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Petrophysical Evaluation of the Jurassic Carbonate Intervals in Northeast Iraq: Insights From Integrated Log Analysis

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ABSTRACT

The East Baghdad (EB) Field, part of the Foredeep Basin of central Iraq and Mesopotamia, is one of the largest but least exploited hydrocarbon deposits of the Middle East. The present study combines both the interpretation of well logs and petrophysical analysis of two sample wells (EB-84 and EB-93) to assess the reservoir potential of the Upper Cretaceous Tanuma, Khasib, and Kifl formations. Neutron density and M-N crossplot lithological identifications show that the successions are dominated by carbonate facies, the major one being limestone with some areas of dolomitization and traces of secondary porosity enhancement in EB-84 through diagenetic dissolution. The petrophysical analysis shows that the Khasib Formation is the most promising unit of the reservoir, with an effective porosity (PHIE) of between 16 and 19 percent and net pay thicknesses of over 85 m, which is comparable to prolific Cretaceous carbonate deposits of the Arabian Plate. Conversely, the Tanuma formation is mostly shale-prone with high water saturations (>0.80 in EB-93), whereas the Kifl Formation, although there are local regions of extensive porosity (>30% in EB-84), is primarily water-bearing. The bulk volume water (BVW) analysis confirms that the EB-84 has hydrocarbon potential (BVW less than 0.06), but lowers the quality of the reservoir of EB-93. These results demonstrate the heterogeneity of the Cretaceous carbonate deposits in the Mesopotamian Foredeep Basin and underline the significance of diagenetic processes to improve the quality of oil reservoirs. The Khasib Formation dominance as a major unit of reservoir is verified by the regional comparison with similar formations (e.g., Mishrif Formation in southern Iraq and Abu Dhabi carbonates) in which Tanuma and Kifl serve as a secondary or marginal interval. This combined research offers an enhanced framework of reservoir quality that underpins the enhancement of exploration and development approaches towards the EB Field.

Keywords: East Baghdad (EB) Field; Mesopotamian Foredeep Basin; Petrophysical log analysis; Reservoir heterogeneity; Secondary porosity.

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1. Introduction

One of the largest undeveloped oil accumulations in Iraq is the East Baghdad (EB) Field (Figure 1), which is in the Mesopotamian Foredeep Basin and the Zagros Basin (Jassim & Goff, 2006). The field is mainly composed of Cretaceous carbonate and clastic reservoirs, such as Tanuma, Khasib, and Kifl, which were deposited under successive marine transgressive−regressive cycles. The Mesopotamian Basin is a prolific hydrocarbon province regionally, with facies changes, diagenesis, and structural setting highly determining the quality of the reservoir (Buday, 1980; Deng et al., 2018; Jassim & Goff, 2006).

The combination of sedimentary activities and diagenetic changes in the East Baghdad Field significantly influences the reservoir properties of the formations. For example, the carbonate ramp stratigraphy of the Khasib Formation features a complex vertical distribution of lithofacies that is essential for interpreting the lateral continuity of the reservoir and its petrophysical characteristics (Al-Ameri, 2011; Sadooni, 2004). Additionally, various diagenetic processes, such as dissolution and compaction, can alter porosity and permeability, ultimately affecting hydrocarbon saturation and recovery potential (J. Wang et al., 2023).

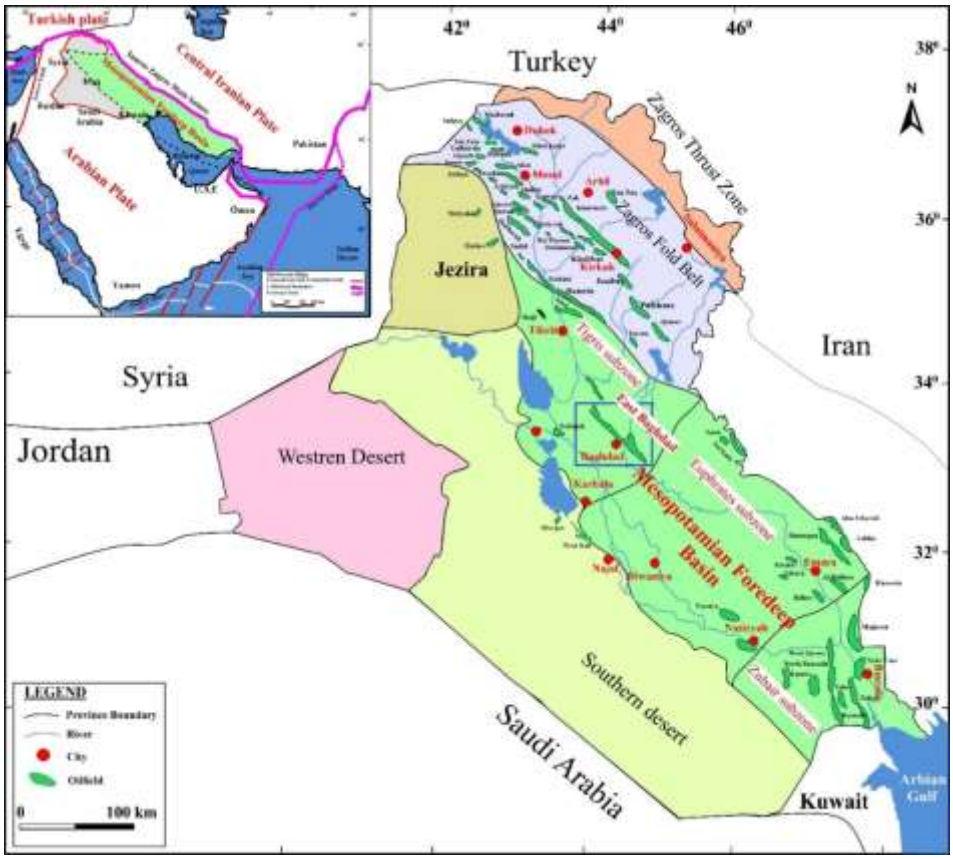


Figure 1. Figure 1. Location map of East Baghdad (EB) Field of the Mesopotamian Foredeep Basin, Iraq (Al-Ameri et al., 2009; Al-Ameri & Al-Khafaji, 2014; Gharib, Abbas, et al., 2024).

