RESERVOIR CHARACTERIZATION ANALYSIS USING WELL LOGS AND CORE DATA OF NUBIAN SANDSTONE RESERVOIR (LOWER CRETACEOUS) IN THREE SELECTED WELLS, EASTERN SIRT BASIN, LIBYA

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Abstract

Analysis of reservoir characterization data are essential for understanding and managing the subsurface hydrocarbon. Given that the Nubian Formation is one of the main hydrocarbon formations in the Sirt basin, its petrophysical properties were examined at three wells (Q2-97, 3V3 and 3V4). The FlexInLog software is used in the current study to evaluate the petrophysical characterizations using well logs and core analysis results. Petrophysical parameters such as volume of shale, clay minerals type, porosity, permeability and fluid saturation, in addition to the volume of matrix are evaluated by using the well log data. Sandstone, siltstone, mudstone, and shale make up the majority of the Nubian Formation's lithology. The upper and lower Nubian sandstone Formations are primarily composed of the clay minerals illite and chlorite, with minor amounts of kaolinite and montmorillonite. 3. The effective porosity of Well Q2-97 is the highest, averaging 9.9%; it reaches 7.6% in the 3V3 well and 6.52% in the 3V4 well. However, well 3V4 had the lowest average permeability value of 0.7 mD, whereas well Q2-97 had the highest average of 2.3 mD. The 3V4 well, with a hydrocarbon saturation of 49%, has the largest net pay thickness, reaching 324 feet. The 3V3 well followed it with a net pay 273 feet and high rate of hydrocarbon saturation reached 66%. Compared to the other two wells, the Q2-97 well has the least amount of net pay thickness, reaching 235 feet.

Keywords: Nubian Formation, Lower Cretaceous, petrophysical properties, well logs, Sirt basin, Libya.

1- Introduction:

Rocks have a diversity of characteristics that make them suitable to serve as reservoirs to accumulate hydrocarbon. The reservoir characteristics of these rocks are significantly influenced by particles composition and their texture. The main reservoir petrophysical characteristics are porosity, fluid saturation, and permeability. A reservoir description is a thorough representation of the three-dimensional distribution and continuity of the reservoir and aquifer system's rocks, pores, and fluids, including any barriers to fluid flow (Barwis et al., 1990).

Reservoir petrophysical characteristics evaluation is the study of physical and chemical reservoir rock properties and their contained fluids. The petrophysical properties of rocks have important role on the fluid storage and their flow within the reservoir. Porosity, lithology, fluid saturation, and permeability are the most significant petrophysical parameters that used to determine the hydrocarbon resources, productivity, recovery, and field development plans (Ma, 2019).

The Sirt Basin is a major intracratonic rift system in central Libya. The sedimentary succession of this basin reflects its tectonic and structural development, which is related to the opening of the Atlantic Ocean and the convergence of Tethys in Mesozoic and Tertiary times (Macgregor et al., 1998). The Sirt Basin has received far more attention than any other region because it contains most of the hydrocarbon in Libya. The Nubian (Sarir) Sandstone Formation is the main reservoir for oil accumulations in the eastern Sirt Basin in Libya (Hallett and Lowes, 2016). It represents the first depositional cycle in the basin and it is composed of sandstone, siltstone, and shale. Three characteristic units are described in the southeastern Sirt basin. The lower and upper units involve fluvial prevailed argillaceous sandstone units, while the middle unit composed of a cleaner quartz arenite sandstone that was deposited due to various transgressive-regressive cycles of marine, marginal marine, and fluvial facies (El-Hawat, 1992). The Upper Nubian member is often the interval that contains hydrocarbons, however in some places, as the Rimal field, both the Upper and Lower Nubian units are productive (El-Hawat et al., 1996).

Marghani et al., 2023 are used core analysis, petrography analysis, and petrophysical measurements as they investigated the relationship between facies and petrophysical parameters and identified the significance of fractures in the pore system enhancement of low-porous reservoirs. The Upper Nubian Member has a sandstone reservoir with low porosity but fair permeability, according to the results of the core analysis. The highest reservoir quality is found in the fluvial meandering and braided channel sandstones, whereas the lowest reservoir quality is found in the flood plain because of the high detrital clay content (Marghani et al., 2023). In light of the significance of the Nubian Sandstone Formation as a reservoir, the present study aims to describe and evaluate the petrophysical properties of the formation and determine the type of common clay minerals using well logs.

2- Location of Study Area:

The study area is located in the eastern part of the Sirte Basin in Libya. This study used three wells from two different oil fields to evaluate the Nubian Sandstone Formation (Fig.1). The studied oil fields are the Gialo Field (3V3 and 3V4 wells) is located between longitude 21º 10' 00" & 21º 40' 00" E and latitudes 28º 36' 00"& 28º 50' 00", and the Hammed Filed (Q2-97 well) is located between longitude 21º40' 00" & 21º 80' 00" E and latitudes 28º 35' 00"& 28º 55' 00" N.

