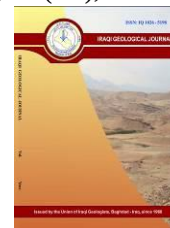




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Petrophysical Properties and Reservoir Modeling of the Mishrif Formation in North Rumaila Oilfield, Southern Iraq

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Abstract

The Mishrif Formation in the North Rumaila oilfield was studied using data from eight wells (R-27, R-36, R-250, R-470, R-491, R-493, R-520, and R-521). In addition, the petrophysical analysis was based on well log data (Caliper, GR, RHOB, NPHI, DT, and Resistivity). The qualitative petrophysical analysis showed that the main rock type of the Mishrif Formation is clean limestone and porous, whereas wells R-250 and R-520 contain argillaceous limestone and porous. According to the resistivity log data, the reservoir is highly saturated with hydrocarbons compared to water. The quantitative petrophysical analysis showed a decrease in the shale volume content within the reservoir. Therefore, the effective porosity was identical to the total porosity values for the studied wells with the exception of wells R-250 and R-520. The lower secondary porosity compared to primary porosity indicates that diagenetic processes had no significant impact. Furthermore, the low bulk volume of water relative to that of hydrocarbons indicates high hydrocarbon saturation. The Mishrif Formation was split into three reservoir units (mA, mB1, and mB2), and the number of subunits was developed based on the petrophysical characteristics (porosity, permeability, hydrocarbon and water saturation, and shale volume) using well log data. The mA unit has the highest oil content at wells R-27 and R-491 in the crest of the field, whereas the lowest at R-470 in the southwest. Meanwhile, the mB1 unit has the highest oil content at R-493 in the north and R-521 in the south, whereas the lowest oil content is observed at R-470. Finally, the mB2 unit has the highest oil content at R-493 in the North and R-250 in the northwest, whereas the lowest is at R-521. The mA unit was divided into two subunits mA1 and mA2, whereas the mB1 unit was divided into three subunits mB1.1, mB1.2 and mB1.3. Moreover, the mB2 unit was not divided into a subunits. Based on the petrophysical analysis and reservoir model, the mB1 unit is identified as the best and most highest reservoir quality. Furthermore, among the subunits mB1.3 and mB1.2 exhibit the best reservoir characteristics.

Keywords: Reservoir units; Petrophysical properties; Reservoir modeling; Mishrif Formation

1. Introduction

The North Rumaila oilfield is one of the most important oilfields in Iraq, and the Mishrif Formation is one of the most important reservoirs in this oilfield. The current study focused on the Mishrif Formation, which is considered a heterogeneous carbonate and represents the second major reservoir for heavy oil production in the North Rumaila oilfield (Al-Omari et al., 1982). The main aims of this

study are to conduct a petrophysical analysis of the Mishrif Formation using open hole well logs and to divide the reservoir units into subunits depending on the petrophysical properties. This study was compared with previous studies, including those of Al-Obaidi (2005) in the same oilfield, Almuhsin (2019) in the West Qurna oilfield, Al-Maliki (2022) in the Zubair oilfield, Al-Sayed (2023) in the West Qurna oilfield, Al-Rubaie (2024) in the North Rumaila oilfield. This study differed from the Al-Obaidi (2005) study in the division of secondary reservoir units: Al-Obaidi divided the main unit mB1 into four subunits, whereas this study divided it into three subunits.

2. Study Area

The North Rumaila oilfield is located in southern Iraq, between longitudes 47°14'46" - 47°26'14" E and latitude 30°5'5.7" - 31°12'41" N. It extends over an area of approximately 50 km west of Basra City and 25 km west of the Zubair oilfield (Jaffar and Abdulnaby, 2018) (Fig. 1).

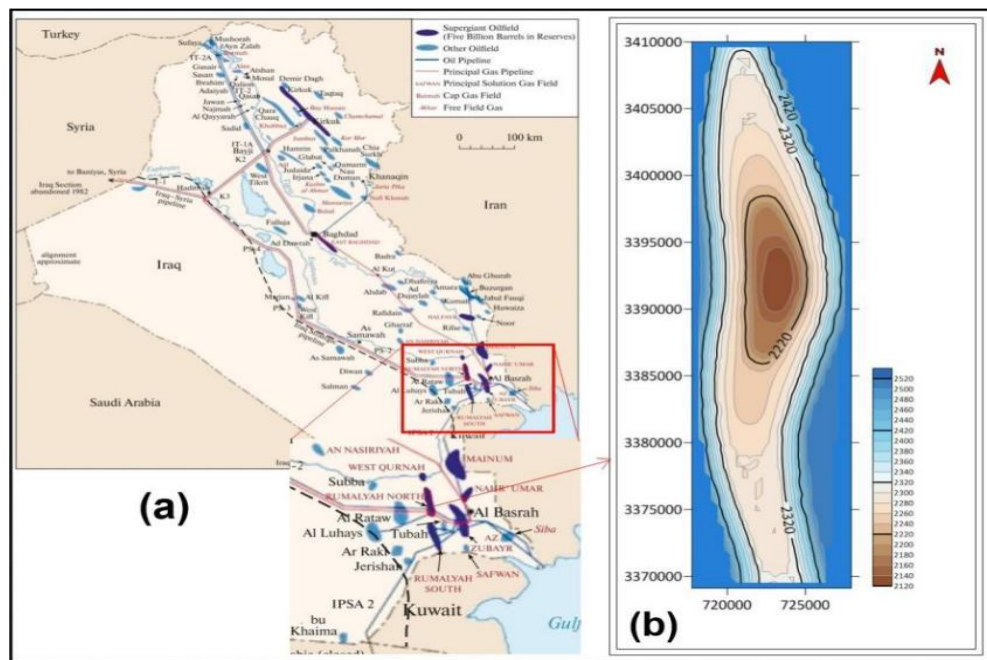


Fig. 1. a) Oil fields map of Iraq shows the location of the study area (Sissakian et al., 2023); b) structural contour map of North Rumaila oilfield (Surfer Software)

3. Geological Setting

The North Rumaila oilfield is tectonically located in the Mesopotamian foredeep, in the Zubair subzone (Fouad, 2015). It is considered a subsurface structural trap of the N-S oriented anticline type (Jassim and Goff, 2006). The North Rumaila oilfield is characterized by an asymmetrical longitudinal anticline covering approximately 256 km². The western flank has a steeper dip than eastern flank, with a dip angle not exceeding 3° (Al-Omari et al., 1982). The Mishrif Formation was deposited during the Cenomanian-Early Turonian depositional cycle, as an extensive shallow-water carbonate platform within the intra-shelf basin (Aqrawi et al., 2010). According to Sharland et al. (2001), the Mishrif Formation is located within the AP8 (TMS) and is considered part of the IV supersequences within the Wasia group (Fig. 2). It is characterized by reef limestone lithology, and its thickness in the North Rumaila oilfield is approximately between 120 and 150m. The Mishrif Formation in the north Rumaila oilfield is subdivided into five units: cap rock 1 (CRI), upper Mishrif (mA), cap rock 2 (CRII), middle Mishrif (mB1), and lower Mishrif (mB2).

4. Materials and Methods

The methods were represented by office work, which included two parts: the first was the final reports and well log data obtained from the Basra Oil Company, and the second was the software. Eight wells were selected (R-27, R-36, R-250, R-470, R-491, R-493, R-520, and R-521) and distributed across the North Rumaila oilfield (Fig. 3 and Table 1). The well log data included Caliper, Gamma ray (GR), Density (RHOB), Neutron (NPHI), Sonic (DT), and Resistivity logs. The software package employed in that study included Didger, which was used to convert structural maps into digital data. Surfer was used to create a structural map of the studied field. Strater was used to create the field's stratigraphic column; interactive petrophysics (IP) was used to display well log responses for qualitative interpretation; and finally, Petrel was used to show the results of quantitative analysis and to build 3D static reservoir models.

