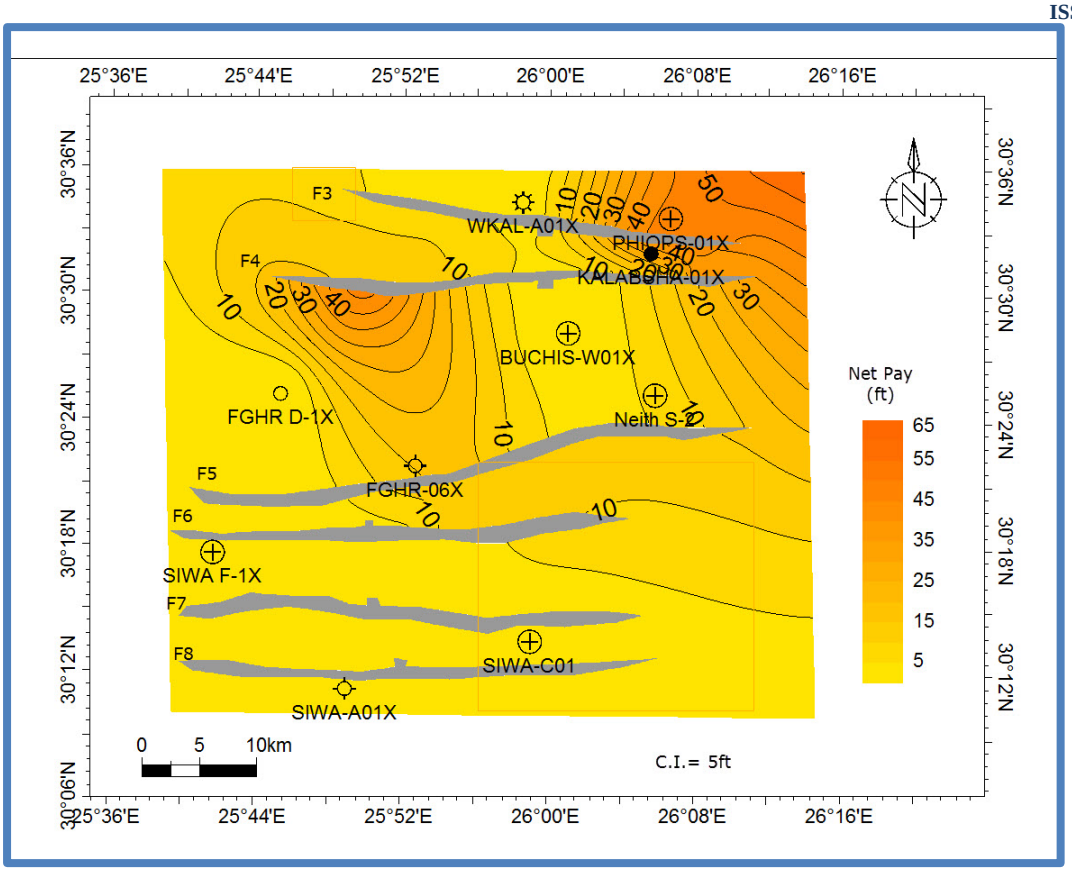

Fig. (8) Net pay map of **Desouqy** reservoir in Faghur-Siwa Basin.

