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Comparison of the Petrophysical Properties of the Zubair Formation in the Rumaila and West Qurna Oil Fields, Southern Iraq

Risan H. Ghareep [1], Munther Dhahir ALAwsi [1], Aiad Ali Alzaidy [2]
[1] Department of Petroleum Geology and Minerals, College of Science, University of Diyala, Diyala Iraq
[2] Department of Geology, College of Science, University of Baghdad, Baghdad Iraq

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ABSTRACT

The Early Cretaceous Zubair Formation is a key clastic reservoir in southern Iraq, but reservoir quality varies laterally between major fields. To evaluate and compare Zubair Formation petrophysical properties in the Rumaila and West Qurna oil fields and determine the main pay intervals and producibility. Open hole logs from four wells (RU145, R25, WQ1, WQ3) were quality checked, environmentally corrected, and interpreted using Interactive Petrophysics (IP v3.5). Shale volume was derived from gamma ray, lithology was identified using GR response, density–neutron crossover, PEF and crossplots, and porosity and fluid saturations were computed (including Indonesia watersaturation modeling). The formation is subdivided into upper, middle, and lower zones. Shale volume and carbonate content increase toward West Qurna, while effective porosity and hydrocarbon saturation improve toward Rumaila (highest in RU145). The middle sand member is the main pay zone, partitioned into reservoir units ZM1–ZM3 separated by barriers B1 and B2; West Qurna shows weak oil indications due to high shale and water saturation. Zubair Formation is producible in Rumaila, but largely nonproducible in West Qurna because increased shale and water saturation degrade porosity and permeability.

Corresponding Author:

Risan H. Ghareep
Department of Petroleum Geology and Minerals, College of Science, University of Diyala, Baqubah City, Diyala Governorate, Iraq.
Email: risaan1234@gmail.com

1. INTRODUCTION

The Zubair Formation is a key Lower Cretaceous clastic reservoir system in southern Iraq, and in the Rumaila oilfield its Upper Sand Member (Main Pay) is commonly treated as the principal producing interval. Within North Rumaila, log based subdivision of the Main Pay into three permeable sandstone dominated units (AB, DJ, LN) separated by two shale barriers (C, K) is repeatedly reported, emphasizing strong vertical layering and flowunit compartmentalization [1]-[2]. Across these units, the fundamental petrophysical descriptors—shale volume (Vsh), porosity, permeability, and hydrocarbon saturation—are derived from suites of openhole logs (e.g., GR, density, neutron, sonic, and resistivity) and are used to identify net pay and reservoir quality variations [1]-[2]. This framework provides a consistent starting point for any fieldtofield comparison because it ties lithologic alternations (sand–shale) directly to producibility indicators [2]. Recent Rumailafocused studies also show a clear methodological evolution from conventional log interpretation toward integrated and quantitative reservoir characterization. In North Rumaila, combining conventional logs with NMRderived porosity and permeability (SDRtype approaches) is used to better constrain permeability variability and improve confidence in reservoir quality ranking among AB–DJ–LN, while also documenting spatial trends such as a northward increase in shale content linked to depositional controls [1]. In South Rumaila, statistical workflows histograms, cluster analysis/electro facies classification, and explicit heterogeneity measures (Dykstra–Parson's permeability variation coefficient) are applied to demonstrate that the Main Pay is heterogeneous and can be partitioned into facies such as sand, shaly sand, sandy shale, and shale based on log responses [14]. Together, these Rumaila studies indicate that heterogeneity is not only observed qualitatively but can be quantified and mapped using consistent petrophysical parameters and classification schemes [1], [14].

For a study titled as a comparison between the Rumaila and West Qurna oil fields, the end of the background should more explicitly articulate *what is missing* and *what is new*. The attached literature provides detailed petrophysical evaluation for North Rumaila (including NMR integration) and South Rumaila (including statistical/heterogeneity analysis), and it notes that Zubair members extend to the West Qurna field; however, these sources do not provide a likeforlike, crossfield petrophysical comparison between Rumaila and West Qurna using the *same* zonation scheme (AB–C–DJ–K–LN), the *same* computations, and the *same* heterogeneity/facies analytics [1]-[2], [14].

Research gap (to state clearly): the absence of an integrated, standardized workflow that compares Rumaila versus West Qurna Main Pay properties and heterogeneity metrics on an equivalent basis. Novelty (to state clearly): a unified comparative approach that applies consistent conventional log calculations (Vsh, PHI, Sw/Sh), optional NMR derived permeability/porosity where available, and common statistical/electro facies and heterogeneity measures to directly quantify how and why Zubair reservoir quality differs between the two adjacent fields.

2. GEOLOGICAL SETTING

The study area is situated in Mesopotamian Foredeep of Iraq and encompasses the West Qurna oil field in Basra, southern Iraq (Figure1). Because of its favorable location and vast reserves, it has become one of the most popular destinations for international oil companies and investors interested in profiting from its production [3]. West Qurna Oil Field is among the top large oil producers globally. It is situated in Basra Governorate 65 kilometers north–west of Basra City. It occupies a large area estimated to be around 8000 km² [4].

Rumaila Oil Field is located about 45km west of Basrah city. It is one of the largest oil fields globally in terms of reserves and production capacity. Rumaila's significance in the global oil market stems from its massive reserves, estimated to exceed 17 billion barrels of oil. The field covers an extensive area of approximately 1,800 square kilometers, making it a crucial asset for Iraq's oil industry.

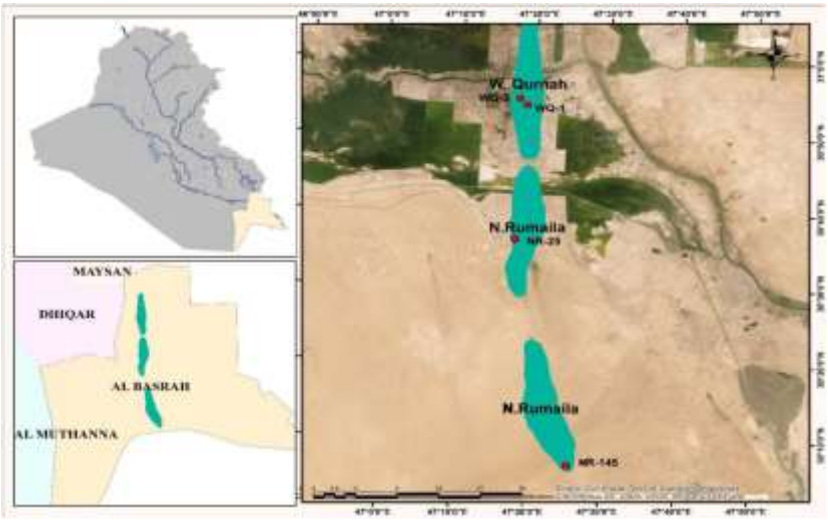

Figure 1. Location map showing the West Qurna Fields.