Geological Age			Group	Mega-sequence	Super-sequence	Depth m	Formation	Lithology	Description	Average thickness (m)	Tectonic events		
Cenozoic	Neogene	Pliocene-Recent	Kuwait	AP 11	IV	500	Dibdibba		sand & gravel	350	Collision & Zagros orogeny		
		Miocene			III		Fatha		Anhydrite, gypsum & salt	170			
	Paleogene	Eocene	Hasa	AP 10	I		Ghar Damman		Sand & gravels	125			
							Limestone & Dolomite	250					
							Rus		Anhydrite with marls	100			
Mesozoic	Cretaceous	Palaeocene	Aruma	AP 9	VI	Umm Er-Radhuqa		Dolomitic limestone & anhydritic	407	Ophiolite obduction			
						Tayarat		Dolomite, silty marl & calcareous shale	200				
						Shiranish		Marly limestone	225				
		Companian		V	Hartha		Glauconitic limestone & organic detrital	200					
		Santonian			Sa'adi		Chalky limestone	176					
		Coniacian			Tanuma		Black & fissile shale	24					
		Turonian		Khasib		Dark grey & marly limestone	54						
		Cenomanian		Wasia	AP 8	IV	Mishrif		Limestone, Rudist & algal lime		130	Opening of southern Neo-Tethys	
							Rumaila		Marly limestone & chalky lime		150		
							Ahmadi		Black silty shale & limestone member		160		
	Mauddud							Limestone with calcareous detritus	150				
	Nahr Umr							Sand & shale	250				
	Shuaiba							Limestone & Dolomite	125				
	Zubair							Shales & sandstone with siltstone	390				
	Jurassic	Thamam		AP 7	I	Ratawi		Limestone with shale	110	subsidence & Rifting			
Yamama						Limestone	360						
Sulaiy						Argillaceous limestone	331						
Gotnia						Anhydrite, Evaporite	620						
Najmah						Oolitic limestone	341						
Sargelu						Dolomitic limestone	74						

Fig.2. The stratigraphic column of North Rumaila oil field (Modified from Sharland et al., 2001; Jassim and Goff, 2006; Aqrabi et al., 2010) (Starter Software)

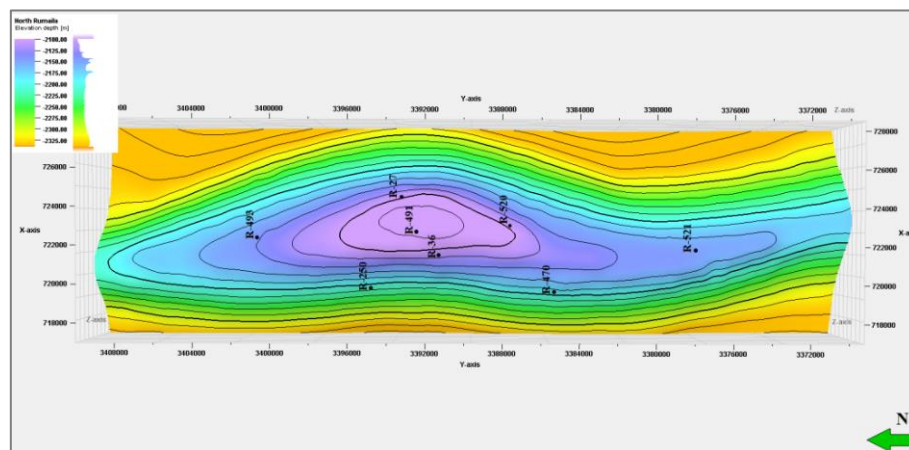


Fig.3. Distribution of wells on structure map of the North Rumaila oilfield (Petrel Software)

Table 1. The depths and thickness of the Mishrif Formation in the studied wells

Well	Top (m)	Bottom (m)	Thickness (m)	KB (m)	Northern (m)	Eastern (m)
R-27	2175	2308.3	133.3	7.1	3393370	724490
R-36	2178.1	2311.5	133.4	7.5	3391640	721487
R-250	2253.90	2390.3	136.4	8.20	3395050	719700
R-470	2261.35	2401.8	140.5	13.1	3385056	719551
R-491	2140.59	2278.1	137.51	10.14	3392302	722666
R-493	2174.18	2295.1	121	13.3	3401010	722325
R-520	2199.5	2329	129.5	16.50	3387515	723013
R-521	2264.5	2396	131.5	26.48	3377109	721933

5. Results and Discussion

5.1. Qualitative Interpretation

Qualitative petrophysical interpretation of well log data is carried out using a quick look method to determine reservoir boundaries, lithology and the type of pore fluid (Asquith and Krygowski, 2004). The lithology of the Mishrif Formation was determined based on the GR log and porosity logs (NPHI, RHOB and DT), where the formation has been differentiated into five units: cap rocks 1(CRI), upper Mishrif (mA), cap rock 2 (CRII), middle Mishrif (mB1) and lower Mishrif (mB2) (Al-Maliki, 2022). From the GR log, three types of rocks can be identified: clean limestone (less than 20 API), argillaceous limestone (20 -70 API), and shale (more than 70 API).

The GR logs show that clean limestone is dominant (Fig. 4), with a small percentage of argillaceous limestone, exception for two wells (R-250 and R-520), which show the opposite. The porosity logs (Neutron–Density) appear overlay, which indicates the lithology of the limestone (Asquith and Krygowski, 2004) (Fig. 4), and from them it is possible to identify two types of rocks: porous and compacted (Cannon, 2016). The mA, mB1 and mB2 units show porous rock, whereas CRI,CRII and the upper part of the mA unit in the studied wells show compacted rock.

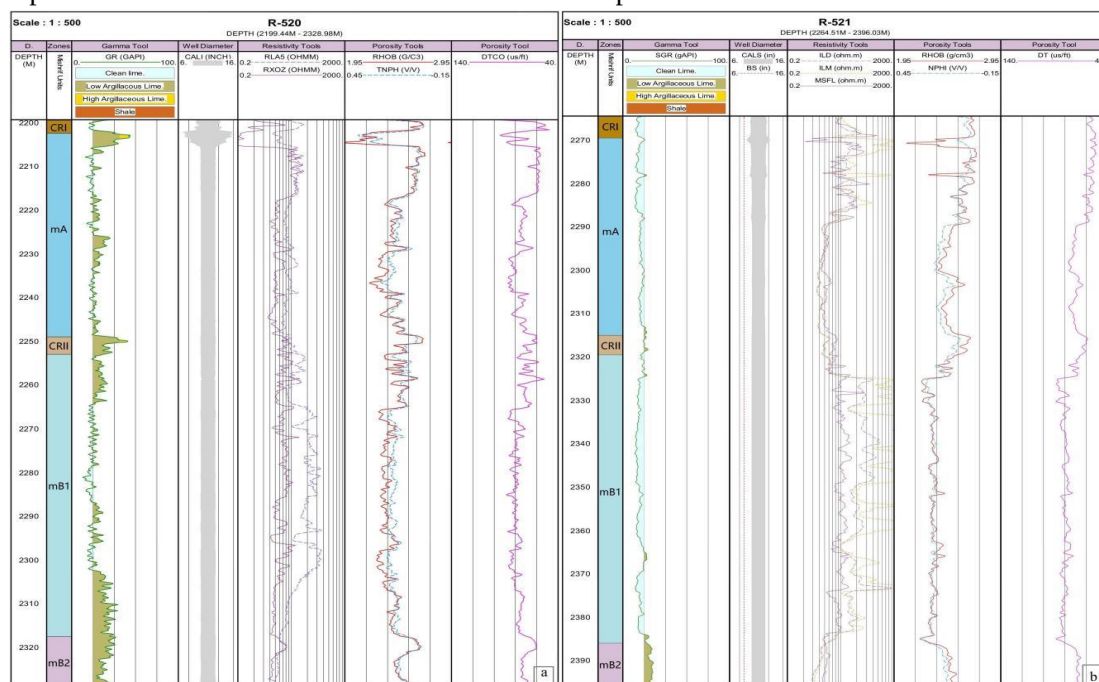


Fig. 4. a) The behavior of logs for Mishrif Formation in R-520; b) The behavior of logs for Mishrif Formation in R-521

The Mishrif Formation is saturated with fluids, the type of which can be identified from resistivity logs (Asquith and Krygowski, 2004), which indicates the presence of a higher hydrocarbon saturation than the water saturation in the studied wells.