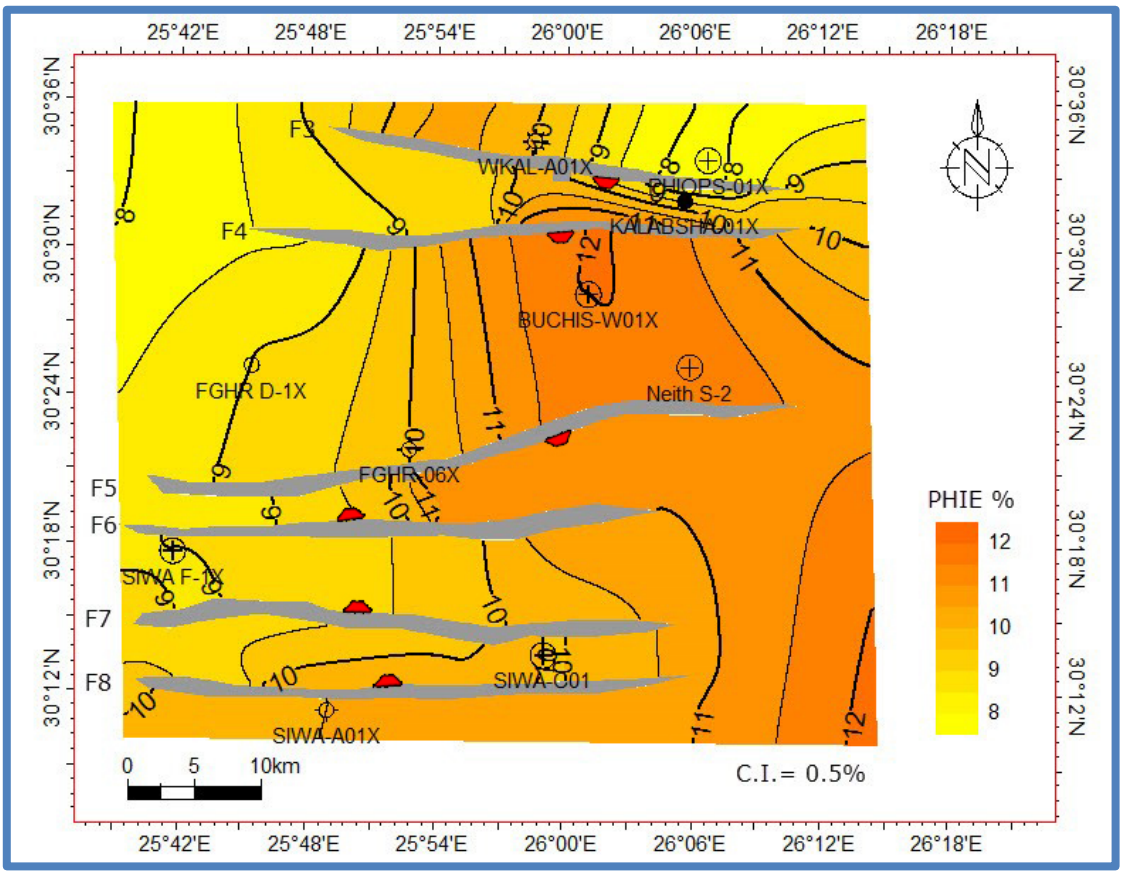

Fig. (9) Effective porosity map of Desouqy reservoir in Faghur Siwa Basin.