During the Late Cretaceous period, narrow, linear anticlines define the region's borders. Zubair Formation, which was formed during the Early Cretaceous period, spans Iraq, Kuwait, Saudi Arabia, Iran, and Syria. The area is known for low Alpine activity and mountain building but experiences sinking and gathering of Quaternary sediments. The basin shows an uneven foredeep shape, with the Neogene succession thickening notably towards the east [5]. During the early Cretaceous era, Zubair Formation, made up mainly of oil containing sandstone and shale layers, served as an important reservoir and oil source. The Zu24 well is characterized by a standard segment, with a thickness of 389.33 m and is separated into five individual layers. The formation consists of five lithological units: Upper Shale (USM), Upper Sandstone (USSM), Middle Shale (MSM), Lower Sandstone (LSSTM), and Lower Shale (LSM). The shale proportion reduces quickly towards the southwest, whereas the sandstone proportion decreases towards the northeast. Significant focus has been placed on the formation following the drilling of the first oil well in southern Iraq in 1948. The area is in the southernmost part of the Mesopotamian zone, specifically in the Zubair subzone [6].

3. MATERIALS AND METHODS

1) Study area and well selection

To assess and compare the petrophysical properties of the Zubair Formation in the Rumaila and West Qurna oil fields, four wells that penetrate the formation were selected: RU145, R25, WQ1, and WQ3. These wells provide representative coverage across the two fields and allow interwell comparison of reservoir quality and fluid distribution.

2) Data set (openhole logs)

The analysis used openhole wireline logs for each well, including:

- Gamma ray (GR)
- Density (RHOB)
- Neutron (NPHI)
- Sonic (DT)
- Caliper
- Resistivity (including deep resistivity, *Rt*)

All logs were provided in LAS digital format.

3) Data quality control and environmental corrections

A qualitycontrol check was first performed to identify missing intervals, spurious readings, tool irregularities, and boreholerelated effects.

Environmental corrections were then applied to reduce the influence of borehole conditions (washouts indicated by caliper, mud effects, and tool response variations) on the log measurements. The corrected log suite was used as the input for all subsequent calculations.

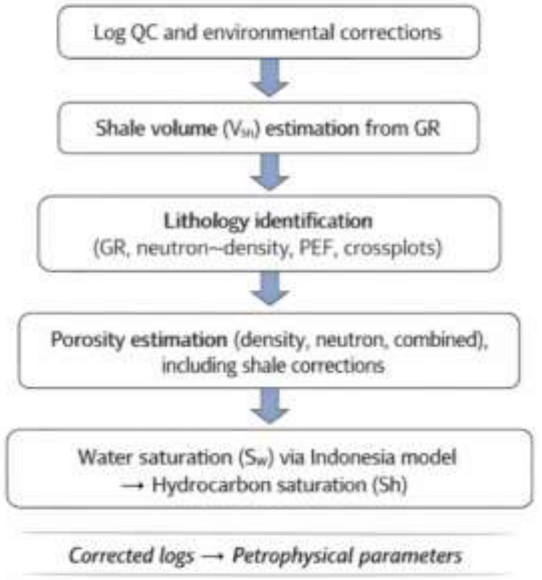

Figure 2. Petrophysical analysis workflow (IP v3.5, 2009).

4) Software and workflow

All log correction and interpretation were performed using Interactive Petrophysics (IP v3.5, 2009). The overall workflow followed these sequential steps (as summarized in the study flowchart and Figure 2):

1. Log QC and environmental corrections.
2. Shale volume (Vsh) estimation from GR.
3. Lithology identification using GR, neutron–density behavior, PEF, and crossplots.
4. Porosity estimation (density, neutron, and combined porosity), including shale corrections.
5. Water saturation (Sw) estimation using the Indonesia model, followed by hydrocarbon saturation (Sh).

3.1 shale volume (vsh) determination

The gamma ray log was used to estimate shale volume because GR responds strongly to radioactive minerals commonly concentrated in shale. Shale volume was calculated using the *older rocks* equation (appropriate here because the Zubair Formation is Cretaceous in age) [7].

$$Vsh = 0.33 * (2^{(2*IGR)} - 1) \quad (1)$$

Where:

- Vsh: Shale volume,
- IGR: Gamma ray index which was acquired using the following equation

$$IGR = \frac{(GRlog - GRmin)}{GRmax - GRmin)} \quad (2)$$

Where:

- GR_{log} = gamma ray log reading (API units)[1]
- GR_{min} = minimum GR in a clean sand interval
- GR_{max} = maximum GR in a shale interval
- V_{sh} = shale volume (fraction)

[1] *Note on API:* When GR is reported as GR (API), it is expressed in standardized American Petroleum Institute units.

3.2. Lithology identification

Lithology identification is a critical step because it directly affects the interpretation of porosity and subsequent saturation calculations. Lithology across the Zubair Formation in the wells studied was identified using an integrated log approach that included:

- Gammaray response (clean vs. shaly intervals)
- Neutron–density crossover/separation
- Photoelectric factor (PEF) responses
- Neutron–density crossplots

Table 1. PEF values for different lithology of sedimentary rocks [8].

Lithology	Typical PEF (barns/electron)
Clean sandstone	1.7–1.8
Shale	3.5–4.0
Limestone	~5.0
Dolomite	~3.0

3.3. Porosity determination

3.3.1 densityderived porosity (φd)

Porosity from the density log was calculated where matrix and fluid densities are known [9]:

$$\Phi D = \frac{(\rho ma - \rho b)}{(\rho ma - \rho f)} \quad (3)$$

Where:

- ϕ_D = densityderived porosity
- ρ_{ma} = matrix density (e.g., 2.71 g/cm³ limestone, 2.87 g/cm³ dolomite, 2.65 g/cm³ sandstone)
- ρ_b = bulk density from the log
- ρ_f = fluid density (typically 1.0 g/cc fresh, 1.1 g/cc saline)

For clean intervals ($V_{sh} \leq 0.10$), Equation (3) was used directly. For intervals where $V_{sh} > 0.10$, density porosity was corrected for shale effect [10]:

$$\Phi \text{ Dcorr} = \phi \text{ D} - (\text{Vsh} * \phi \text{ Dsh}) \quad (4)$$

Where ϕ_{Dsh} is density porosity in a nearby shale reference.

3.3.2 neutronderived porosity (φn) and shale correction

Neutron porosity was taken from the neutron log and corrected in shaly intervals [10]:

$$\Phi N_{\text{corr}} = \Phi \text{N} - (V_{\text{sh}} * \Phi N_{\text{sh}}) \quad (5)$$

Where ϕ_{Nsh} is neutron porosity in nearby shale.