5.2. Quantitative Interpretation

5.2.1. Shale volume

The Gamma Ray (GR) log is among the most effective logs for calculating the shale volume, due to its ability to detect the natural radioactivity contained within the shale (Cannon, 2016). Calculating the gamma ray index (I_{GR}) is the first step in determining shale volume from equation (1), followed by determination of shale volume from equation (2) (Asquith and Krygowski, 2004).

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

$$V_{sh} = (2^{(2 \cdot I_{GR})} - 1) / 3 \quad (2)$$

5.2.2. Porosity

Porosity is one of the most important properties of a rock due to the fact that it measures the volume of possible storage of hydrocarbons (Lucia, 2007). Porosity was calculated from the neutron density, as shown in Equation 3, and the sonic logs. Porosity is geologically classified into primary porosity, which can be calculated from the sonic log using Equation 4, and secondary porosity (SPI) (Tiab and Donaldson, 2015) as shown in Equation 5. Engineering classification of porosity is of two types: absolute (total) porosity, which can be calculated from neutron and density logs using Equation 6, and effective porosity (Tiab and Donaldson, 2015), which can be calculated using Equation 7.

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad (3)$$

$$\phi_S = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \quad (4)$$

$$SPI = \phi_{N.D} - \phi_S \quad (5)$$

$$\phi_{N.D} = \frac{\phi_N + \phi_D}{2} \quad (6)$$

$$\phi_e = \phi_{N.D} * (1 - V_{sh}) \quad (7)$$

5.2.3. Water saturation and hydrocarbon saturation

Water saturation (S_w) in the uninvaded zone is calculated using the Archie (1942) equation, as in Equation 8, and determine formation factor from Equation 9.

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

$$F = \frac{a}{\phi^m} \quad (9)$$

Water saturation in the flushed zone (S_{xo}) is also based on the Archie equation (1942) as in equation 10 and determines resistivity of mud filtrate (Equation 11), formation temperature (Equation 12), and geothermal gradient (Equation 13).

$$S_{xo} = \sqrt{(F * R_{mf}) / R_{xo}} \quad (10)$$

$$R_{mf} @ T_f = R_{mf} @ T_s * \left(\frac{T_s + 21.5}{T_f + 21.5} \right) \quad (11)$$

$$T_f = (G.G * d) + T_s \quad (12)$$

$$G.G = \frac{BHT - T_s}{TD} \quad (13)$$

Hydrocarbon saturation calculated using Equation 14.

$$Sh = 1 - Sw \quad (14)$$

5.2.4. Movable oil saturation and residual oil saturation

Movable oil saturation (MOS) is the amount of oil that can be produced from the reservoir and is calculated using Equation 15 (Cannon, 2016). Residual oil saturation (ROS) is the amount of oil remaining in pores and cannot be easily produced using conventional methods (Cannon, 2016). It is calculated using Equation 16.

$$MOS = S_{xo} - S_w \quad (15)$$

$$ROS = 1 - S_{xo} \quad (16)$$

5.2.5. Bulk volume of water and bulk volume of hydrocarbons

Bulk volume of water in the uninvaded zone was calculated from Equation 17, bulk volume of water in the flushed zone was calculated from Equation 18, and the bulk volume of hydrocarbon was calculated from Equation 19.

$$BVW = SW * \emptyset N.D \quad (17)$$

$$BVXO = S_{xo} * \emptyset N.D \quad (18)$$

$$BVh = Sh * \emptyset N.D \quad (19)$$

The results of quantitative calculations showed that the shale volume content is low at all studied wells; therefore the effective porosity is identical to the total porosity, except for two wells, R-250 and R-520. The lower secondary porosity compared to primary porosity indicates that diagenetic processes had no significant impact. The hydrocarbon saturation is higher than the water saturation, so the bulk volume of water is small compared to the bulk volume of hydrocarbon. Fig. 5 shows the quantitative calculations for R-520 and R-521.

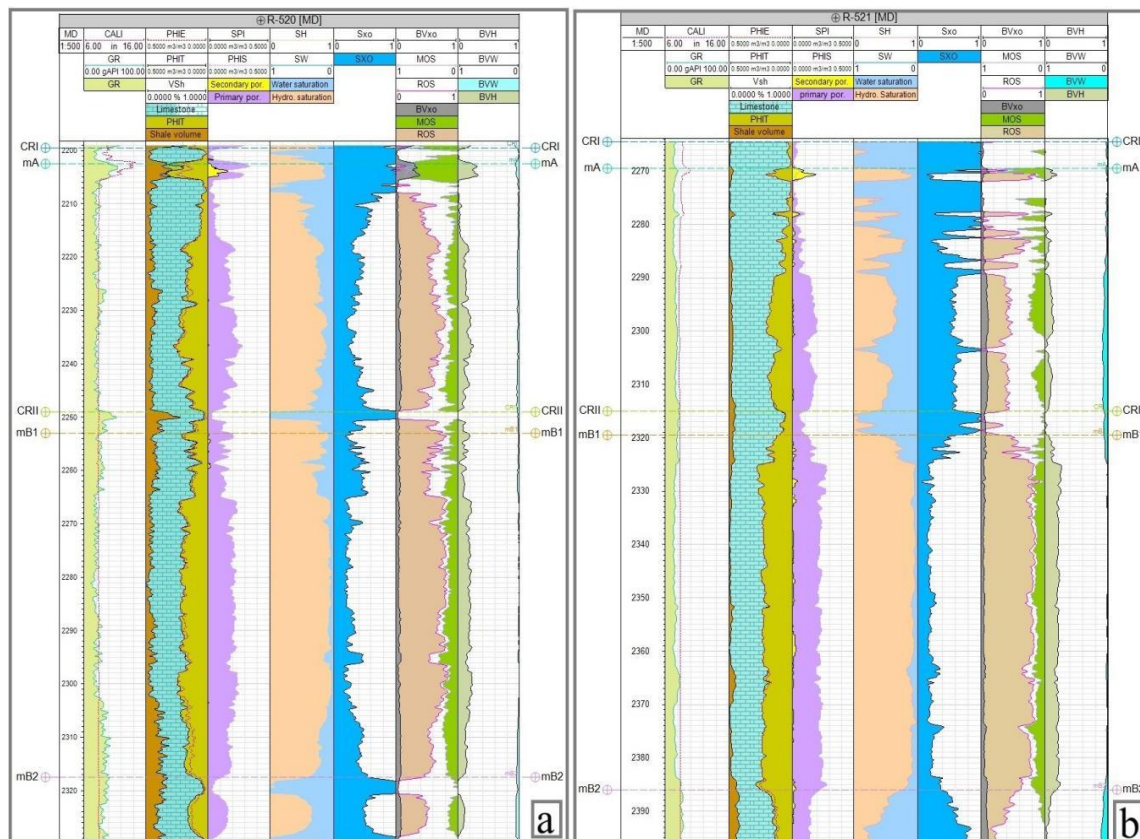


Fig. 5. a) Petrophysical properties calculated for well R-520; b) Petrophysical properties calculated for well R-521

5.3. Permeability

Permeability is defined as the reservoir's ability to allow fluids through the rock matrix, that is, its ability to allow fluid flow (Ahmed, 2016). In this study, well logs data were used to calculate permeability and this method is valid only when the reservoir is at an irreducible water saturation (Swirr). A hyperbolic line plot of effective porosity versus irreducible water saturation (Schlumberger, 2009) was used to determine the bulk volume of water for each reservoir unit in the studied wells. If the points are parallel to one of the hyperbolic lines and constant, it indicates the possibility of calculating permeability; if the points are scattered, it indicates the impossibility of calculating permeability due to the presence of reducible water saturation. The results showed that it is possible to estimate the permeability of all reservoir units except the mA unit for R-36 and R-521, and the mB2 unit for R-493, due to the presence of reducible water saturation. Subsequently, the permeability was calculated using the Wyllie and Rose formula (1950) (Equation 20). Fig. 6 shows a hyperbolic line plot for reservoir units of R-520 and R-521 wells.

$$K = [C * (\frac{\phi^3}{Swirr})]^2 \quad (20)$$

Where: K: permeability (mD), C: Constant, its value equals 250 for oil and 79 for dry gas, ϕ : effective porosity, Swirr: irreducible water saturation.

