



Research Article

A full update of Lithological, Petrophysical, and Geomechanical evaluation for the Sadi Formation in the Mesopotamia Basin, Southern Iraq

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Abstract: The Sadi Formation in the Mesopotamia Basin is part of the Santonian-Campanian interval. This study was conducted to update the lithology, petrophysical, and geomechanical characteristics in four southern Iraqi fields with the new exploration data using data from 21 wells in the Mesopotamia basin, which represent the Sadi formation in the Zubair, Rumaila, Majnoon, and West Qurna/1 fields. The results indicated that the maximum horizontal stress azimuth should be 55 and 318 degrees toward the northeast, and the fault system type is Normal. The lithology consists mainly of limestone, with a low percentage of Dolomite and sandstone, and some Shale content. Hydrocarbon potential in the Sadi Formation in the West Qurna/1 Field will increase as wells are drilled toward the south, and the northeastern part of the field has gas potential (condensate gas). Only the Rafdiya dome in the Zubair Field could contain hydrocarbons. On the other hand, there is no hydrocarbon potential for the Safwan dome or those on the west flank, and no hydrocarbon potential in the Rumaila Field except on the east side. The hydrocarbons in the southern part of the Majnoon field are more likely and will decrease toward the north. Future work must focus on the flanks of the Sadi Formation in the Majnoon field, drilling more wells east of the crest (possibly on the east flank), and in the West Qurna/1 Field in the south to discover more about the Sadi Formation in this area. Net pay thickness in formations that potentially contain hydrocarbons ranges from 5.6 meters in the West Qurna oilfield to about 79 meters in the Zubair oilfield, with average porosities of 14.5% and 15.8%, and a high water saturation in most fields.

Keywords: Lithology, Geomechanics, petrophysical properties, Sadi Formation, Mesopotamia Basin.

1 Introduction

Lithology recognition represents the base of geological knowledge that demands identifying stratigraphy, reservoirs, or sedimentary facies details (Rajput and Pathak, 2025). Lithology is considered the entrance to reservoir evaluation and development prospects, and it is the basis for reservoir description, ideal drilling, and reservoir parameter procurement (Chen, 2022; Zholtaev et al., 2026). One of the leading roots of all reserves is the carbonate Formations, where the petrophysical attributes play a pivotal role in hydrocarbon outputs (Follows, 2025). Borehole geophysical procedures have turned into requisite in oil and gas reconnaissance and is utilized to assess, reveal formations, and estimate formation characteristics from rock types and fluids (Keys, 2017; Uzbekgaliev et al., 2025). Wireline logs (GR, SP, NPHI, RHOB, DT, and Resistivity logs LLD, LLS, LLM) and core analysis are essential tools to project any formation properties (Zhang et al., 2024). Porosity, permeability, and saturation are the carbonate reservoir's most important petrophysical properties that can be estimated by either well logs, core tests, or together (Stadt Müller and Jarzyna, 2023; Alisheva et al., 2025).

One of the imperative difficulties in formation evaluation is reservoir attribute (Ganguli and Dimri, 2023; Salman et al., 2023). The water saturation, permeability, and porosity are related to diverse factors (rock texture, lithology, diagenesis, and environmental circumstances) (Yang and Wei, 2017). Rabanit (1952) was the first to describe the Sadi formation. The formation description was represented by Owen and Nasr (1958) as a type section. The qualifiers and era identification of the formation submitted diverse alterations subsequently (Chatton and Hart, 1961). The medium shelf was proposed as an essential sedimentary environment for the whole sequence, with the manifest impact of the exterior shelf or open marine (Ismail et al., 2025). The Khasib, Tanuma, and Sadi formations were disputed according to petrophysical multitude, assessment of microfacies, paleoenvironments, and sequence stratigraphy (Alkhaykane, 2015; Al-

Edani, 2017; Mazban et al., 2022; Hashim et al., 2025).

In-situ stress precise estimation regarding azimuth and direction of the permeable cracks is essential to evaluate well output, where in-situ stresses, pore pressure, and the rock solidity impact the borehole stability (Al-Dujaili, 2025). Many studies discussed the ideal well route based on drilling and production influenced by various in-situ stress regimes. A tangible effect on the wellbore tendency and azimuth could be specified during the sanding production outset operation (Kumari and Ranjith, 2019), proving that production issues should be considered in optimum trajectory design of the planned wells to prohibit sand production (Alabduh et al., 2025). Nine limitations affect rock stresses, of which six are freelances (Li et al., 2024). Three essential stresses could be defined that influence the wellbore stability (WBS), including the vertical (σ_v), maximum horizontal (σ_H), and the minimum horizontal (σ_h) stresses, in addition to their trends (Song et al., 2024). Those techniques would minimize high pressure and relieve the passive effects of formation destruction (Jinsheng et al., 2024). The wellbore stability modification for wells under design will guarantee acceptable stress intensity concerning the well, leading to preserving wellbore stability.

This manuscript aims to determine the petrophysical parameters for Sadi Formation in the Majnoon, West Qurna/1, Zubair, and Rumaila Fields to discover the hydrocarbon potential. In addition, this study is comprehensively analyzing the mechanical behavior of the formation, evaluate potential drilling challenges, and propose effective wellbore stability management strategies. By utilizing well logs, core samples, rock mechanics experiments, and drilling data, this study provides valuable insights to optimize drilling operations and ensure safe and efficient development of the Sadi Formation in the West Qurna/1 oilfield. The novelty of this study lies in the fact that, unlike previous studies which were limited to a specific oil field, it extended to include the giant fields in the Mesopotamian Basin.

2 Geological setting

The Majnoon Field features a banana-shaped, crested anticline stretching predominantly north-south (Al-Dujaili et al., 2025). It is believed to be a compressional fold, likely underlain by salt beneath the Jurassic level. The field comprises four primary and seven secondary reservoirs that range in age from the Lower Cretaceous to the Paleocene, covering a vertical thickness of approximately 3000 meters (Abbas and Watheq, 2021). The noticeable reservoirs (listed from profound to shallow) are the Yamama, Zubair, Ahmedi, Mishrif, and Hartha formations (Al-Khafaji et al., 2022), which together account for 80% of the hydrocarbons in the Majnoon Field (Khalid and Al-Mashhadani, 2022). The Yamama and Mishrif formations share 50% of the primary reservoir's gross volume (Mahmood and Sadeq, 2023). The Khasib, Sadi, Tanuma, Ghar, Shiranish, and Shuaiba (Minor reservoirs) may also hold hydrocarbon potential (Al-Dujaili, 2024a) (Figure 1-a).

In southern Iraq (southwest of Basra, about 20 km), a giant field known as Zubair spans a geographical area between coordinates 47° 32' and 47° 45' and 30° 05' and 30° 42' (Dawood and Al-Dulaimi, 2023) (Figure 1). The field is surrounded by two fields: the Nahran Ummr oil field to the north and the Rumaila oil field to the west, and the Kuwait-Iraq border to the south, within an area of approximately 1170 km², with dimensions of 18 km in width and 65 km in length (Al-Dujaili, 2024b) (Figure 2). Rumaila is a supergiant oil field about 50 km west of Basrah City, southern Iraq (Al-Abadi et al., 2024) (Figure 1). It consists of multiple clastic and carbonate reservoirs that account for 33% of Iraq's total oil production (Chafeet and Handhal, 2024) (Figure 1). The Rumaila structure is a gently tilted longitudinal anticline that stretches (approximately 83 km in

length and 12 km in width) (Al-Ameri et al., 2020). The northern part of the Rumaila structure narrows to about 42 km in width, sloping southward and forming a saddle that separates it from the southern part (Mahdi and Hosseinian, 2024). Two main faults, the Takadid-Qurna and Al-Batin, have been identified as running in a northeast-to-southwest direction (Handhal et al., 2019; Al-Khafaji et al., 2021). The supergiant oilfields of Iraq are predominantly situated in the southern region. One notable example is the West Qurna oilfield (Al-Dujaili et al., 2021 and 2023; Asad et al., 2026), located northwest of Basra city, within the Zubair Subzone. Structurally, it is part of a large isocline that trends to the north and is estimated to hold recoverable reserves of around 30 to 40 billion barrels (Al-Dujaili, 2023). The West Qurna oilfield is considered the northern extension of the vast Rumaila oilfield (Al-Dujaili et al., 2024) (Figure 1-a).