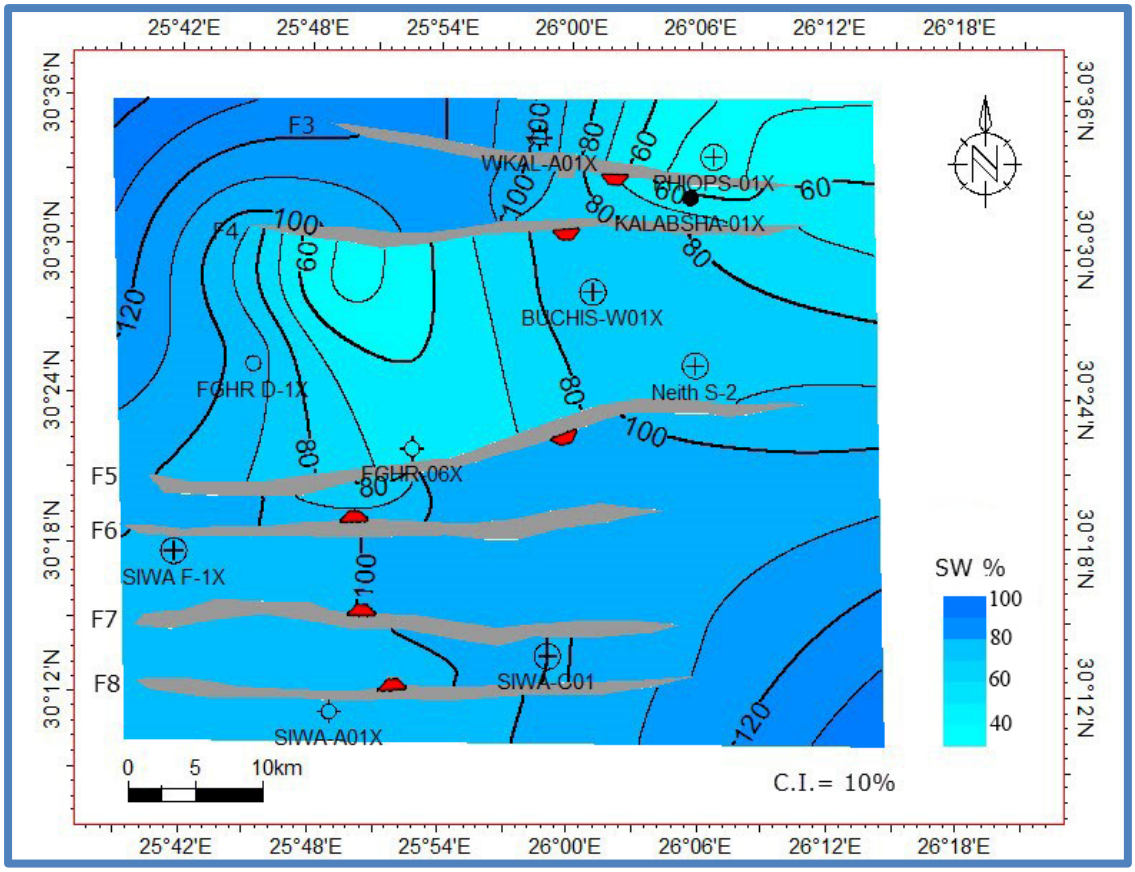

Figure (10) Water saturation map of Desouqy reservoir in Faghur Siwa Basin.

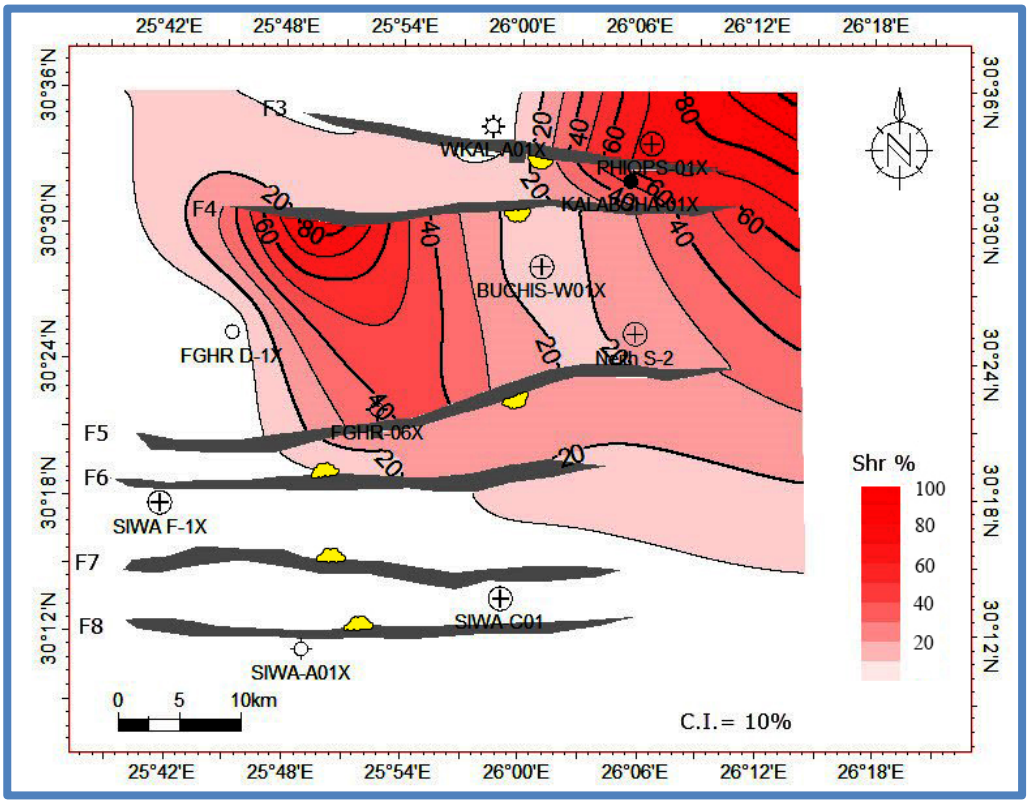

Fig. (11) Movable Hydrocarbon saturation map of Desouqy reservoir in Faghur-Siwa Basin.

4.5 Vertical Variation of Petrophysical Characteristics

Figure (12) shows that the vertical distribution of hydrocarbon occurrences can be explained and presented through the construction of the litho-saturation cross-plots. Litho-saturation cross-plot is a representation, zone-wise, for the content of fluids and rocks with depth through the studied well. The contents of rocks include shale and matrix, while the contents of fluids include water and hydrocarbon saturation. The litho-saturation cross-plots of Desouqy Formation show that .The shale content ranges between (4%-7%), and the effective porosity ranges between (7%-12%),

While the hydrocarbon saturation is about (73%) in Phiops and Tayim wells only where the structure is high. That related to Caledonian cycle that led to uplift and widespread erosion.

4.5.1 Correlation Charts

The aim of correlation chart is to follow the changes in lithologic characters or any break in the depositional continuity. It shows the equivalency of stratigraphic units, and to exhibit thickness variation.