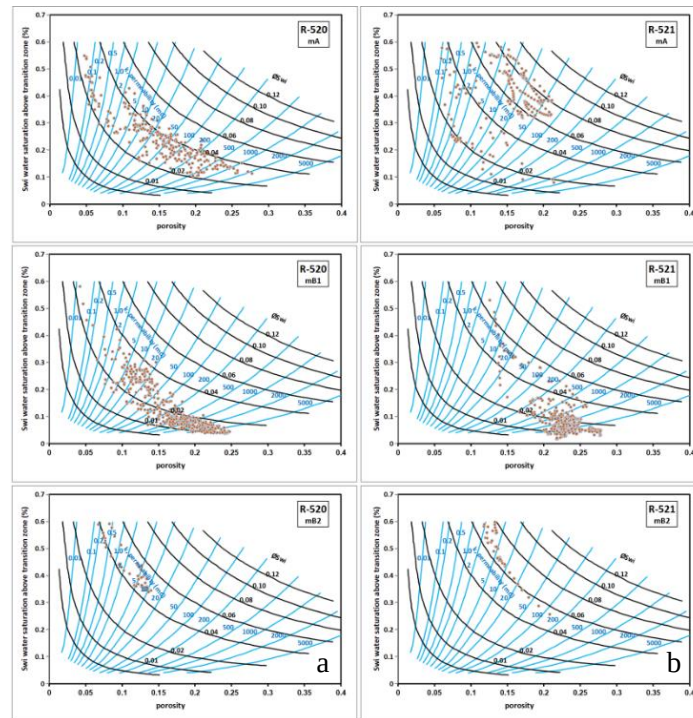


Fig. 6. a) Chart effective porosity and Swirr (Schlumberger, 2009) of reservoir units (mA, mB1, and mB2) for R-520; b) Chart effective porosity and Swirr of reservoir units (mA, mB1, and mB2) for R-521

5.4. Reservoir Units

The Mishrif Formation in the North Rumaila oil field was divided into three reservoir units: upper Mishrif (mA), middle Mishrif (mB1) and lower Mishrif (mB2) (Table 2). In this study, these reservoir units were divided into subunits based on their petrophysical properties (porosity, permeability, water and hydrocarbon saturation, and shale volume). The following paragraph describes these reservoir units and their subunits.

5.4.1. mA unit

The first reservoir unit, which is bounded from above by the CRI unit and from below by the CRII unit, is characterized by rocks ranging from compact to porous rocks. The thickness of this unit is between 38.5 m at R-36 in the crest of the field and 75.7 m at R-470 in the southwest of the field (Table 2). This unit has a high oil content and productivity at R-27 and R-491 in the crest of the field, whereas it is lower at R-470 southwest of the field. This unit was divided into two secondary subunits, mA1 and mA2.

First, the mA1 subunit is located at the upper part of the mA unit and is characterized by porous with compact rock in the studied wells, except for two wells (R-27 and R-250) which have only porous rock; the thickness varies between 19.3 and 35.2 m. In addition, the shale volume is between 4 and 18%, porosity is between 13 and 25%, permeability ranges from medium to excellent (Tiab and Donaldson, 2015), hydrocarbon saturation is about 44-89%, and water saturation is between 11 and 56% (Table 3).

Second, the mA2 subunit is below the mA1 subunit and is characterized by a porous rock with a thickness of 11 to 22.5m. Meanwhile, the shale volume is about 3-10%, the medium to excellent porosity is about 14-22%, and the permeability is good to very good (Tiab and Donaldson, 2015). Hydrocarbon saturation is about 53-87% while water saturation is between 13 and 47%. The mA2 subunit is mostly thinner than the mA1 subunit in the studied wells, although it shows a better reservoir quality than the mA1 subunit in terms of its petrophysical properties (Table 3).

Table 2. The top and thickness of the Mishrif reservoir units for the studied wells

Well	Unit	Top (m)	Thick (m)	Well	Unit	Top (m)	Thick (m)
R-27	mA	2180.7	39.2	R-491	mA	2143.5	46.9
	mB1	2225.2	74.7		mB1	2196.2	73.8
	mB2	2299.9	8.4		mB2	2270	8.1
R-36	mA	2183.3	38.5	R-493	mA	2180.2	50
	mB1	2225	74.7		mB1	2237.1	43.9
	mB2	2299.7	11.8		mB2	2281	14.1
R-250	mA	2262.5	43.3	R-520	mA	2202.5	46.5
	mB1	2312.7	67.5		mB1	2253	64.5
	mB2	2380.2	10.1		mB2	2317.5	11.5
R-470	mA	2269.8	57.7	R-521	mA	2269.5	45.5
	mB1	2333.5	51.4		mB1	2319.5	66.5
	mB2	2384.9	16.9		mB2	2386	10

Table 3. Average petrophysical properties of the mA unit (mA1 and mA2 subunits) for the studied wells

Well	Sub unit	Top (m)	Thick (m)	Vsh %	PHIT %	PHIE %	SW %	SH %	K (mD)
R-27	mA1	2180.7	19.3	5	23	23	11	89	1389.9
	mA2	2200	19.9	5	22	22	15	85	780.8
R-36	mA1	2183.3	21.7	4	5	5	56	44	
	mA2	2205	16.8	5	14	14	26	74	
R-250	mA1	2262.5	22.5	10	18	17	32	68	146.9
	mA2	2285	20.8	9	21	19	13	87	444.5
R-470	mA1	2269.8	35.2	5	13	13	43	57	12.8
	mA2	2305	22.5	5	16	16	33	67	59.7
R-491	mA1	2143.5	24.5	4	18	18	20	80	347.8
	mA2	2168	22.4	4	20	20	15	85	665.4
R-493	mA1	2180.2	31.8	6	20	20	23	78	460.8
	mA2	2212	18.2	3	19	19	21	79	304.95
R-520	mA1	2202.5	25.5	18	14	10	32	68	42.04
	mA2	2228	21	10	19	18	22	78	197.3
R-521	mA1	2269.5	34.5	8	11	11	33	68	
	mA2	2304	11	5	17	16	47	53	

5.4.2. mB1 unit

The second reservoir unit, located below the CRII unit, is characterized by porous rock. Its thickness ranges from 51.4 m at R-470 in the southwestern part of the field to 74.7m at wells R-27 and R-36 in the crest of the field (see Table 2). In this unit R-493 in the north and R-521 in the south have the highest oil content and well R-470 has the lowest. This unit was divided into three secondary reservoir subunits.

The mB1.1 subunit is the first subunit of the mB1 unit, which is positioned at the top and has a thickness ranging from 12.9 to 32.5 m in the studied wells. The shale volume is approximately 2-18%, porosity values are about 13-22% and a fair to excellent permeability (Tiab and Donaldson, 2015). The saturation of the hydrocarbon varies between 59 and 97%, while the water saturation is about 3-41% (Table 4).

The mB1.2 subunit is located below the mB1.1 subunit and its thickness ranges from 13m at well R-521 in the southern part of the field to 23m at R-27 in the crest of the field. The volume of the shale varies between 2 and 19%, with a porosity of about 12-23% and excellent permeability (Tiab and Donaldson, 2015), except for the wells R-250 and R-470, where the permeability is low. The saturation of hydrocarbon is between 66 and 98%, while the saturation of water is about 2-34% (Table 4).

The mB1.3 subunit is located below the mB1.2 subunit, and its thickness ranges from 16m at R-493 in the north of the field to 31.7m at R-36 in the crest of the field. The shale volume is between 3 and 18%, characterized by porosity of about 17-23% and very good to excellent permeability (Tiab and Donaldson, 2015). The hydrocarbon saturation is approximately 69-95%, while the water saturation is between 5 and 31%. The mB1.2 and mB1.3 reservoir subunits have high reservoir quality, surpassing the mB1.1 unit in terms of petrophysical properties (Table 4).

