Characterization of flow units, rock and pore types for Mishrif Reservoir in West Qurna oilfield, Southern Iraq by using lithofacies data

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Abstract

This study has been accomplished by testing three different models to determine rocks type, pore throat radius, and flow units for Mishrif Formation in West Qurna oilfield in Southern Iraq based on Mishrif full diameter cores from 20 wells. The three models that were used in this study were Lucia rocks type classification, Winland plot was utilized to determine the pore throat radius depending on the mercury injection test (r35), and (FZI) concepts to identify flow units which enabled us to recognize the differences between Mishrif units in these three categories. The study of pore characteristics is very significant in reservoir evaluation. It controls the storage mechanism and reservoir fluid properties of the permeable units while pore structure is a critical controlling factor for the petrophysical properties and multiphase-flow characteristics in reservoir rocks. Flow zone indicator (FZI) has been used to identify the hydraulic flow units approach (HFUs). Each (HFU) was reproduced by certain FZI and was supposed to have similar geological and petrophysical properties. The samples were from four lithofacies, mA, CRII, mB1, and mB2. Because of the wide range of cored-wells samples (20 wells), this paper is updated the previous studies and indicated some differences in the resulting categories. It was noticed as results of this study that the rocks types of the lower Mishrif were mostly ranged from wackestone to packstone in the upper part of mB2 which reflected mid-ramp facies while the upper part of mB2 referred to shoal facies and for the mB1 unit the rocks types mostly range from packstone to grainstone with some points as wackestone marked as shoal and rudist bioherm facies. Grainstone relatively decreases with the increasing of depth from upper to lower Mishrif while wackestone and packstone indicated increasing in the same direction. The unit mA is marked as mesopores and macropores, while megapores and macropores feature increased in mB1 which has been noticed in the northern part of West Qurna oilfield due to increasing shoal and rudist bioherm facies, the mB2 unit revealed increasing in mesoporous and decreasing in megaporous. The upper Mishrif (mA) has three flow units, while the lower Mishrif (mB1, mB2) has eight flow units four for each reservoir unit.

Keywords West Qurna · Mishrif formation · Rocks type · Pore throat radius · Flow units

Introduction

It's known that carbonate rocks cover about 30% of the sedimentary rocks and comprise 60% of the convention hydrocarbon in global reservoirs (Ahr 2008). Heterogeneity and complication are the challenges to comprehend the

depositional model and facies distribution. Core tests are the first tool to study petrophysical properties but it's not likely to get plugs from each well to understand rocks' properties and stratigraphic accumulating patterns.

Rock type and pore throat radius dominate the relationship between porosity and permeability. Porosity and permeability can be determined directly as in this study from core analysis. The pore characteristics are one of the quite considerable properties in reservoir evaluation. It dominances the storage mechanism and reservoir fluid properties of the permeable units while pore structure is a critical prevailing factor for the petrophysical properties and multiphase-flow characteristics in reservoir rocks. Flow zone indicator (FZI) has been used to identify the hydraulic flow units approach

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(HFUs). Each (HFU) is reproduced by certain FZI and is supposed to have similar geological and petrophysical properties. Core data from 20 wells were used to determine the rocks type, the pore throat radius, and flow units for each reservoir unit. Core data from 20 wells were used to determine the rocks type, the pore throat radius, and flow units for each unit of Mishrif Formation in West Qurna oilfield in Southern Iraq. The discrete facies sequence is produced either from core measurements (lithofacies) or clustered from the well logging data (electrofacies) (Tang et al. 2004).

Recently partitioning algorithms Partitioning Around Medoids (PAM) and *K*-means cluster analysis have been used to analyze well log data in R-statistical computing language (McCreery and Al-Mudhafar 2017).

Literature review

Rocks type

The pore system can be classified according to the structure of the selective deposits (Choquette 1970). Geologists, analysts, and reservoir managers used the Archie and Lucia tabulations. Lucia's procedure disparities the sedimentologic and diagenesis practicability with physical properties depending on Archie's compilation (Liu 2018), which has three main pore type classes, and the distribution and interconnection of pores are different for each kinds (Lucia 2007).

Rocks type was classified into types that have the same deposition conditions and identical diagenesis practicability (Lucia 2007). Pore size, porosity, sorting, and separate vugs porosity are the main factors affecting rocks types. This classification has three categories of rocks type (Lucia 2007) Table 1:

Lucia (2007) gives a comprehensive formula known as rocks fabric number (RFN) Fig. 1.

$$\log k = \{9.7982 - 12.0803 \log (\text{RFN}) + [8.6711 - 8.2965 \log (\text{RFN})] \log \varphi\} \quad (1)$$

Many papers have been published focused on rocks type for Mishrif Formation in West Qurna oilfield (Liu et al.

Fig. 1 Lucia rocks type

2018), (Ismail and Al-Najm 2019), (Deng Ya et al. 2016), and (Hussain et al. 2020).

Clustering analysis has been used by Abbas et al. (2019) as an unsupervised machine learning technique to collect a set of data into clusters with no predefined classes for three wells in the upper shale member/Zubair formation in Luhais oil field southern Iraq. In the research of (Al-Mudhafar et al. 2019), data from heterogeneous carbonate reservoir and two different clustering algorithms, *K*-mean approach and Calinski-Harabasz solution were used to classify reservoir facies based on the given data.