The first correlation chart (A-A') extends in N-W directions and passing through Wkal-A1X, Tayim W-1 and Faghur D- 1x wells (Fig. 13). The correlation chart shows that the Safa S1 unit has a great thickness in Tayim W- 1wll more than the other wells, the Safa R1 reservoir is a thin layer has a little thickness and pinched out at Tayim W-1 and Wkal-A1X wells, but has thick layer in Faghur D- 1x well.

The second correlation chart (C-C') extends in W-E directions and passing through Tayim W-1, Buchis W-1 and Neith S-2 wells (Fig. 14). The correlation chart shows that the Safa S1 unit has a great thickness in Tayim W- 1well more than the other wells, the Safa R1 reservoir is a thin layer has a little thickness and pinched out at Tayim W-1well.

The Paleozoic Dhiffah S1 source rock has a large thickness in Neith S-2 well reduced and abrupt in Buchis W-1 well. The Paleozoic Desouqy R1 has continuity through this section but with great variety in thickness. The Paleozoic Zeitoun S1

source rock appeared with different thickness in only two wells (Buchis W-1 and Neith S-2 wells) at the east direction.

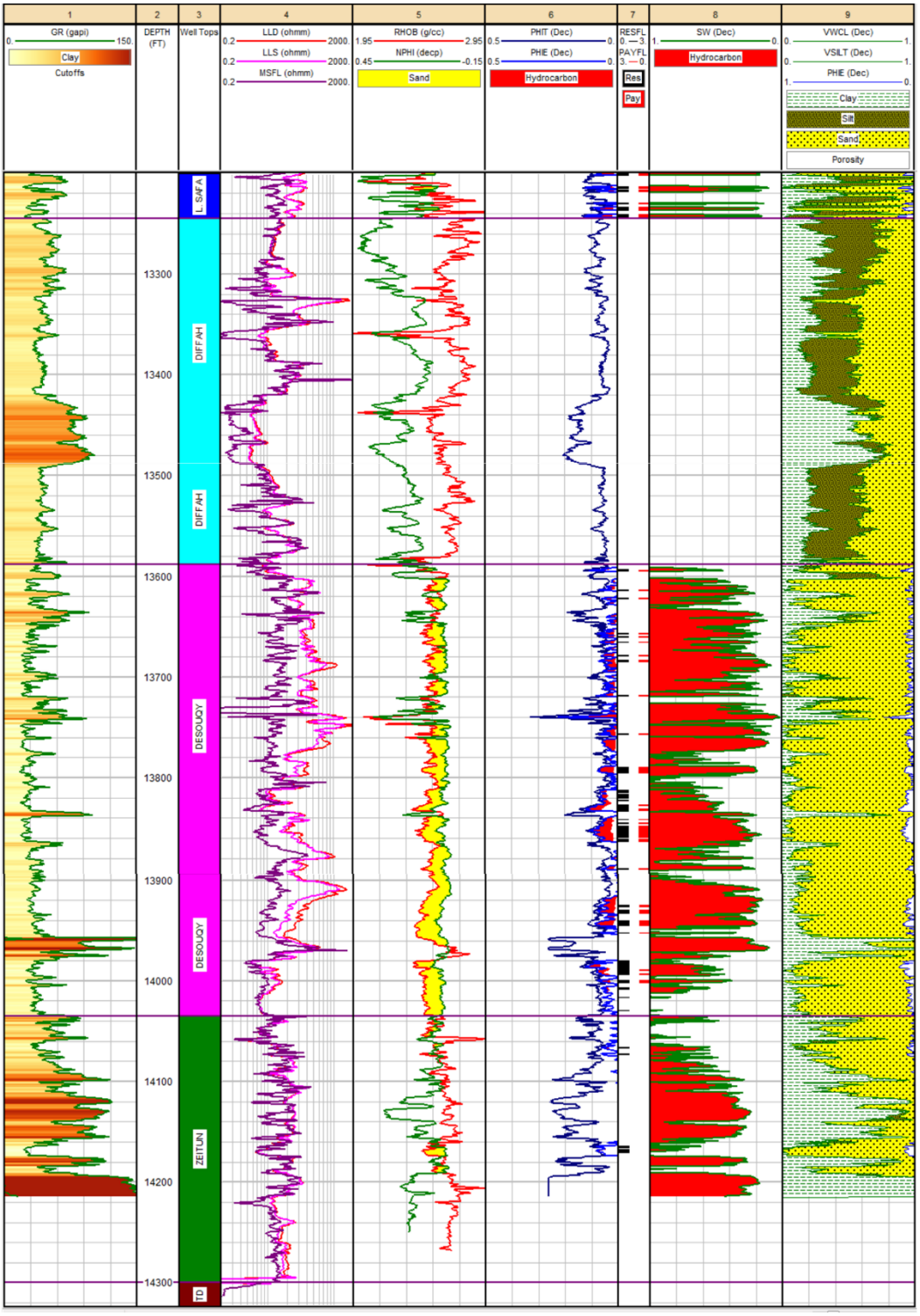

Fig. (12): Computer processed interpretation (CPI) plot for Desouqy reservoir in Faghur-Siwa Basin.