3.3.3 total and effective porosity

Total porosity was computed as the average of corrected neutron and corrected density porosity:

$$\Phi N.D = \frac{(\phi Ncorr + \phi Dcorr)}{2} \quad (6)$$

Effective porosity was then obtained by correcting total porosity for shale volume (Schlumberger, 1998) [11]:

$$\text{Øe} = \text{Øt} * (1 - V_{\text{sh}}) \quad (7)$$

3.4. Determination of water and hydrocarbon saturation

3.4.1 water saturation (sw) — indonesia model

Water saturation in the Zubair Formation was estimated using the Indonesia equation (Poupon–Leveaux) [12], which is widely applied to shaly clastic reservoirs and is suitable for fresh to brackish formation water conditions. The model uses effective porosity, shale volume, shale resistivity, formation water resistivity, and true deep resistivity:

$$S_{windonesia} = \left(\frac{\sqrt{\frac{1}{R_t}}}{\left(\frac{V_{sh}^{(1-0.5V_{sh})}}{\sqrt{R_{sh}}} \right) + \left(\sqrt{\frac{\varphi_e^m}{a.R_W}} \right)} \right)^{\frac{2}{n}} \quad (8)$$

Where:

- R_t = deep (true) resistivity
- R_{sh} = shale resistivity
- R_w = formation water resistivity
- ϕ_e = effective porosity
- a, m, n = Archie/Indonesia parameters (tortuosity factor, cementation exponent, saturation exponent).

3.4.2 hydrocarbon saturation (sh)

Hydrocarbon saturation in the uninvaded zone was calculated directly from water saturation [13]:

$$Sh = 1 - Sw \quad (9)$$

Where**:**

Sh: hydrocarbon Saturation of the uninvaded zone.

4. RESULTS AND DISCUSSION

4.1 shale volume

The results of Shale volume analysis show that Zubair Formation can be classified as clean sand, shaly sand and shale. For Rumaila oil field, the average shale volume of 0.16 v/v and 0.25 v/v in wells RU145 and R25 respectively, v/v means volume per volume (also written as *vol/vol*). It is a dimensionless volumetric fraction that expresses “how much of something (by volume) exists in a total volume.” Most parts of Zubair Formation in Rumaila wells are considered as clean zones, although some shaly zones, while shale zones which are supported by high gamma ray readings, were recognized at the top and bottom of the formation and as a thin layer in some depth intervals in the middle of Zubair Formation (Figure 3). In contrast, in wells of West Qurna oil field, the average shale volume of 0.33 v/v and 0.35 v/v in wells WQ 1 and WQ3 respectively. Most parts of Zubair Formation West Qurna wells considered as shale zones (high gamma ray reading), except some parts in the middle of the formation considered as clean to shaly zone.

It is obvious from the results of calculated average shale volume, that Zubair Formation might be shaly nature in the wells, and the shale volume is increased towards the west Qurna oil field in comparison with the Rumaila oil field. These variations in shale content are related to variations in the depositional environment and tectonic activity of the studied fields. West Qurna oil fields may have other depositional conditions involving the accumulating a higher rate of shale.

The shale volume (Vsh) results derived from gammaray responses indicate that the Zubair Formation spans clean sand → shaly sand → shale, which is consistent with log-based workflows that use GRindex/Larionov type transforms and commonly separate *clean* from *unclean* intervals around Vsh ≈ 0.10 (10%) [1],[14]-[15]. In the Rumaila wells, the comparatively lower average Vsh you report (0.16 v/v in RU145 and 0.25 v/v in R25) and the recognition of shale prone intervals at the formation top and base align with published Rumaila interpretations that the main pay is dominantly sandstone (AB, DJ, LN) separated by shale baffles (C, K) and that electrofacies/lithofacies vary from sand to shale due to reservoir heterogeneity [1],[14],[16]. By contrast, the higher average Vsh in West Qurna (0.33–0.35 v/v in WQ1 and WQ3) is compatible with

independent evidence from West Qurna Zubair cores, where spectral gammaray/mineralogical analysis indicates a wide shale volume range (including shale rich samples), supporting a generally more argillaceous character in parts of the reservoir [17]. Such between field differences are plausibly linked to spatial shifts in depositional setting and stratigraphic architecture within the Zubair clastic system where sand body distribution and shale drapes/baffles are expected to vary laterally and they matter because shale content is repeatedly shown to degrade effective reservoir quality (porosity–permeability and saturation estimates) and to strengthen the shale signature on GR logs [16],[18].

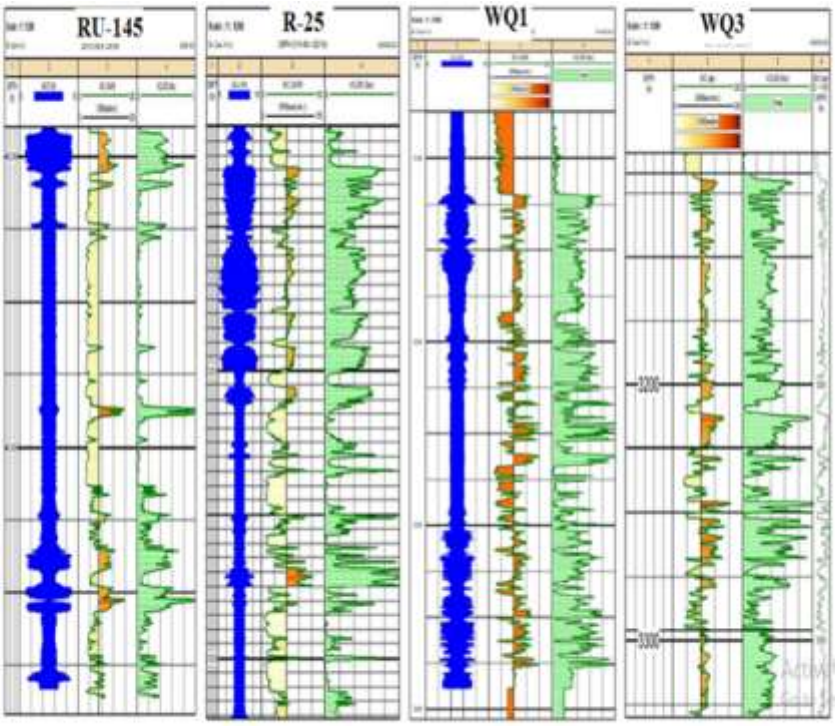

Figure 3. Variations in shale volume of Zubair Formation in the studied wells.

4.2. Lithology identification

Based on the lithology logs response (gamma ray, DensityNeutron crossover (separation) and Photoelectric Factor (PEF), Zubair Formation can be divided into three main zones (upper, middle and lower) (Figure 4). The dominant lithology of the upper zone was shale (probably claystone and siltstone). It is characterized by high Gammaray reading, high Vshale content, large positive separation crossover (High Neutron value), and PEF values of about 3.5 4(b/e). The middle part of Zubair Formation is comprised of dominant sandstone layers separated by barriers of shale layers. This zone is characterized by low gamma ray reading, low Vshale value and PEF values of about 2 (b/e) against the sandy layer. The alternating of clearly defined sand and shale layers shows switching between negative and positive separations in the density neutron log curves, where the negative separation indicates the sand layer, a small positive separation indicates a shaly sand layer and a large positive separation indicates the shale layer. The lower zone of Zubair formation is highly dominated by shale, containing very thin layers characterized by narrow interlayers of sand, where the gammaray, V shale, PEF, neutron and density logs give higher values compared to the middle zones. In WQ1 and WQ3 wells, there are some depth intervals at which the PEF value indicates the presence of carbonate lithology (limestone and dolomite), which probably occurs as cement materials.