Table 4. Averages petrophysical properties of mB1 unit (mB1.1, mB1.2 and mB1.3 subunits) for studied wells

Well	Subunit	Top (m)	Thic k (m)	Vsh %	PHIT %	PHIE %	SW %	SH %	K (mD)
R-27	mB1.1	2225.2	12.8	9	17	16	25	75	5068.4
	mB1.2	2247	23	3	23	23	5	95	4727.6
	mB1.3	2270	29.9	3	23	23	5	95	4868
R-36	mB1.1	2225	22	8	13	13	14	86	290.8
	mB1.2	2247	21	16	12	10	23	77	28.4
	mB1.3	2268	31.7	5	22	22	5	95	5583.8
R-250	mB1.1	2312.7	19.3	18	14	11	34	66	2.60
	mB1.2	2332	20	19	14	11	27	73	2.50
	mB1.3	2352	28.2	10	20	19	7	93	21553
R-470	mB1.1	2333.5	16.5	8	13	13	41	59	12.21
	mB1.2	2350	15	11	14	14	34	66	6.95
	mB1.3	2365	19.9	9	17	16	31	69	653.5
R-491	mB1.1	2196.2	28.8	7	13	13	25	77	49.8
	mB1.2	2225	15	3	19	19	4	96	3425.9
	mB1.3	2240	30	3	21	21	5	95	102152
R-493	mB1.1	2237.1	12.9	2	20	20	3	97	740968
	mB1.2	2250	15	2	22	22	2	98	266925
	mB1.3	2265	16	10	17	17	12	88	659.6
R-520	mB1.1	2253	25	11	17	15	16	84	487.2
	mB1.2	2278	18	9	21	19	8	92	1066.7
	mB1.3	2296	21.5	18	19	16	15	85	1259.3
R-521	mB1.1	2319.5	32.5	3	22	22	10	90	4634.6
	mB1.2	2352	13	4	23	23	9	91	1751.4
	mB1.3	2365	21	5	23	23	9	91	2038.9

5.4.3. mB2 unit

The third reservoir unit is located below the mB1 unit. In the studied wells the lithology is porous limestone except for well R-520, which is composed of compact and porous rocks. The unit shows a thickness ranging from 8.1m at R-491 in the crest of the field to 16.9m at R-470 in the southwest. In addition, the shale volume content varies between 3 and 20% and shows approximately porosity 14-22%, as shown in Table 5, while the permeability is fair to moderate (Tiab and Donaldson, 2015) in the studied wells, except for the R-27 and R-470 wells, where it is relatively good (Tiab and Donaldson, 2015). The hydrocarbon saturation is about 52-93%, whereas the water saturation is in the range of 7-48%, (Table 5). This unit in R-493 north of the field and R-250 northwest of the field, recording the highest oil content, and in R-521 at the south, the lowest. Fig. 7 shows the correlation of petrophysical properties of the studied wells in front of the reservoir units and subunits of the Mishrif Formation in the North Rumaila oilfield.

Table 5. Average petrophysical properties of mB2 unit for the studied wells

Well	Top (m)	Thick (m)	Vsh%	PHIT%	PHIE%	SW %	SH %	K (mD)
R-27	2299.9	8.4	10	16	15	24	76	111.8
R-36	2299.7	11.8	9	16	16	25	75	41
R-250	2380.2	10.1	13	16	14	8	92	17.07
R-470	2384.9	16.9	5	22	22	18	82	967.6
R-491	2270	8.1	6	14	14	40	60	15.4
R-493	2281	14.1	3	22	22	7	93	
R-520	2317.5	11.5	20	14	11	42	58	1.48
R-521	2386	10	14	16	14	48	52	3.7

When inspecting the petrophysical results for all reservoir units (mA, mB1, and mB2) of the Mishrif Formation in the North Rumaila oilfield, the main unit mB1, is considered the highest quality and most productive hydrocarbon unit in the studied wells. Among the reservoir subunits (mA1, mA2, mB1.1, mB1.2, and mB1.3), the mB1.2 and mB1.3 subunit exhibit the best reservoir quality.

5.5. Petrophysical Modeling

A 3D static reservoir model was created using Petrel software. The wellhead, well top, well log and structural map files have been prepared and entered into the Petrel software. Subsequently, the petrophysical properties, including porosity, permeability, hydrocarbon saturation, water saturation and shale volume were distributed across the main and secondary reservoir units in the model.

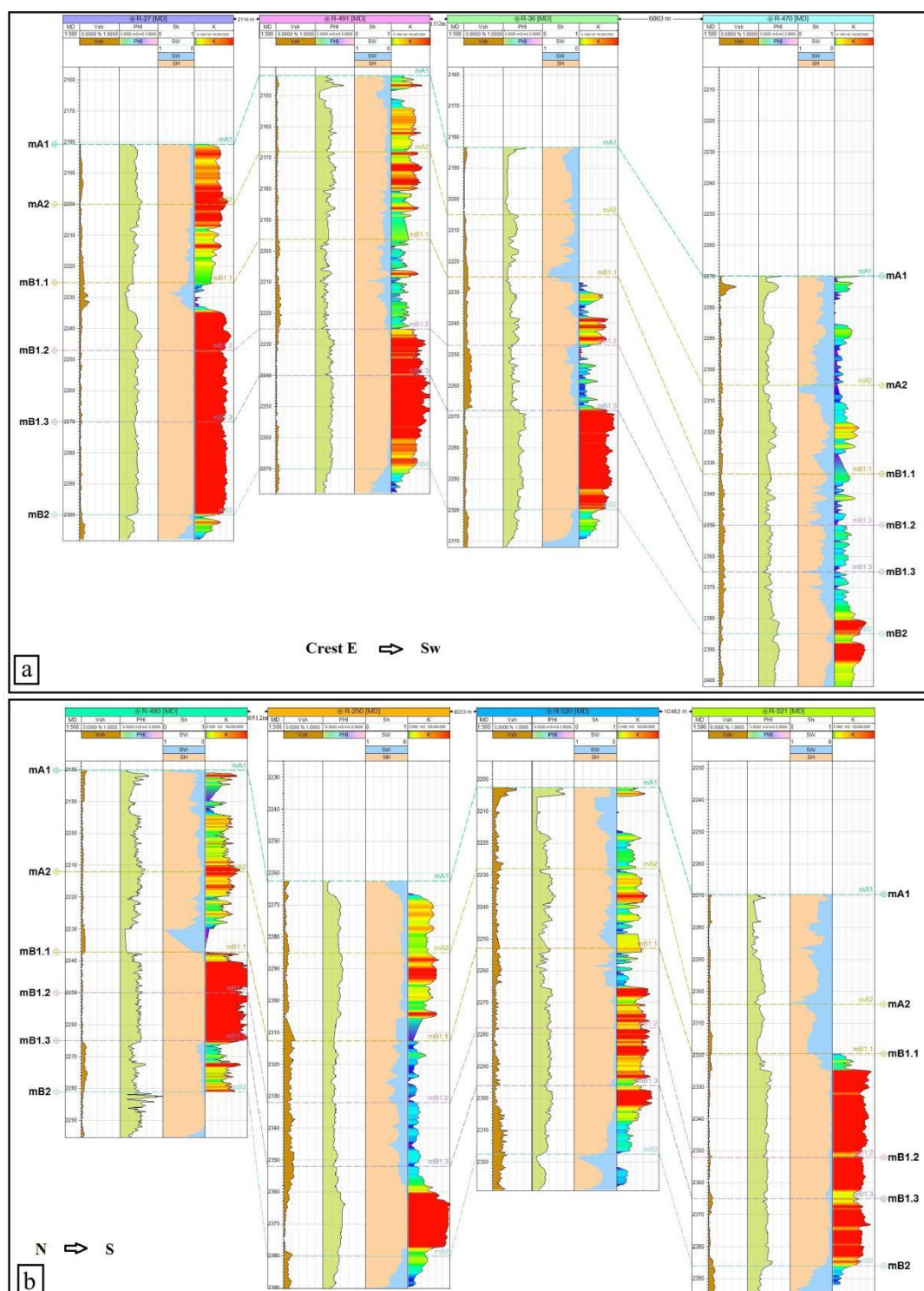


Fig.7. a) Well correlation for wells R-27, R-491, R-36 and R-470; b) Well correlation for wells R-493, R-250, R-520 and R-521

5.5.1. Structural modeling

As the first step in the construction of the reservoir model, this step is based on the structural map of the Mishrif Formation in the North Rumaila oilfield (Fig. 8). The data of this map are combined with the data of the layered surfaces from the wells to build a 3D grid and horizons. The cell size was chosen to be 100x100 and the grid cells of 164x372x51, so the total number of grid cells is 3111408. The structural model shows that the North Rumaila oilfield is an asymmetrical convex fold (Fig. 8).