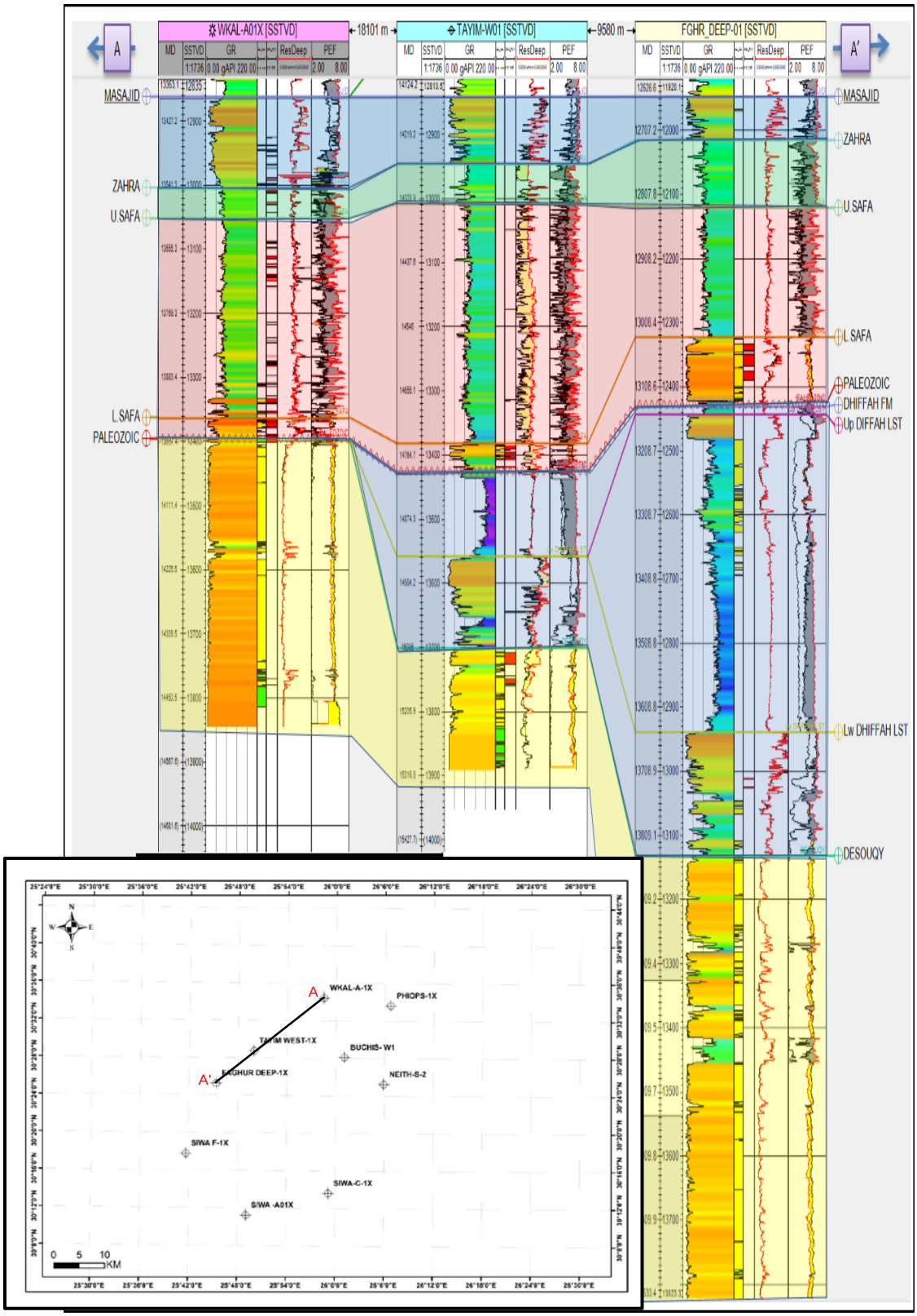

Fig. (13) Correlation chart along the profile (A-A')