In addition to GR, Volume of Shale, PEF and Density Neutron separation, the Density Neutron cross plot was used for lithology identification of the wells (Figure 5). The distribution of data points of Zubair Formation in Rumaila wells indicates clean sand, shaly sand and shale lithology. The clean data of low gammaray response aligns on the sand line while shaly data and shale move toward the shale effect location in the cross-plot curves. In west Qurna wells, most of the data points of high gamma ray responses shifted towards the shale trend because of the shale effects.

The lithology log responses you report (GR, density–neutron separation, and cross plot behavior) support a tripartite vertical organization of the Zubair Formation into shale dominated upper and lower intervals bracketing a middle, reservoir prone interval of alternating sandstone and shale, which is consistent with Rumaila studies where low GR and negative NPHI–RHOB separation characterize cleaner sandstone reservoir units (e.g., AB/DJ/LN), while high GR and positive separation mark shale/dirty intervals and sealing/barrier units [1],[16]. In South Rumaila, the same concept of log defined facies variability is reinforced by electro facies/cluster results that classify the main pay into sand → shaly sand → sandy shale → shale based on GR and porosity log behavior, emphasizing heterogeneity even within the productive upper sand member [14]. Likewise, neutron–density cross plots have been shown to effectively separate cleans and clusters from shale effect trends in Rumaila's Zubair succession (e.g., the Middle Shale Member subunits), strengthening the interpretation that cross plot shifts toward the shale trend reflect increased clay influence rather than merely porosity changes [18]. When compared to Rumaila, your observation that West Qurna data points shift more strongly toward the shale trend is compatible with core-based evidence from the West Qurna Zubair reservoir showing wide variability in shale volume and mineralogical heterogeneity within sandstone samples [17], as well as regional log-based evaluations of the Zubair upper sand that document alternating clean/dirty sands and shale packages at reservoir unit scale [15]. Finally, the occasional indication of non-siliciclastic components in West Qurna (e.g., carbonate signatures) is plausibly consistent with laboratory observations of carbonate presence/limestone like behavior in some West Qurna Zubair core plugs, which could locally influence density related to log responses and apparent lithology [17].

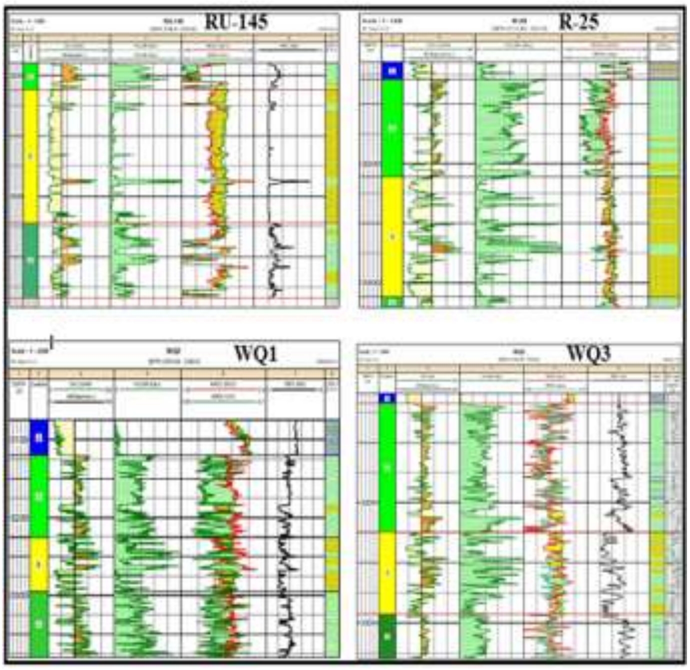

Figure 4. lithology identified from logs response of Rumaila and West Qurna wells

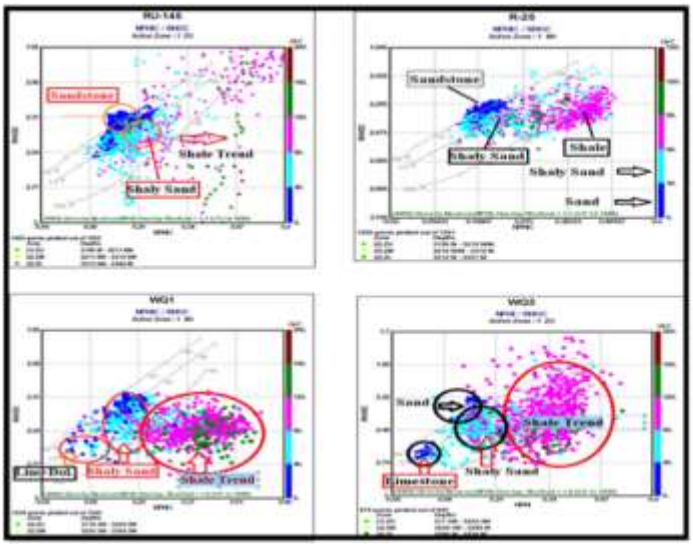

Figure 5. Neutrondensity crosses plot of Rumaila and west Qurna wells.

4.3. EFFECTIVE POROSITY DETERMINATION.

The results of calculated effective porosity for different zones in the wells were summarized in Table 2. In addition, Figure 6 demonstrates that the minimum value of effective porosity is in the shale zones (upper and lower Zubair zones), while in the sandstone zone (ZM) the effective porosity is almost the same value as the total porosity. The average value of effective porosity for the upper and lower zones (ZU and ZL) of Zubair Formation in both fields ranges from Negligible to poor porosity, while for the sandstone zone (ZM) range from good porosity for Rumaila wells to poor for wells of West Qurna oil field. The effective porosity of the sandstone zone (ZM) reaches the highest average value of 0.17(v/v) at the RU145 well and decline to reach the minimum of 0.7(v/v) at the WQ3 well northern of the studied area. The average effective porosity of sandstone (ZM) decreases along the direction where sandstone thickness decreases and shale volume increases. Accordingly, the decreasing in effective porosity of middle zone (ZM) is caused by combined effect of compaction and increasing shale and silt content, whereas increasing clay particles lead to close the pores and caused in reducing porosity of sand stone layer, and this is leading to lack of oil production in west Qurna oil field in comparisons with Rumaila oil field.

Table 2. Effective porosity in different zones of the wells.