2.1 Sadi Formation

The Sadi Formation is part of the Santonian-Campanian interval within the AP9 mega sequence (Han et al., 2015; Jassam et al., 2023). This formation is subdivided into two main sections. The upper section predominantly consists of chalky limestone, which may occasionally transition into marl limestone within the study area. The lower section, is mainly composed of limestone that also overlies marl limestone (Buday, 1980). Further division of the lower part into three distinct units (A, B, and C) is based on well-log data and petrophysical analysis. The Sadi Formation is conformably overlain by the Tanumma Formation, with a clear boundary marked by black calcareous shale at the top, transitioning into white chalky limestone at the base (Al-Fandi and Hadid, 2020). The contact between the Sadi and the Hartha Formation is characterized by an erosional unconformity (Sissakian, 2013) (Figure 1b).

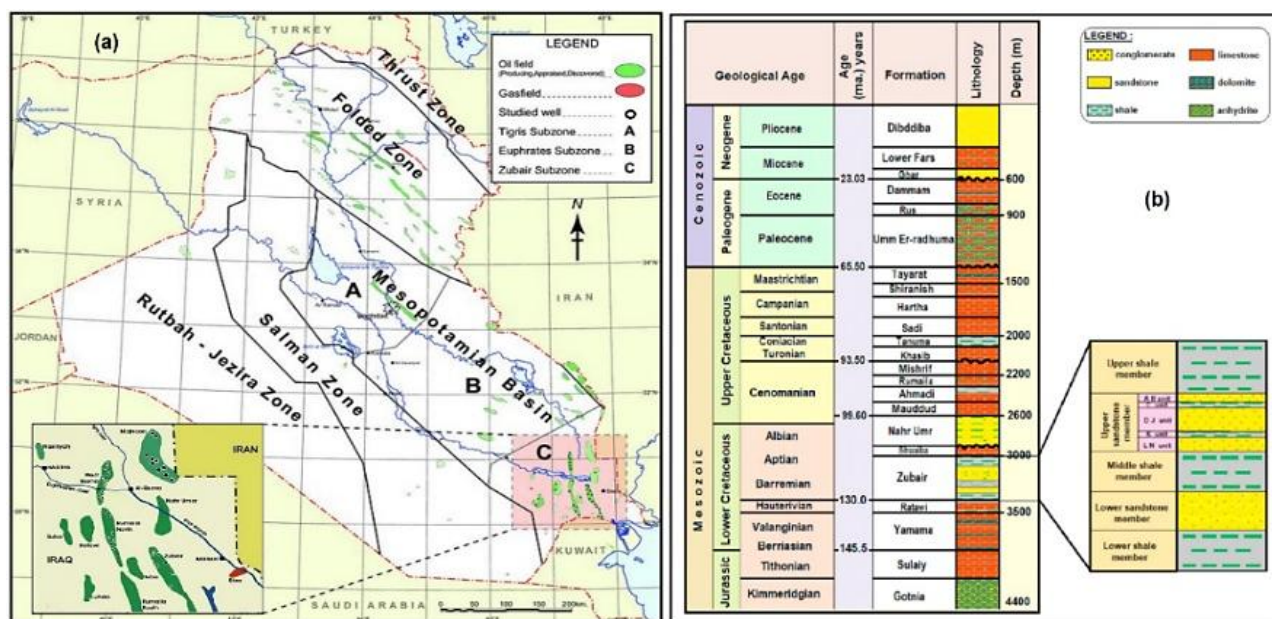


Figure 1. (a) locations of the wells under study and the date of the drilling process (Handhal et al., 2019), (b) Stratigraphic column in southern Iraq (Al-Khafaji et al., 2021)

Table 1. Wireline, stresses, and rock properties logs for Sadi formation in the Zubair, Rumaila, Majnoon, and West Qurna 1 Fields

Field	Wells	Open hole logs	Stresses logs	Rock properties	Core samples
Zubair	Zb-X89		√		
	Zb-X04		√		
	Zb-X16	√			
	Zb-X23	√			
	Zb-X26	√			
	Zb-X41	√			
	Zb-X53	√			
	Zb-X74	√			
North Rumaila	RN-X26	√			
	RN-X33		√	√	
	RN-X41	√			
	RN-X93	√			
Majnoon	Mj-X7	√			
	Mj-X1	√			
	Mj-X3	√			
West Qurna 1	WQ1-XX2				√
	WQ1-X36	√	√		
	WQ1-X38	√			
	WQ1-X39		√	√	
	WQ1-X40	√			
	WQ1-X52		√	√	
	WQ1-X63	√	√		

3 Data and Methods

3.1 Data

This research based on well log data from available obtained from 21 wells in the Mesopotamia basin,

which represent the wireline, stresses, and rock properties logs for Sadi formation in the Zubair, Rumaila, Majnoon, and West Qurna 1 fields (Table 1 and Appendices). Fig. 2 shows location of wells under study.