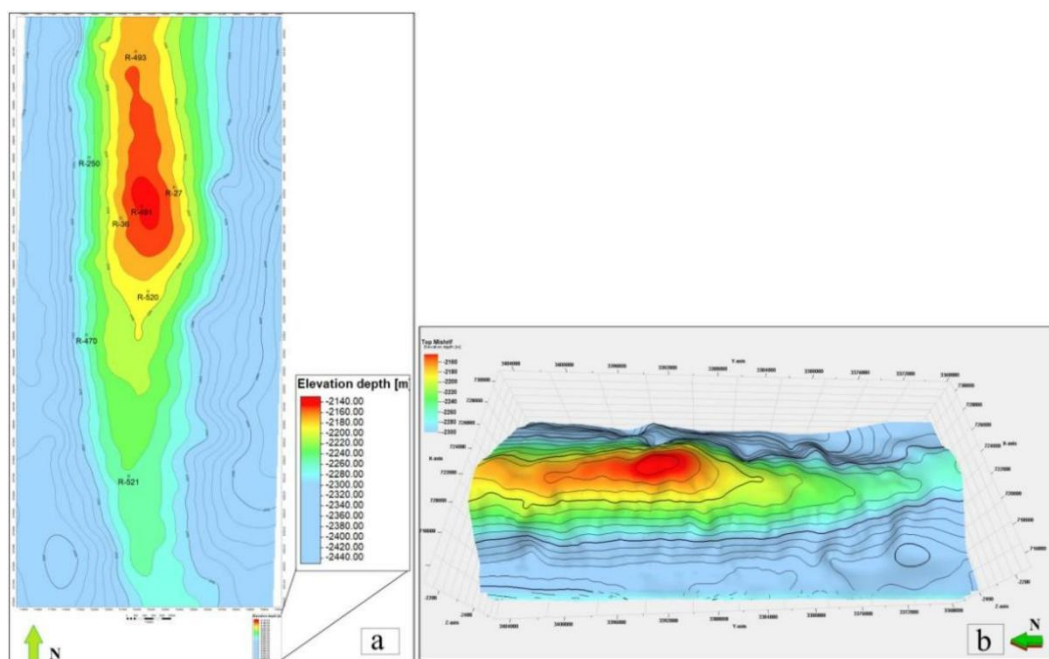


Fig. 8. a) Structural map of top Mishrif Formation (mA unit) within the studied wells; b) Structural model of top Mishrif Formation (mA unit) in the studied oilfield

5.5.2. Porosity distribution

According to the created porosity model for the mA1 subunit, the porosity decreases in the west and increases in the east of the reservoir, and is excellent in the south of the reservoir (Fig. 9). In addition, the porosity of the mA2 subunit increases at the north and east while decreasing at the southwest of the reservoir. Meanwhile, the mB1.1 subunit porosity is excellent in the north and south, whereas rest of the study area shows moderate porosity. Moreover, the mB1.2 subunit porosity is good to excellent except in the west of the reservoir where it is low (Fig. 9). The mB1.3 subunit has good porosity in the north and southwest, while it is excellent in the rest of the reservoir. Finally, the mB2 unit has low porosity at the crest of the reservoir and good to excellent porosity elsewhere (Fig. 9).

5.5.3. Hydrocarbon and water saturations distribution

The mA1 subunit shows a very good hydrocarbon saturation at the eastern flank and crest of the reservoir, with decreasing at the rest of the studied formation (Fig. 10). Accordingly, the water saturation shows an inverse distribution, with good values at the western flank of the reservoir and low values at the rest of the studied formation (Fig. 11). Meanwhile, the mA2 subunit characterized by very good hydrocarbon saturation throughout the reservoir except in the south and southwest of the reservoir, where it is low (Fig. 10). Consequently, the south and southwest of the reservoir show high values of water saturation (Fig. 11). In addition the mB1.1 subunit exhibits good hydrocarbon saturation; however, it decreases in the southwest of the reservoir (Fig. 10), where water saturation correspondingly increases (Fig. 11). Similarly, the mB1.2 subunit is characterized by excellent hydrocarbon saturation throughout the reservoir, although it becomes moderate in the southwest of the reservoir (Fig. 10), which is associated with elevated water saturation in this zone (Fig. 11). In contrast, the mB1.3 subunit show very good to excellent hydrocarbon saturation overall, but a decreased in the west of the reservoir (Fig. 10), coinciding with higher water saturation values (Fig. 11). Finally, within the mB2 unit hydrocarbon saturation increases in the north and west of the reservoir, whereas it decreases in the south of the reservoir (Fig. 10), where water saturation correspondingly increase (Fig. 11).

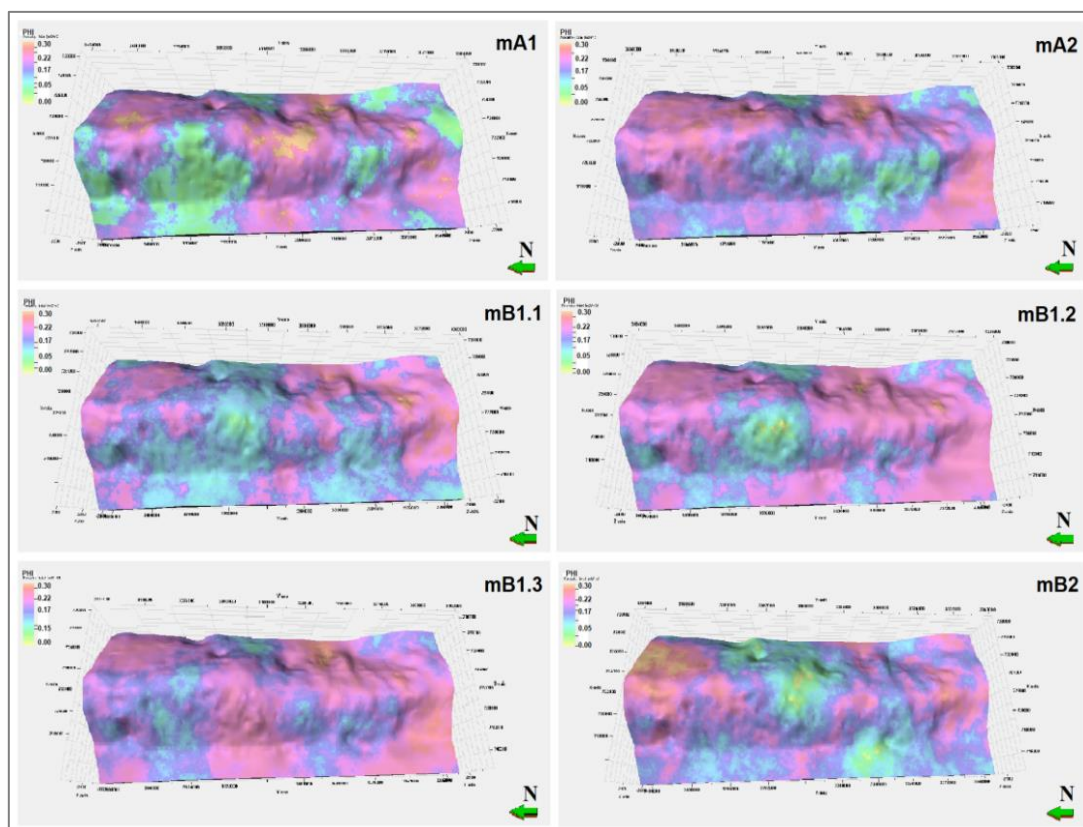


Fig.9. Porosity model of reservoir units and subunits for the Mishrif Formation in the studied oilfield

5.5.4. Permeability distribution

The permeability at the mA1 subunit is fair at the northwest and the crest of the reservoir, while it is excellent at the rest of the studied formation (Fig. 12). In addition, the mA2 subunit exhibits excellent permeability at the north and crest of the reservoir, while it decreases at the rest of the reservoir. Meanwhile, the mB1.1 subunit has excellent permeability in the south, while it fair in the rest of the reservoir (Fig. 12). Moreover, the mB1.2 subunit permeability decreases at the crest and the western flank of the reservoir while being excellent at the rest (Fig. 12). In contrast, within the mB1.3 subunit, permeability is moderate at the northwest of the reservoir and excellent for the rest of the reservoir. Finally, the mB2 unit exhibits good permeability at the western flank of the reservoir, while it is fair elsewhere (Fig. 12).

