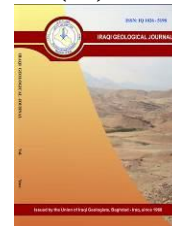




Iraqi Geological Journal

Journal homepage: <https://www.igi-iraq.org>



Integrated Petrophysical Characterization and 3D Static Modeling of the Early Cretaceous Zubair Reservoir: Implications for Hydrocarbon Asset Evaluation in Luhais Oilfield, Southern Iraq

Afrah M. Al-Ghazi^{1,*}  and Amer J. Al-Khafaji¹ 

¹ Department of Geology, College of Science, University of Babylon, Babylon, Iraq

* Correspondence: afrahghazzi999@gmail.com

Received:
12 March 2026
Accepted:
27 June 2026
Published:
31 August 2026

Abstract

This study presents an in-depth reservoir properties of the Zubair Formation in the Luhais Oil Field in southern Iraq. Geologically speaking, the formation is situated in the Thamama Group, which is part of the Early Cretaceous Eighth Megasequence (AP8). By integrating wireline log data with 3D structural and petrophysical modeling, the study evaluates the reservoir's spatial heterogeneity and storage capacity. Sandstone intervals with adjacent shale successions comprise most of the Zubair Formation, which has been split into three members and four distinct reservoir units. The upper sand member is the primary interval that contains hydrocarbons, according to the analysis results. Based on petrophysical analyses, the sandstone-dominated Units A and C have good reservoir quality, with moderate-to-high permeability levels between 76 and 328 mD and porosity values between 15% and 25%. Also, these units show quite low water saturation (0.22–0.37), suggesting a high potential for hydrocarbon accumulation. On the other hand, due to their high water saturation and low permeability, Units B and D which have a high shale content act as non-reservoir intervals; these intervals are thought to serve as both hydraulic barriers and potential source rock facies. The most productive zones are contained within the upper sand member, as confirmed by the developed 3D geological and petrophysical models that successfully define the geographic distribution of these characteristics.

Keywords: Zubair formation; Petrophysical characterization; 3D modeling; Luhais oilfield

1. Introduction

The Zubair Formation is one of the most important clastic reservoir units in the southern Iraqi oil and gas fields. It was deposited during the Lower Cretaceous period (Jassim and Goff 2006), representing a major hydrocarbon-bearing stratigraphic unit in Iraq and neighboring countries of considerable economic importance. The formation is mainly composed of interbedded sandstone, shale, and siltstone, with limestone in the uppermost part (Bellen et al., 1959). The upper shale interval is characterized by alternating sand and shale beds, indicating deposition in a transitional deltaic to shallow marine environment (Sadooni, 1996).

The Zubair Formation is an aspect of an integrated petroleum system in the southern Mesopotamian Basin, composed of shale successions developed primarily on top of laterally extensive sandstone reservoir units (Bellen et al., 1959). In addition to being effective seals, these shale intervals could serve

as potential source rocks. In some parts of southern Iraq, the Zubair source rocks have attained sufficient thermal maturity to generate hydrocarbons. The proven oil generated from nearby source rocks, maybe from Zubair Formation itself (Al-Khafaji et al., 2019), further supports the effectiveness of this petroleum system. This suggests that hydrocarbons are actively generated, migrated, and accumulated in the basin. Al-Khafaji et al. (2019) also identified the source rocks which are Sargelu, Sulaiy and Zubair source intervals, as bituminous limestones with high sulfur (S) concentrations, a higher ratio of total organic carbon (TOC), and hydrogen index (HI) values greater than 400 mg HC/g.

Based on earlier stratigraphic research, the Zubair Formation is typically divided into five major members (Sadooni, 1996). In the Luhais Oilfield, the formation is represented by three primary members: the top shale member, the middle sand member, and the lower shale member. The middle sand member, that shows differences in depositional environment appears when the middle shale member disappears, and the upper and lower sand units combine (Alher et al., 2018). The Luhais Oilfield is located in southeast Iraq between latitudes 30°13'–30°24' N and longitudes 47°14'–47°19' E. It is close to 900 km² in extent and is located 105 km west of Basra City (Sadooni, 1996).

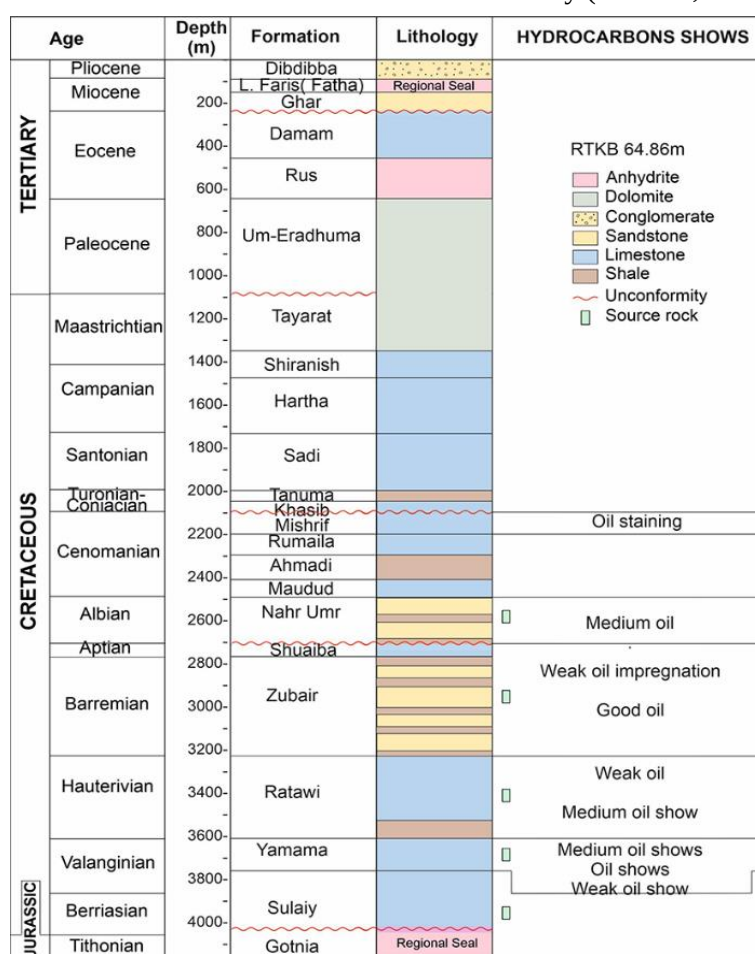


Fig. 1. The general lithological column with hydrocarbon shows of southern Iraq (Al-Khafaji et al., 2019)

The Zubair Formation was first discovered in the Zubair Oilfield by Nasr and Hudson (1953 in Dunnington, 2005). The formation comprises sandstone, shale, and limestone deposited in various environments, including fluvial-deltaic, deltaic, and marine settings (Al-Kharsan, 1975; Sadooni, 1996; Al-Shahwan et al., 2018). In the Luhais Oilfield, the uppermost part of the Zubair Formation is structurally characterized by multiple domes and an asymmetrical anticline structure (Alher et al., 2018), as illustrated in the upper sand contour map (Fig. 3).

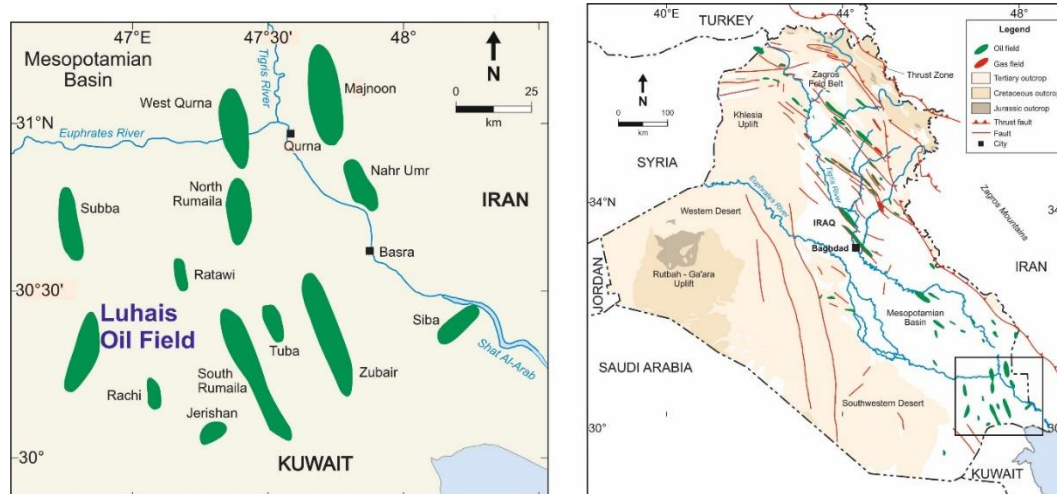


Fig. 2. Map of oil and gas fields in southern Iraq showing the studied area (modified after Al-Khafaji et al., 2019)

A one-dimensional interpretation of well logs is insufficient for modern reservoir management. Also, it is necessary to build a three-dimensional static model that accurately reflects the subsurface of the geological reality (Al-Zaidy and Mohammed, 2017; Alher et al., 2018). Petrophysical characteristics can be distributed throughout the inter-well space using sophisticated geostatistical techniques such as Sequential Gaussian Simulation (SGS), which can reduce uncertainty in volumetric estimates and flow simulation (Al-Zaidy and Mohammed, 2017).