Studying these factors thoroughly will not only help optimize extraction strategies but also enhance the overall understanding of reservoir behavior in this hydrocarbon−rich region. This comprehensive approach could lead to more effective exploration and extraction methods in other geological fields worldwide (H. Wang et al., 2024).

In central and southern Iraq, previous works have revealed that the Upper Cretaceous formations are highly heterogeneous with changing porosity, clay content, and fluid saturation (Al-Ameri et al., 2009, 2016; Al-Ameri & Al-Khafaji, 2014; Gharib, Abbas, et al., 2024). Specifically, the Khasib Formation has been

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demonstrated to be one of the main oil−bearing units, although the petrophysical characteristics differ laterally as a result of depositional and diagenetic processes (A. Mohammed et al., 2022). Although the EB Field has the potential that is recognized, not much of the integrated petrophysical investigations have been conducted at the multi−well scale; most researchers have reported findings on petrographic and organic geochimecal descriptions in central and southern Iraq (Abdel-Fattah et al., 2022; Al-Fandi et al., 2020; Al-Jawad & Kareem, 2016; A. Mohammed et al., 2022; Sadooni, 2004; H. Wang et al., 2024).

In the non−continuous core coverage case, well logs and petrophysical analysis are the best tools for characterizing these reservoirs. The gamma ray (GR), resistivity (LLD, LLS), and MSFL, sonic (DT), bulk density (RHOB), and neutron porosity (NPHI) are all standard logs permitting estimation of shale volume, porosity, and fluid saturation. Combined parameters like total porosity (PHIT), effective porosity (PHIE), and water saturation (Sw), along with cutoffs, are needed to characterise net−gross ratios and pay thickness (Bowen, 2003; Herrmann & Bucksch, 2014).

In this work, multi−log petrophysical processes of two wells (EB−84, EB−93) are used to assess the quality of the reservoir in Tanuma, Khasib, and Kifl formations. Volumes of shale are determined through gamma ray response, porosity through density−neutron and sonic cross−plots, and water saturation through the Archie equation. Each formation has net and gross thicknesses reported, and minimum, maximum, and average statistics presented to describe the variability in the reservoirs. The findings give a consistent reservoir−quality framework to the EB Field, sealing gaps in the previous literature and informing reservoir modeling and field development strategies in one of the most important but least exploited Iraqi oil fields.

2. Geological Setting

2.1. Stratigraphy

The East Baghdad (EB) Field is located in the central part of the Foredeep Basin of Mesopotamia, which is one of the major hydrocarbon provinces of the Arabian Plate (Aqrawi et al., 2010; Jassim & Goff, 2006). The major oil deposits in the field are of the Upper Cretaceous period, which are characterized by the Tanuma, Khasib, and Kifl formations (Figure 2).

The Tanuma Formation (Coniacian−Santonian) is made up of argillaceous limestone with interbedded marl and shale. It is a transgressive sequence that is deposited in comparatively deeper−marine environments that partially serve as a source and reservoir unit. The Khasib Formation (Santonian−Campanian) is the most prolific reservoir in Iraq, as shown in Figure 2. It consists mainly of shallow to mid−ramp carbonates of changing grainstone and packstone. Primary intergranular porosity controls reservoir quality and is locally reinforced by secondary dissolution porosity (Jassim & Goff, 2006; Mohialdeen & Raza, 2013). The Kifl Formation (Campanian−Maastrichtian) is a limestone and marly carbonate structure of shallow seas with a greater content of clay compared to the Khasib. Despite its tightness overall, local porous areas play a role in the cumulative reserves (Odin, 2001).

Regionally, the Cretaceous successions are covered by overlying marls and shales, which contain good traps in relation to structural closures. The hydrocarbon source is mainly of Jurassic and Lower Cretaceous age, and the source moved vertically through the faulted regions into the Upper Cretaceous reservoirs (Abdula et al., 2020; Q. Abeed et al., 2011; Al-Dolaimy, 2021; Gharib, Haseeb, et al., 2024; Gharib, Ismael, et al., 2024).

2.2. Structural Setting

The EB Field is situated within the Foredeep Basin of the Mesopotamian Northeast front of the Arabian Plate, which formed through flexural subsidence associated with the Late Cretaceous−Cenozoic Zagros Orogeny (Buday & Jassim, 1987). It trends NW−SE (Figure 1), parallel to the Zagros Fold Belt, and is characterized by dense accumulations of Jurassic to Cenozoic sediments (Aqrawi et al., 2010).

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The EB Field has a structural expression of a broad and low−relief anticline blocked and cut by basement−involved faults that were reactivated in the Alpine tectonism (Jassim and Goff, 2006). The elements of these structures were important in the entrapment of hydrocarbons, formation of fault−assisted closures, and amplification of vertical migration pathways. The anticlinal geometry was controlled by regional tectonic compressional forces and fracture systems, which affect the permeability in tight carbonates (Aqrawi et al., 2010).

The EB Field has a complex structure that is further enhanced by the fact that it is surrounded by fault systems that not only affect the continuity of the reservoirs, but also determine the direction through which fluids are going to be moving. Recent investigations probably indicate that interaction between these faults and the adjacent sedimentary layers can form localized areas of increased permeability, which could be channels for hydrocarbon flow, or they could be barriers in terms of their orientation and ability to seal (Aqrawi et al., 2010). Moreover, the aspect of tectonic activity in the Late Cretaceous−Cenozoic era was also a relevant factor to the stratigraphic distribution of the reservoir quality, which was reflected in the inconsistent thickness and composition of the formations throughout the field (Buday & Jassim, 1987). Such dynamic interactions are important to understand to optimize the methods of extraction and enhance recovery factors, especially in the face of the changing technological environment in the exploration and production of hydrocarbons. The foredeep subsidence, anticlinal folding, and stratigraphic variability combination that controls hydrocarbon accumulation and reservoir heterogeneity in the EB Field.