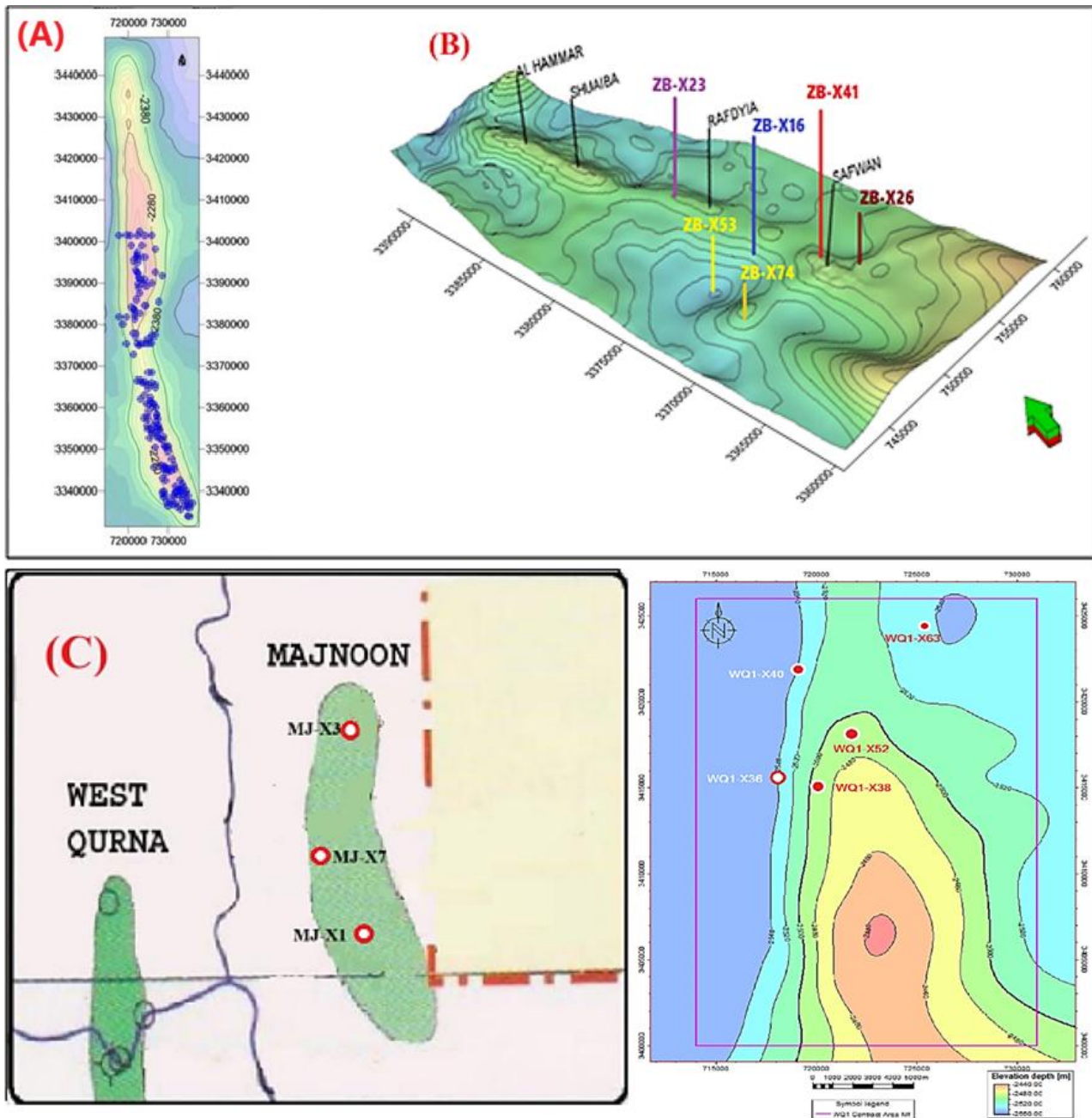


Figure 2. Location of wells under study, A- for Rumaila (Jaffar and Abdalnaby, 2019), B- Zubair, C- Majnoon, and D- West Qurna/1 fields

3.2 Methods

3.2.1 Geomechanics and Wellbore Stability

Workflow for Sadi Formation- Horizontal section

Rock mechanic properties (UCS, Poison Ratio) were obtained from laboratory testing for wells in the formation using widely known correlations embedded in the Geomechanics software – Drillworks and Techlog. Calibration of the Geomechanical Model to rock mechanics properties

is required. Then the Geomechanical Model is calibrated to the events and data of offset wells with similar wellbore characteristics. Image Logs for identification of possible breakouts, wellbore shape, natural or induced fractures, and maximum horizontal stress azimuth in the objective well at the curve are needed before drilling the horizontal section. A Wellbore Integrity Test (WIT) was performed to estimate the wellbore integrity before

entering the horizontal section to well TD. WIT will provide information on the maximum achievable wellbore pressure in the curve and the lateral section. Early recognition of potential micro-fractures and Identification of the azimuth of maximum horizontal stress hence the determination of the fault regime. If fractures are not present, then the wellbore shape or possible breakouts may help to identify the azimuth of S_h max. The potential existence of micro-fractures will aid in foreseeing loss severity in the lateral section.

Rock mechanic properties (Uniaxial compressive strength (UCS), Poison Ratio) from laboratory testing in nearby wells in the same formation will decrease the uncertainty of the calculated rock mechanic properties using widely known correlations embedded in the Drillworks software. Other petrophysical characteristics of the targeted horizon, such as absolute and effective porosity, permeability, and mineralogy would also enhance the overall geomechanical and completion analysis.

3.2.2 Petrophysical properties

Identifying the precise porosity is convoluted when the formation lithology is obscure or involves two or more undefined characteristic minerals. Single and double-log can be applied to define porosity. The single-log porosity method uses density, sonic, and neutron logs. In contrast, the double-log (method for estimating effective porosity) uses a combination of neutron-density and neutron-sonic logs (Hasoon and Farman, 2024). Permeability is a fundamental indicator that impacts fluid flow in the reservoir, measured using feasible procedures (both time and cost-consuming) such as core analysis and well tests. Permeability is considered an important flow parameter that describes the ability of a subsurface formation to transmit fluid, even though it is the most spatially varied, uncertain, and hard to predict of all the formation properties (Tixier, 1949). Determining water saturation in heterogeneous carbonate reservoirs can be inconsistent because Archie's equation is used only for clean and homogeneous formations, and has a strong dependence on the physical characteristics of the rock (Hamada et al.,

2013). Indonesia water saturation equation is one of the best models to estimate SW in clayey rocks ($VSH > 0$) (Battigelli et al., 2021). In this study, the Pickett plot was used to estimate Archie parameters (n , a , and m). Petrophysical plots and net-to-gross ratios are essential tools for reservoir characterization and estimation. It helps filter out non-existent areas in the reservoir, measure effective porosity and hydrocarbon saturation, and calculate the net reservoir thickness and volume (Dou et al., 2023).

4 Results and discussion

4.1 Geomechanics and Wellbore Stability

Drilling a horizontal section in the Sadi formation is feasible with optimum planning. Offset and laboratory data will be helpful for Geomechanics and Wellbore Stability modeling (Figure 3). Fig. 3-a shows that pore pressure (PPG) and fracture gradients (FG) were stable. Fig. 3- a and Fig. 4 illustrate that the correlation between the vertical (S_v), maximum horizontal (S_H), and minimum horizontal stresses (S_h) is $S_v \geq S_H \geq S_h$, which indicates that the fault system type is Normal. Fig. 3-b shows that a caving issue can occur in the formation even if the drilling was balanced with a stable rotation per minute and weight on bit (WOB), the torque will increase in the Sadi formation, referring to pre-existing weak formation, or the mechanical action of the drilling process and tools. The geomechanical parameters, such as the Young's modulus (E), Uniaxial Compressive Strength in Psi (UCS), were increased, and the Friction Angle (FA) is between (24-35) degrees (Fig. 3-c). The results show that the minimum mud weight required for wellbore stability is 1.1 gm/cm^3 (Figure 3-d). Wellbore Imaging and Wellbore Integrity Test (WIT) can decrease uncertainty before drilling the lateral section and enhance the operating window between the fracture gradient and the collapse gradient. WIT provides the maximum achievable wellbore pressure in the curve and lateral paths in the Sadi formation. The maximum drill pipe and choke pressures are 5960 and 5910 psi, respectively (Fig. 5).

According to Figs. 3- (d) and 5 - Left, the formation was examined for drilling and geomechanical parameters to identify issues in the wellbore (if instability is suspected), wellbore collapse, unexpected losses, pack-off, tights, and differential

sticking, and to determine the best drilling process. The results show that the maximum horizontal stress azimuth was 55 degrees toward the northeast, and the optimum well azimuth will be 318 degrees toward the northwest.