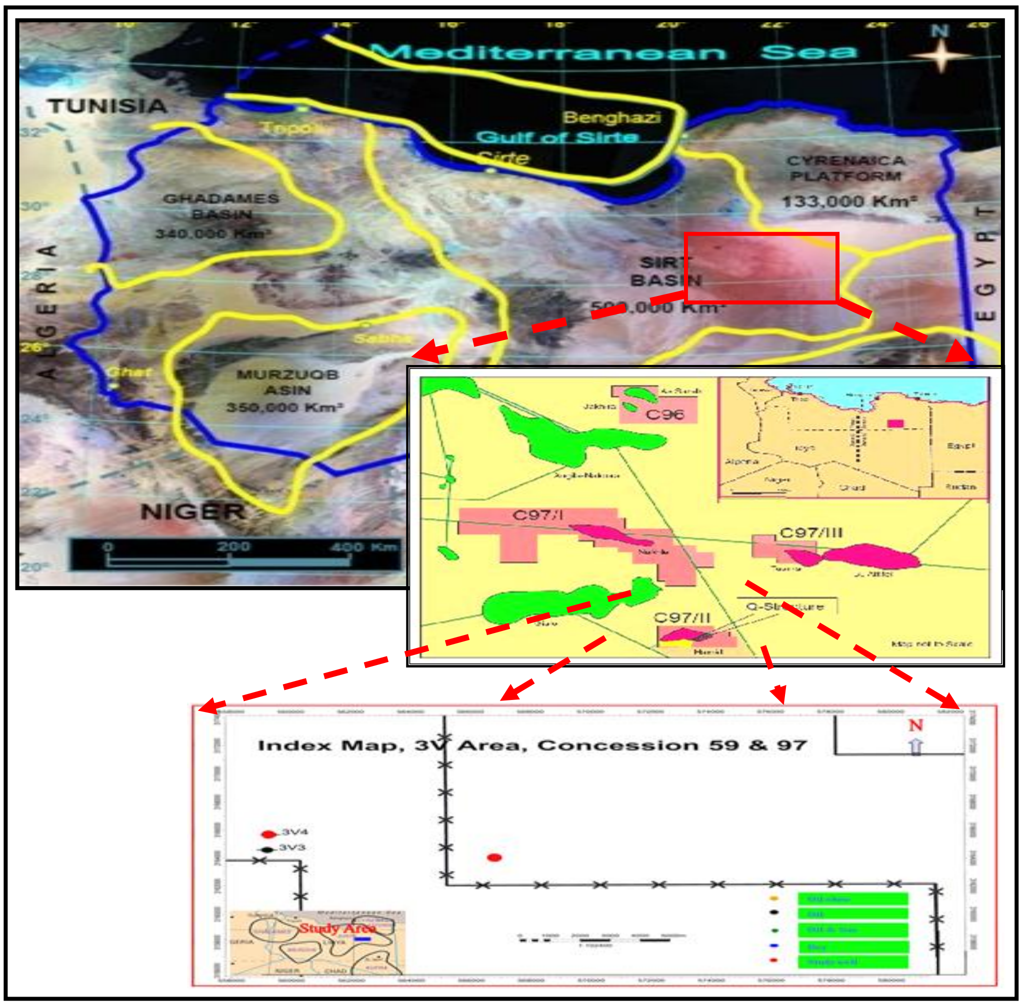


Figure (1): Shows Location map of the Study Area

3- Geological Setting of Sirt Basin:

The Sirte Basin represents the main oil producing sedimentary basin in Libya as well as in all African Basins (Abadi, 2002). Three significant groups is recognized the Sirte Basin's regional structural elements (Fig.2). NW-SE trending of major grabens (Hun, Zallah, Maradah, and Ajdabiya graben) and intervening horsts (Waddan–Al Zahra-Al Bayda platform, Zelten-Jahma platform, and Amal–Arkab high), which step progressively downward to the east, where Ajdabiya trough represents the deepest portion of the basin (Abadi, 2002). The second, NE-SW trending represents Abu Tumayam Trough, and the third E-W trending represents Sarir and Hameimat Troughs, and Messla basement high. These zones correspond to the Sirte, Tibisti, and Sarir arms respectively (Fig. 3). A series of northwest-trending horsts and grabens that step gradually to the east characterize the Late Cretaceous rifting event. The deepest part of the basin is the Sirte Trough (Ahlbrandt, 2001).

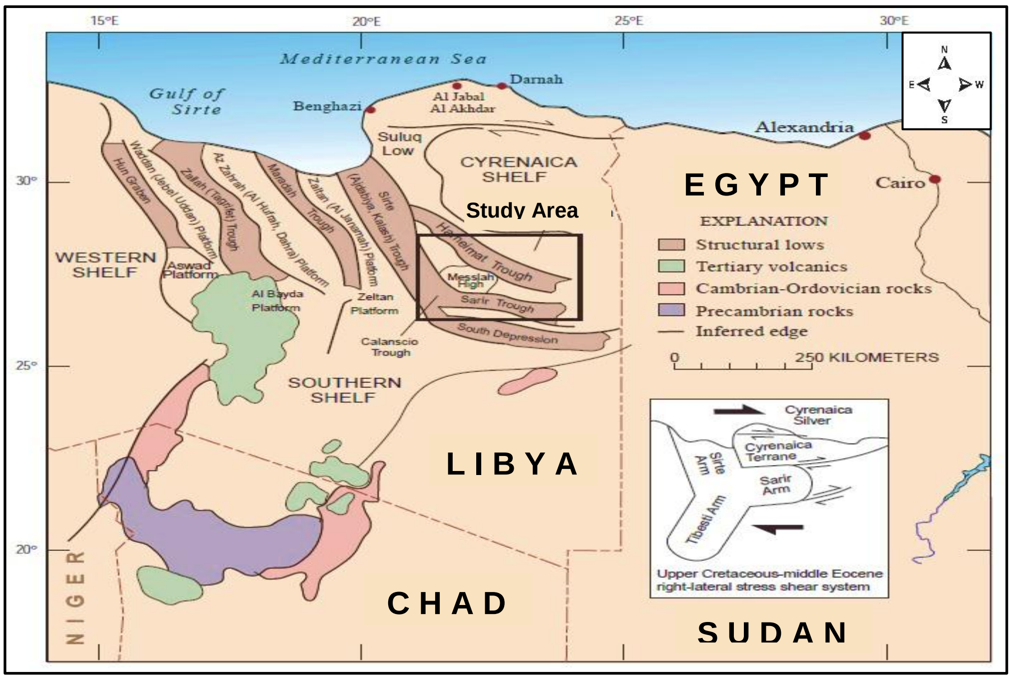


Figure (2): Structural elements of Sirt Basin (Ambrose, 2000).

The tectonic events of Sirte Basin probably took place during late Precambrian time, causing structural weakness of the area. Many stages of uplift and subsidence occurred when Pan African orogeny worked to assemble proto-continental fragments into Gondwana. It was followed by NW-SE horsts and grabens, which had been aged in early Paleozoic time. Then Hercynian orogeny constructed series of structural elements with mainly NE-SW trending of which Sirte-Tibisti arch formed most of the area of Sirte basin. The subsurface crop map shows an influence of the erosion over a crest of Sirte-Tibisti arch. According, this evidence suggests deep erosion of the arch at the end of Paleozoic, continued erosion of the arch during the early Mesozoic with progressive reduction of relief, prior to the collapse of the arch, and major marine incursion of the late Cretaceous. Early Cretaceous rifting was the primary tectonic event that has been identified and significantly influences basin structure. Three major stages have been established for this. Initial rifting took place in Early Cretaceous, reached its climaxin Late Cretaceous and ended in Early Tertiary (Abadi , 2002).