The objectives are to provide a comprehensive reservoir characterization of the Zubair Formation in the Luhais Oilfield. By integrating wireline log analysis with three-dimensional geological modeling, this study seeks to:

1. Define the petrophysical characteristics (porosity, permeability, and fluid saturation) across the different members of the formation along the Luhais structure.
2. Establish a high-resolution zonation based on reservoir quality.
3. Construct a 3D static model to determine spatial heterogeneity, and reservoir units' quality.

2. Geological Setting

2.1. Zubair Formation Stratigraphy and Depositional Environment

Zubair Formation is located in the Zubair Subzone of the Mesopotamian Basin. As shown in Fig. 1, it was deposited during the Early Cretaceous period (Al-Zaidy and Mohammed, 2017), more precisely during the Arabian Plate (AP8) sedimentary cycle of the Thamama Group and the Late Tithonian-Aptian secondary cycle, known as Hauterivian -Aptian, approximately 131–113 million years ago (Al-Saedi and Flori, 2018). The formation, which mostly consists of oil-producing sandstone and shale strata, is a regional feature that is present in Iraq, Kuwait, Saudi Arabia, Iran, and Syria. Significant hydrocarbon reserves have been reported, making it a productive reservoir unit in this region.

2.2. Geology of the Luhais Oilfield

According to Fig. 3, the Luhais oilfield has an asymmetrical anticline fold structure (Al Musawi et al., 2018) and an amebic shape with no obvious structural axis within Iraq. The field has a straightforward, northwest-southeast extended anticline that dips gradually. The field is roughly twenty km long. Al-Saedi and Flori (2018) carried out a thorough investigation using well and seismic data to examine the field's structural elements and pinpoint important characteristics, including the anticline

and significant faults. According to the study, there were notable differences in permeability and porosity throughout the area, and the reservoir showed considerable compartmentalization. Because various parts of the field can require different ways to enhance recovery, this has significant consequences for production plans.

3. Methodology

3.1. Data Acquisition and Methodology

This study applied a complete data collection procedure, including many different sources, to ensure a valid reservoir evaluation of the Luhais Oilfield. The main data were obtained from the Basra Oil Company (BOC), in addition to pre-existing analyses, geological reports, field maps, and previous petrophysical studies on the Luhais Field. Five important oil wells were chosen for an in-depth reservoir study based on their availability and the presence of extensive openhole log data. These wells were needed to collect subsurface data (Table 1).

Table 1. Basic information to studied wells

Well	Top (m)	Bottom (m)	CALI (inch)	GR (API)	NPHI (%)	RHOP gcm ³	DT (μsec/ft)	MSFL (Ohm. m)	ILD (Ohm. m)
LU-2	2785	2853	✓	✓	✓	✓	✓	✓	✓
LU-3	2777	2834	✓	✓	✓	✓	✓	×	✓
LU-7	2789	2852	✓	✓	✓	✓	✓	×	✓
LU-8	2774	2832	✓	✓	✓	✓	✓	×	✓
LU-14	2795	2879	✓	✓	✓	✓	✓	×	✓

The data were processed and analyzed using multiple software tools. The development, maintenance, analysis, and mapping of the many spatial datasets enabled by GIS v.10.7 (Geographic Information System) led to a thorough understanding of the geological setting. The main resource for integrating wellbore data and performing advanced analysis at the time was Interactive Petrophysics (IP) software version 2018 (V3-5). The IP software enables analysis of log data using petrophysical parameters derived specifically from LAS (Log ASCII Standard) files. The Petrel (V: 2019) program built many petrophysical models, ensuring the availability of all necessary logs for accurate assessments of water saturation, hydrocarbon saturation, effective and total porosity, and shale volume (V_{sh}). Petrophysical cut-off values: The vertical boundaries between units (clean reservoir, low-quality reservoir, and non-reservoir/barrier) were structurally determined using quantitatively calibrated cut-off values for effective porosity (effective porosity) and Shale Volume (V_{sh}) from CPI (computer processed interpretation) logs.

3.2. 3D Geological Model

3.2.1. Structural modeling

The geological model, which illustrates the specifics of subsurface formation and explains any potential fault or fold effects, is the main stage of this study. Fig. 3 shows the top of Zubair structure. Before the data were imported into the Petrel software stage, the reservoir contour map was utilized to create a structural model that was digitized using Digger 5 software.

3.2.2. Gridding

Using Petrel software (2019), grids were created based on the contour map explanation. The Early Cretaceous Zubair reservoir in the Luhais Oilfield has a total gross thickness of about 120 m, as shown

in the 3D structural model and structural contour maps in Fig. 4. The horizontal grid resolution (X and Y axes) was set to a standard grid spacing of 100 x 100 m in order to optimize the distribution of lateral properties within the anticlinal structure.

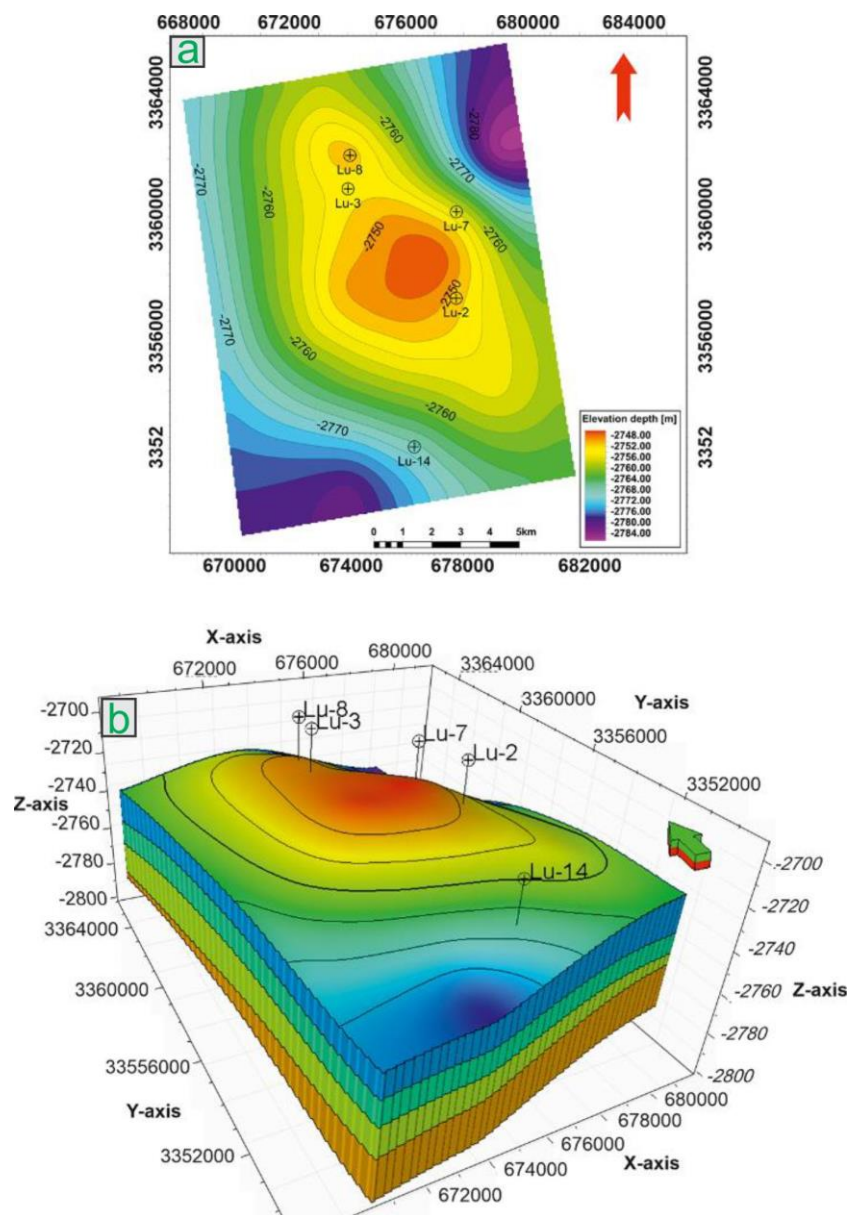


Fig. 3. a) Top of the Zubair Formation in Luhais structure; b) 3D structure map of Zubair Formation in Luhais oilfield

The color-coded subdivisions in Fig. 4 illustrate how the vertical grid resolution (Z axis / Grid Cell Thickness) is divided into five main stratigraphic layers. Average vertical grid cell thickness of 1.5 m (which varies between 1 and 2 m depending on local structural thickness variations) is achieved by further sub-gridding the major layers into finer sub-layers.