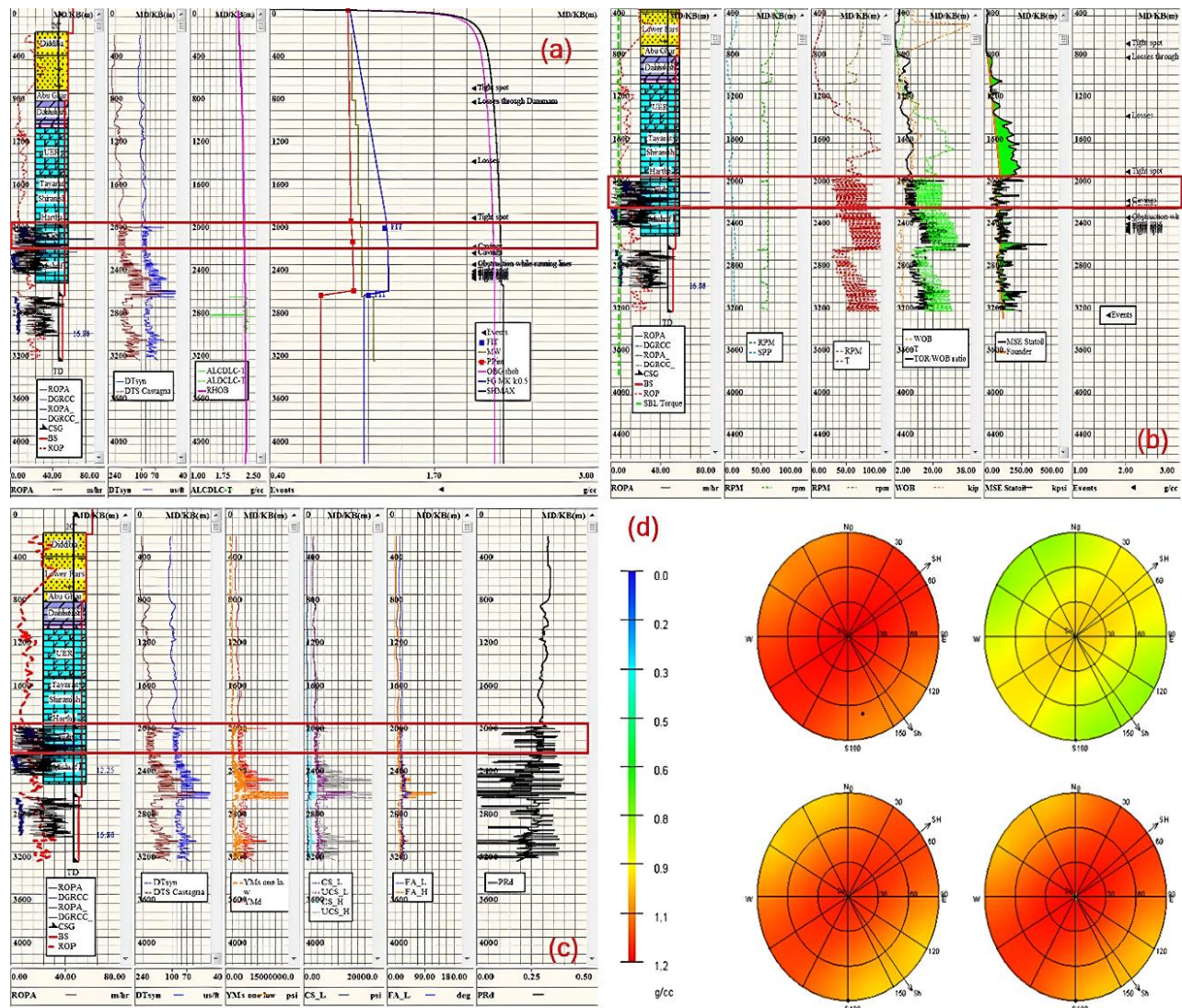


Figure 3. Geomechanics Assessment of the Sadi Formation in the West Qurna Oilfield, a- Well data, b-Drilling Optimization, c-Rock Mechanics, d-Wellbore Stability

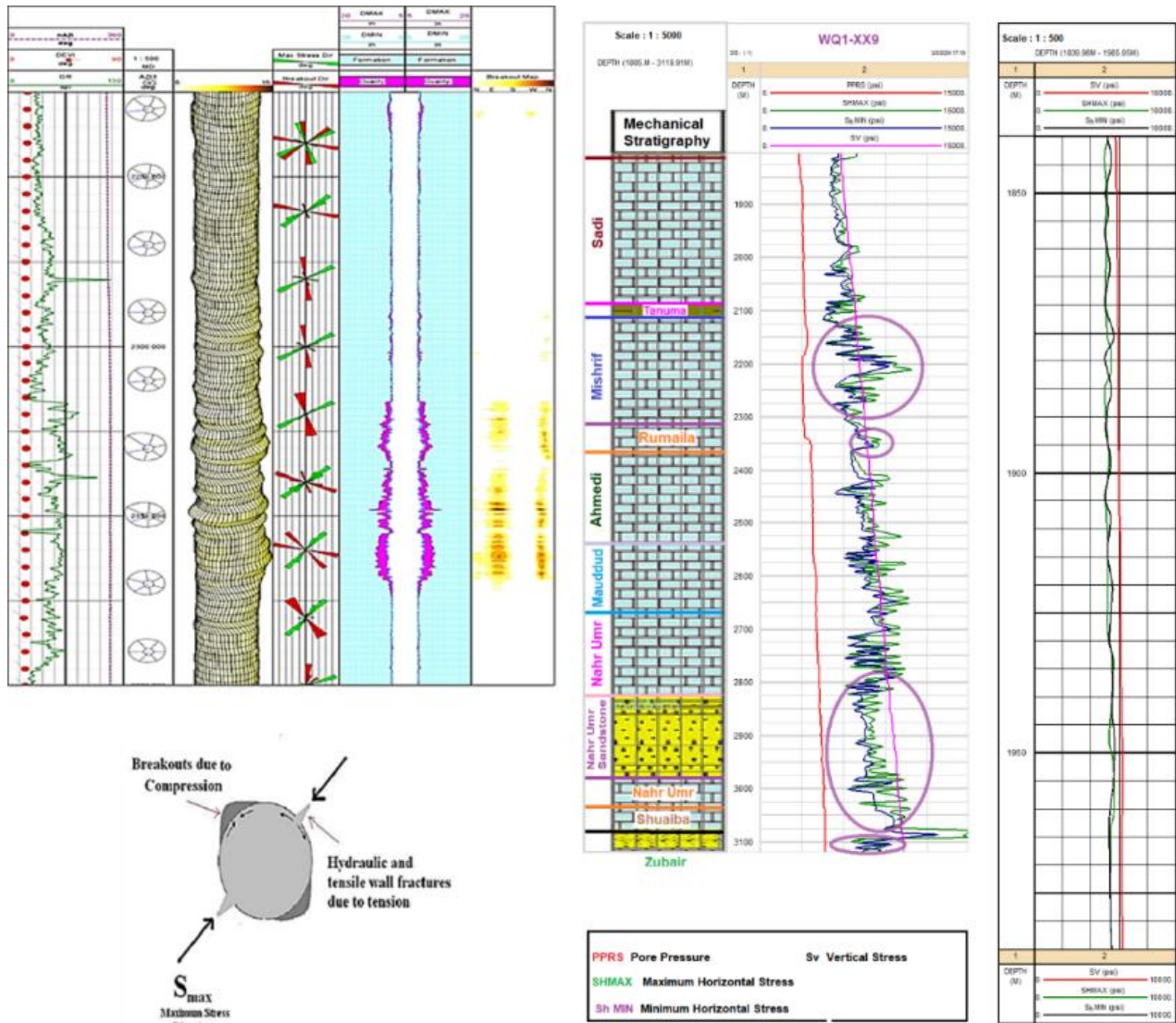


Figure 4. Left- X-tended range micro imaging log (XRMI) structure applications of the Sadi Formation, Right- stresses for the well WQ1-X39 and WQ1-X38 in the West Qurna Oilfield

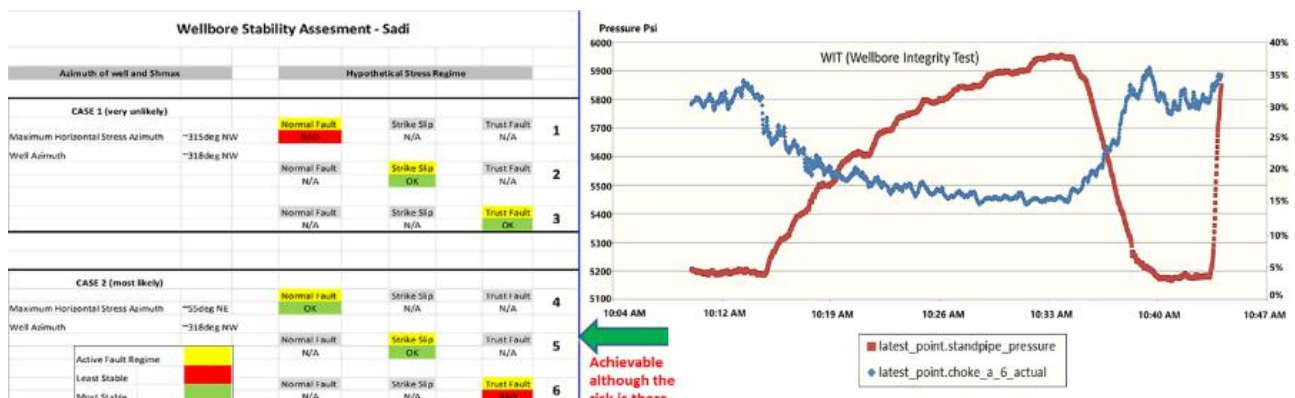


Figure 5. Left- Stress Regime Scenarios, Right- Wellbore Integrity Test for Sadi Formation in the well WQ1-X52