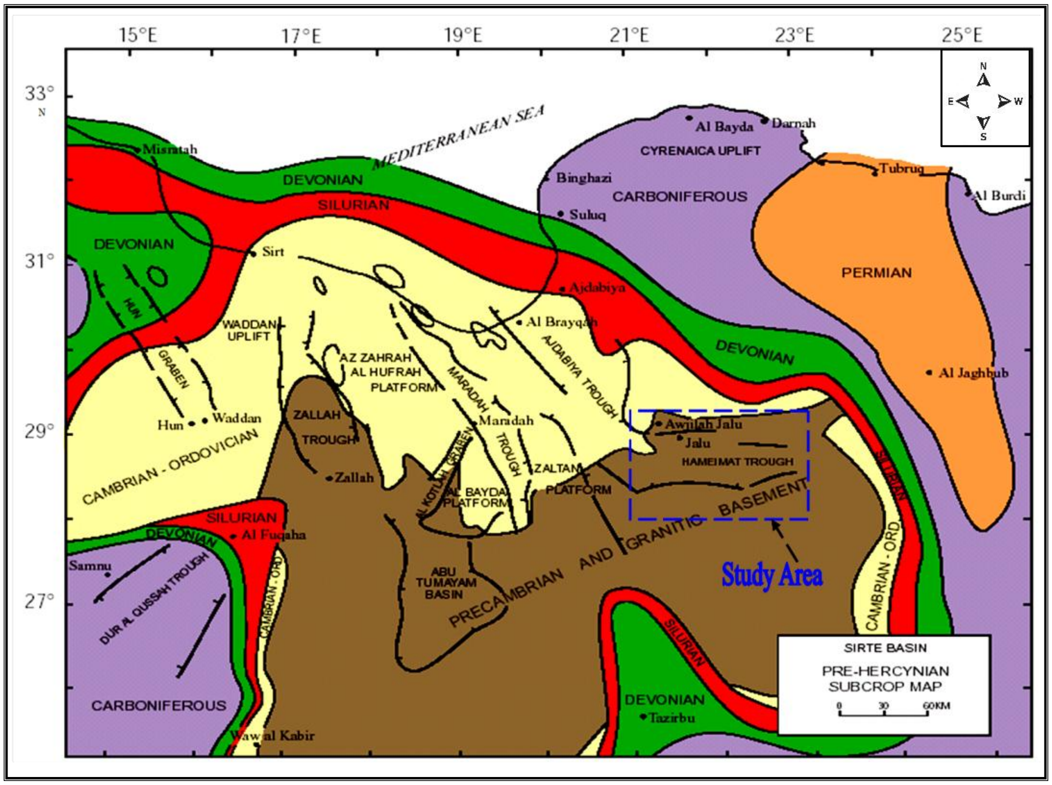


Figure (3): Pre-Hercynian map of Sirt Basin (Ahlbrandt, 2001).

Sirte Basin is a major oil producing basin and has major distinct structures, which can be divided into two important parts of the basin namely; the northwestern part, including the Zallah, Maradah, and Ajdabiya grabens, and intervening horsts, and the Southeastern part including the As-Sarir– Al Hamamat Troughs. As a result of this, distributed regional stratigraphy and petroleum occurrence is different in the two area of the Basin (Abadi ,2002).

4- Available Data and Methodology:

Well logs and core data from three oil wells are used for the current study (Table-1). The well log data include gamma ray, spectral gamma ray, photoelectric factor PEF, SP, caliper resistivity, density, neutron and sonic logs. To initiate clear idea about the studied reservoir the quick- look method helps to find out most of the required features of the reservoir. The FlexInLog software is used in the current study to evaluate the petrophysical characterizations using well logs and core analysis results. In addition to using the results of routine core analysis such as the permeability and porosity that were calculated by (Wintershall Oil Company, 2006).

Table-1: The Formation tops and bottom of the Nubian Formation in the study area.

Name of well	Well Q2-97/ll	Well 3V3-59E	Well 3V4-59E
Top (KB)ft	10715	10285	10214
Bottom (KB)ft	10986	10720	10546
Thickness (ft)	285	435	332

5- Resullts:

5-1 Well Logs Analysis:

5-1-1 Calculation Volume of Shale (Vsh):

The presence of shale in a reservoir can cause erroneous values for water saturation and porosity that are derived from logs.

The gamma ray logs can be used to calculate volume of shale in porous reservoir by formula from Schlumberger, 1972 and Dresser Atlas (1979) (Table-2).

$$I_{GR} = \frac{GR_{sh} - GR}{GR_{sh} - GR_{cl}} \quad \text{……………………. (1)}$$

$$V_{sh} = 0.33\left(2^{\left(2*I_{GR} - 1.0\right)}\right) \quad \text{………………… (2)}$$

Where: I_{GR}= gamma ray index, GR = gamma ray log API, GR_{sh} = gamma ray in front of shale, GR_{cl} = gamma ray in front of sandstone, Vsh = volume of shale.

Table-2 : The averages bulk volume of shale in the studied wells

Well Names	Well Q2-97	Well 3V3-59E	Well 3V4-59E
Volume of Shale %	27%	20.5%	37.04%

5-1-2 Lithological Identification:

Determining the lithology and mineralogical composition of the rock formation is too important for the evaluation of a reservoir. The current study is used two cross plots relations to determine the rocks' types from well logging. These relations are Neutron- Density and MN cross-plots. Neutron-density cross-plot has shown that the Nubian Formation composes of mixture sandstone (Fig.4).

The M-N Crossplot (Fig.5) uses the density, compensated neutron, and compressional sonic logs to Identify binary and ternary mixtures of minerals. M and N values are estimated using (Schlumberger, 1972) equations:

$$M = \frac{\Delta t_f - \Delta t_{\log}}{\rho b_{\log} - \rho b_f} * 0.01 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3)$$

$$N = \frac{\Phi n_f - \Phi n}{\rho b_{\log} - \rho b_f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where: Δt_{log} = Sonic log reading from log, Δt_f = Travel time in fluid= 189µsec/ft (salt mud), ρb_{log} = Bulk density log reading from log, ρb_f = Density value of fluid (1.1g /cc), Øn=Neutron porosity of the formation from compensated neutron, Ønf = Neutron porosity of fluid (use 1.0)