4. Results and Discussion

4.1. Lithological Identification

Lithological determination is based on the differential responses of porosity logs to different mineral types. Each of the three porosity logs (neutron, density, and sonic) can provide an accurate

indicator of formation lithology. The Zubair Formation in both wells consists mainly of sandstone with minor shale intervals.

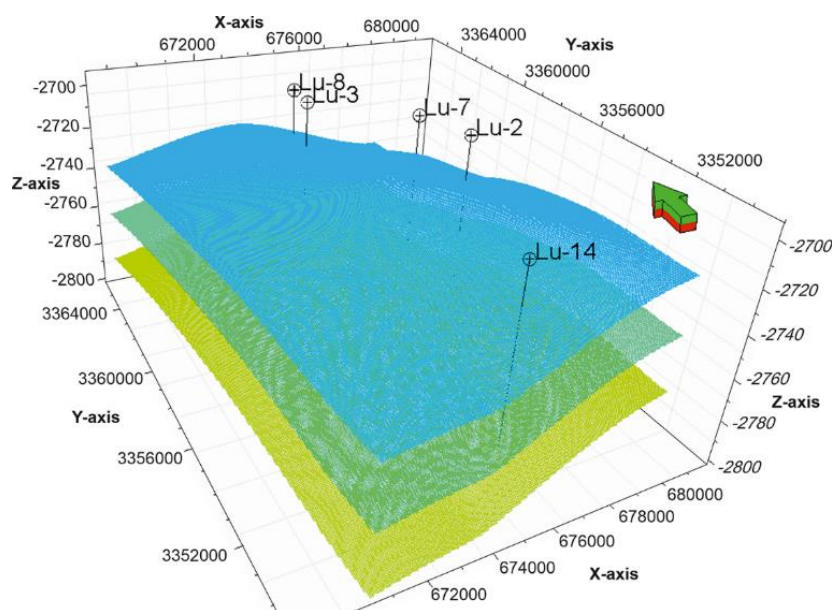


Fig.4. 3D skeletons of Zubair Formation in Luhais oilfield

4.1.1. Zone and layering

This stage requires inserting the main reservoir horizons into the grid. The structure can form isolated reservoir zones above, between, and below the major horizons, as shown in Fig. 5.

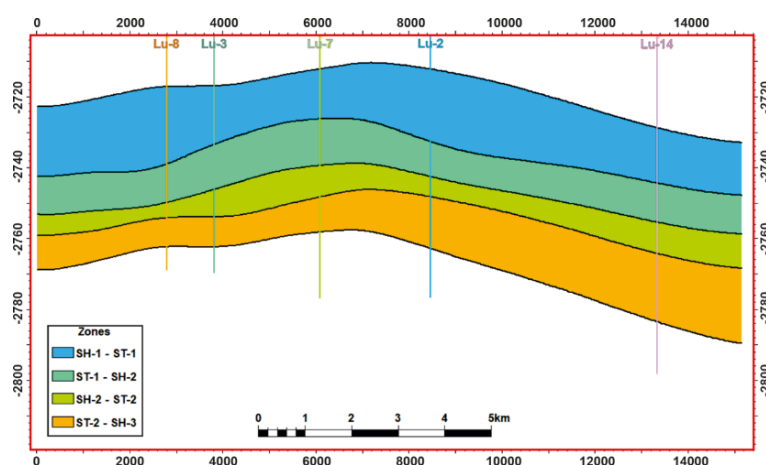


Fig. 5. 2D zonation and layering of the upper Zubair Formation in Luhais oilfield

4.1.2. M-N cross-plot

The main objective of this cross-plot is to identify the data from the three porosity logs to determine the lithology-dependent M and N values. In the Sonic-Neutron and Sonic-Density cross-plots, the parameters M and N show the slopes of specific lithology lines, respectively. Because of the M and N are primarily independent of porosity, their cross-plot is a robust tool for mineralogical identification. The mathematical definitions of the M and N parameters were built by Gibson (1982) and subsequently detailed in Schlumberger (2005) lithology charts.

According to the M–N cross-plot, the reservoir formation is primarily composed of sandstone with a thin layer of shale. The majority of data points are found in the sandstone field, indicating that both wells have a predominant sandy lithology (Fig. 6).

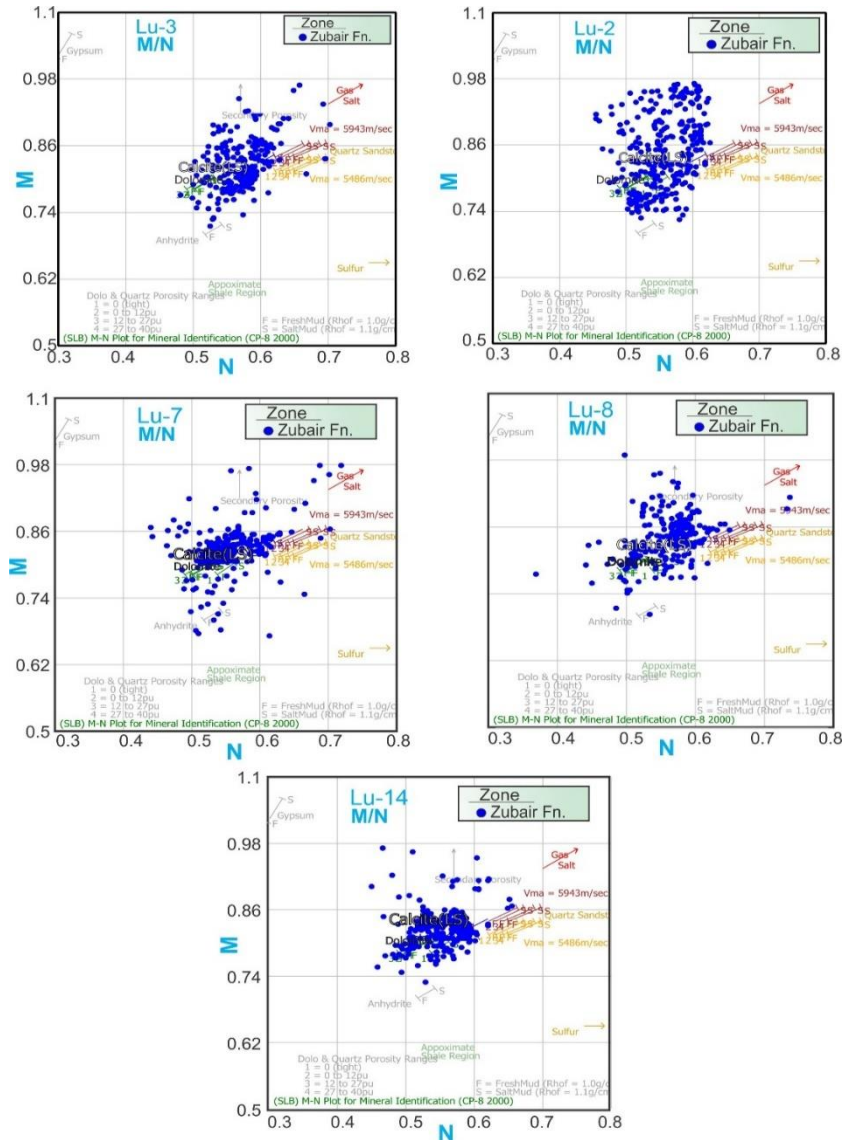


Fig. 6. M – N cross plots cross plots of the main reservoirs

The equations suggested by Schlumberger (2005) for the two independent variables, M and N, are described using this methodology.

$$M = \left(\frac{\Delta t_f - \Delta t}{\rho_b - \rho_f} \right) \times 0.01 \quad (1)$$

$$N = \frac{(\emptyset N_f - \emptyset N)}{(\rho_b - \rho_f)} \quad (2)$$

where Δt_f = Travel time of fluid within the formation ($\mu\text{s}/\text{ft}$), Δt = Travel time of the formation ($\mu\text{s}/\text{ft}$), ρ_b = The density of the formation (g/cm^3), ρ_f = The density of the fluid (g/cm^3), $\emptyset N_f$ = The neutron porosity of the fluid (v/v), $\emptyset N$ = The neutron porosity of the formation (v/v).

4.1.3. (MID) Cross-Plot

Lithology, gas, and secondary porosity can also be detected using the matrix identification (MID) cross plot. Lithology can be readily ascertained using the apparent transit time in a rock matrix (Atma). Three logs are required to use the MID cross plot: density, neutron, and sonic logs. The lithology of

these logs is important (Asquith and Krygowski, 2004). The apparent total porosity (ϕ_{ta}) must be computed using the observed neutron density.

According to the MID cross-plot, quartz (sandstone) predominates in the reservoir lithology, a relatively low dolomite content. The majority of data points group together close to the quartz field, showing that both wells have a mostly sandy reservoir with a small carbonate input (Fig. 7).