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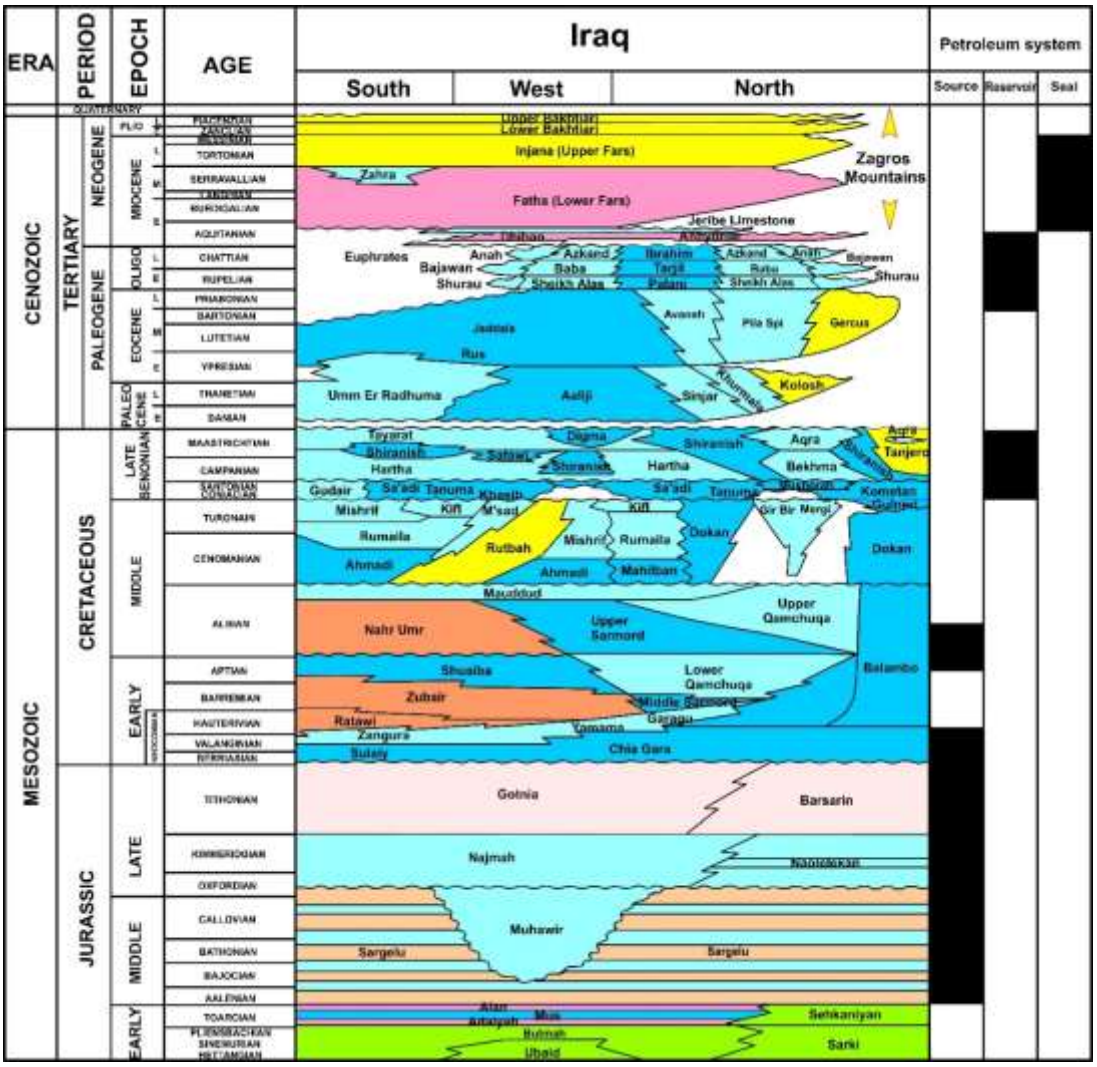


Figure 2. Generalized stratigraphic column of the Mesopotamian Foredeep Basin, Iraq, including the study wells.

3. Materials and procedures

This study was conducted based on well logs acquired from two wells (EB–84, EB–93), which were provided by the North Oil Company (NOC).

Well logging data, which includes gamma ray (GR), density log (FDC), neutron log (CNL), sonic log (DT), and resistivity logs (LLD and MSFL).

These logs were digitized using Digger software and Neural Log software. Environmental corrections were also applied to these logs, and depth calibrations were performed utilizing Interactive Petrophysics 3.5. This software was utilized in order to calculate several parameters, such as volume of shale (Vsh), total porosity (PHIT), effective porosity (PHIE), water saturation (Sw), oil saturation (Sh), and hydrocarbon mobility. CorelDRAW v.2021 and Surfer 16 were used to visualize and determine the petrophysical parameters of the intervals under investigation, and the average values are shown in Tables 1 and 2.

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Table 1. Petrophysical parameters (minimum, maximum, average) of Tanuma, Khasib, and Kifl formations in Wells EB−84 and EB−93. Parameters are total porosity (PHIT), effective porosity (PHIE), water saturation (Sw), volume of shale (Vcl), bulk volume water (BVW), and flushed bulk volume water (BVWSXO).

Well	Formation	Curve	Min	Max	Average
EB−84	Tanuma	PHIT	0.05	0.35	0.22
		PHIE	0.00	0.29	0.17
		SW	0.00	1.00	0.28
		VCLGR	0.14	0.51	0.27
		BVW	0.00	0.09	0.04
		BVWSXO	0.00	0.19	0.10
	Khasib	PHIT	0.02	0.33	0.22
		PHIE	0.00	0.30	0.19
		SW	0.00	1.00	0.15
		VCLGR	0.13	0.37	0.19
		BVW	0.00	0.05	0.02
		BVWSXO	0.00	0.12	0.06
	Kifl	PHIT	0.01	0.45	0.32
		PHIE	0.00	0.45	0.31
		SW	0.00	1.00	0.22
		VCLGR	0.00	0.26	0.05
		BVW	0.00	0.10	0.06
		BVWSXO	0.00	0.15	0.08
EB−93	Tanuma	PHIT	0.07	0.31	0.20
		PHIE	0.00	0.25	0.14
		SW	0.18	1.00	0.86
		VCLGR	0.21	1.00	0.49
		BVW	0.00	0.25	0.11
		BVWSXO	0.00	0.25	0.12
	Khasib	PHIT	0.05	0.34	0.20
		PHIE	0.00	0.31	0.16
		SW	0.00	1.00	0.56
		VCLGR	0.19	0.68	0.32
		BVW	0.00	0.25	0.08
		BVWSXO	0.00	0.25	0.09
	Kifl	PHIT	0.01	0.45	0.17
		PHIE	0.00	0.45	0.15
		SW	0.00	1.00	0.57
		VCLGR	0.00	0.43	0.08
		BVW	0.00	0.19	0.07
		BVWSXO	0.00	0.19	0.10

Before the calculation procedures, the lithology types were determined using neutron, density, and sonic logs. Moreover, M–N cross plots represents most significant techniques for mineralogy estimation; three

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logs were performed to be calculated and illustrated, and they are neutron, density, and sonic geological well logs. Density and sonic logs are taken as input parameters in M values using equation no. 1.