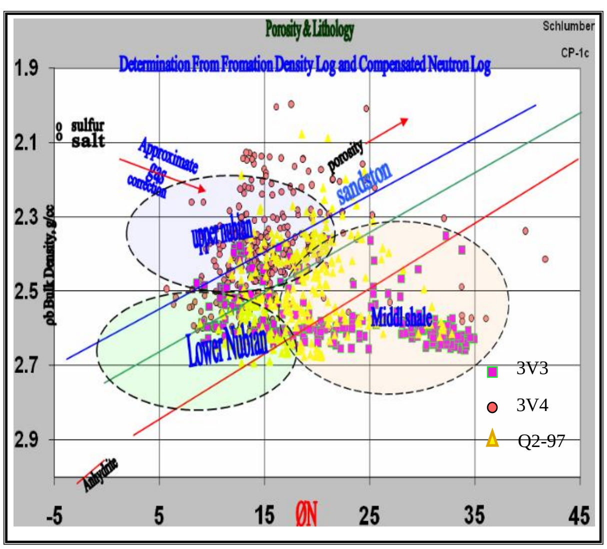


Figure (4): The density and neutron cross-plot of Nubian Sandstone Formation in the three wells

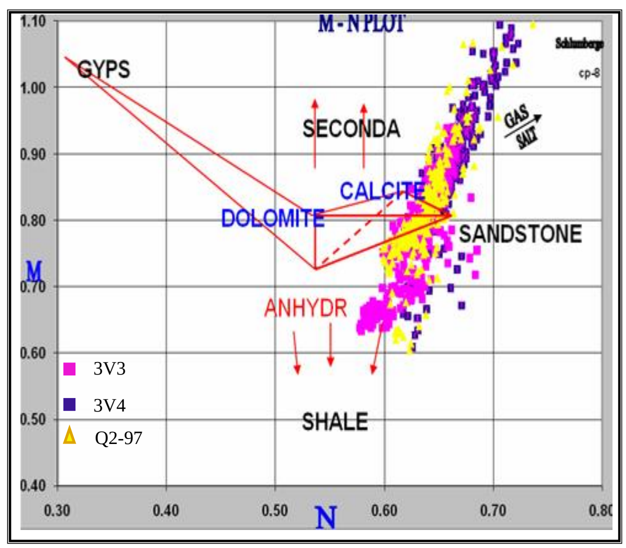


Figure (5): Cross-plot M-N lithology for the Nubian Sandstone Formation in the three wells

5-1-3 Mineral Identification:

The natural gamma ray spectrometry log is one of the most crucial instruments for detecting potassium (K), uranium (U), and thorium (Th) concentrations, and is a reliable indicator for defining the lithological type from well-logging records (Schlumberger, 1991). In addition to determining the type of clay mineral, Th, U, and K concentrations are used to evaluate sediment conditions (Al-Jafar and Al-Jaberi, 2022).The Nubian Sandstone Formation is studied using thorium-potassium and photoelectric log- potassium cross-plots for the identification of clay minerals in the formation (Fig.6 and Fig.7).

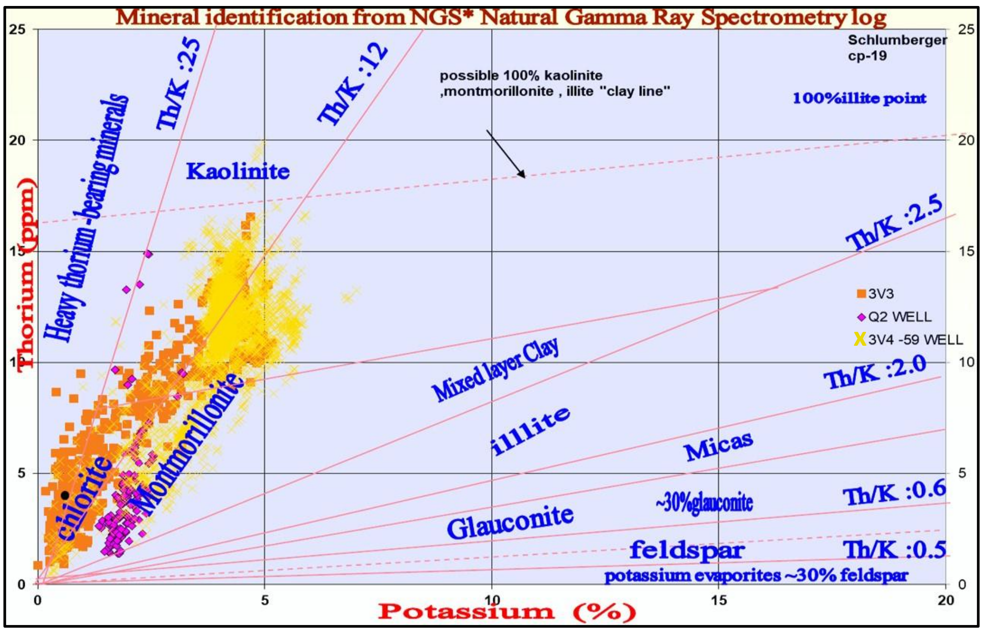
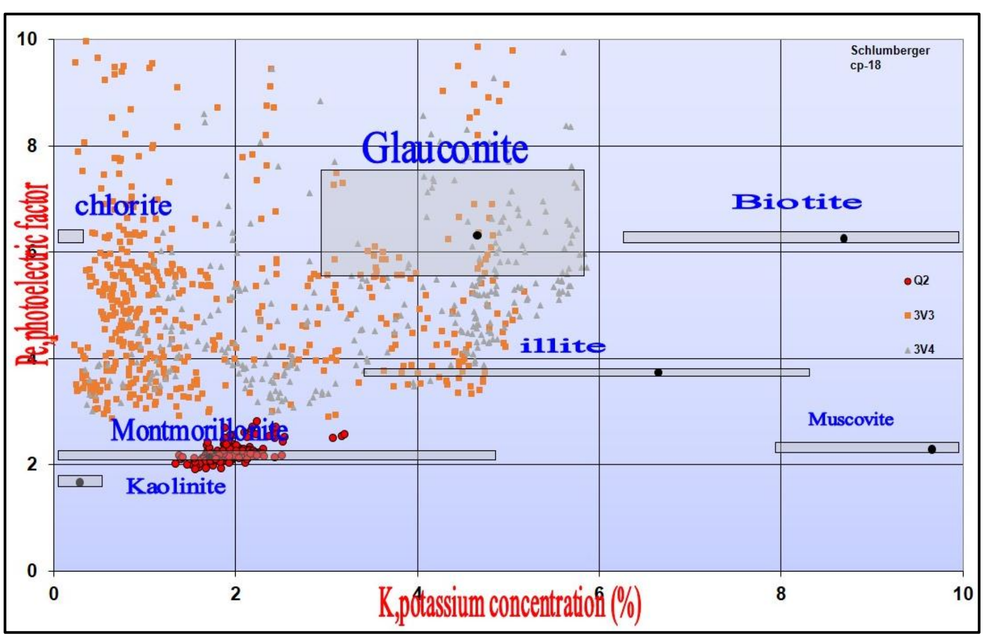


Figure (6): Thorium-potassium cross plot for the Nubian Sandstone Formation in the three wells



5-1-4 Porosity Estimation:

Density and Neutron porosity logs were used to determine quantitatively the total and effective porosities (Table-3) using the (Schlumberger 1974) equation:

$$\phi_d = \frac{\rho b_{\log} - \rho b_{ma}}{\rho b_f - \rho b_{ma}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where: Φd = porosity from density log, ρb_{log} = bulk density log reading from log, ρb_f = density value of fluid (1.1g /cc), and ρb_{ma} = density value of rock.