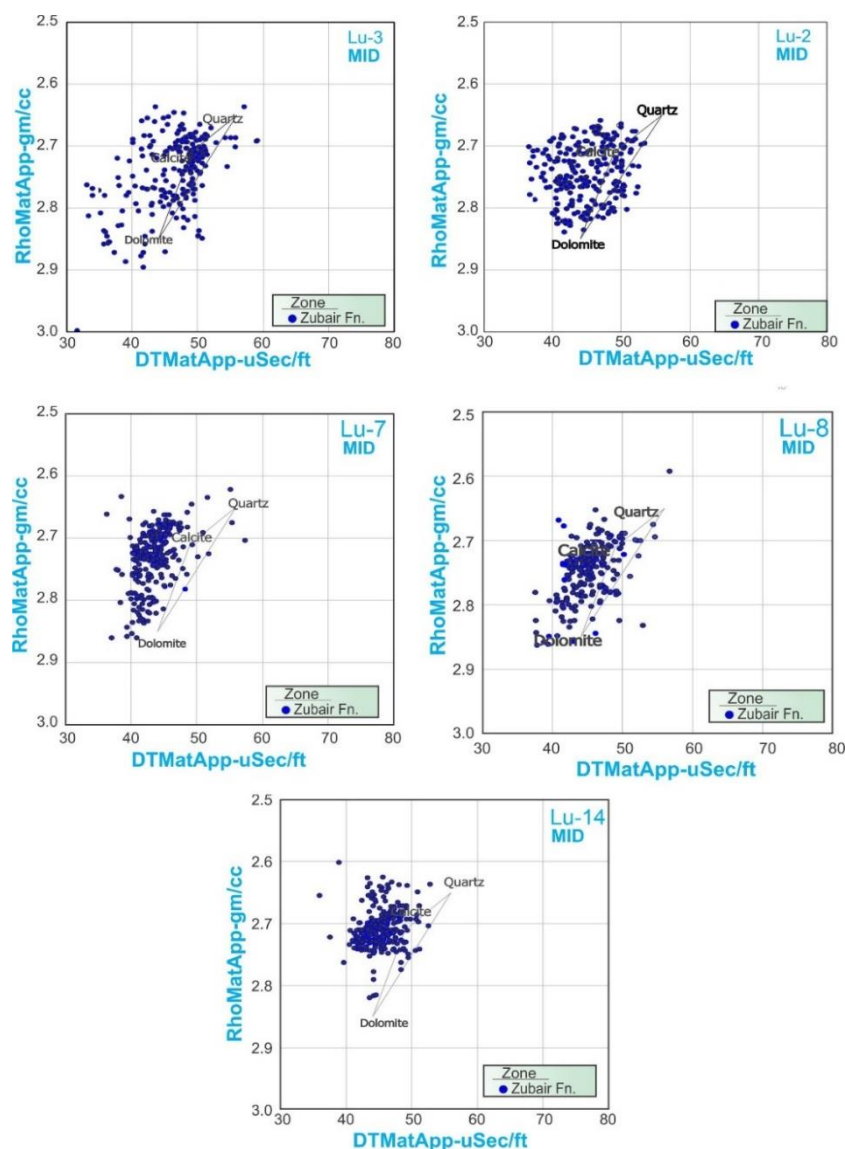


Fig. 7. M – N cross plots cross plots of the main reservoirs

4.2. Petrophysical Parameters

4.2.1. Shale volume (V_{sh}) determination and Its impact on reservoir evaluation

Shale's influence on resistivity measurements is its main negative impact. Compared to pure (shale-free) reservoir rocks saturated with hydrocarbons or formation water, shale frequently contains clay minerals with cation exchange capacity and adsorbed water, which results in decreased resistivity (Hilchie, 1978; Bassiouni, 2019). Equations 3 and 4 show that the shale volume in the Cretaceous era reservoirs was estimated using the older rock equation developed by Larionov (1969). Shale volume is often estimated using gamma-ray logs. Shale Volume (V_{sh}) was calculated using an Interactive

Petrophysics program by determining the maximum and minimum values of the shale, as shown in Table 1.

$$IGR = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (3)$$

$$V_{sh} = (0.33 \times 2^{(2 \times IGR)} - 1) \quad (4)$$

where: IGR = Gamma ray index (v/v), GR_{log} = Gamma-ray reading from the log (API), GR_{min} = GR reading in the clean zone (API), GR_{max} = GR reading in the Shale zone (API), V_{sh} = Shale volume (v/v).

4.2.2. Porosity estimation

Porosity is an important property of rock formations that directly affects their capacity to transfer and store fluids. When defining the reservoir and figuring out how much fluid may be held, the diameters of these pores are crucial. Porosity can be calculated using a variety of techniques, including density, density-neutron, and sonic measurements. Density is one of these techniques that is crucial to this study because it requires fewer adjustments than other techniques (such as mud weight and mud cake corrections). In sand-shale formations, the sonic approach indicates the formation's main porosity, whereas the density-neutron method tends to overestimate the total porosity.

- Total porosity

Total porosity is the ratio of a rock's total pore space to its bulk volume is known as total porosity. An equation to calculate the total porosity using neutron and density logs was proposed by Schlumberger (1974) (Table 1), as follows:

$$\phi_{N.D} = \frac{\phi_N + \phi_D}{2} \quad (5)$$

where $\phi_{N.D}$ = Combination of neutron and density porosities (total porosity ϕ_t), ϕ_N = porosity from neutron, ϕ_D = porosity from density

- Effective porosity

Effective porosity is defined as total porosity less than the percentage of pore spaces occupied by shale and clay. Total porosity and effective porosity are comparable in a clean formation. The effective porosity can be computed using the following formula (Schlumberger, 1972).

$$\phi_E = \phi_{N.D} \times (1 - V_{sh}) \quad (6)$$

where: ϕ_E = effective porosity, $\phi_{N.D}$ = total porosity.

Studying the porosity readings in all the wells of the oilfield (Table 1; Fig. 6), it was discovered that the porosity typically ranges from good (15-20%) to very good (20-25%) according to the classification (North, 1985). Fig. 8 shows the distribution of PHIE of Zubair reservoir after upscaling data from the well logs.

4.2.3. Fluid and formation analysis

Calculation of Water and Hydrocarbon Saturation

In the rock's pores, water and oil come into contact (Hughes, 1999). Because water saturation is a necessary step in determining the amount of hydrocarbon, it is crucial to first determine the amount of water. According to the equation (Schlumberger, 1987), the remaining volume of the voids in the rock indicates the hydrocarbon saturation (S_h), whereas S_w is the ratio of the voids occupied by water to the total volume of voids in the rock (Asquith et al., 2004).

$$S_h = 1 - S_w \quad (7)$$

The Archie (1944) equation for the sand zone that is, for depths with less than 10% log is used to determine water saturation in the uninvaded zone.

$$S_w = \sqrt{\frac{F * R_w}{R_t}} \quad (8)$$

In the flashed zone, water saturation is calculated using the equation of Archie (1944).

$$S_{xo} = \sqrt{\frac{F * R_{mf}}{R_{xo}}} \quad (9)$$

where S_w = water saturation of the uninvaded zone, R_w = water resistivity, ϕt = porosity, R_t = true or deep resistivity of the uninvaded zone, F = Formation Factor.

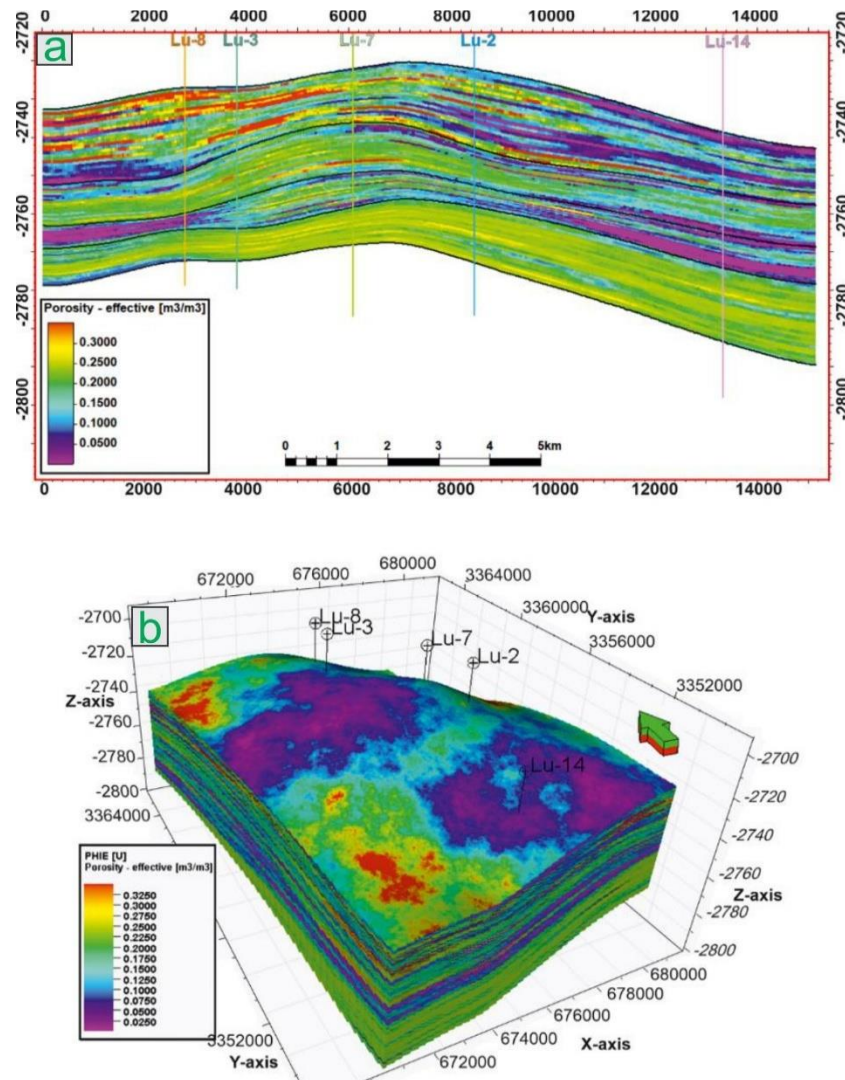


Fig. 8. (a) Porosity distribution of Zubair reservoir along the Luhais structure, (b) 3D model shows porosity distribution of Zubair reservoir in the Luhais Oilfield

Fig. 9 shows the distribution of S_w in the Zubair reservoir after upscaling the data from the well logs.