$M = (DTf - DT)/(pb - pf)\ x0.01$ …(1)

Furthermore, neutron and density logs are utilized in order to detrmine N values (Asquith & Gibson, 1982; Herrmann & Bucksch, 2014; Schlumberger, 1989):

$$N = (\emptyset_N f - \emptyset_N)/(Pb - pf).....(2)$$

All logs were calibrated using the environmental correction method by depth; gamma ray (GR) serves as a calibration curve. Volume of shale (Vsh) was derived at each of the operative intervals using the GR log using the following equation (Bowen, 2003; Darling, 2005a; Donaldson, 1989; Jorgensen, 1989):

$$I_{GR} = \frac{GRlog - GRmin}{GRmax - GRmin}.....(3)$$

$$V_{Sh} = 0.083[2^{(3.7IGR)} - 1.....(4)$$

GRlog = gamma–ray log reading, GRrmin = lowest gamma–ray reading, GRmax = highest gamma–ray reading in the shale region, IGR is the gamma–ray index, and the cut–off was = 0.35.

Porosity values determination for the investigated intervals, including PHIT and PHIE, based on the neutron and sonic logs, respectively (Darling, 2005b; Donaldson, 1989; Schlumberger, 1989). The parameters of the calculation are obtained in the following equations 5 and 6:

$$PHIT = (\emptyset Ncorr + \emptyset Dcorr)/2.....(5)$$

$$PHIE = PHIT\ (1 - Vsh).....(6)$$

Water saturation (Sw) is a fraction of the occupied fluids in the porosity of the hydrocarbon reservoirs, and Sw has a PHIE cut–off of ≥0.08, and Sw is less ≤0.60 (Tiab & Donaldson, 2003).

But Vsh and resistivity logs (LLD, MSFL) data are input into equations 7 and 8 to find Sw:

$$S_w = \sqrt[n]{\frac{a}{\emptyset^m}}\, x \frac{Rw}{Rt}.....(7)$$

$$S_{xo} = \sqrt[n]{\frac{a}{\emptyset^m}}\, x \frac{Rmf}{RXO}.....(8)$$

Where: Rt is actual resistivity based on LLD value; RXO is resistivity in the invaded zone, based on MSFL value; a=1, m=n=2.

A clean, consolidated carbonate rock reported average values close to a=1, m, and n=2. These values are used in the absence of core–calibrated intervals (Archie, 1941; Herrmann & Bucksch, 2014; Liu, 2017; Tiab & Donaldson, 2003). Rw is the resistivity of water, and Rmf is the mud filtrate resistivity at formation temperature.

Finally, hydrocarbon saturation (Sh) was calculated using equation no. 9 (Tiab & Donaldson, 2015):

$Sh = 1 - SW$ .....(9)

A correlation between the porosity curves, shale volume curves, water and oil saturation curves, and the movement of hydrocarbons for all wells to determine the reservoir units with good characteristics that have oil or gas, and compare them with the sedimentary units. The cutoff values are presented in Table 2.

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Table 2. Composite log interpretation: Gross and net thicknesses of Tanuma, Khasib, and Kifl formations in Wells EB−84 and EB−93. A porosity and saturation cutoff were used to determine the net thickness.

Well	Formation	Gross Thickness (m)	Net Thickness (m)
EB−84	Tanuma	116.92	98.25
	Khasib	103.50	94.50
	Kifl	16.50	14.50
EB−93	Tanuma	115.60	64.25
	Khasib	101.20	85.75
	Kifl	12.62	9.25

4. Results

4.1 Lithology Identification

Neutron−density crossplots (NPHI−RHOB) were estimates lithology of wells EB−84 and EB−93. Based on the crossplots (Figure 3), the majority of the data points are concentrated along the lines of the limestone and dolomite, indicating that the investigated formations are of a carbonate nature. EB−84 shows that many points are not on the line of the limestone, refering to the secondary porosity region, which is usually linked to dolomitization and dissolution processes. This diagenetic overprinting has increased the porosity of limited areas, especially in the Khasib and Kifl intervals. In comparison, EB−93 is more concentrated in the limestone zone and less scattered, which implies a smaller number of diagenetic changes and more homogeneous limestone facies.

More evidence of the dominance of carbonates is given by the M–N plots (Figure 4). Clusters in EB−84 are located in the calcite−dolomite areas and scattered throughout the secondary porosity. This indicates that there was diagenetic dissolution affecting sections of the succession, which resulted in enhanced connectivity of the pores. The data plot is more concentrated in the calcite field and has a slight influence of dolomite in EB−93, which is in agreement with the evidence of the crossplot that the lithologies are uniform and secondary porosity has less developed. Both crossplots (Figures 3 and 4) show that the investigated intervals in two wells consist of carbonate, thus EB−84 has a higher lithological diversity and diagenetic porosity enrichment.

4.2 Petrophysical Parameters

The calculated petrophysical parameters of the investigated formations in two wells are presented in Table 1. The results show that the Tanuma Formation in EB−84 has PHIT values 0.05 to 0.35 (mean 0.22), and low values of 0.17 (mean 0.17) as a consequence of shale content. Sw is low (average =0.28), and the Vcl is moderate (average 0.27), which reflects poor quality of the reservoir regardless of a moderate porosity. The Khasib is doing better with average PHIT and PHIE of 0.22 and 0.19, respectively, and a lower average Sw of 0.15. It is also less in terms of Vcl = 0.19 and thus indicates that the Khasib has the best reservoir conditions. Kifl Formation is the highest porosity, and PHIT and PHIE have average valiues of 0.32 and 0.31, respectively. Nevertheless, Sw is 0.22, which, although low, means that it is partially saturated with hydrocabons.