5.5.5. Shale volume distribution

According to the created shale volume model, the mA1 subunit is characterized by increase shale volume at the crest and northwest of the reservoir, whereas observed decrease at the rest of reservoir (Fig. 13). In a similar manner, the mA2 subunit exhibits an increase in shale volume in the northwest of reservoir, accompanied by a general decrease in the rest of the reservoir. Likewise, the mB1.1 subunit shows increase in shale volume at both the crest and the northwest of reservoir, whereas decrease at the rest of the reservoir (Fig. 13). Meanwhile, the mB1.2 subunit shows an increase in shale volume at the western flank of the reservoir, whereas it decreases in the remaining of reservoir (Fig. 13). Moreover, the mB1.3 subunit exhibit increase shale volume at the crest and northwest of the reservoir, with a decrease in rest of reservoir. Finally, the mB2 unit shows increase shale volume in the northwest and south of the reservoir, whereas decrease in the rest of the reservoir (Fig. 13).

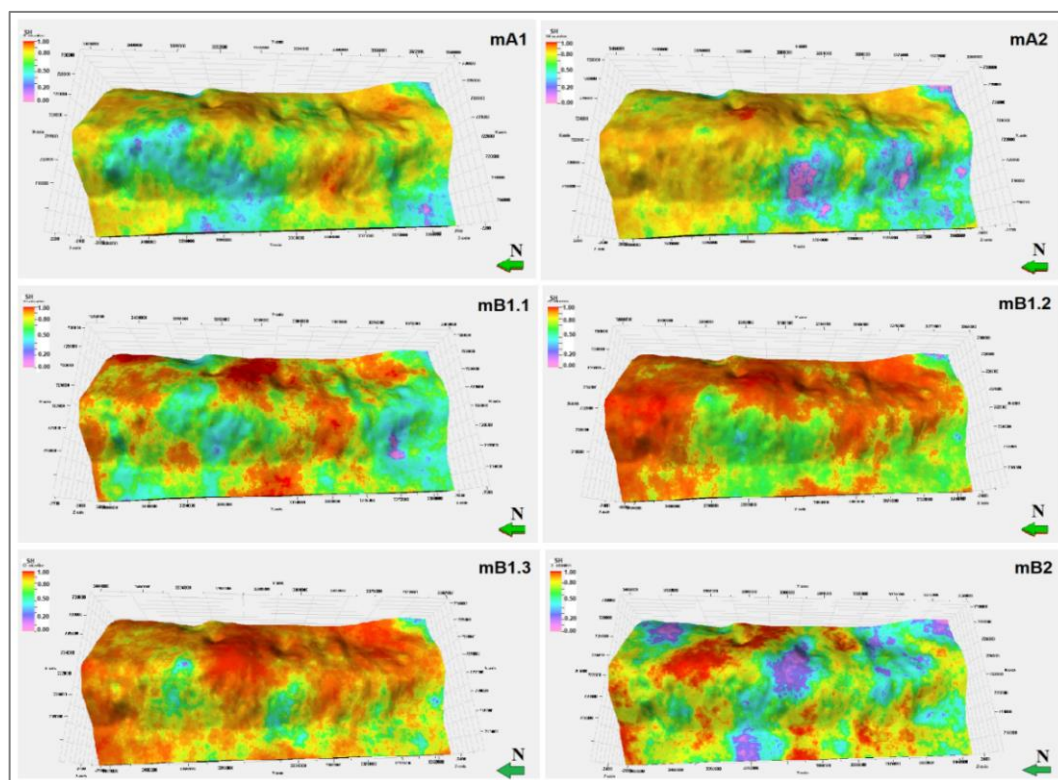


Fig. 10. Hydrocarbon saturation model of reservoir units and subunits for the Mishrif Formation in the studied oilfield

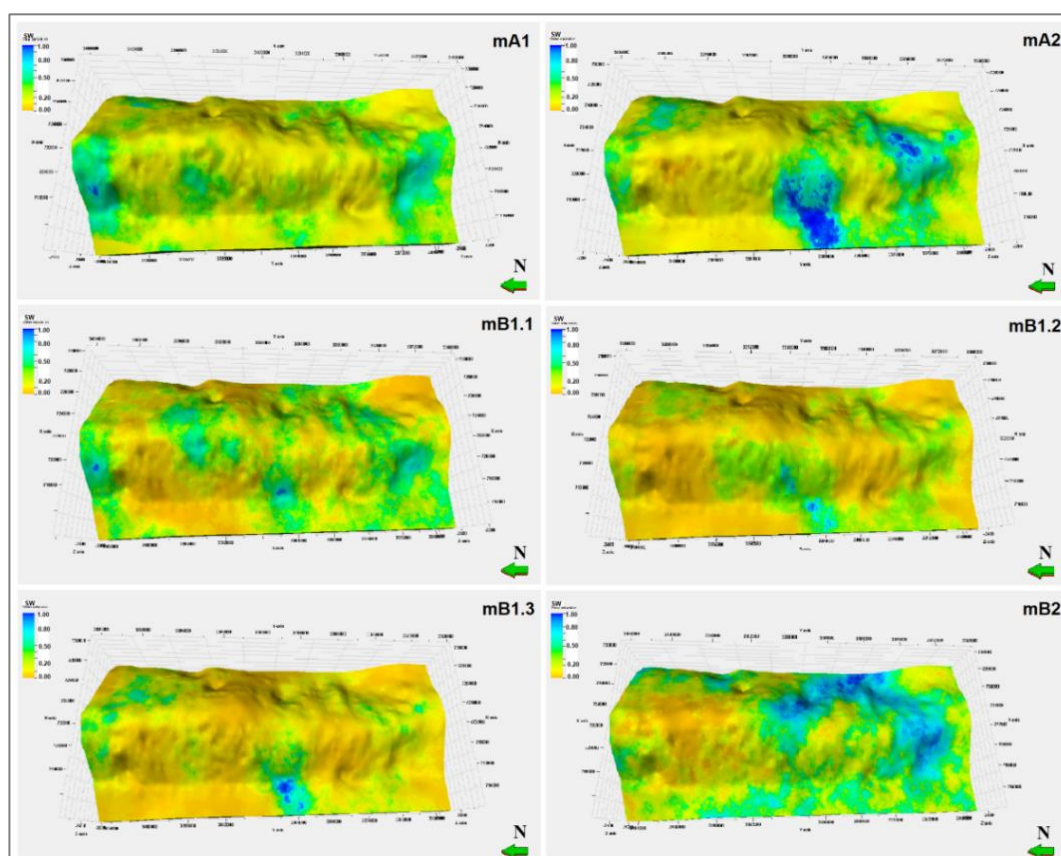


Fig. 11. Water saturation model of reservoir units and subunits for the Mishrif Formation in the studied oilfield