- Calculation of bulk volume water and movable hydrocarbon

Total volume of water BVW (Fig. 9): The uninvaded zone was calculated using bulk volume water, which is defined as the product of the formation's porosity (ϕ) and water saturation (equation 10). The invaded zone was calculated using Equation (11) (Schlumberger, 1998):

$$BVW = S_w * \phi_{N.D} \quad (10)$$

$$BVSXO = Sxo * \phi_{N,D} \quad (11)$$

where BVW is the bulk volume of water non-invaded area. BVSXO is the bulk volume of water in invaded area.

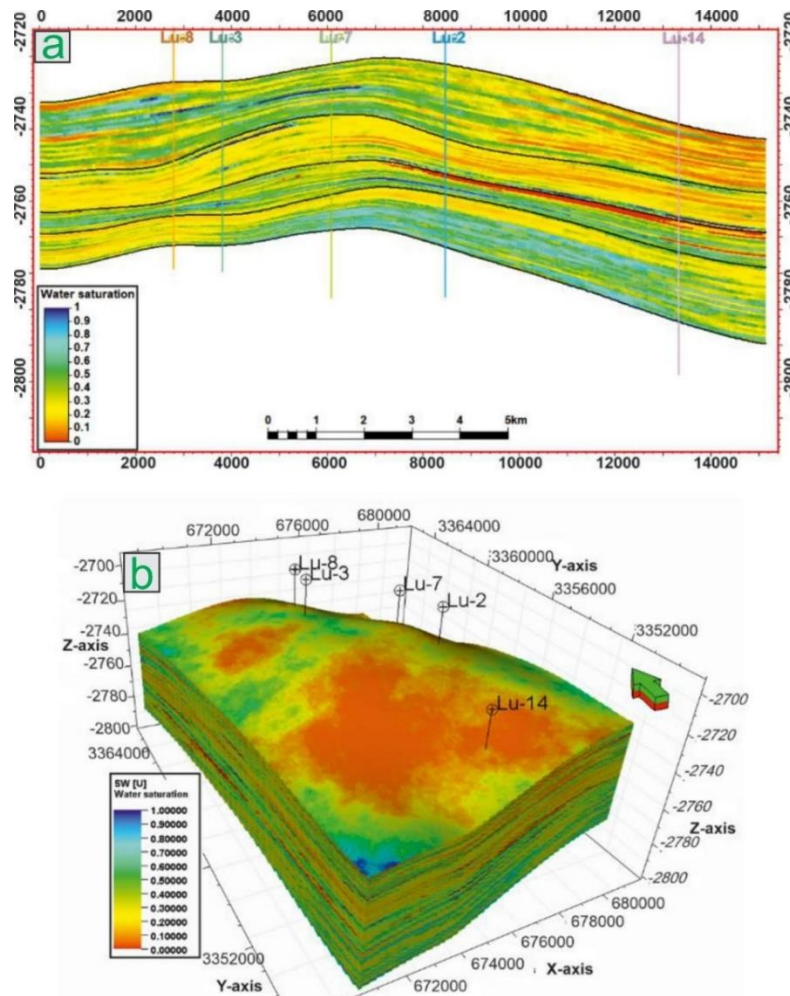


Fig. 9. a) Water saturation distribution of Zubair reservoir along the Luhais structure; b) 3D model of water saturation distribution of Zubair reservoir in Luhais oilfield

It also uses the following equation (Eq. 12) to obtain the movable oil saturation (MOS) (Spain, 1992).

$$MOS = Sxo - Sw \quad (12)$$

The following formula (Eq. 13) is used to determine the residual oil saturation (Schlumberger, 1998).

$$ROS = 1 - Sxo \quad (13)$$

4.3. Calculation of Permeability

Reservoirs can be categorized as poor if their permeability is K1, fair if their permeability is 1K10, moderate if their permeability is 10K50, good if their permeability is 50K250, and very good if their permeability is K>250 MD. The permeability of a reservoir can be evaluated in three ways (Selley, 2000). There are three ways to evaluate the permeability of a reservoir. A permeameter is the third method for determining permeability, followed by the wireline logs (Selley, 2000). In this work, permeability was estimated using wireline logs and the Timur formula, as shown in Fig.10.

$$K = 0.136 * \frac{\phi^{4.4}}{SWi^2} \quad (14)$$

where K = permeability in mD, SWi = irreducible water saturation.

Fig. 10 shows distribution of permeability of the Zubair reservoir after upscaling the data from the well logs.

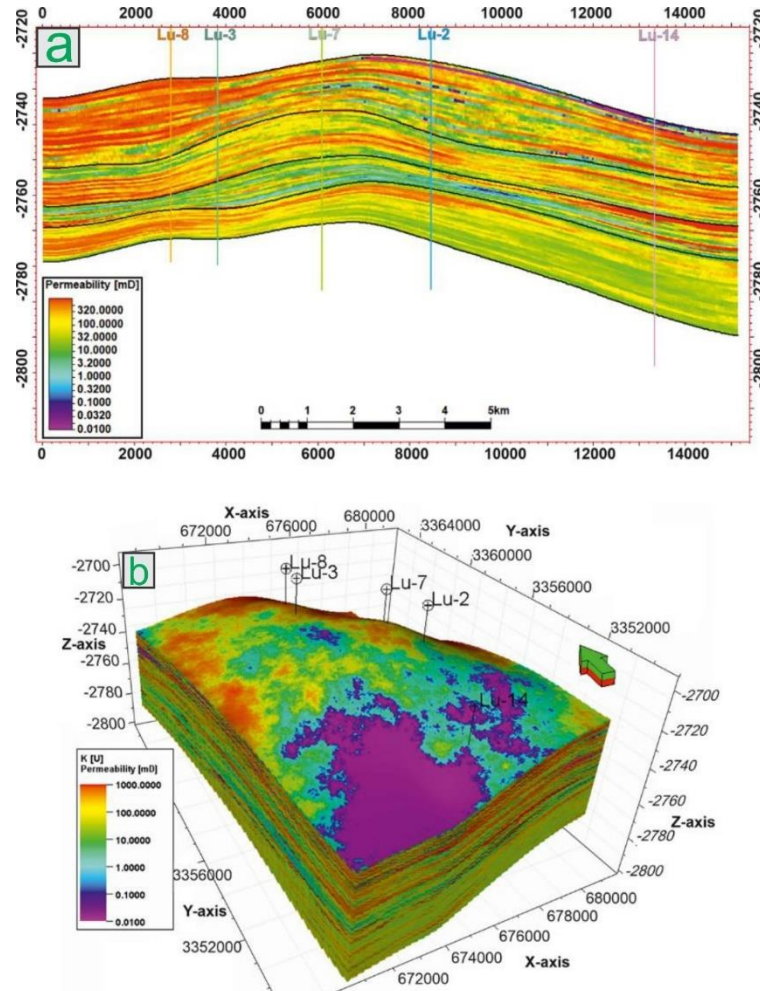


Fig.10. a) Permeability distribution of Zubair reservoir along Luhais structure; b) 3D model of the permeability distribution of the Zubair reservoir in Luhais Oilfield.

4.4. Zubair Formation Reservoir Units Characterization

4.4.1. Unit SH-1

This unit has a thickness of about 12–22 m and is characterized by shale volume ranging from 0.21 to 0.43. Water saturation varies between approximately 0.43 and 0.49, while hydrocarbon saturation ranges from 0.51 to 0.57. Effective porosity ranges from 0.13 to 0.27 and permeability from about 25 to 248 mD, indicating poor to fair reservoir quality. Figs 11–15 show the CPI for wells 2 and 3 (Table 2).

4.4.2. Unit ST-1

This unit shows a thickness of about 9.5–13 m with lower shale volume (0.22–0.71). Water saturation ranges between 0.23 and 0.38 and hydrocarbon saturation between 0.62 and 0.77. Effective porosity varies from about 0.17 to 0.22 and permeability from about 142 to 328 mD, indicating good to excellent reservoir quality as shown in Figs. 11-15 of Luhais Oilfield (Table 2).