The current study used the following equations (Schlumberger,1995 and Schlumberger 1997) to correct the porosity from volume of shale impact:

$$\Phi dcorr = \Phi d - \left[\left(\Phi dclay / 0.45\right) * 0.30 * Vsh\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (6)$$

$$\Phi ncorr = \Phi n - \left[\left(\Phi nclay / 0.45\right) * 0.30 * Vsh\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where: Φd_{corr} = density porosity corrected for shale, Φn_{corr} = neutron porosity corrected for shale, Vsh = volume of shale, Φn_{clay} = neutron porosity of adjacent shale, and Φd_{clay} = density porosity of adjacent shale.

$$\Phi_t = \sqrt{\frac{\Phi dcorr^2 + \Phi corr^2}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$\phi e = \frac{(1.65\,\phi\,\mathrm{dcorr} + \phi\,\mathrm{ncorr})}{2.65} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (9)$$

Where: Φt = total porosity and Φe = effective porosity.

Table -3 : The average values of total and effective porosity in the studied well

Type of porosity	Well Q2-97/ll	Well 3V3-59E	Well 3V4-59E
Effective porosity (Øeff %).	9.9	7.6	6.52
Total porosity (Øt%)	12.6	10.6	10.25

5-1-5 Water Saturation (S_w):

Based on (Waha Oil, ٢٠٠٤ and Wintershall Companies, 2006) core analysis, the water resistivity (R_w) value for studied wells is 0.017 Ωm at 272 F^0 . The Archie parameters that used to estimate water saturation are illustrate in (Table-4). In this study, the (Simandoux,1963) equation was used.

$$Sw = (\frac{0.4 * Rw}{\phi^2}) * \left(-\frac{Vsh}{Rsh} + \sqrt{(\frac{Vsh}{Rsh})^2 + \frac{5\phi^2}{Rt * Rw}} \right) \quad \text{……………………. (10)}$$

Where:

S_w = Water saturation uninvaded zone, n = the saturation exponent and equals to 2, m = the cementation factor, Φe = Effective porosity, R_w = Resistivity of formation water at formation temperature, R_t = True formation Resistivity as measured by a deep reading Resistivity log,
V_{sh} = Volume of Shale, and R_{sh} = Resistivity of adjacent shale.

Table-4: Shows the average Effective Porosity, Cementation Exponent (m) and Formation Factor in the studied area

Parameters Values	Well Q2-97	Well 3V3 59E	Well 3V4-59E
Cementation factor(m)	1.81	1.75	1.75
Formation Factor (F)	28.92	33.6	34
Interal Gemtery Factor (a)	1.026	0.739	0.54

The relationship between the Water Saturation in the uninvaded zone and that in the flushed zone can be used as an indicator of hydrocarbon moveability. (Table-5) Summarizes the averages Movable and Residual hydrocarbon in the study Area.

Table -5: The averages of movable and residual hydrocarbon saturation in the studied wells

Saturation Average %	Well Q2-97/ll	Well 3V3	Well 3V4
Water saturation	61	34	51
Movable oil saturation	20	37	23
Residual oil saturation	19	29	26

5-1-6 Calculation of Permeability

Permeability is the property of the rock to permit the passage of fluid through the rock particles. Waha Oil Company (1993) equation was used to determine permeability for the Nubian Sandstone Formation:

$$K = 10^{(0.169*Øe - 3.301)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

Where Øe = Effective Porosity.

6- Discussion:

The Late Jurassic-Albian Nubian Sandstone Formation is the main oil reservoir in Libya's eastern Sirt Basin. Because it has 82% of the oil and 32% of the gas found in Libya, the Sirt Basin has drawn significantly more interest than any other region (Shaltami *et al*., 2021). Well logging interpretation and core analysis data were used to evaluation and identifying the reservoir characterization of Nubian Formation.

Generally, the core samples shown the main lithology of the Nubian sandstone reservoir is composed of sandstone, siltstone, mudstone and shale. A routine core analysis of the Nubian reservoir are shown the matrix porosity ranges between low percentages to 23 %. In addition to the matrix permeability (Kh) ranges between (0.01 to 100 mD). The beds of the Nubian reservoir that have high values of (Kh) and lower porosity can be attributed to late authogenetic diagnesis (Wintershall Oil Company 2006).

Several cross-plots were used to evaluate the lithology of the formation using well logs. According to the neutron-density and M-N cross-plots (Figures 4 and 5), the lithology for the Nubian Formation consists of a mixture of sandstone, shale, and shaly-sand. The thorium-potassium and photoelectric-potassium cross-plots were used to detect the clay minerals in the formation (Figures 6 and 7). These cross-plots demonstrate that the major clay minerals in the upper and lower Nubian sandstone Formation are illite, chlorite, with minor amounts of montmorillonites and kaolinite. Illite mineral and mixed clay layers are seen to be dominant in the middle of the formation, in contrast. In general, clay mineralogy is relatively significant in the lower Nubian sandstone as compared to the upper Nubian sandstone.

The FlexInLog Software was used in the current study to handle quantitative well log analysis and formation evaluation for the three studied wells (Figures 8, 9, and 10). From the beginning 1959 until the present, this software has been used to assess the oil and gas reserves in Libya. According to the well log analysis results, the total porosity in the Nubian Formation ranges from (6-20%) with average (12%), (10.6%), and (10.25%) for Q2-97, 3V3, and 3V4 wells, respectively. Effective porosity averaged 9.9% in the Q2-97 well, 6.52% in the 3V4 well, and 7.6% in the 3V3 59E well. The permeability values range from 2.41 to 91.0 mD with average (2.3), (2.2), and (0.7) for Q2-97, 3V3, and 3V4 wells, respectively.