In EB−93, the Tanuma Formation has an average total porosity of 0.20 with a lower PHIE (0.14) and a high Sw level (0.86), showing that this formation is mostly of water−bearing intervals. The Vsh is also high (average 0.49), which reflects lower reservoir quality. In contrast, the Khasib Formation displays a PHIT of 0.20 and a PHIE of 0.16 with a moderate value of Sw (0.56) and Vsh content (0.32). The Kifl Formation is

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recording 0.17 (PHIT) and 0.15 (PHIE) porosities but contains 0.57 (Sw), which restricts its reservoir potential.

Another important hydrocarbon potential discriminator is BVW. In EB−84, the average of BVWs is less than 0.06 in all the formations, which is consistent with the irreducible water conditions and indicates the presence of hydrocarbons. BVW in the case of EB−93, however, tends to be greater than 0.07 to 0.12, which implies the presence of movable Sw and a lower potential of hydrocarbons. These findings highlight the fact that EB−84 offers a more developed reservoir as compared to the EB−93 well.

4.3 Net and Gross thickness

The contribution of each formation is identified by gross and net thickness data (Table 2; Figures 5 and 6). In EB−84, the Tanuma Formation measures about 117 m and 98 m gross and net thickness, but the shales decrease the reservoir performance. The most significant reservoir interval is the Khasib Formation with a gross and net thickness of approximately 104 and 94.5 m, respectively. The Kifl Formation is much thinner (16.5 m gross; 14.5 m net) yet has areas of increased porosity. Thicknesses in EB−93 are widely similar, that of Tanuma is 116 m gross and 64 m net, Khasib 101 m gross and 85.75 m net, and Kifl 12.6 m gross and 9.25 m net. These values indicate that both wells have thick carbonate formations, although EB−93 has a shale−filled Tanuma that lowers the effective pay in comparison with EB−84.

Furthermore, EB−84 exhibits increased resistivity and porosity response in the Khasib interval, but EB−93 is characterized by the gamma−ray and density−neutron responses that are characteristic of shalier carbonates and high Sw.

5. Discussions

5.1 Lithology and shale content

Shale volume has a powerful influence on the levels of reservoir performance during the intervals considered. The elevated Tanuma gamma−ray values recorded in Tanuma are reflected in Vcl values of 0.27−0.49, and this material is predominantly composed of shale−rich facies, which block the pore spaces, thus reducing the effective porosity. In comparison, the Khasib has cleaner carbonate intervals with smaller volumes of shale, this being the reason it has better performance as a reservoir. The Kifl is thinner but with less shale content (<0.25) and preserves the primary porosity better, but with low saturation of the hydrocarbons. These observations underscore the need to combine gamma−ray, density, and neutron logs to help in differentiating between clean reservoir sections and shale−inflicted periods.

5.2 Reservoir evaluation

The petrophysical comparison of Wells EB−84 and EB−93 emphasizes the high heterogeneity of the Cretaceous carbonate succession of the East Baghdad Field. The Khasib Formation is always the most promising reservoir interval. It has moderate to high PHIT (0.20−0.22), PHIE (0.16−0.19), and a relatively low Vsh (0.19−0.32) in both wells. Significantly, BVW values in EB−84 are generally less than 0.06, still less than the irreducible water saturation value, and this indicates the possibility of a hydrocarbon charge. In comparison, EB−93 exhibits higher values of BVW, indicating that there is increased mobility of the water and, therefore, less hydrocarbon potential. The Khasib is the most productive and effective reservoir unit in that the net pays of the Khasib are 94.5 m (EB−84) and 85.75 m (EB−93), affirming its supremacy on the field.

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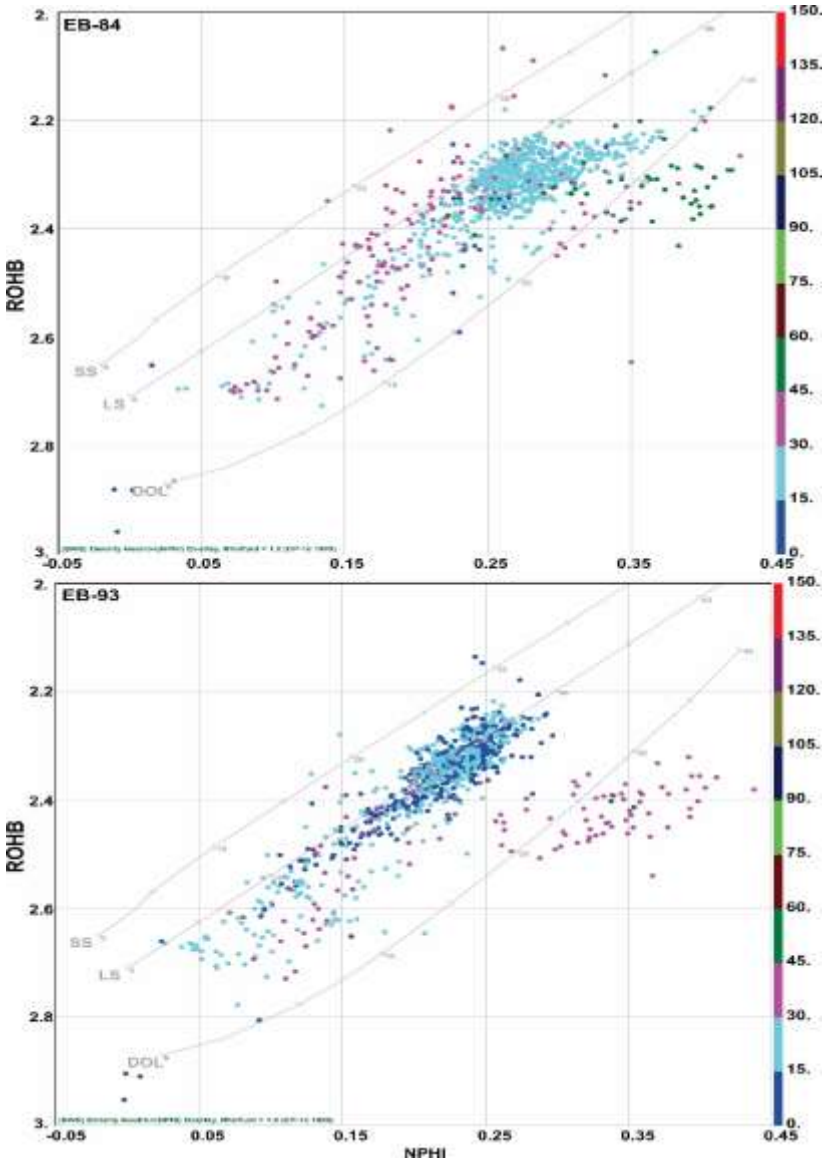


Figure 3. Neutron–density (NPHI–RHOB) plots of wells EB−84 (top) and EB−93 (bottom). Sandstone (SS), limestone (LS), and dolomite (DOL) lithology reference lines are indicated, together with porosity trends (10–40%). Most of the data lie on the limestone and dolomite trends, which means that the lithologies are carbonate with variable porosity. The limestone lines represent clean carbonate formations.