Table 2. Petrophysical properties of Luhais Oilfield

Unit	Thick. (m)	PHIE	PHIT	S _w	SH	V _{sh}	K	Interpretation
Well LU-2								
SH-1	22	0.12	0.168	0.42	0.57	0.43	24.58	Oil-bearing shale sand with moderate reservoir qualities
ST-1	9.5	0.16	0.18	0.22	0.77	0.22	328.37	Main Pay Zone: High permeability, low SW, excellent potential
SH-2	3.5	0.14	0.17	0.41	0.58	0.38	146.95	Productive unit with good flow capacity and hydrocarbon storage
ST-2	15.75	0.22	0.23	0.54	0.45	0.06	90.79	Clean sand, high porosity but acting as a transition zone (High S _w)
SH-3	14.25	0.11	0.15	0.85	0.14	0.43	3.98	Non-reservoir/Wet zone due to high water saturation
Well LU-3								
SH-1	12	0.26	0.26	0.49	0.50	0.21	248.8	Excellent oil-bearing reservoir with high effective porosity
ST-1	13	0.22	0.22	0.37	0.62	0.71	141.8	Poor quality reservoir due to excessive shale volume (V _{sh} > 70%)
SH-2	14.5	0.20	0.20	0.35	0.64	0.29	76	High-quality hydrocarbon-bearing zone with stable flow potential
ST-2	6.5	0.25	0.25	0.33	0.66	0.024	137.8	Superior clean sand reservoir with high oil saturation
SH-3	12	0.28	0.28	0.35	0.64	0.29	310.4	Highly productive interval with exceptional petrophysical traits
Well LU-7								
SH-1	14.25	0.20	0.27	0.45	0.54	0.38	446.8	Very good permeability, highly productive shale sand unit
ST-1	13.5	0.18	0.21	0.23	0.76	0.15	333.2	Primary Pay Zone: Excellent saturation and clean formation.
SH-2	6.25	0.13	0.20	0.40	0.59	0.34	50.61	Moderate quality reservoir; commercial oil potential exists
ST-2	11	0.22	0.23	0.53	0.46	0.08	78.24	Porous clean sand but significantly affected by water saturation
SH-3	13.5	0.13	0.19	0.50	0.50	0.9	67.79	Shale-dominated interval; likely non-productive or seal hole
Well LU-8								
SH-1	21.25	0.19	0.24	0.42	0.57	0.35	293.6	Good productive shaly sand with decent flow capacity
ST-1	12.5	0.18	0.21	0.26	0.73	0.18	27.424	Clean sand with high oil saturation; limited permeability
SH-2	3	0.011	0.09	0.55	0.44	0.63	388.15	Tight interval with negligible effective porosity, despite it acts as an on-reservoir or a tight rock
ST-2	8.75	0.19	0.22	0.21	0.78	0.19	16.356	Stable oil-bearing zone with excellent hydrocarbon saturation
SH-3	9.5	0.09	0.16	0.51	0.48	0.45	354.73	Marginal storage, high permeability may suggest fractures
Well LU-14								
SH-1	14.75	0.06	0.16	0.47	0.52	0.41	512.8	Tight shaly sand interval with very low porosity; acts as a marginal reservoir
ST-1	11.25	0.13	0.18	0.43	0.56	0.31	299.3	Moderate reservoir quality with commercial hydrocarbon potential
SH-2	9	0.06	0.14	0.71	0.28	0.46	424.4	High water saturation zone; poor reservoir storage
ST-2	20	0.21	0.23	0.79	0.20	0.09	46.91	Wet Zone: Predominantly water-bearing clean sand
SH-3	10	0.13	0.18	0.72	0.27	0.26	97.97	Wet Zone: Non-productive shale sand unit

4.4.3. Unit SH-2

This unit has a thickness of about 3.5–14.5 m and shale volume of about 0.29–0.38. Water saturation ranges from 0.35 to 0.41 and hydrocarbon saturation from 0.59 to 0.65. Effective porosity varies from about 0.14 to 0.21 and permeability from about 76 to 147 mD, indicating fair reservoir quality shown in Figs. 11–15 of Luhais Oilfield (Table 2).