The Nubian Formation has a relatively low hydrocarbon content in the Q2-97 well. It has been noted that there is considerable water saturation with average (61%) and low oil saturation with average (20% for movable oil and 19% for residual oil). The 3V3 well had the largest hydrocarbon content at 66%, which was distributed between moveable oil and residual oil at 37% and 29%, respectively. In the case of the 3V4 well, it had been revealed that the hydrocarbon content was 49%, split between 20% for moveable oil and 19% for residual oil.

The net pay is 235 ft. at 6% porosity cut-off for the Q2-97 well, while in the 3V3 well is 273.5 ft. with a moveable oil saturation of 5.64 ft. and a thickness of residual oil 7.133 ft. The net pay of the 3V4 well equals 324.0 ft., at 6% porosity with moveable oil saturation is 3.05ft., residual oil column high is 2.701 ft., and oil saturation is 54.66%.

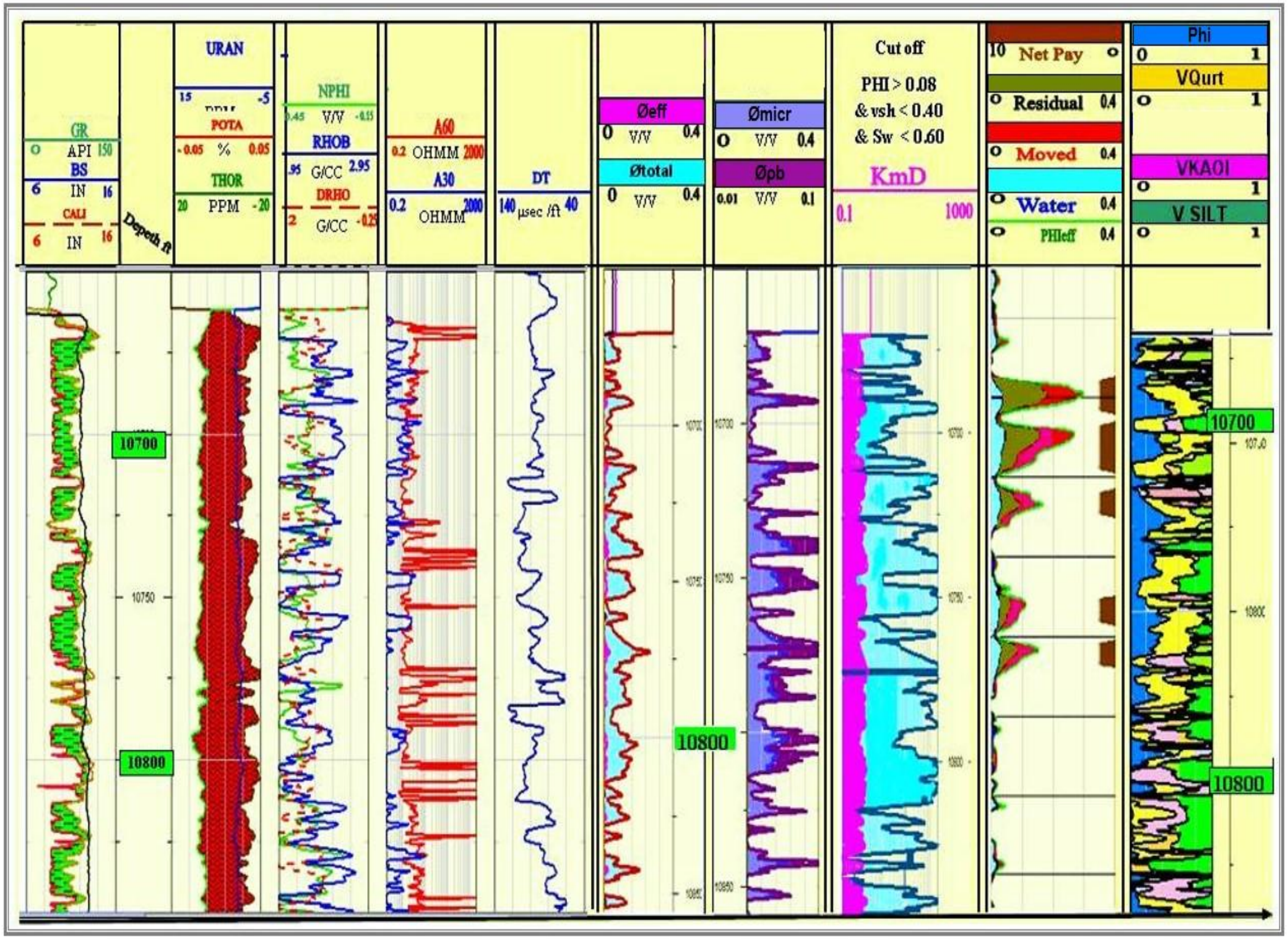


Figure-8 Show Lithological compositions (Strip log) in the Nubian Reservoir of the well Q2-97/Ii in the study Area