Study wells applied to the density-neutron cross plot of wells MJ-X1 and WQ1-X63 revealed that the Sadi

Reservoir has a specific limestone lithology that is thought to be the Formation's primary lithology, with

shale and dolomite. A few sporadic data points emerge, impacted by elevated gamma levels occurring at the shale zones between reservoir units (Figure 6). Figure 7 shows the M-N cross-plots for the Zubair wells (ZB-X23, X26, X41, and X53) and

(RN-X26 and RN-X41) For North Rumaila wells, where calcite (represented by the limestone region) and dolomite are the main minerals in the Sadi Reservoir. Scatter points appear due to the gas effect, due to high gamma rays (high shale content).

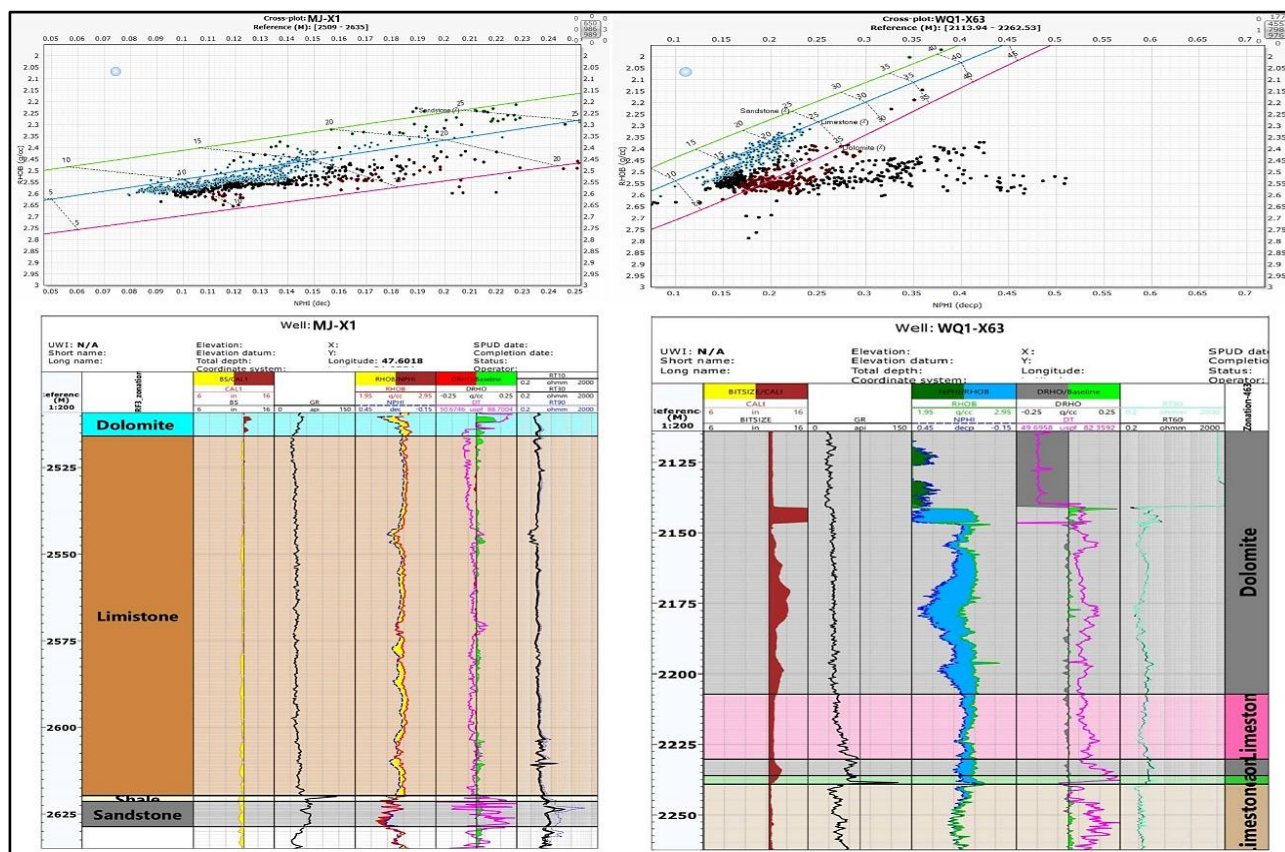


Figure 6. Top- Cross plots of NPHI and RHOB of wells MJ-X1 and WQ1-X63, Bottom- Expected lithology using wireline logs by Techlog™

One hundred plug samples were obtained from core analysis for the Sadi Formation in the well WQ1-XX2. According to Lucia, the rock type analysis. The results indicated that Grainstone dominate in this formation (Fig. 8A). Pore throat radius was estimated using the Winland correlation (Winland, 1976). Good pores were noticed in this Formation (Fig. 8B). Fig. 8C shows that the Sadi Formation consists of 3 flow units.

4.3 Petrophysical properties

Computer-processed interpretation (CPI) of geophysical well logs data was carried out with the

aid of Techlog software V 2015. It gives a continuous reading of lithology, porosity, fluid saturation, and other petrophysical properties. The quality of the logs was assessed before the application of computer-processed interpretation to minimize errors in the derived parameters. The results in Fig. 9 illustrates that five wells showed a good petrophysical properties (good porosity and permeability and low water saturation). Appendices A1-A3 show the petrophysical properties (porosity, permeability and water saturation) for the wells under study.