Well no.	ZONE Name	Effective porosity (v/v)		
		Minimum.	Maximum.	Average
Ru145	ZU	0	0.34	0.05
	ZM	0	0.26	0.17
	ZL	0	0.4	0.08
R25	SH	0	0.16	0.06
	ZU	0.006	0.25	0.09
	ZM	0	0.24	0.13
	ZL	0.03	0.14	0.09
WQ1	SH	0	0.17	0.06
	ZU	0.002	0.21	0.08
	ZM	0	0.26	0.09
	ZL	0	0.23	0.07
WQ3	SH	0	0.04	0.01
	ZU	0	0.43	0.1
	ZM	0	0.22	0.07
	ZL	0	0.32	0.09

The effective porosity pattern across the Zubair Formation zones is strongly lithology controlled, with negligible–poor effective porosity in the shale dominated intervals (ZU and ZL) and markedly better values in the sandstone dominated middle zone (ZM), where effective porosity approaches total porosity because the pore system is more interconnected and less clay bound. This behavior is consistent with regional Zubair evaluations in Rumaila that report good reservoir quality where shale volume is low and sandier reservoir units dominate, while shale rich intervals act as barriers and reduce effective pore volume [1],[14],[16]. The observed decrease of ZM effective porosity from Rumaila (e.g., up to ~0.17 v/v) toward West Qurna (down to ~0.07 v/v in WQ3) can be explained by the combined effects of increasing shale/silt content and compaction, which elevate shale volume, introduce more clay bound water, and physically occlude pore throats—mechanisms widely documented in Zubair sand–shale successions where higher Vsh is associated with degraded porosity and poorer flow capacity [1],[15],[18].

In addition, the Zubair reservoir is commonly heterogeneous and facies variable (sand, shaly sand, sandy shale, shale), so lateral facies shifts and clay distribution styles can amplify between field differences even within the same stratigraphic member [14],[16]. Supporting evidence from West Qurna core-based work shows that porosity and permeability vary significantly with depth and mineral/clay content, and that higher shale/clay proportions can adversely affect reservoir quality consistently with the poorer effective porosity and reduced oil productivity inferred for West Qurna relative to Rumaila in the ZM interval [17].

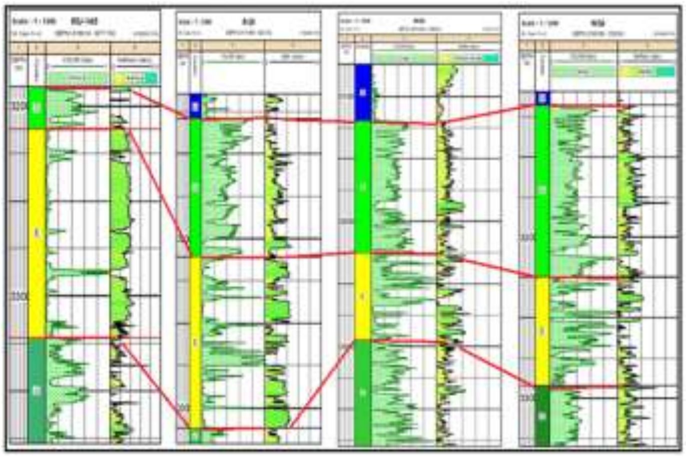

Figure 6. Variations of effective porosity in different zones of Zubair Formation.

4.4. Water and hydrocarbon saturation

The distribution of water and Hydrocarbon saturation for the zones of Zubair Formation are related to shale volume content, as shown in (Figure 7). The lateral variations revealed that the highest values of water saturation and lowest value of hydrocarbon saturation toward the west Qurna oil field, due to the increasing of shale content. The vertical variations indicate that the middle zone of Zubair Formation (ZM) has the highest hydrocarbon saturation in comparison with the upper and lower zones (ZU and ZL). Therefore, based on values of fluid saturation, the middle zone (ZM) represents the main pay zone of Zubair Formation in both the Rumaila and west Qurna oilfields. The observed inverse relationship between shale volume and hydrocarbon saturation is consistent with established petrophysical behavior in the Zubair Formation, where increased shale content degrades effective reservoir quality and can bias resistivity-based saturation estimates toward higher water saturation (Sw) and therefore lower hydrocarbon saturation (Sh) in shaly intervals [16],[18].

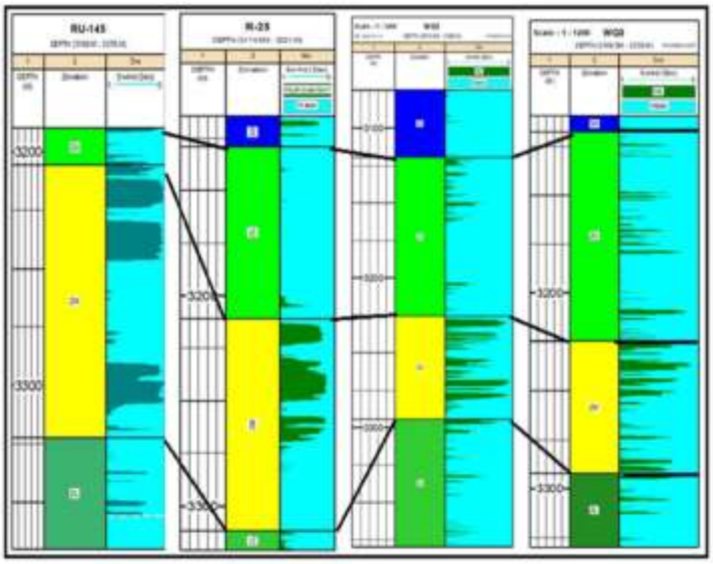

Figure 7. Variations in water and hydrocarbon saturation in different zones of Zubair Formation in the studied wells.

In Rumaila, multiple log-based studies of the Upper Sand Member (main pay) show that the cleaner sandstone reservoir units (e.g., AB and DJ, and in some cases parts of LN) tend to maintain relatively high Sh, whereas intervals with more shale (or poorer reservoir quality) show reduced hydrocarbon saturation and/or higher water influence [1],[14], [16]. Your vertical pattern—with the middle zone (ZM) carrying the highest Sh compared with upper and lower zones—also matches the way productive Zubair intervals are repeatedly identified in Rumaila as those combining low Vsh and favorable porosity, such as the key productive subunits in the Middle Shale Member (notably MSM20 and MSM25), which are characterized by lower shale content and better hydrocarbon potential than the more shale rich, less productive subunits (Hussein et al., 2024).

For the Rumaila–West Qurna comparison, core-based work from West Qurna confirms that Zubair sandstones can contain substantial shale volumes in some intervals (and associated quality variability), which supports your interpretation that higher shale content toward West Qurna could plausibly contribute to higher Sw and lower Sh relative to cleaner reservoir packages [17]. Overall, the saturation distribution you report is therefore consistent with the broader Zubair literature: shale enrichment laterally increases Sw, while the middle (pay) interval in each field concentrates the most favorable saturation signature and should be treated as the principal target for development [1],[14], [16],[18].

4.5. Archie equations

Archie in 1942 was introduced an empirical equation to calculate water saturation. Archie's equation was created primarily for clean sands (no clay minerals) but it does not account for clay minerals such as shaly sands. Based on shaly sands occurrences in Zubair Formation in the studied fields, the existence of shale produces a discrepancy in the reservoir's total resistivity reading, causing the water saturation anticipated by Archie's equation to overestimated. To encounter shaly sand problems and to identify water saturation practically with optimum accuracy.