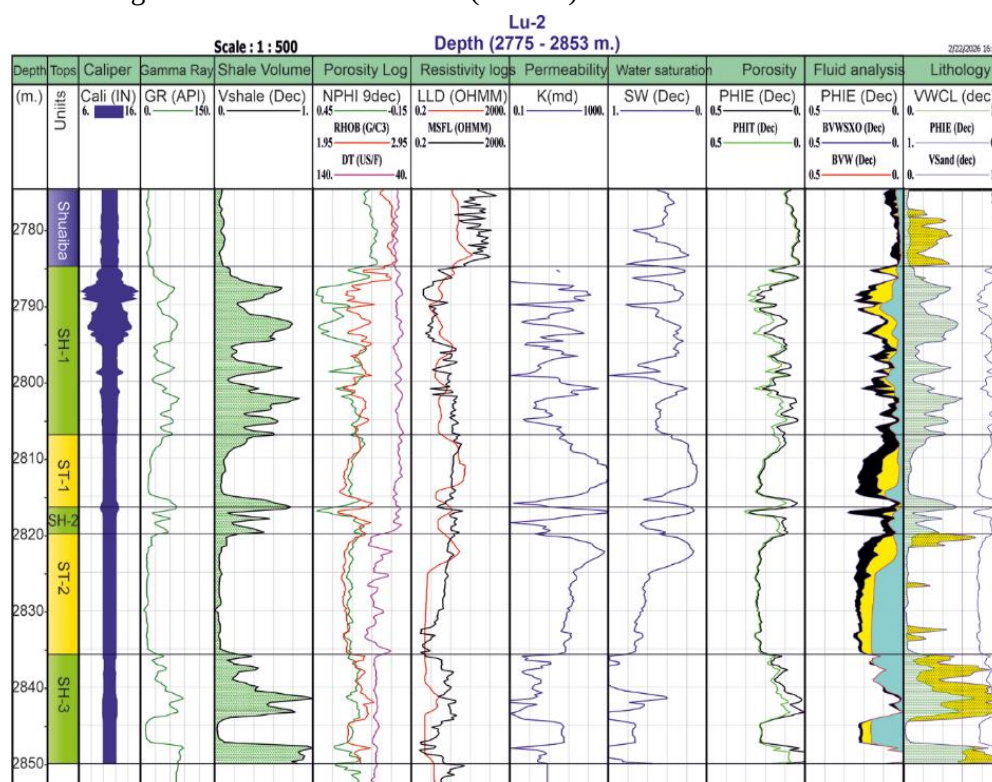


Fig. 11. The CPI of the upper Zubair Formation for the well Lu 2

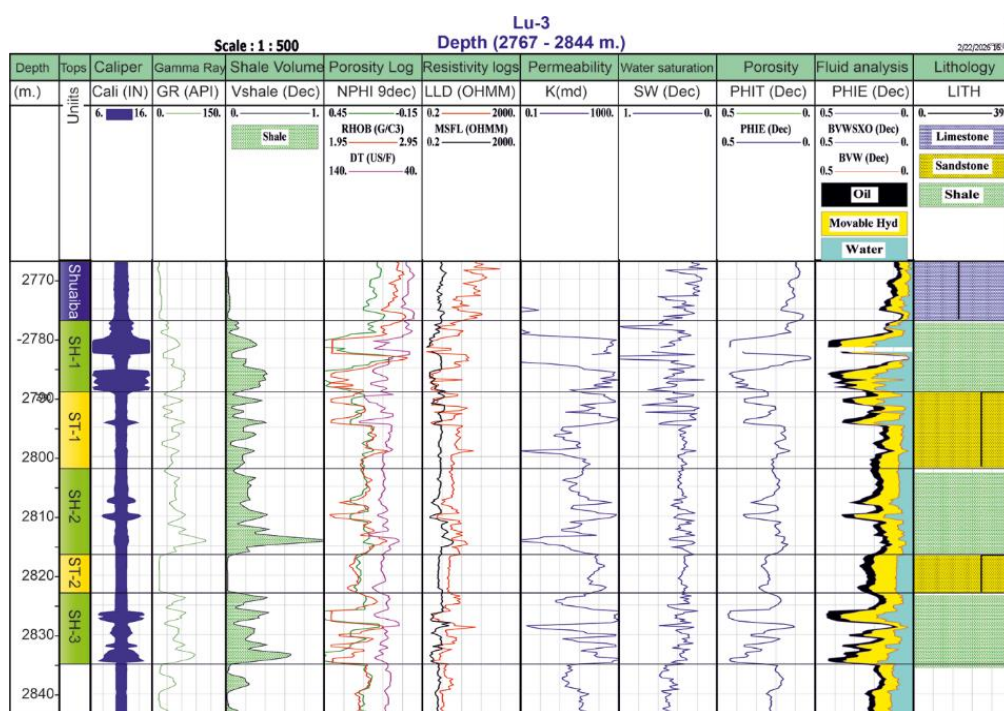


Fig. 12. The CPI of the upper Zubair Formation, an example for the well Lu 3

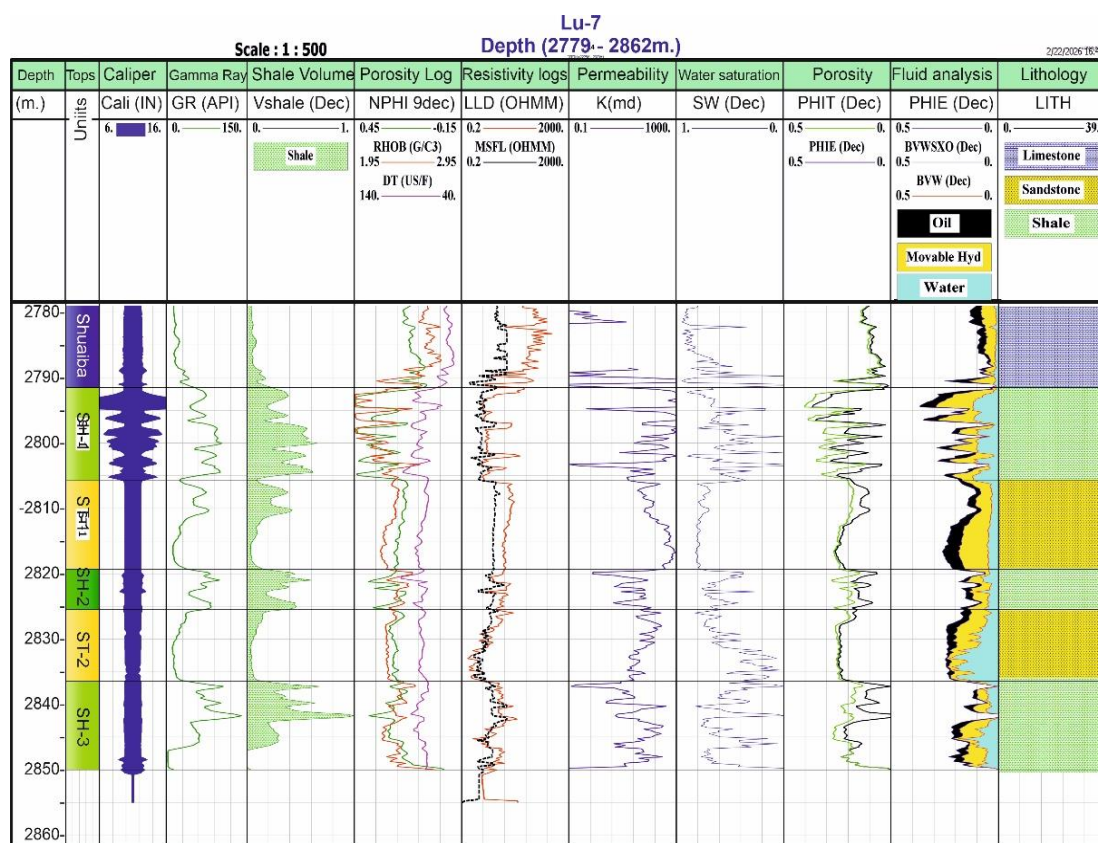


Fig. 13. The CPI of the upper Zubair Formation, for the well Lu 7

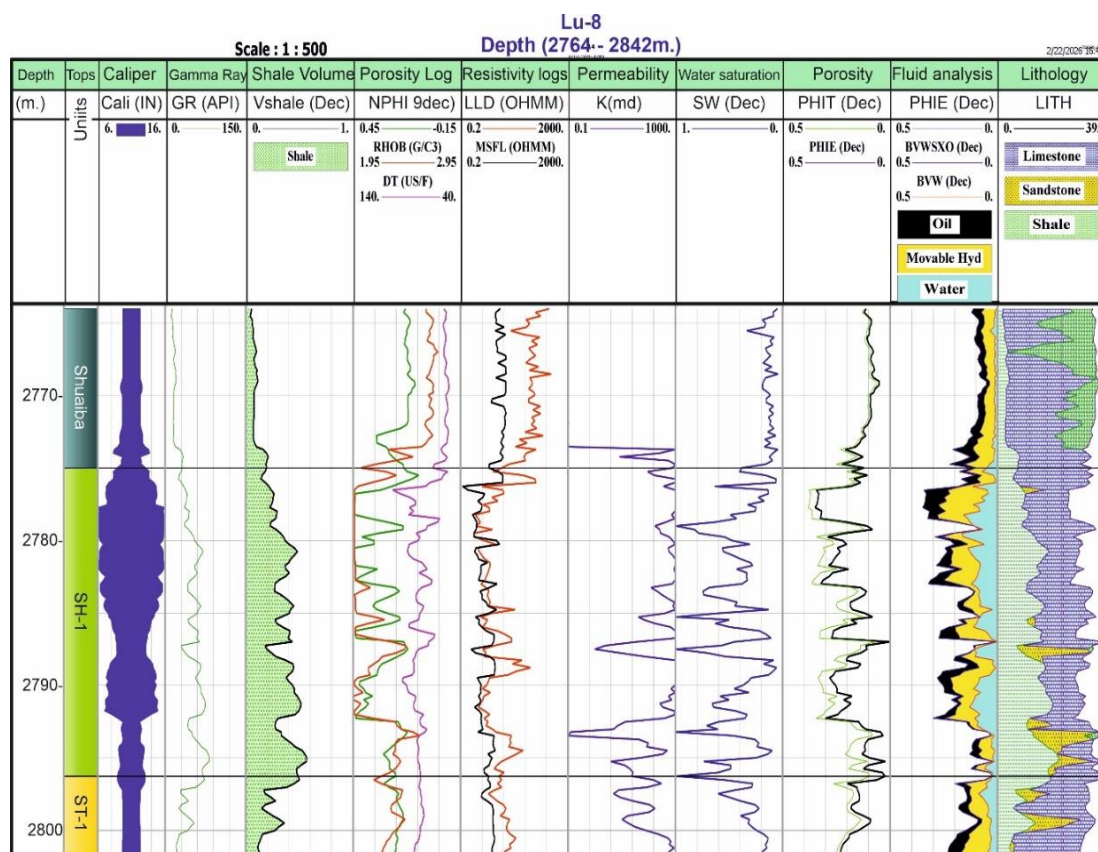


Fig. 14. The CPI of the upper Zubair Formation, an example for the well Lu-8

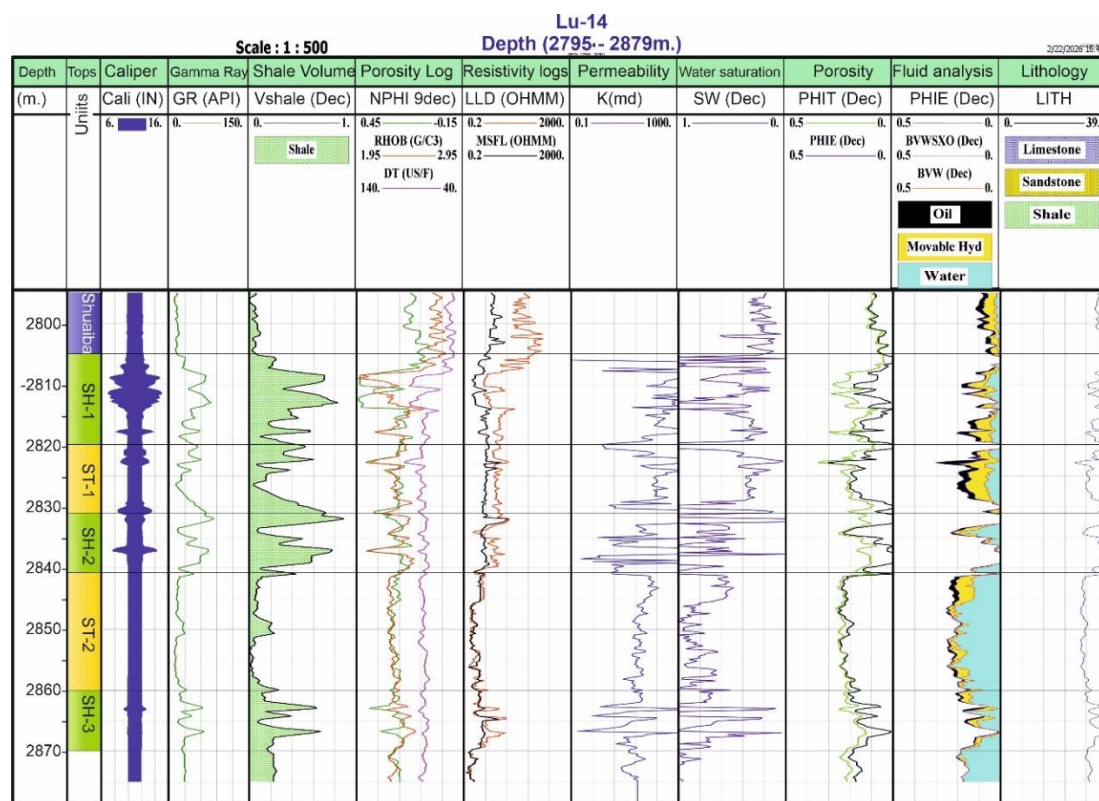


Fig. 15. The CPI of the upper Zubair Formation, an example for the well Lu 14

4.4.4. Unit ST-2

This unit shows a thickness of about 6.5–15.75 m and very low shale volume (0.02–0.06). Water saturation ranges from 0.33 to 0.54 and hydrocarbon saturation from 0.46 to 0.67. Effective porosity varies from about 0.23 to 0.25 and permeability from about 91 to 138 mD, indicating moderate to good reservoir quality, as shown in Figs. 11–15 of the Luhais Oilfield (Table 2).