High content of shales is negatively affecting the Tanuma Formation, which has an impressive gross thickness (>115 m). In EB−84, the Vsh is 0.27, whereas in EB−93 well, it is considerably higher (0.49). PHIE values are low (0.14−0.17), and Sw values are 0.86 in EB−93. These properties correspond to the earlier evidence that Tanuma tends to be a transition or source−prone unit with minimal reservoir input (Aqrawi, 1996; Deng et al., 2018)

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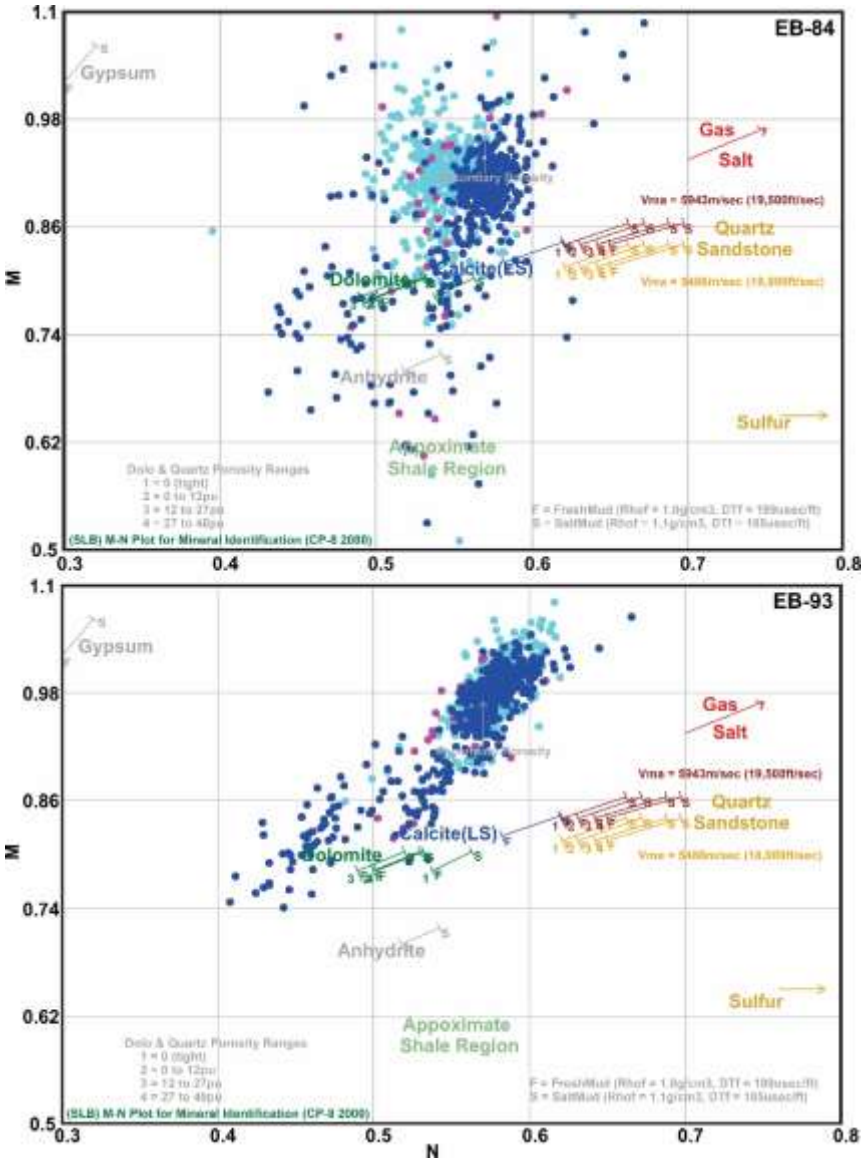


Figure 4. M–N plot of Well EB−84 (top) and Well EB−93 (bottom) to identify minerals and estimate porosity. Data points are clustering mostly on the trends of calcite (limestone) and dolomite, which validates the lithology of the Tanuma, Khasib, and Kifl formations, which are dominated by carbonates. The presence of clustering around the calcite line means that limestone is the dominant mineral, and the dispersion around the dolomite line means mixed dolomite intervals. The secondary porosity can be traced in the upward movement of the points, with minor scattering towards the shale area, indicating the localized influence of the clay. The separation of the plots with the quartz/feldspar trends also supports the characterization of the carbonate reservoirs.

The Kifl Formation shows local improvement of porosity, particularly in the EB−84, where the PHIE is as high as 0.31 in some sections. The values of average water saturation, at EB−84 at 0.22 and at EB−93 at >0.55, suggest that much of this porosity is water−filled. Therefore, the Kifl intervals only have net pay (less than 15 m) of significance, which validates its low economic importance.