5. EVALUATION OF RESERVOIR UNITS

Commercially, the upper and lower Zubair Formation are not significant in terms of reservoir, therefore the current section focuses on the middle zone which is believed to be the main reservoir unit in the wells. Based on the final results of computer processing interpretation (CPI using IP V.35 software), the middle zone of Zubair Formation (Sand member) can be divided it to three reservoir units, marked from top to the bottom as ZM 1, ZM 2, and ZM 3, separated by two low porous barrier units namely B1 and B2 (Figures 8,9,10 and 11). These figures show the petrophysical properties and fluid analysis of Zubair Formation in the wells which have been concluded by interpretation of log data. The evaluation of these reservoir units is explained as follows:

1) Reservoir unit ZM1: This unit represents the uppermost units of the middle Zubair Formation. Generally, it is characterized by low gamma ray readings and varying resistivity values, ranging from high to low. The average effective porosity in the RU145 and R25 wells is considered intermediate to good, with values between 0.13 and 0.17, respectively. In contrast, the effective porosity in the WQ 1 and WQ3 wells is poor, measuring approximately 0.09. The average water saturation recorded a low value (0.12) in the RU145 well and increased gradually toward the west Qurna oil field to reach a higher value (0.47) in the WQ3 well. Therefore, this unit is considered an important reservoir unit within the middle of Zubair Formation in Rumaila oil field due to high hydrocarbon saturation in comparison to wells of the west Qurna oil field which are characterized by higher water saturation. The thickness of this unit ranges between 17.25-38m.
2) Reservoir unit ZM2: This unit represents the second reservoir unit in the middle Zubair Formation. The larger thickness of this unit is 57m. in the RU145 well and decreases toward the west Qurna oil field until missing in the WQ 3 well. The higher average effective porosity value of 0.17 is recorded in the RU145 well, decreasing gradually towards the west Qurna oil field due to the increasing of silt content, where it reaches a lower value of 0.1 in the WQ 1 well. In the RU145 well, this unit cab be separated in to two parts, the upper part at depth intervals between 3228.4 and 3246.4 m. characterized by high resistivity reading, low water saturation value representing hydrocarbon bearing part, while the lower part which extend from depth interval 3246.4m3285.4m. is characterized by lower resistivity reading and highwater saturation value representing water bearing part. The average water saturation recorded a low value (0.3) in the R25well and increased to be the highest value (0.52) in the WQ 1 well.
3) Reservoir unit ZM3: This unit represents the lowest units of the middle Zubair Formation. The average effective porosity in the RU145 and R25 wells is considered intermediate to good, with values between 0.12-0.18. In contrast, the average effective porosity in the WQ 1 and WQ 3 wells is poor with an average range between 0.1-0.09. The average water saturation recorded a low value (0.29) in the RU145 well indicating hydrocarbon bearing units, while the higher average value of water saturation was 0.86, 0.46 and 0.53 recorded in R25, WQ 1 and WQ 3 wells respectively indicating water bearing unit with low potential hydrocarbon saturation. The thickness of this unit ranges between 23-36.8 m.

The two impermeable barrier layers (B 1and B 2) which separate reservoir units are characterized by variable thickness increased from 5.2 m in RU145 (southern the study area) to 8 m. In WQ1 well, until merged to be one layer with thickness of 18m in WQ3 well (north of the study area) due to the missing of the reservoir unit ZM2 and increasing shale content in this well. Based on reservoir properties (effective porosity and water saturation) and resistivity log readings of middle Zubair units in the wells, the reservoir units in Rumaila oil field represent the main oil-bearing units and the best units that produce hydrocarbon except ZM3 unit in R25 well which represent water bearing unit due to the highwater saturation value and low resistivity log reading. In contrast, these reservoir units in the west Qurna oil field are characterized by very weak oil show due to the highwater saturation content in the wells of this field under study.

The application of Archie's equation (developed for clean, clay free sands) to the Zubair Formation in Rumaila and West Qurna should be treated cautiously because shaly sand intervals introduce additional electrical conductivity that can bias resistivity based saturation estimates and therefore inflate calculated water saturation (Sw) if clay effects are not corrected; this is consistent with regional Zubair petrophysical workflows that switch from Archie in clean zones to shaly sand saturation models (Simandoux or Indonesia type formulations) when shale volume is significant [1],[14],[15]. In the evaluated middle Zubair sand member, the subdivision into ZM1–ZM3 separated by barrier layers (B1, B2) and the observed increase of Sw westward toward West Qurna, along with local thinning to disappearance of ZM2 and barrier merging where shale content rises, collectively indicate lateral deterioration of reservoir quality and connectivity as argillaceous/silty material increases—an interpretation that aligns with Rumaila studies showing that the best performing Zubair subunits are typically those with lower Vsh, higher effective porosity, higher resistivity, and higher permeability, whereas higher shale content and heterogeneity suppress permeability and productivity [16],[18]. Moreover, Rumaila mainpay studies consistently describe sandstone reservoir packages partitioned by shale baffles (e.g., AB–DJ–LN separated by shale units) and highlight heterogeneity and facies mixing (sand to shaly sand/sandy shale/shale) as key controls on saturation and flow behavior [1],[14]. The comparatively weaker performance toward West Qurna is further supported by West Qurna core-based evidence from the Zubair reservoir showing large depth related variability in porosity and permeability, appreciable shale/clay volumes in some samples, and mineralogical/clay related effects that can degrade flow capacity and complicate log–core agreement [17]. Overall, the Rumaila–West Qurna contrast in ZMunit porosity–Sw behavior is most plausibly explained by increasing shale content and heterogeneity toward West Qurna, reinforcing the need to pair Archie with shaly sand corrections and unit scale stratigraphic partitioning when comparing petrophysical properties across these fields [1,15,18].