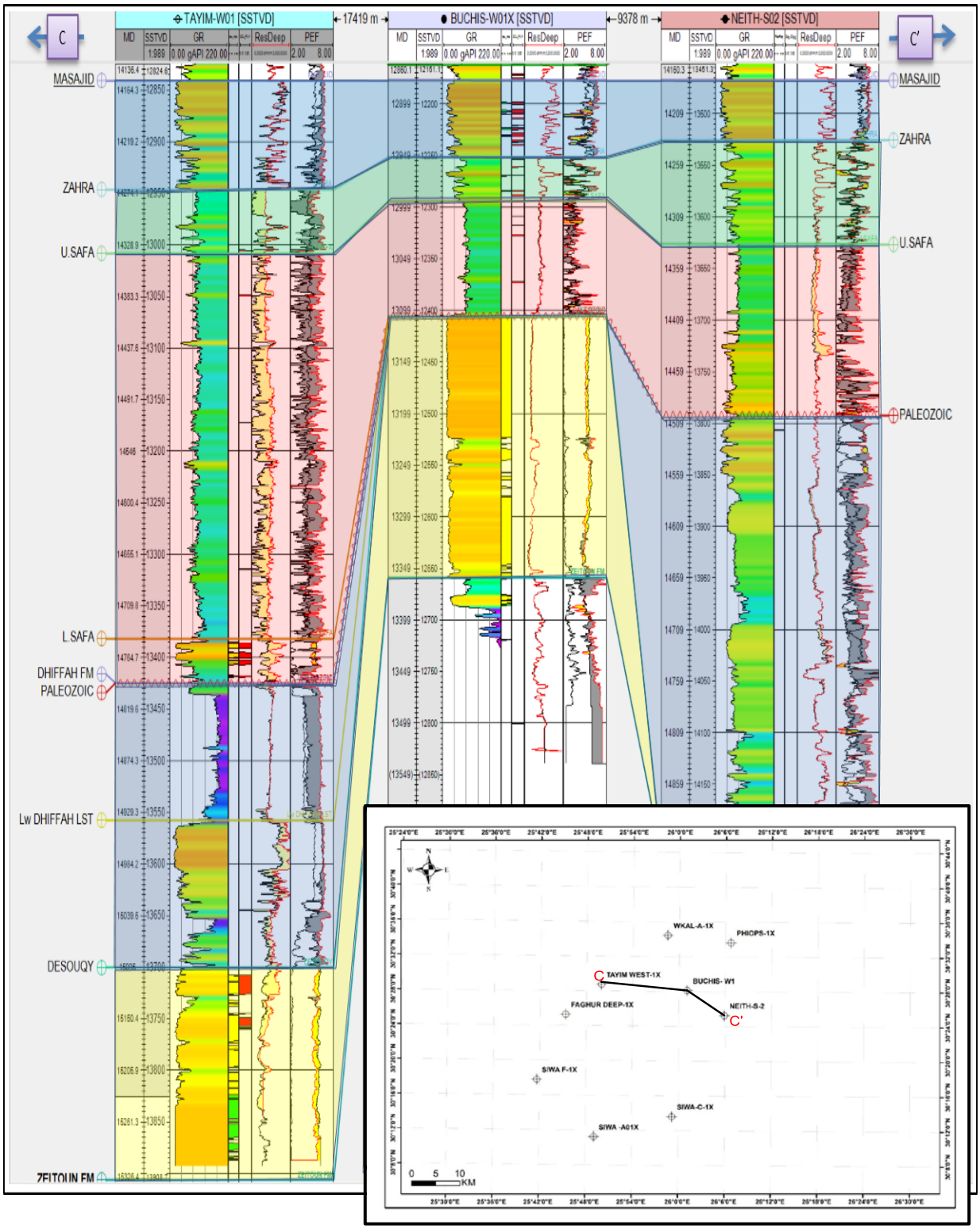

Fig. (14) Correlation chart along the profile (C-C')

4.6 Structural map on the top of Desouqy Formation

The time reflection map delineated on the top of the Carboniferous age. Figure (15) reveals an irregular distribution pattern with maximum value of 2800 msec (structurally low), at the southeastern parts of the study area. On the other hand, the time decreases on the uplifted footwall of the faults on the area recording values 1800 msec (structurally high) at the western part of the study area. The basin trend at both the southeastern and the northeastern parts while platform at the southern part of study area. The major strikes NE- SW and E-W, this group during (Cambrian-Devonian) related to Caledonian to (Turonian- Santonian) related to Sub-Hercynian - Early Syrian Arc. After the Variscan event that led to uplift and widespread erosion that were associated with the Caledonian phase during these times. This faults trend was emphasized in seismic section in (Fig. 16).