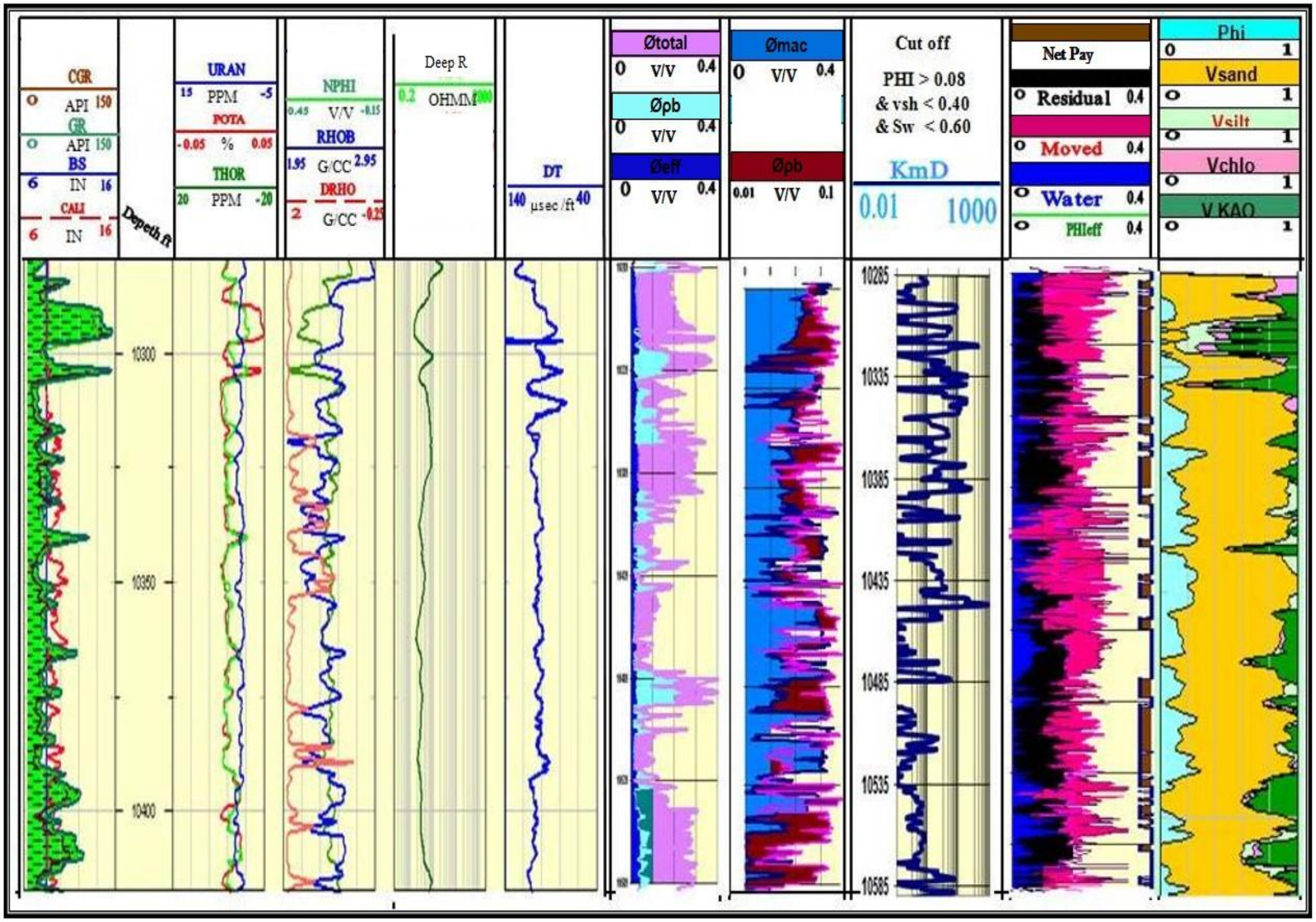


Figure- ٩: Show Lithological compositions (Strip log) in the Nubian Reservoir of the well 3V3 in the study Area

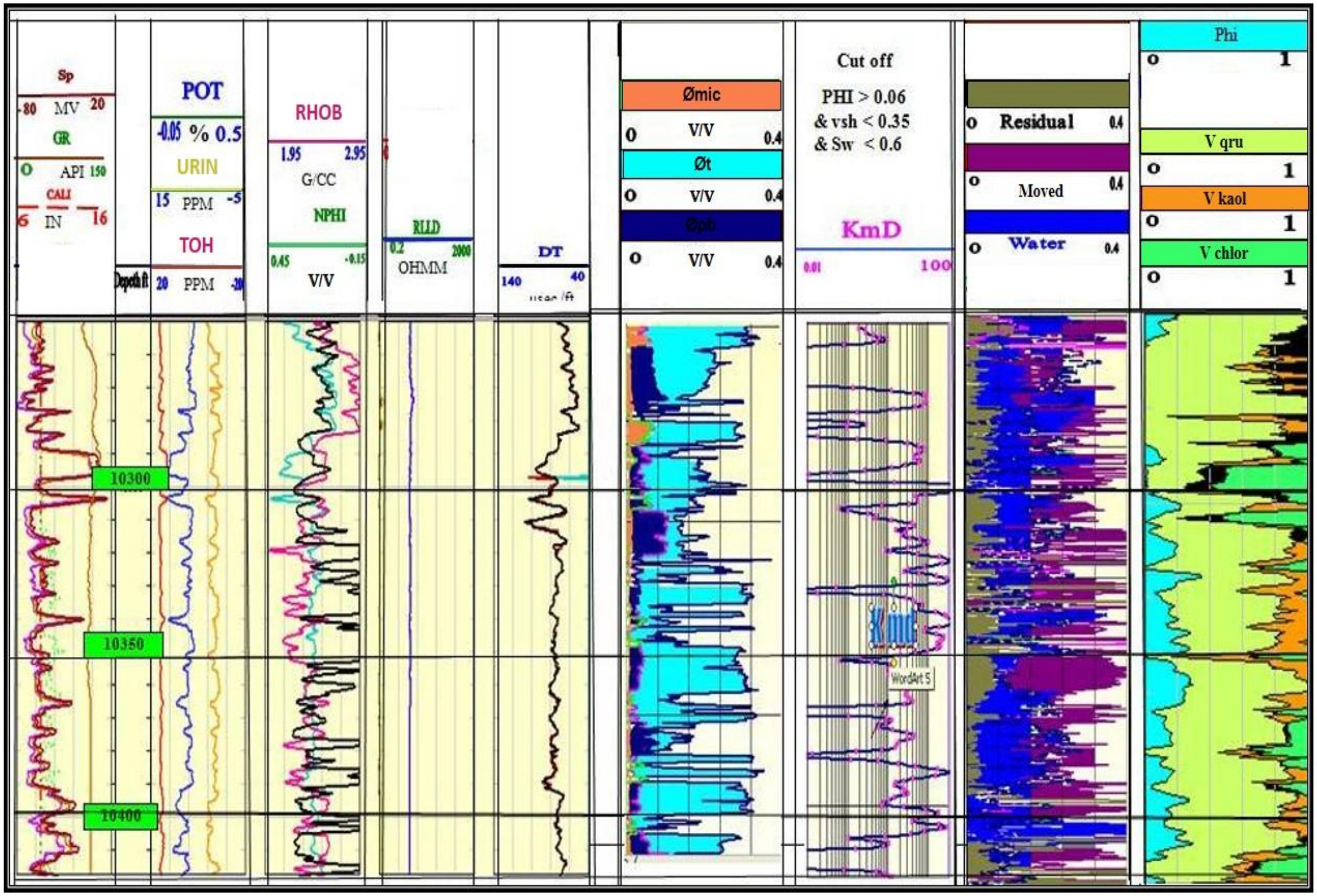


Figure-10-: Show Lithological compositions (Strip log) in the Nubian Reservoir of the well 3V4 in the study Area

7- Conclusions:

Well logs are used to determine the characteristics of a reservoir, such as its porosity, lithology, permeability, common clay mineral type, matrix volume, and fluid types for the Nubian sandstone reservoir in the East Sirt Basin, Libya. The principal findings of the present study are as follows:

1. According to the core samples, the Nubian Formation composed of sandstone, siltstone, mudstone and shale. A routine core analysis of the Nubian reservoir are shown the matrix porosity ranges between low percentages to 23 %. In addition to the matrix permeability (Kh) ranges between (0.01 to 100 mD).
2. The well logs results shown the major clay minerals in the upper and lower Nubian sandstone Formation are illite, chlorite, with minor amounts of montmorillonites and kaolinite. Illite mineral and mixed clay layers are seen to be dominant in the middle of the formation, in contrast.
3. Well Q2-97 has the highest values of effective porosity with average 9.9%, while it reach 7.6% in the 3V3 well , and 6.52% in the 3V4 well. However, the highest value of permeability was in Q2-97 well with average 2.3 mD, while the lowest value was in well 3V4 with average 0.7 mD.
4. Despite the high porosity and permeability in Q2-97 well, the percentage of hydrocarbon saturation in it is low compared to the other two wells, as the average reaches 39%. According to the results of the present study, the 3V3 well showed a high rate of hydrocarbon saturation (66%), which was split between movable and residual oil (37% and 29%, respectively). It was found that the hydrocarbon content of the 3V4 well was 49%, with 20% of the oil being movable and the remaining 19% being residual.

5. According to the study's findings, the 3V3 well has the highest net pay thickness at 324 feet, followed by the 3V3 well at 273 feet. Reaching 235 feet, the Q2-97 well has the least amount of net pay thickness when compared to the other two wells.

8- Acknowledgments

We would like to express our appreciation to the Waha and Wintershall Oil Companies for providing the data for this study.

9- References:

- Abadi, A.M., 2002. Tectonics of the Sirt Basin: Inferences from Tectonic Subsidence Analysis, Stress Inversion and Gravity Modelling. 187 P. PhD Thesis, Univ. Vrije, Holland.
- Ahlbrandt, Th. S., 2001. The Sirte Basin Province of Libya-Sirte-Zelten Total Petroleum System, *US Department of the Interior*, *US Geological Survey*.
- Al-Jafar, M.K., Al-Jaberi, M.H., 2022. Determination of Clay Minerals Using Gamma Ray Spectroscopy for the Zubair Formation in Southern Iraq. *J. Petrol. Explor. Prod. Technol.*, 12, 299–306. https://doi.org/10.1007/s13202-021-01371-3
- Ambrose, G., 2000. The Geology and Hydrocarbon Habitat of the Sarir Sandstone, SE Sirt Basin, Libya. *Jour. Pet. Geol*., 23, p. 165-192.
- Archie, G.B. (1942). The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics. *Jour. Pet. Technol*., 146, 55-62.
- Barwis, J. H., McPherson, J. G. and Studlick, J. R J., 1990. Sandstone Petroleum Reserooirs. *Springer-Verlag, Berlin*. 598 P.
- Dresser A. (1979). Log Interpretation Charts. Dresser Atlas Division, *Dresser Industries, Houston*, TX, 125P.
- El-Hawat, A.S., Missallati, A.A., Bezan A.M. & Taleb, M.T., 1996. The Nubian Sandstone in Sirt Basin and its correlatives. In: Salem, M.J., El-Hawat, & A.M. Sbeta, A.S. (eds.).The Geology of Sirt Basin, vol. II. *Elsevier*, Amsterdam.
- El Hawat, A., 1992. The Nubian Sandstone sequence in Sirte Basin, Libya: Sedimentary Facies and Events, Geology of the Arab World, 1, Cairo Univ., p. 317-327.

- Hallett, D. and Lowes D.C., 2016. Petroleum Geology of Libya. (2nd ed), *Elsevier B.V.*, *Amsterdam*, *Netherlands*, 392 P.
- Ma, Y.Z. (2019). Quantitative Geosciences: Data Analytics, Geostatistics, Reservoir Characterization and Modeling, *Springer*, *Switzerland*, 640 P.
- Macgregor, D.S., Moody, R.T., and Lowes, D.D.C. ١٩٩٨. Petroleum Geology of North Africa, *Geological Society*, London, Special Publications, 132 P.
- Marghani, M.M.A., Zairi, M., and Radwan, A.E., 2023. Facies Analysis, Diagenesis, and Petrophysical Controls on the Reservoir Quality of the Low Porosity Fluvial Sandstone of the Nubian Formation, East Sirt Basin, Libya: Insights into the Role if Fractures in Fluid Migration, Fluid Flow, and Enhancing the Permeability of Low Porous Reservoirs. *Marine and Petroleum Geology*, 147. 105986. https://doi.org/10.1016/j.marpetgeo.2022.105986.
- Schlumberger (1974). Log Interpretation: Application. Vol. II, Schlumberger well services Inc., *Houston, USA*, 116 pp.
- Schlumberger, 1995. Well Evaluation Conference of Egypt. Technical Editing Services, Ltd., Chester, 87.
- Schlumberger, 1997. Log Interpretation Charts, Wirline and Testing, *Houston*, Texas.
- Schlumberger, 1991. Log Interpretation Principles/Applications, Schlumberger Educational Services.
- Schlumberger, 1992 Logging while drilling. Schlumberger Educational Services, *Houston*, Texas.
- Schlumberger, 1994 Log Interpretation Charts. Wirline and Testing, *Houston*, Texas.
- Shaltami, O.R., Fares, F.F, El Oshebi, F.M, Elojaly, R.B., Elmasli, A.A. Mohamed, I.I, Aljazwi, M.S., El-Ehfifi, S.S., Errishi, H., Algomati, A. E., and Geniber, O.A., 2001. Evaluation of Hydrocarbon Source Rock Potential of Well 2A1-59, Western Sirte Basin, Libya, University Bulletin – ISSUE, 23 (3), p. 105-118

- Simandoux, P., 1963. Dielectric Measurements in Porous Media and Application to Shaly Formation: Revue de L'Institut Français du Pétrole, 18, Supplementary Issue, p. 193–215.
- Waha Oil Company, 1993. Unpublished Regional Map of the Tectonic Features in the Sirt Basin.
- Waha Oil Company (2004): Unpublished Internal Report'' Core analysis study of the Nubian Formation of the study area.
- Wintershall Oil Company, 2006. Unpublished Regional Map of the Tectonic Features in the Sirt Basin.