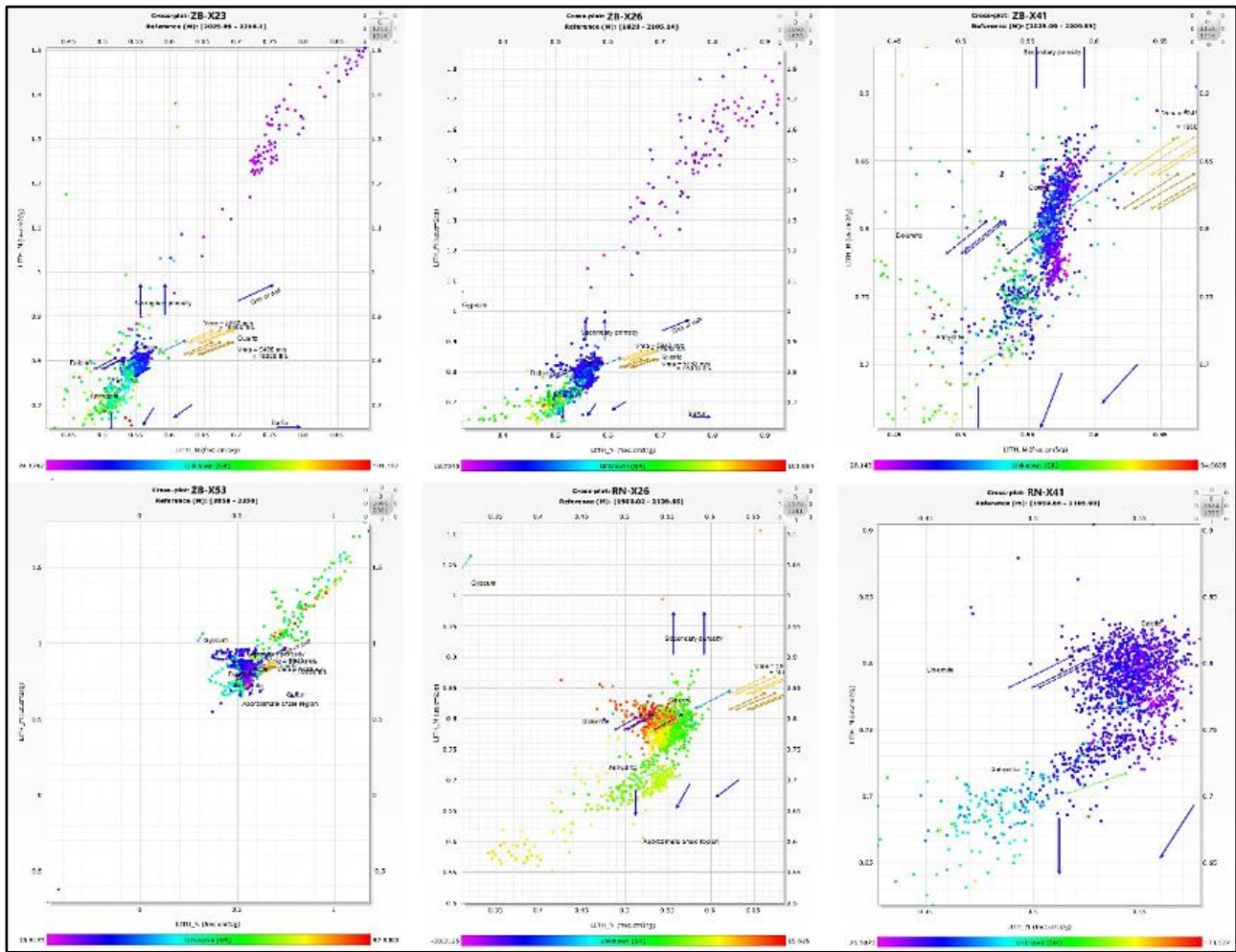


Figure 7. Lithology of Sadi formation by M-N cross plots for wells in the Zubair and Rumaila fields

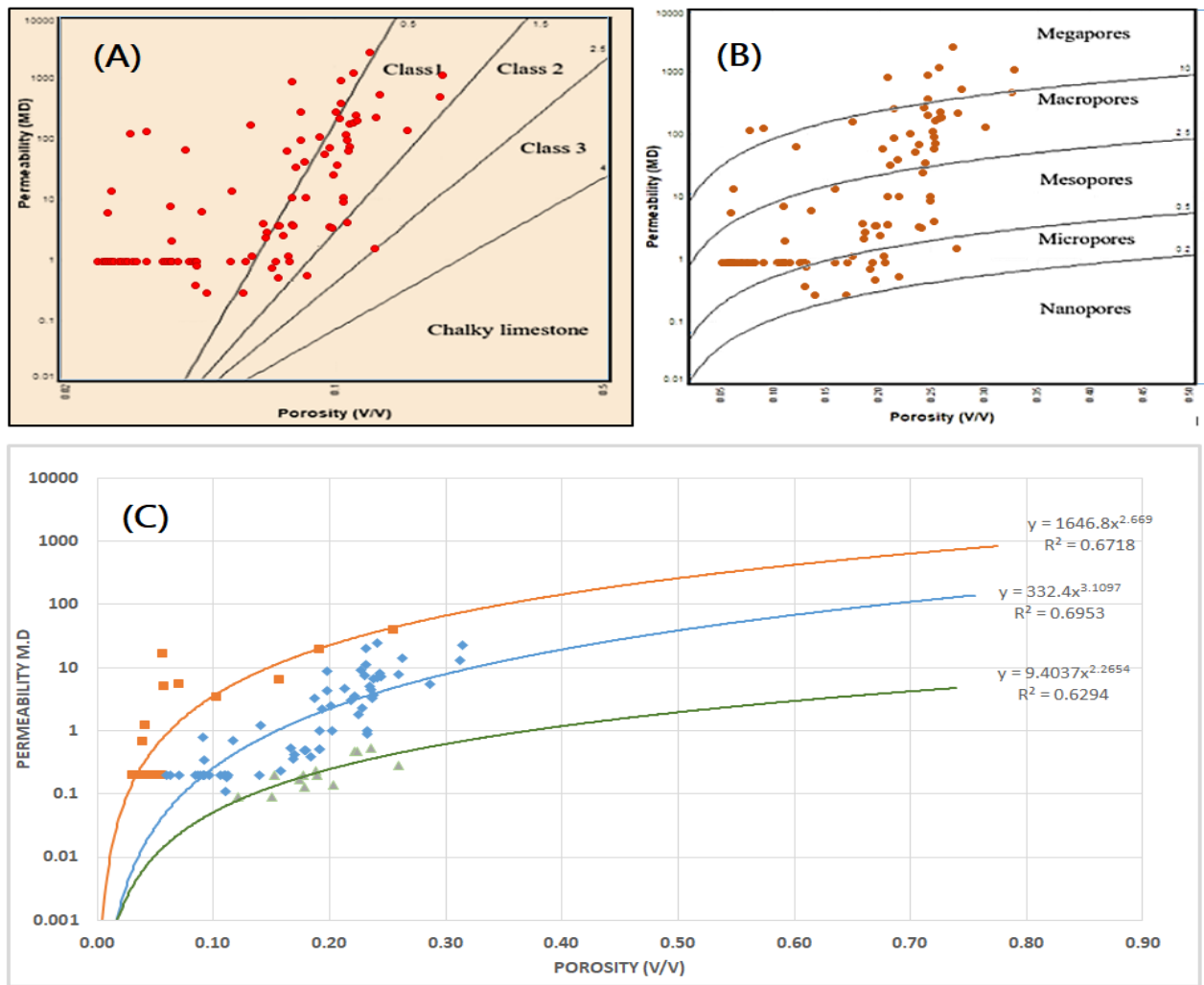


Figure 8. A- Rock types, B- Pore throat radius, and C- Flow units for Sadi Formation