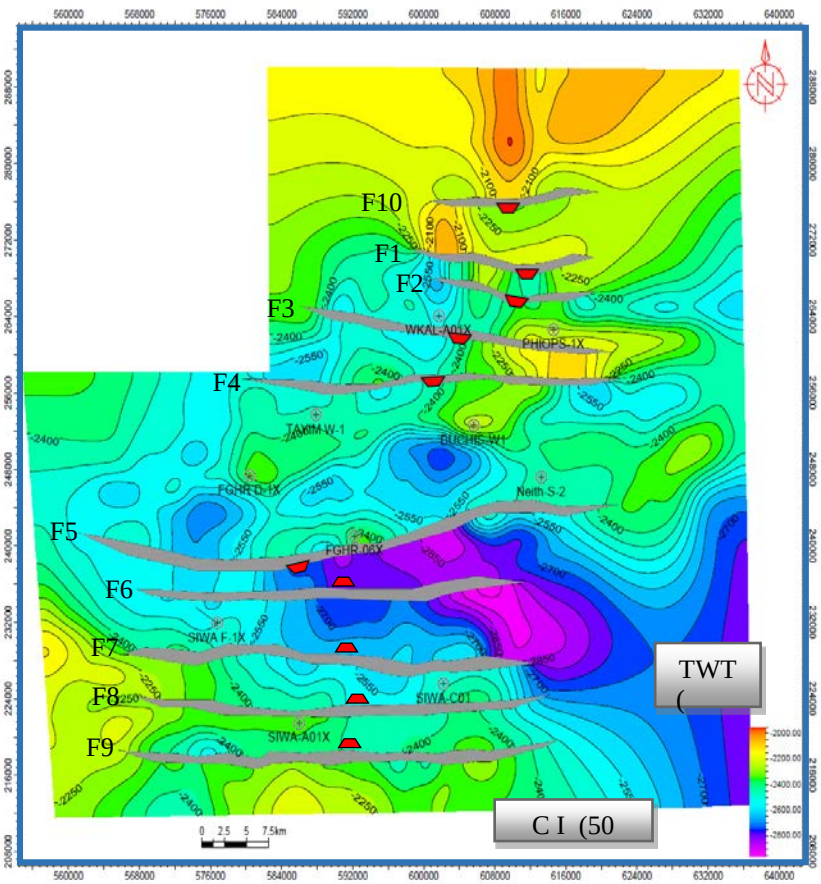

Fig. (15): Two-way time structural contour map on the top of Desouqy Formation in Faghur and Siwa basin.

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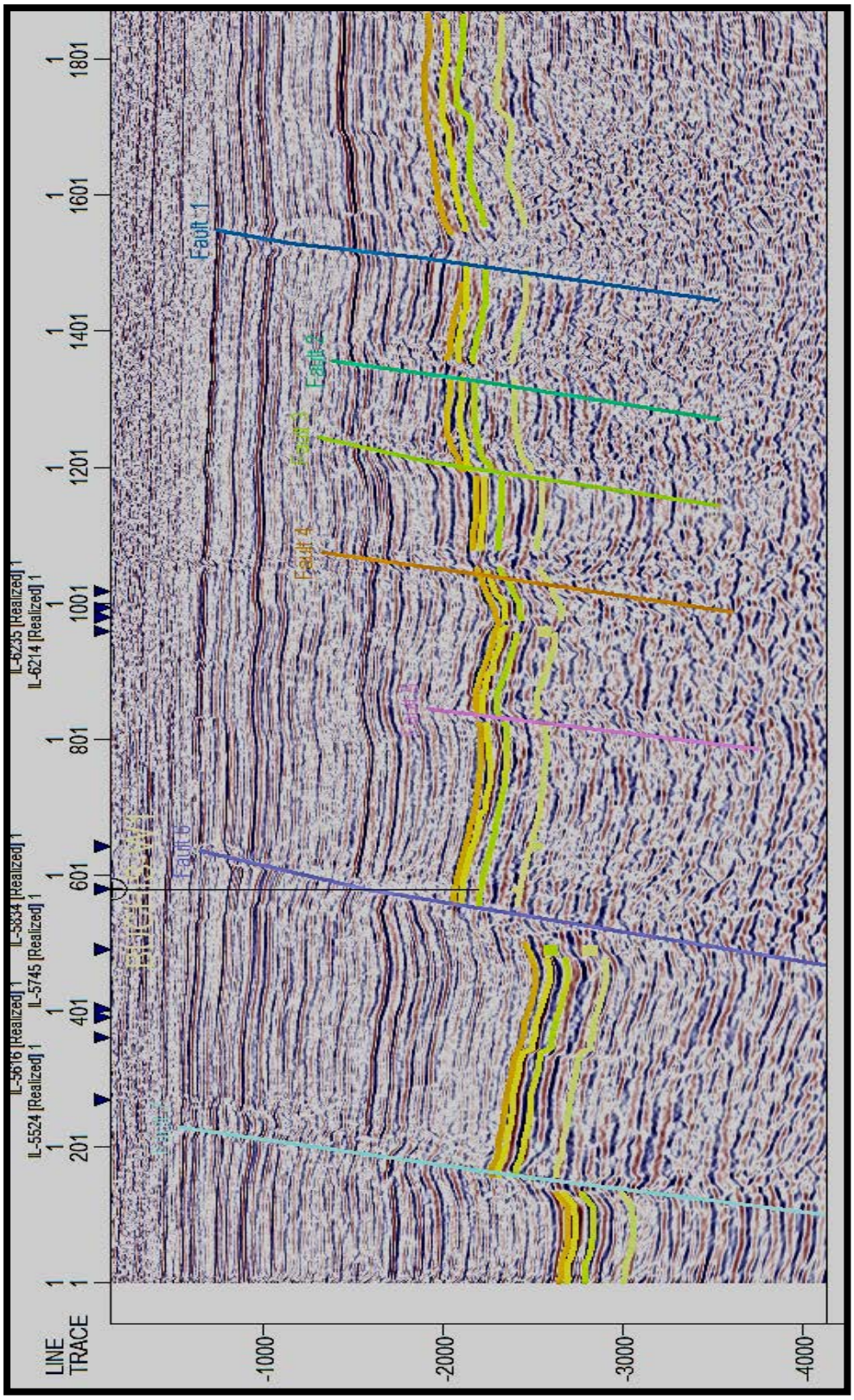