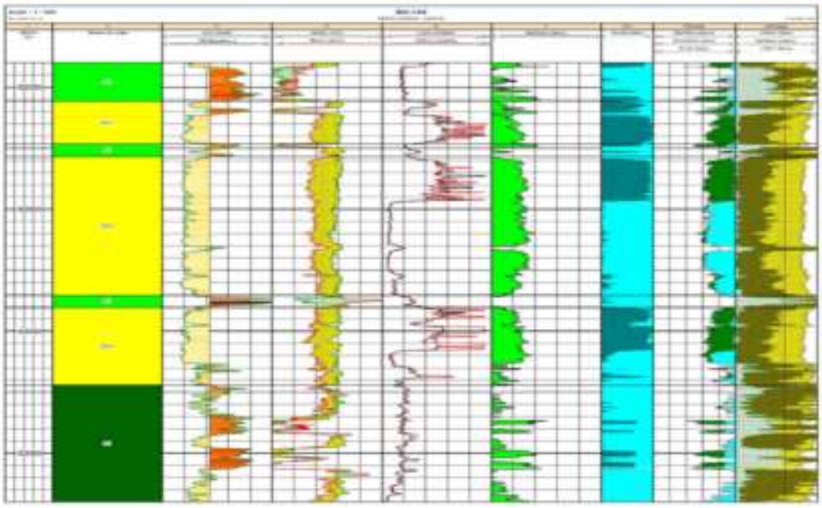

Figure 8. Computer Processed interpretation (CPI) for Ru145 well

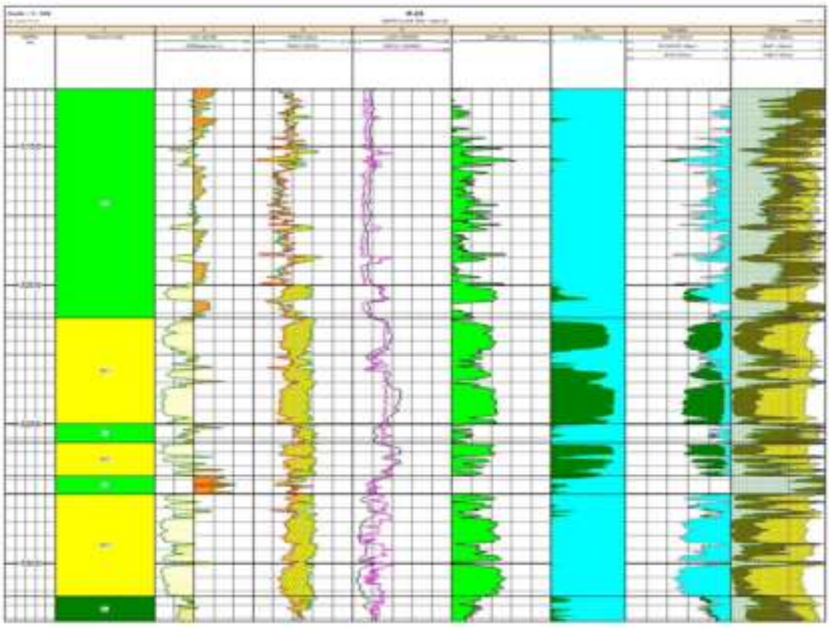

Figure 9. Computer Processed interpretation (CPI) for R25 well

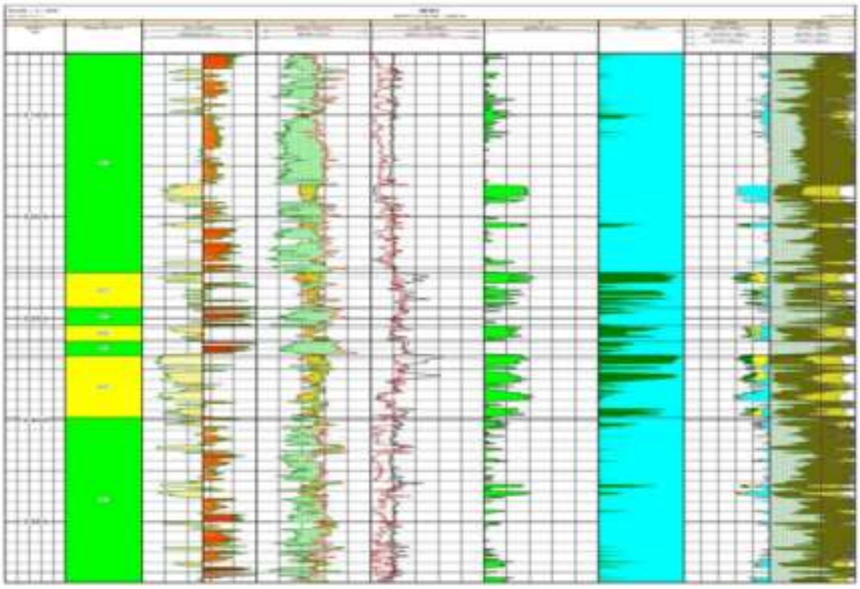

Figure 10. Computer Processed interpretation (CPI) for WQ1 well.

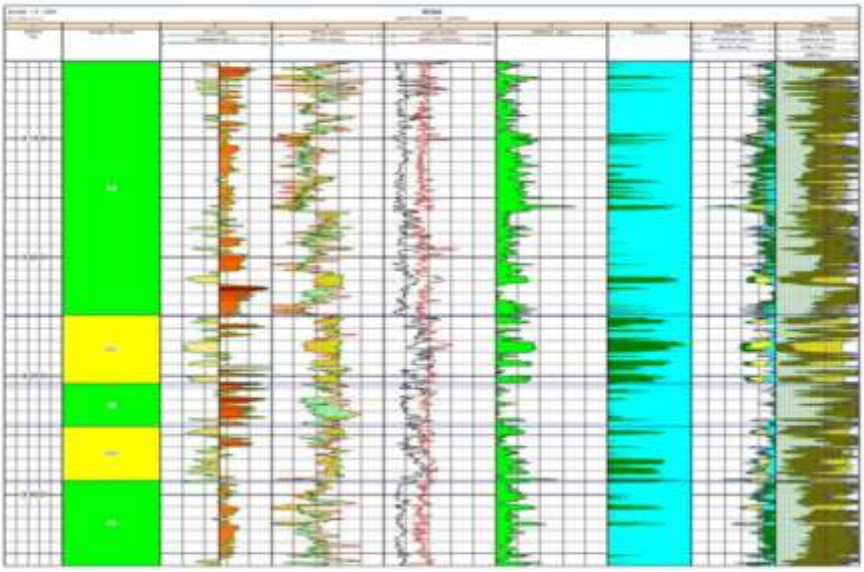

Figure 11. Computer Processed interpretation (CPI) for WQ3 well

6. CONCLUSION

The petrophysical evaluation of the Early Cretaceous Zubair Formation using environmentally corrected open hole logs (RU145, R25, WQ1, WQ3) demonstrates clear lateral reservoir quality deterioration from the Rumaila Oil Field toward the West Qurna Oil Field. The Zubair interval is consistently organized into three main zones: shale dominated upper (ZU) and lower (ZL) zones that are generally non reservoir, and a sandstone dominated middle zone (ZM) that constitutes the principal reservoir interval. Lithology indicators (GR, density–neutron behavior, PEF and crossplots) confirm that cleaner sandstone packages are more prevalent in Rumaila, whereas West Qurna shows stronger shale effects and local indications of carbonate material (likely cement) in some intervals. Shale volume is a primary control on the observed field to field differences. Average shale volume is lower in Rumaila (0.16 v/v in RU145 and 0.25 v/v in R25) and higher in West Qurna (0.33 v/v in WQ1 and 0.35 v/v in WQ3), indicating a more argillaceous character toward West Qurna. This increased shale content is reflected in log responses and is interpreted to relate to lateral changes in depositional conditions (and associated stratigraphic architecture) across the studied area.Effective porosity results reinforce the same trend and confirm that reservoir quality is concentrated in the middle sandstone zone (ZM). While ZU and ZL show negligibletopoor effective porosity in both fields, ZM displays good porosity in Rumaila but poor porosity in West Qurna: the average effective porosity in ZM reaches about 0.17 v/v in RU145 and 0.13 v/v in R25 but decreases to about 0.09 v/v in WQ1 and 0.07 v/v in WQ3. The reduction in ZM porosity toward West Qurna is attributed to the combined effects of increased shale/silt content and compaction, which reduce pore volume and likely restrict porethroat connectivity, thereby degrading permeability and producibility.Fluid saturation behavior is consistent with the shale and porosity patterns, with higher water saturation and weaker hydrocarbon indications toward West Qurna. Vertically, the ZM interval has the highest hydrocarbon saturation compared with the upper and lower zones, identifying it as the main pay zone in both fields; laterally, West Qurna exhibits higher Sw and lower Sh due to increased shale content.