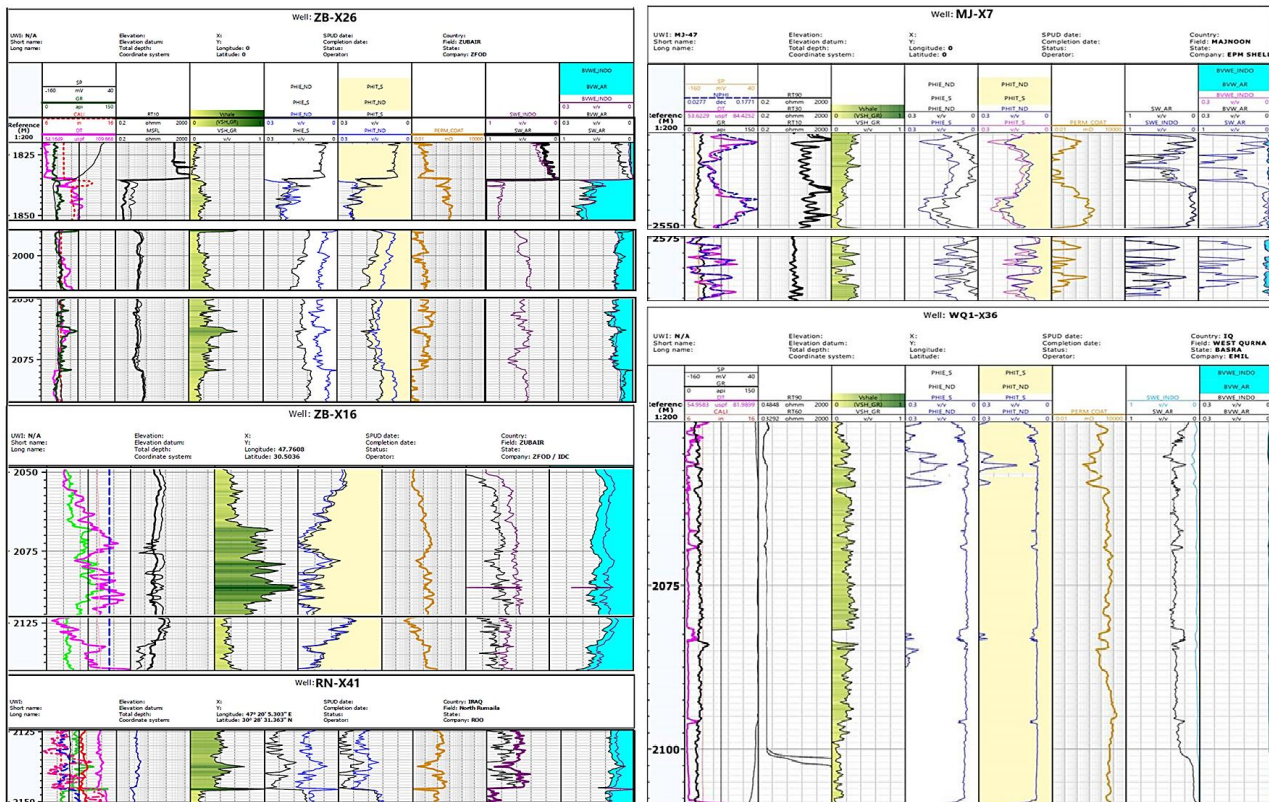


Figure 9. The layers that show good Petrophysical properties in five of the studied wells

4.4 Net-To-Gross (NTG)

The thickness of the productive (net) reservoir rock can be represented by the net-to-gross ratio compared to the thickness of the entire reservoir (gross) (Zeyghami and Taghizadeh Sarvestani, 2023), i.e, it describes the area of the hydrocarbon reservoir. ϕ , V_{sh} , S_w , and k are the most common parameters to extract the net-to-gross (Lucia, 2007). Net pay and reservoir rock can be identified by cutoffs, where the value of reservoir rock is described using 30% and 60% cutoff for porosity and water saturation, respectively. The 30% porosity cut-off value calculates the reservoir's net thickness. The saturation cutoff and unique core analysis can predict the

relative permeability ratio. A portion of the hydrocarbons-in-place is left out of the reserves to estimate net pay using cutoffs. Cutoffs must be carefully chosen to ensure that the hydrocarbons excluded are truly nonproductive (Fig. 10). A net-to-gross pay thickness is the thickness of pay zones relative to reservoirs. The term "net pay" refers to the depth of the porous and permeable zones that contain economically viable amounts of hydrocarbons, the results show that only the wells Zb-X16 and ZB-X26 in the Zubair Field, RN-X41 in the Rumaila, MJ-X7 in the Majnoon, and WQ1-X63 in the West Qurna/1 Field contain hydrocarbon, while the rest of the wells do not contain hydrocarbon (Fig. 10 and Tables 2-7).



Figure 10. Cut-off and net pay for the wells under study by Techlog TM

Table 2. Cut-off and net pay for the well WQ1-X63

	Zones	Flag Name	Top	Bottom	Gross	Net	Not Net	Un known	N/G	N/G unknown	BVW	POR-TH	HCPOR-TH	Vsh	Phi	Sw
1	Dolomite	ROCK	2113.94	2236.22	99.21	92.354	6.855	0	0.931	0.931	6.249	8.998	2.749	0.193	0.097	0.694
2	Dolomite	RES	2113.94	2236.22	99.21	37.795	61.414	0	0.381	0.381	4.114	5.311	1.197	0.22	0.141	0.775
3	Dolomite	PAY	2113.94	2236.22	99.21	5.639	93.571	0	0.057	0.057	0.269	0.819	0.55	0.183	0.145	0.328
4	Limestone	ROCK	2207.2	2230.23	23.03	16.764	6.266	0	0.728	0.728	1.326	1.326	0	0.177	0.079	1
5	Limestone	RES	2207.2	2230.23	23.03	3.353	19.677	0	0.146	0.146	0.38	0.38	0	0.068	0.113	1
6	Limestone	PAY	2207.2	2230.23	23.03	0	23.03	0	0	0						
7	Shale	ROCK	2236.24	2239.06	2.82	0	0.078	2.742	0	0						
8	Shale	RES	2236.24	2239.06	2.82	0	0.078	2.742	0	0						
9	Shale	PAY	2236.24	2239.06	2.82	0	0.078	2.742	0	0						
10	Limestone	ROCK	2239.08	2262.47	23.39	11.735	11.522	0.133	0.502	0.505	1.17	1.197	0.027	0.238	0.102	0.978
11	Limestone	RES	2239.08	2262.47	23.39	5.944	17.313	0.133	0.254	0.256	0.744	0.771	0.027	0.201	0.13	0.966
12	Limestone	PAY	2239.08	2262.47	23.39	0	23.257	0.133	0	0						

Table 3. Cut-off and net pay for the well MJ-X1

	Zones	Flag Name	Top	Bottom	Gross	Net	Not Net	Un known	N/G	N/G unknown	BVW	POR-TH	HCPOR-TH	Vsh	Phi	Sw
1	Dolomite	ROCK	2509.06	2515.87	M	6.81	4.745	1.875	0.19	0.697	0.717	0.134	0.134	0	0.217	0.028
2	Dolomite	RES	2509.06	2515.87	M	6.81	0	6.62	0.19	0	0					
3	Dolomite	PAY	2509.06	2515.87	M	6.81	0	6.62	0.19	0	0					
4	Limestone	ROCK	2515.89	2619.6	M	103.71	89.5	11.975	2.235	0.863	0.882	3.415	3.433	0.018	0.233	0.038
5	Limestone	RES	2515.89	2619.6	M	103.71	1.75	99.725	2.235	0.017	0.017	0.197	0.197	0	0.189	0.113
6	Limestone	PAY	2515.89	2619.6	M	103.71	0	101.475	2.235	0	0					
7	Shale	ROCK	2619.76	2621.35	M	1.59	0.85	0.625	0.115	0.535	0.576	0.05	0.125	0.074	0.114	0.146
8	Shale	RES	2619.76	2621.35	M	1.59	0.6	0.875	0.115	0.377	0.407	0.035	0.105	0.069	0.072	0.174
9	Shale	PAY	2619.76	2621.35	M	1.59	0.6	0.875	0.115	0.377	0.407	0.035	0.105	0.069	0.072	0.174
10	Sandstone	ROCK	2621.37	2628.68	M	7.31	1.56	5.625	0.125	0.213	0.217	0.065	0.174	0.109	0.224	0.112
11	Sandstone	RES	2621.37	2628.68	M	7.31	1.13	6.055	0.125	0.155	0.157	0.051	0.15	0.099	0.21	0.133
12	Sandstone	PAY	2621.37	2628.68	M	7.31	1.13	6.055	0.125	0.155	0.157	0.051	0.15	0.099	0.21	0.133