Fig. (16) Seismic interpretation of the N-S seismic line showing faults trend.

Conclusion

The petrophysical characteristics of a Desouqy Formation show that, the shale content (V_{SH}) increases towards the west and south directions where it achieves the upper limit value (6.7%) at SIWA C-1X and BUCHIS W-1X wells and decreases towards the northeast and north-central parts to reach (3.8%) as a lower limit value at NEITH S-2, TAYIM W-1X wells. The effective porosity (Φeff) is increasing from the northeast to the north-central part directions where it reaches (12.1%) at BUCHIS W-1X and SIWA A-1X wells. On the other hand, it falls towards the west direction to reach (7.5%) as a lower limit value at FAGHUR D-1X and PHIOPS-1X wells.

The hydrocarbon saturation (Shr) decreasing towards west and the south directions where it passes the minimum value (0.3%) at SIWA A-1X, SIWA C-1X and SIWA F-1X wells. The increasing is observed towards the northeast and the central part directions where the upper limit value was (73%) at TAYIM W-1X and PHIOPS-1X wells.

M-N cross-plots for mineralogical composition of the Paleozoic reservoir show that, The majority of the plotted points are scattered to fill the space between sandstone and limestone points but tend to be near to sandstone point more than limestone one. This may indicates the presence of mixed sandstone and limestone lithology. The effect of secondary porosity appears in shifting of some points upwards. 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 average value is about 42%.

The best reservoir characteristics of Desouqy reservoir occur in the northeast and north-central parts having high effective porosity, low water saturation and shale content.

The source facies are expected to occur in the basinal areas between F6, F7 and F5 (graben blocks). The hydrocarbons are assumed to be generated within the basinal

areas and then migrated to the step fault blocks of the northwestern sector between F5 and F4 and the south-central sector between F6 and F7 faults. So, faults F5 and F6 are expected to represent leaking faults.

The RFT data of Desouqy reservoir showed that, the water gradient (0.5 psi/ft) in Faghur deep-1x. Also RFT data indicates a probable oil water contact at 13865 ft. TVDSS. The reservoir pressure decline of Desouqy is usually very gradual, so it is considered as active water drive reservoir.

The main objective of the subsurface structure study was to explore the structural interpretation of the Desouqy rocks in Faghur and Siwa basins, for arriving to the best localities for drilling developmental wells in this field. This goal is achieved through the interpretation of 2D seismic data of fifty 2D seismic reflection lines take N-S and E-W trends.

The result of relation among E-W fault directions initiated step fault blocks and graben gave rise to varying structural closures. These closures formed good sites for the entrapment of hydrocarbons.

As a result of the present study, using the subsurface and petrophysical evaluation, it is recommended to drill prospect wells in the northeast and the north-central part in the area under investigation to drain the oil from the extended reservoirs expected to be above OWC.

Also, it is recommended to cover the area by 3D seismic acquisition to enhance the seismic data.

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