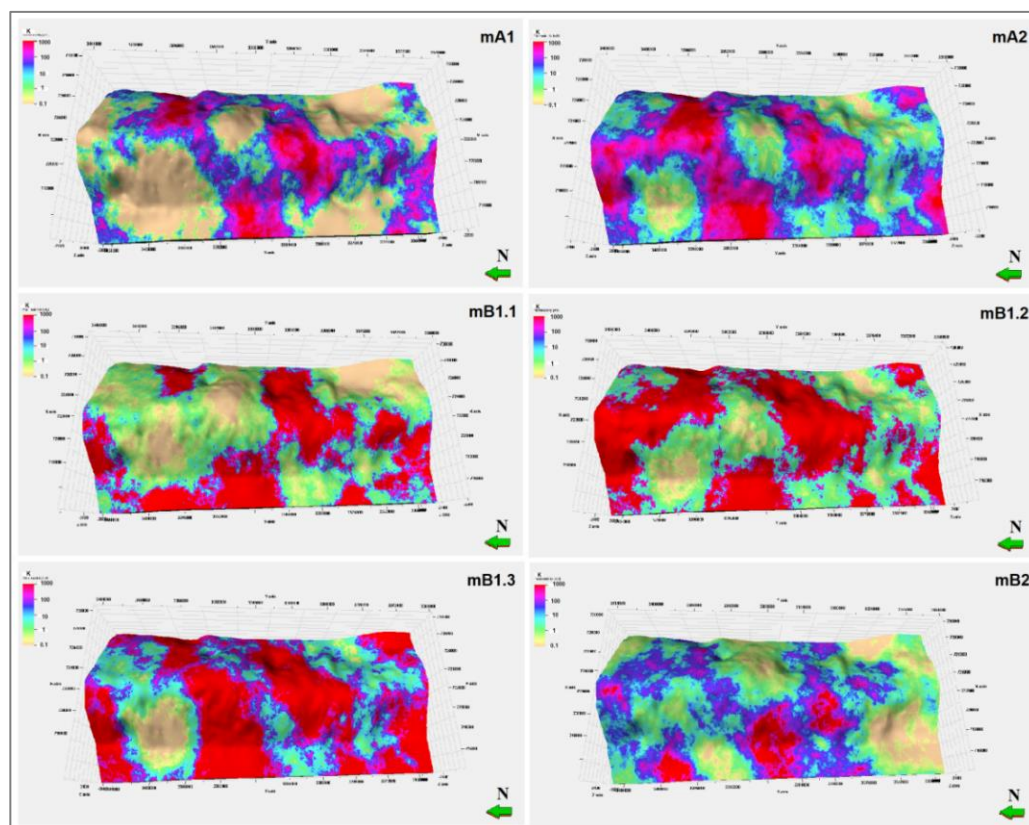


Fig. 12. Permeability model of reservoir units and subunits for the Mishrif Formation in the studied oilfield

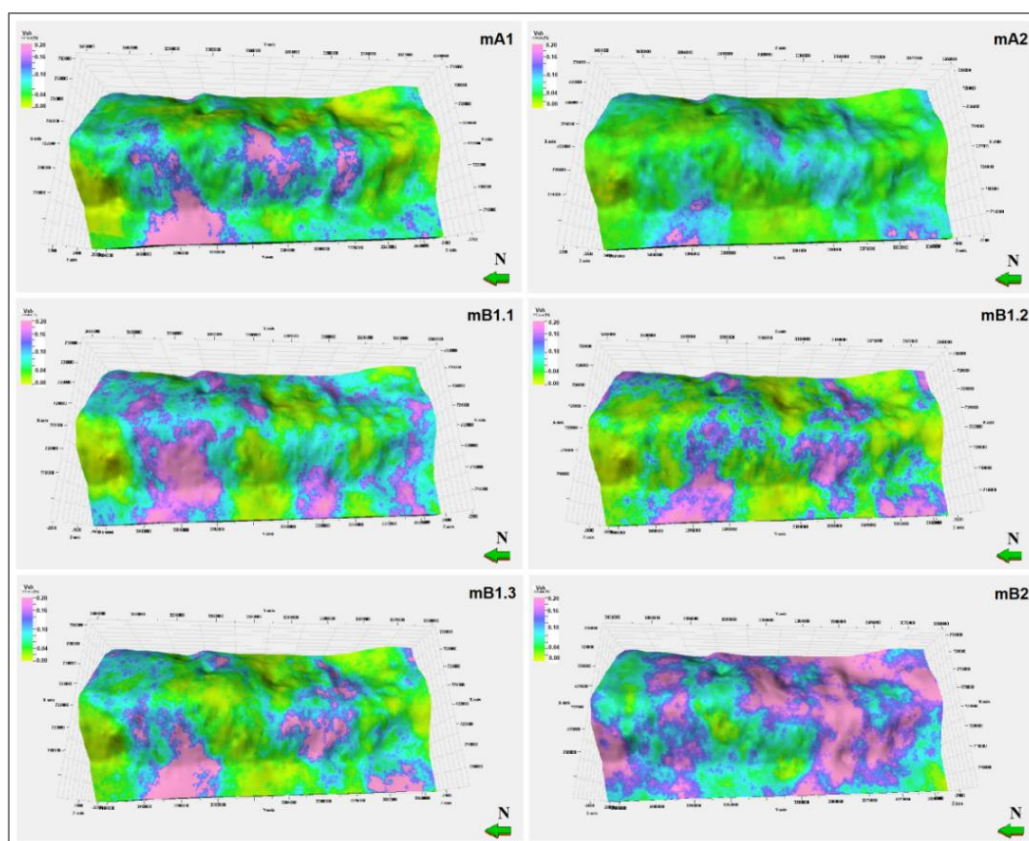


Fig.13. Shale volume model of reservoir units and subunits for the Mishrif Formation in the studied oilfield

6. Conclusions

In this study, qualitative and quantitative petrophysical analyses of the Mishrif Formation in the North Rumaila oilfield were performed using well log data from eight wells distributed across the field. The results of the qualitative analysis showed that the main rock type of the Mishrif Formation is clean limestone and porous, whereas the wells R-250 and R-520 content argillaceous limestone and porous. According to the resistivity log data, the reservoir is highly saturated with hydrocarbons compared to that with water. The quantitative petrophysical analyses showed a decrease in shale volume content within the reservoir. Therefore, the effective porosity is identical to the total porosity for the studied wells, except for wells, R-250 and R-520. The lower secondary porosity compared to primary porosity indicates that diagenetic processes have had no significant impact. Furthermore, the low bulk volume of water relative to hydrocarbons indicates high hydrocarbon saturation.

The mA unit has the highest oil content at wells R-27 and R-491 in the crest of the field, whereas the lowest oil content is at R-470 in the southwest. Meanwhile, the mB1 unit has the highest oil content is at R-493 in the north and R-521 in the south, whereas the lowest is at R-470. Finally, the mB2 unit has the highest oil content is at R-493 in the north and R-250 in the northwest, whereas the lowest is at R-521. The mA unit was divided into two subunits, mA1 and mA2, whereas the mB1 unit was divided into three subunits mB1.1, mB1.2, and mB1.3. Moreover, the mB2 unit was not divided into a subunits. Based on the petrophysical analysis and reservoir model, the mB1 unit is identified as the best and highest quality reservoir. Furthermore, among the subunits, mB1.3 and mB1.2 exhibit the best reservoir characteristics.

Author Contributions: CRediT

- Conceptualization: Shaimaa developed the research idea for the Mishrif Formation in the North Rumaila oilfield, and prof. Dr. Fahad reinforced this idea.
- Data Curation: Shaimaa collected and organized all well data from Basrah Oil Company.
- Formal Analysis: Shaimaa performed the analysis of all the data and the construction of the reservoir model, Dr. Fahad verified the accuracy of data analysis.
- Funding Acquisition: Research was primarily self-funded by Shaimaa.
- Investigation: Shaimaa conducted all research work, including data analysis and evaluation of petrophysical properties and build 3D model.
- Methodology: Shaimaa applied the research methods; Prof. Dr. Fahad guided the overall approach and methodology.
- Project Administration: Prof. Dr. Fahad oversaw and directed the progress of the research.
- Resources: Well data were provided by Basra Oil Company.
- Software: Shaimaa used didger, Surfer, Strater, interactive petrophysics (IP), and Petrel.
- Supervision: Prof. Dr. Fahad supervised all stages, providing guidance and review throughout.
- Validation: Shaimaa study was compared with previous studies, including the study of Al-Obaidi (2005) in the same field, and they were results identical in that the predominant porosity is effective and the secondary porosity is very low. Also, Al-Maliki's study (2022) in the Zubair oil field, which showed that the shale volume is very low in the Mishrif Formation. And also the Al-Rubaie study (2024) in the same field, which showed very good porosity and permeability of the study reservoir
- Visualization: Shaimaa has created all forms including maps, qualitative and quantitative wells and distribution of petrophysical properties on reservoir units
- Writing – Original Draft: Shaimaa prepared the initial draft of the manuscript.
- Writing – Review and Editing: Prof. Dr. Fahad reviewed the draft and Shaimaa edited it; both authors refined the content and finalized the manuscript.

Declaration of Competing Interest

The authors, Shaimaa H. Khalil and Fahad M. Alnajm, declare that they have no competing financial interests or personal relationships that could influence the work reported in this study.

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Data Availability

The data supporting the findings of this study are not publicly available due to confidentiality agreements with Basra Oil Company. Access to the data can be requested from the corresponding author under appropriate conditions.

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