Table 4. Cut-off and net pay for the well MJ-X7

	Zones	Flag Name	Top	Bottom	Gross	Net	Not Net	Un known	N/G	N/G unknown	BVW	POR-TH	HCPOR-TH	Vsh	Phi	Sw
1	Limestone	ROCK	2520	2553.73	M	33.73	20.7	13.03	0	0.614	0.614	0.14	1.147	1.007	0.221	0.055
2	Limestone	RES	2520	2553.73	M	33.73	4.6	29.13	0	0.136	0.136	0.049	0.65	0.601	0.11	0.141
3	Limestone	PAY	2520	2553.73	M	33.73	4.6	29.13	0	0.136	0.136	0.049	0.65	0.601	0.11	0.141
4	Sandstone	ROCK	2553.77	2583.32	M	29.55	25.32	4.23	0	0.857	0.857	0.341	0.845	0.504	0.22	0.033
5	Sandstone	RES	2553.77	2583.32	M	29.55	0.6	28.95	0	0.02	0.02	0.014	0.069	0.056	0.181	0.116
6	Sandstone	PAY	2553.77	2583.32	M	29.55	0.6	28.95	0	0.02	0.02	0.014	0.069	0.056	0.181	0.116
7	Limestone	ROCK	2583.35	2613.89	M	30.54	21.84	8.7	0	0.715	0.715	0.127	0.218	0.091	0.255	0.01
8	Limestone	RES	2583.35	2613.89	M	30.54	0	30.54	0	0	0					
9	Limestone	PAY	2583.35	2613.89	M	30.54	0	30.54	0	0	0					

Table 5. Cut-off and net pay for the well RN-X41

	Zones	Flag Name	Top	Bottom	Gross	Net	Not Net	Un known	N/G	N/G unknown	BVW	POR-TH	HCPOR-TH	Vsh	Phi	Sw
1	ALL	ROCK	1959.864	2195.932	236.06_8	224.942	10.973	0.152	0.953	0.953	23.658	28.997	5.339	0.152	0.129	0.816
2	ALL	RES	1959.864	2195.932	236.06_8	203.911	28.956	3.2	0.864	0.876	20.372	24.703	4.331	0.152	0.121	0.825
3	ALL	PAY	1959.864	2195.932	236.06_8	11.582	221.285	3.2	0.049	0.05	0.856	1.572	0.716	0.337	0.136	0.545

Table 6. Cut-off and net pay for the well ZB-X16

	Zones	Flag Name	Top	Bottom	Gross	Net	Not Net	Un known	N/G	N/G unknown	BVW	POR-TH	HCPOR-TH	Vsh	Phi	Sw
1	ALL	ROCK	1924	2140.103	M	216.103	189.738	26.213	0.152	0.878	0.879	30.63	35.487	4.857	0.151	0.187
2	ALL	RES	1924	2140.103	M	216.103	109.271	106.68	0.152	0.506	0.506	14.466	17.5	3.034	0.163	0.16
3	ALL	PAY	1924	2140.103	M	216.103	23.774	192.176	0.152	0.11	0.11	1.867	3.764	1.897	0.207	0.158

Table 7. Cut-off and net pay for the well ZB-X26

	Zones	Flag Name	Top	Bottom	Gross	Net	Not Net	Un known	N/G	N/G unknown	BVW	POR-TH	HCPOR-TH	Vsh	Phi	Sw
1	ALL	ROCK	1820	2105.14	M	285.14	244.297	40.691	0.152	0.857	0.857	30.111	43.565	13.454	0.182	0.178
2	ALL	RES	1820	2105.14	M	285.14	158.344	126.644	0.152	0.555	0.556	15.005	23.463	8.458	0.193	0.148
3	ALL	PAY	1820	2105.14	M	285.14	78.943	206.045	0.152	0.277	0.277	4.37	9.893	5.524	0.19	0.125

For the West Qurna/1 Field, a high-permeability layer exists in the upper part of the Sadi Formation, which is evident for petroleum potential in Sadi Formation with pay zones not exceeding 5 meters. According to the porosity and permeability estimation by well logs, rocks have high porosity (about 15–28%) and high permeability (The top of the wells WQ1-X36, X40, and X63), which can be identified as flow units. From the results of this study, the location of the wells has not affected the existence of hydrocarbons in the Sadi Formation (Figure 10 and Table 2).

From Figure 10, and Table 3, it is clear that hydrocarbons in the Sadi Formation in the Majnoon Field can be prevalent regardless of the location of the wells. The thickness of the net pay zone is about 5 m for all the wells under study, with moderate permeability in the pay zones, while the other zones have very low permeabilities.

The well ZB-X16 contains two possible zones, the first is 50 m (from 2050 to 2100 m) and the second is about 15 m (from 2125 to 2140 m). The results indicate that only the wells in the Rafdiya dome for the Sadi Formation in the Zubair Field contain a hydrocarbon, while no possibility of hydrocarbon for

the wells in the Safwan dome or those in the west flank (Figure 10 and Table 6).

Additionally, the hydrocarbons can exist in well ZB-X26 and have lower quantities in wells ZB-X16. In the well ZB-X26 (Figure 10 and Table 7), the thickness of the first net pay zone is about 15 m (from 1820 to 1835m), and the second is about 25 m (from 1990 to 2015m), while the third is about 40 m (from 2050 to 2090m)

The interpretation of the Rumaila Field logs for the Sadi Formation showed that the hydrocarbon potential is less than in the Zubair Field. The well RN-X41 (located in the east of the field) shows a hydrocarbon potential in one zone. The thickness of the zone is about 25 m (from 2125 to 2150 m). The results also indicate that there is no hydrocarbon potential in the Rumaila Field except on the east side (Well RN-X41) (Figure 10 and Table 5). The expansion of exploration for the Sadi Formation in the Rumaila Field requires drilling additional wells to the east of the crest (in the east flank) to discover more about the Sadi Formation in this area, while the rest of the wells (ZB-X23, X41, X53, and ZB-X74) do not contain hydrocarbon.

According to Figure 10 and table 4, the hydrocarbon in the top zone of the well MJ-X7 and MJ-X3, and the bottom zone of the well MJ-X1, contains oil. The well WQ1-X63, located in the northeastern part of the field, has gas potential (condensate gas). Generally, higher water saturation values were obtained using the Archie model than the Indonesia model in the wells of the two fields. To ensure the accuracy of the water saturation estimation, the Indonesian model water saturation was utilized, and the results were nearly Archie model.

5 Conclusions

This study identified the lithology, geomechanical, and petrophysical properties of the Sadi formation in the Majnoon, West Qurna/1, Zubair, and North Rumaila fields, utilizing wireline logs and core analysis in twenty-one wells. The results indicated that:

1. The maximum horizontal stress Azimuth should be 55 and 318 degrees toward the northeast, and the fault system type is Normal.
2. The lithology consists mainly of limestone, with a low percentage of Dolomite and sandstone, and some Shale content.
3. Hydrocarbon potential in the Sadi Formation in the West Qurna/1 Field will increase as wells are drilled toward the south, and the northeastern part of the field has gas potential (condensate gas).

Only the Rafdiya dome in the Zubair Field could contain hydrocarbons. On the other hand, there is no hydrocarbon potential for the Safwan dome or those on the west flank, and no hydrocarbon potential in the Rumaila Field except on the east side. The hydrocarbons in the southern part of the Majnoon field are more likely and will decrease toward the north.

4. Future work must focus on the flanks of the Sadi Formation in the Majnoon field, drilling more wells east of the crest (possibly on the east flank), and in the West Qurna/1 Field in the south to discover more about the Sadi Formation in this area.
5. Net pay thickness in formations that potentially contain hydrocarbons ranges from 5.6 meters in the West Qurna oilfield to about 79 meters in the Zubair oilfield, with average porosities of 14.5% and 15.8%, and a high-water saturation in most fields.
6. New wells should be drilled using advanced and modern logging tools such as the Electromagnetic Propagation Tool (EPT) log, the Nuclear Magnetic Resonance (NMR) log, etc. to increase the accuracy of the formation evaluation. More wells and more basic data (special and routine core analysis) are necessary to improve the quality of interpretation.

Ethics declarations

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Author Contributions

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Data availability

Data is provided within the manuscript.

Competing interests' policy

We declare that the authors have no competing interests as defined by Nature Research, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

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