4.4.5. Unit SH-3

This unit has a thickness of about 12–14.25 m and shale volume of about 0.29–0.43. Water saturation ranges widely from 0.35 to 0.85 and the hydrocarbon saturation ranges from 0.15 to 0.65. Effective porosity varies from about 0.11 to 0.29 and permeability from about 4 to more than 300 mD, indicating mainly poor reservoir quality, as shown in Figs. 11–15 of Luhais Oilfield (Table 2).

5. Conclusions

The integrated petrophysical and 3D geological study of the Early Cretaceous Zubair Formation in the Luhais Oilfield has critical conclusions.

The Upper Zubair Formation is a heterogeneous clastic sequence that is effectively divided into five reservoir units. The Upper Sand (SH-1) unit is considered the primary hydrocarbon-bearing interval. Zonation reveals that this unit has the highest Net-to-Gross (N/G) ratio.

Quantitative studies indicate high-quality reservoir characteristics for the sandstone facies, especially in the upper unit (SH-1). The effective porosity (ϕ_e) ranges between 15% and 25%, while permeability values (76–328 mD) suggest a high flow capacity. The low water saturation (S_w) values, which range between 0.22 and 0.37 in these units, indicate important hydrocarbon columns.

The spatial distribution of petrophysical characteristics is successfully demonstrated by the 3D static model constructed using Sequential Gaussian Simulation (SGS). The high-porosity trend in this model is clearly oriented NNW-SSE direction. It sits on the Luhais structural crest. This pattern indicates that the structural axis has the highest depositional energy. The anticline's synchronous growth during the sediment burial history could be the cause of this.

In the field, ST-1 unit is considered a regional intra-formational seal in this part of the Zubair Formation. This is due to the shale volume (V_{sh}) exceeds 60%. By successfully separating the Upper and Lower Sand members, this unit prevented vertical fluid communications.

The findings confirm that the upper sand member of the Zubair Formation is the primary target for hydrocarbon production and has the best reservoir qualities.

Author Contributions: CRediT

Afrah M. Al-Ghazi: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Software, Visualization, Writing original draft preparation.

Amer J. Al-Khafaji: Supervision, Validation, Methodology support, Interpretation of results, Writing review & editing, Project administration

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could influence the work reported in this study.

Funding Sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sector.

ORCID

Afrah M. Al-Ghazi <https://orcid.org/0009-0006-0937-2726>

Amer J. Al-Khafaji <https://orcid.org/0000-0001-8489-394X>

Acknowledgments

The authors express their sincere gratitude to Basra Oil Company for providing all the necessary information to complete this research, as well as for their invaluable cooperation and facilitation of our task. The authors also wish to extend their thanks and appreciation to the Department of Applied Earth Sciences at the College of Science, University of Babylon, for supporting the researchers and utilizing the department's resources to complete this study.

References

- Al Musawi, J.M., Al Jawad, M.S., 2019. Study of different geostatistical methods to model formation porosity (Cast study of Zubair formation in Luhais oil field). In IOP Conference Series: Materials Science and Engineering, 579(1), 012031. IOP Publishing. <https://doi.org/10.1088/1757-899X/579/1/012031>
- Alher, A.A., Aljawad, M.S., Ali, A.A., 2018. Static model of Zubair reservoir in Luhais oil field. Iraqi Journal of Chemical and Petroleum Engineering, 19(1), 57-60. <https://doi.org/10.31699/IJCPE.2018.1.7>
- Al-Khafaji, A.J., Sadooni, F., Hindi, M.H., 2019. Contribution of the Zubair source rocks to the generation and expulsion of oil to the reservoirs of the Mesopotamian Basin, Southern Iraq. Petroleum Science and Technology, 37(8), 940-949. <https://doi.org/10.1080/10916466.2019.1575869>
- Al-Kharsan, A., 1975. Lower Cretaceous Geology of Southern Iraq. AAPG Bulletin.

- Al-Saedi, H.N., Flori, R.E., 2018. Enhanced oil recovery of low salinity water flooding in sandstone and the role of clay. *Petroleum Exploration and Development*, 45(5), 927-931. [https://doi.org/10.1016/S1876-3804\(18\)30096-X](https://doi.org/10.1016/S1876-3804(18)30096-X)
- Al-Shahwan, M.F., AL-Yasiri, A.A., Saqer, M.H., 2018. Petrophysical properties of the reservoir unit (1C) for Upper Shale Member from Zubair Formation in Luhais field. *Iraqi Journal of Science*, 1936-1949. <https://ijs.uobaghdad.edu.iq/index.php/eijs/article/view/529>
- Al-Shahwan, M.F., AL-Yasiri, A.A., Sequer, M.H., 2018. Petrophysical properties of the reservoir unit (1C) for Upper Shale Member from Zubair Formation in Luhais field. *Iraqi Journal of Science*, 59(4A), 1936-1946. <https://doi.org/10.24996/ijs.2018.59.4A.17>
- Al-Zaidy, A.A., Mohammed, K.S., 2017. Petrophysical evaluation and reservoir characterization of the Zubair formation in the Luhais and Rachi oil fields, southern Iraq. *International Journal of Advanced Engineering Research and Science*, 4(12), 237332. <http://dx.doi.org/10.22161/ijaers.4.12.13>
- Archie, G. E., 1944. The electrical resistivity log as an aid in determining some reservoir characteristics. *Petroleum Technology*, 5, 54-62.
- Asquith, G.B., Krygowski, D., 2004. *Basic Well Log Analysis* (2nd ed.). AAPG Methods in Exploration Series 16. AAPG, Tulsa.
- Asquith, G.B., Krygowski, D., Gibson, C.R., 2004. *Basic Well Log Analysis*. American Association of Petroleum Geologists.
- Bassiouni, Z., 2019. Well Logging. In: Davis TL, Landrø M, Wilson M, eds. *Geophysics and Geosequestration*. Cambridge University Press. pp. 181-194.
- Dunnington, H.V., 2005. Generation, migration, accumulation, and dissipation of oil in Northern Iraq. *GeoArabia*, 10(2), 39-84. <https://doi.org/10.2113/geoarabia100239>
- Gibson, C.R., 1982. *Basic Well Log Analysis for Geologists*. American Association of Petroleum Geologists
- Hilchie, D.W., 1978. *Applied Open Hole Log Interpretation*. Douglas W. Hilchie Inc., Golden
- Hughes, 1999. *Petroleum Geology*. Houston, Texas, Baker Hughes.
- Jassim, S.Z., Goff, J.C., 2006. *Geology of Iraq* published by Dolin, Prague and Moravian Museum, Srno.
- Larionov, E.A., 1969. On the number of fixed points of a linear-fractional transformation of an operator ball onto itself. *Mathematics of the USSR-Sbornik*, 7(2), 195-204.
- North F.K., 1985. *Petroleum Geology*. Allen and Unwin Inc..
- Sadooni, F.N., 1996. Stratigraphic and lithological characteristics of Upper Cretaceous carbonates in central Iraq: *Journal of Petroleum Geology*, 19(3), 271-288. <https://doi.org/10.1111/j.1747-5457.1996.tb00434.x>
- Schlumberger, 1972. *Log Interpretation charts*, Houston, Schlumberger Well Services, Inc., Vol.2.
- Schlumberger, 1974. *Log Interpretation*, vol. II Applications: New York.
- Schlumberger, 1987. *Log interpretation charts*, USA.
- Schlumberger, 1998. *Log Interpretation Principles/Applications*. March, Sugar Land.
- Schlumberger, 2005. *Petrel property modeling course*, Schlumberger, 10-320.
- Selley, R. C., 2000. *Applied Sedimentology* (2nd ed.). Elsevier.
- Spain, D.R., 1992. Petrophysical evaluation of a slope fan/ basin floor fan complex: Cherry Canyon Formation, Ward County. *AAPG Bulletin*, 76(6), 805-827. <https://doi.org/10.1306/BDF88E4-1718-11D7-8645000102C1865D>
- Van Bellen, R.C., Dunnington, H.V., Wetzel, R., Morton, D.M., 1959. *Iraq: Lexique Stratigraphique International*. Centre National de la Recherche Scientifique, III, Asie, Fasc. 10a, Paris, 333.