This is evident within the ZM reservoir units, for example in ZM1 where average Sw increases from about 0.12 in RU145 to about 0.47 in WQ3, and in ZM3 where Sw is about 0.29 in RU145 but rises to 0.86 in R25 and remains relatively high in West Qurna (about 0.46 in WQ1 and 0.53 in WQ3). Reservoirunit analysis of the middle sand member shows that ZM can be subdivided into three reservoir units (ZM1–ZM3) separated by two low porosity barriers (B1 and B2), and that stratigraphic/flow unit continuity also degrades toward West Qurna. ZM2 is thickest in RU145 (up to 57 m) but thins toward West Qurna and is absent in WQ3; concurrently, the barrier layers thicken from about 5.2 m in RU145 to about 8 m in WQ1 and merge into a single thicker barrier (~18 m) in WQ3. These changes, together with poorer porosity and higher Sw, explain why Rumaila contains the more prospective oil-bearing units (with the noted exception of ZM3 in R25, which is interpreted as water bearing), whereas West Qurna reservoir units show only weak oil indications.

Overall, the study concludes that the Zubair Formation is producible in the Rumaila Oil Field, where lower shale volume, better effective porosity, and more favorable saturation conditions occur within the ZM pay interval but is largely non producible in the West Qurna Oil Field in the investigated wells because higher shale volume and higher water saturation degrade reservoir quality. Given the shalysand nature of parts of the Zubair Formation, saturation estimation should continue to rely on shalysand models (such as the Indonesia approach applied here) rather than Archie's cleansand equation in clayaffected intervals to avoid overestimating water saturation. Practically, field development and further detailed evaluation should prioritize the ZM reservoir units where resistivity, porosity, and saturation responses indicate hydrocarbon potential, while West Qurna intervals require careful unitbyunit screening because shale enrichment, barrier thickening, and elevated Sw substantially reduce expected performance.

REFERENCES

[1] Z. Abdallah, A. M. Handhal, and R. A. AlAli, "Petrophysical Evaluation of the Zubair Formation's Main Pay Zone Using Conventional and NMR Log Data: Insights from the North Rumaila Field, Southern Iraq," *Iraqi Geological Journal*, vol. 58, no. 1D, pp. 103–122, Apr. 2025. https://doi.org/10.46717/igj.2025.58.1D.7

[2] H. AlAraidi, F. Alnajim, and A. AlKhafaji, "Reservoir Properties of the Upper Sand Member of the Zubair Formation in North Rumaila Oil Field," *Iraqi Geological Journal*, vol. 55, no. 1C, pp. 97–111, Mar. 2022. https://doi.org/10.46717/igj.55.1C.8Ms20220327

[3] C. H. Ali, "Yamama reservoir characterization in the West Qurna oil field, Southern Iraq," *Iraqi Journal of Science*, vol. 57, no. 2A, pp. 938–947, 2016. https://ijs.uobaghdad.edu.iq/index.php/eijs/article/view/7465

[4] T. K. AlAmeri *et al*., "Programed oil generation of the Zubair Formation, Southern Iraq oil fields: Results from PetroMod software modeling and geochemical analysis," *Arabian Journal of Geosciences*, vol. 4, no. 7, pp. 1239–1253, 2011. https://doi.org/10.1007/s125170100160z

[5] A. M. Abdulaziz, A. S. A. Dahab, and M. Y. Najmuddin, "Well log petrophysics of the Cretaceous pay zones in Zubair Field, Basrah, South Iraq," *Open Journal of Geology*, vol. 7, no. 10, pp. 1552–1568, 2017. https://doi.org/10.4236/ojg.2017.710104

[6] R. C. van Bellen, H. V. Dunnington, R. Wetzel, and D. M. Morton (eds.), *Lexique Stratigraphique International*, vol. III, Asie, Fascicule 10a: Iraq. Paris: Centre National de la Recherche Scientifique (CNRS), 1959, 333 p.

[7] V. V. Larionov, *Borehole Radiometry*. Moscow, U.S.S.R.: Nedra, 1969, 127 p.

[8] G. B. Asquith and C. R. Gibson, *Basic Well Log Analysis for Geologists*. Tulsa, OK, USA: American Association of Petroleum Geologists (AAPG), 1982, 216 p. https://doi.org/10.1306/MTH3425

[9] M. R. J. Wyllie, A. R. Gregory, and L. W. Gardner, "Elastic wave velocities in heterogeneous and porous media," *Geophysics*, vol. 21, no. 1, pp. 41–70, 1956. https://doi.org/10.1190/1.1438217

[10] R. Desbrandes, *Encyclopedia of Well Logging*. Paris: Éditions Technip (Institut Français du Pétrole), 1985.

[11] G. Asquith, D. Krygowski, S. Henderson, and N. Hurley, "Basic relationships of well log interpretation," 2004. https://doi.org/10.1306/MTH16823C1

[12] D. A. Krygowski, *Guide to Petrophysical Interpretation*. 2003.

[13] J. Bowler, "The LithoDensity Log," *The APPEA Journal*, vol. 21, no. 1, pp. 200–212, 1981. https://doi.org/10.1071/AJ80022

[14] H. A. AlSamer and F. M. AlNajm, "Petrophysical and Statistical Analysis of Main Pay of the Zubair Formation in South Rumaila Oil Field," *Iraqi Journal of Science*, vol. 65, no. 1, pp. 210–222, 2024. https://doi.org/10.24996/ijs.2024.65.1.19.

[15] Z. M. H. ALTool, I. A. Allamalah, and F. M. AlNimj, "Petrophysical properties evaluation using well logging of the upper sand member of Zubair Formation in Zubair oil Field, Southern Iraq," *Basrah Journal of Science*, vol. 37, pp. 456–480, 2019, https://doi.org/10.2907/basjs.201903089.

[16] H. AlAraji, F. Alnajim, and A. AlKhafaji, "Reservoir Properties of the Upper Sand Member of the Zubair Formation in North Rumaila Oil Field," *Iraqi Geological Journal*, vol. 55, no. 1, pp. 97–111, 2022, https://doi.org/10.46717/jgi.55.1.3.CSmos202203.

[17] M. S. Aljawad, A. A. Ali, and M. D. Abdulkhadim, "Comparison of Petrophysical Properties Measurement Methods in Sandstone Rocks," *Iraqi Journal of Chemical and Petroleum Engineering*, vol. 19, no. 2, pp. 15–20, Jun. 2018. https://doi.org/10.31699/IJCPE.2018.2.3

[18] H. A. Hussein, H. A. Al-Saad, and A. M. Handhal, "Determining Petrophysical Properties Using PLTs and Conventional Logs of the Middle Shale Member (4th Pay) of the Zubair Formation in the South Rumaila Oil Field, Southern Iraq," *Iraqi Geological Journal*, vol. 57, no. 2(E), pp. 183–204, 2024. https://doi.org/10.46717/igj.57.2E.15ms-2024-11-24