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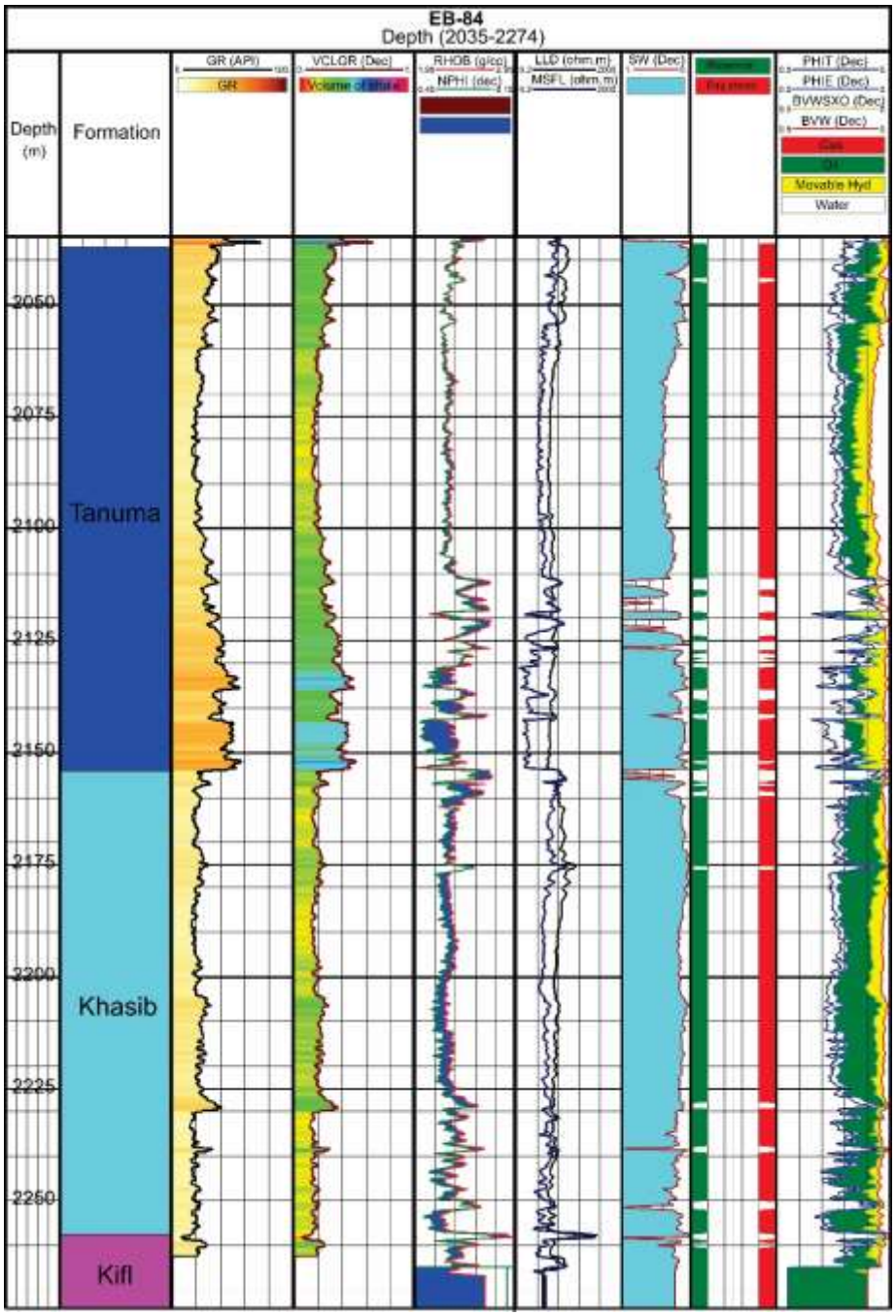


Figure 5. Composite well logs of well EB−84 (depth interval: 2035–2274 m), petrophysical interpretation of Tanuma, Khasib, and Kifl formations. Colored cutoff bars indicate reservoir intervals, red indicating hydrocarbon−bearing pay intervals, and green indicating water−bearing intervals.

5.3 Diagenesis and secondary porosity.

The results of crossplot and M−N plot analysis show that secondary porosity is a significant factor that affects the reservoir quality, especially in the EB−84. The secondary porosity region in neutron density crossplots scattered outward of the main limestone line towards the secondary domain of dissolution and partial dolomitization.

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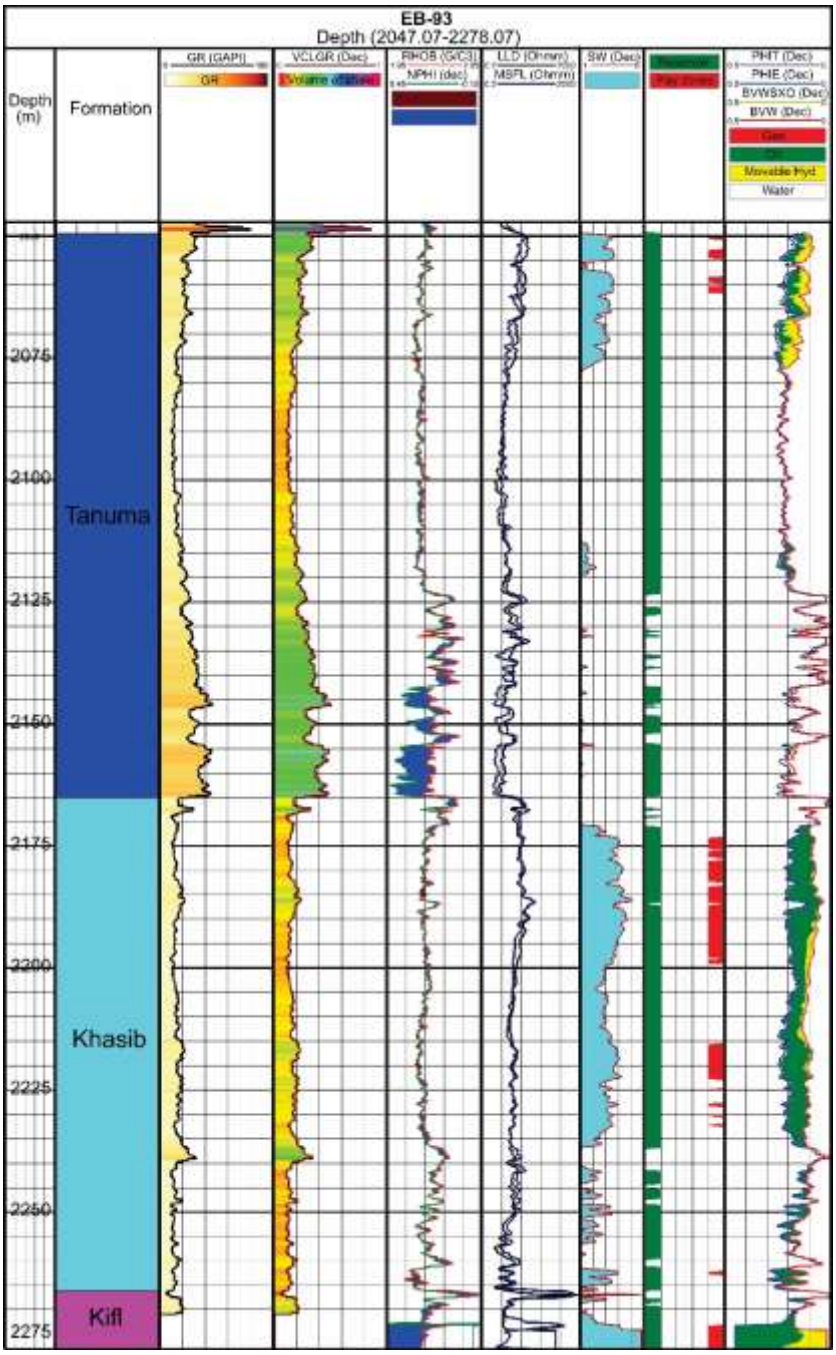


Figure 6. Composite well logs for well EB−93 (depth interval 2047.07–2278.07 m), illustrating petrophysical interpretation of the Tanuma, Khasib, and Kifl formations. Colored cutoff bars with red intervals indicating pay zones, green for water−bearing, and yellow for movable hydrocarbons.

These diagenetic processes increase porosity and permeability even at the intervals where primary depositional porosity was restricted. EB−84 indicates that dissolution has been more productive in this well, which has led to a better quality of the reservoir as opposed to EB−93. This has been observed extensively in Cretaceous carbonates of the Middle East, where porosity development by leaching and dolomitization is a key factor in the productivity of the reservoir (Ehrenberg et al., 2007; Gillespie et al., 2021; Morad et al., 2019).

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5.4 Reservoir thickness and continuity

Both Tanuma and Khasib have gross and net thickness values that illustrate that they provide important stratigraphic thicknesses throughout the East Baghdad Field. But the Khasib alone consistently offers effective reservoir intervals, which are thick. In EB−84, Khasib and Tanuma have high net−to−gross ratios (0.81−0.91), and EB−93 reveals a lowering in effective pay, especially in Tanuma, which slips to 0.55. This variance implies the horizontal inconsistency of carbonate deposition and diagenesis in the Mesopotamian Foredeep Basin. This heterogeneity implies that the Khasib is going to need specific targeting to recover optimally.

5.5 Regional correlation

The EB−84 and EB−93 reservoir behavior are in line with the pattern reported over the Mesopotamian Basin. Khasib Formation is a prolific carbonate deal recorded in southern and central Iraq, and porosities are usually 0.15−0.22 with thick net pay (Aqrawi et al., 2010). The Tanuma Formation is also characterized as a poor reservoir owing to high shale content, which serves as a source or sealing unit. Although localized porosity is found, the Kifl Formation has low hydrocarbon potential, and findings were also determined for similar intervals in the central and southern parts of Iraq (Al-Zaidy, 2023; M. M. Mohammed et al., 2022).

In addition, the effects of the diagenetic processes on the quality of reservoirs are not only confined to the Khasib Formation, implying that the same processes could be used to increase the hydrocarbon potential in other carbonate reservoirs in the Mesopotamian Fordeep Basin. To illustrate, the discovery of secondary porosity due to dissolution and dolomitization in the Kifl Formation (with some limited occurrence) might mean untapped reserves of hydrocarbons that need to be explored.

The East Baghdad reservoir intervals also have some good analogies to other Cretaceous carbonate reservoirs of the Arabian Plate. The Khasib Formation is similar to the Mishrif carbonates in Abu Dhabi and in southern Iraq, where porosities of 0.15−0.22 and net pays of more than 50 m are common (Abdulnaby, 2019; A. T. Abeed et al., 2019; Alsharhan & Nairn, 2003a, 2003b).

The Tanuma Formation is analogous to the Burgan transition zone in Kuwait, which is composed of shale−based carbonates with little contribution to the reservoir (Naqi et al., 2023; Strohmenger et al., 2006). The Kifl Formation resembles the Wasia Group in Saudi Arabia, which also includes high−porosity yet mostly water−bearing carbonates (Alsharhan & Nairn, 1994). These foreign counterparts prove that East Baghdad is fitting as a part of the wider range of heterogeneous Cretaceous carbonates in the study region.

6. Conclusions

1. Neutron density and MN crossplots verified the presence of carbonate lithologies of Tanuma, Khasib, and Kifl formations, with the primary components being limestone and dolomite. EB−84 demonstrates features of secondary porosity related to dissolution and dolomitization, whereas EB−93 consists of more homogenous limestone facies.
2. The most promising reservoir unit is the Khasib Formation, whose PHIE range is 0.16− 0.19, the content of shale is relatively low, and net pay intervals are 85 95 m thick. These values have been compared with the regional Cretaceous carbonate reservoirs, including the Mishrif Formation in southern Iraq and Abu Dhabi.
3. However, being a thick formation (>115 m), the Tanuma Formation is very shale−prone and has a high Sw (as high as 0.86 in EB−93), thus, it is a poor−quality reservoir. This is consistent with earlier works that ranked Tanuma as being transitional between reservoir and source facies.
4. Kifl Formation has areas with the highest porosity (>0.30 in EB−84), but Sw values (>0.55) restrain its commercial importance. This analysis is indicated by the BVW result, which indicates a lower EB−84

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(under the irreducible water threshold), indicating evidence of the presence of hydrocarbons, whereas EB−93 indicates a higher BVW (>0.07), indicating worse hydrocarbon potential.

5. Diagenesis is important in optimizing the reservoir quality, especially in EB−84, where secondary porosity formation is enhanced in the permeability and the storage capacity of hydrocarbons. This indicates the importance of petrophysical and petrographic studies that have been integrated in order to describe heterogeneous carbonate intervals in the Mesopotamian Foredeep and Zagros Basin.

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Author Contributions

Ali H. Dohan: Data collecting, methodology, supervision, preparation of tables, manuscript review, and editing. **Ali S. Abbas**: Methodology design, well log data evaluation, preliminary draft writing. **Mohammed Y. Najmuldeen**: Log digitizing, estimation, and plotting of petrophysical CPI results. **Abbas F. Gharib*:** Conceptualization, supervision, geological setting explanation, and manuscript review. **Ayshagul S. Najmuldeen**: Literature review, comparative analysis with the international carbonate reserves, and language editing.

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