Pore throat radius

A new empirical relationship between porosity, air permeability had been developed. Winland, who was concerned about the pores interconnecting consistently with a saturation of mercury in 35% which is written as to form (r35) for a group of sandstones and carbonates samples (Winland 1976). Winland computed the regressions for percentiles (e.g., 30, 40, and 50), but the best regression (highest *R*) was obtained at 35%. Why 35% resulted in the best correlation, no explanation was given.

Winland's R35 Equation is as follows:

Table 1 Rocks type according to (Lucia, 2007)

Class #	Grain size μm	Rocks type	Affecting factors
Class 1	More than 100	Almost grainstone	Grain size, sorting, and inter-grain cement content
Class 2	Between 20 and 100	Predominated by packstone	Grain size, inter-grain micrite, and cement
Class 3	Less than 20	Pack-wackestone, wackestone, and mudstone	Inter-particle porosity and micrite particle size

Table 2 Pore throat type

Pore throat type	Radius microns
Megapores	More than 10
Macropores	Between 2.5 and 10
Mesopores	Between 0.5 and 2.5
Micropores	Between 0.2 and 0.5
Nanopores	Smaller than 0.2

Fig. 2 Pore throat radius classification

$$\log 35 = \{0.732 + 0.588 \log (k_{\text{air}}) - 0.864 \log \varphi\} \quad (2)$$

Pore throat radius can be recognized as (Porrás and Campos 2001) Table 2, Fig. 2.

(Awadeesian et al. 2015) studied the facies classification, and associated most important diagenetic impacts on pore development for Mishrif Formation in West Qurna oilfield. (Ismail and Al-Najm 2019) was concerned with the relevance between petrophysical properties (porosity and permeability), using lithofacies and NMR data, and then corresponding the results to define rocks type and pore throat radius.

It can conclude that the Winland R35 method is the best method of rock typing in predicting the core permeability values (Haikel et al. 2018).

Flow units

Flow unit is defined as a part of the reservoir, where the petrophysical and geological properties that impact fluid flow are regular and proportionally foretell by the features of other rock sizes (Ebanks 1992). While it is defined as stratigraphically continuous segregation of a similar reservoir process that regards the geological framework and preserves the rock type characteristics (Gunter 1997). In simplification terms, the porosity, permeability, and bed thickness data are using to determine the flow unit. Cores flow units specified in the sedimentary environment, structure, capillary curves, and petrophysical properties (Abbaszadeh 1996).

The concept of flow unit contributes to:

- Quantitative definition and mapping of the parts of the reservoir in terms of reservoir behavior.
- Realistic building block for reservoir zonation, which was advantageous to numerical simulation of the reservoir performance (Hearn et al. 1984).

Various methods have been developed for flow unit identification, based on descriptions of pore geometry, a depositional environment of rock structure, and diagenetic process. These methods include relationships between reservoir quality and rock type.

The Reservoir quality index (RQI) and Flow zone indicator (FZI) concepts have been identified to derive flow units. The RQI and FZI are defined as in the Eqs. (3–5) (Amaefule et al. 1993).

$$\text{RQI}(\mu\text{m}) = 0.0324 \left(\sqrt{K/\varphi_e} \right) \quad (3)$$

$$\text{FZI} = \text{RQI}(\varphi_z) \quad (4)$$

The (φ_z) is the ratio of pore volume to grain volume and defined mathematically as:

$$\varphi_z = \left(\frac{\varphi_e}{(1 - \varphi_e)} \right) \quad (5)$$

where K = permeability, φ_e = effective porosity.

Field geography

West Qurna is one of the supergiant oilfields in southern Iraq, 70 km northwest of Basra city, and 14 km far off West Qurna city, the oilfield is neighboring to North Rumaila oilfield Fig. 3.

Fig. 3 West Qurna oilfield (Liu et al. 2018)

Structurally. This field is a section of the long axis-asymmetrical outspread isocline extended 10 km width and 40 km length. The isocline trends North–South, the trend changes at Northern field to NW–SE. The eastern flank's dip is about 1.6° , while the west flank's dip ranges 2° – 3.5° . The field is located on the outer platform of the Arabian Plate, in Mesopotamia's foredeep basin (Fouad 2010).

Geological setting

Mishrif Formation which represents the middle Cretaceous is the main carbonate reservoir in southern Iraqi fields, featured by heterogeneity and complication, this reservoir comprises six facies that graduated from mid-ramp facies to supratidal facies. Mishrif Formation in West Qurna oilfield is composed of three major reservoir units: mA, mB1, and mB2 with two cap rocks units CRI and CRII. Mishrif Formation is a section of a second-Order system trajectory of Arabian huge sequence 8 (AP8) (Sharland et al. 2001), this order begins from the Albian era to early Turonian. The Age of Mishrif is late Cenomanian to early Turonian from 95 to 89 MA (MA means mega-annum = million years from the present) Fig. 4.

Mishrif Formation clarifies shallowing upward two periods in decline platform sort, this Formation shows six

depositional environments Fig. 5. These environments are (Mahdi and Aqrabi 2014):

1. Mid-ramp environment facies that cover the open marine facies.
2. Rudist bioherm, these kinds of environments facies assorted as moderate to high energy with level and large-scale fragment structure as rudist.
3. Shoal facies, Peloidal skeletal is packstone to grainstone rudists firmness, floatstone, and rudstone are describing the shoal environment facies.
4. Back-shoal facies, this environment combination known as skeletal peloids packstone, wackestone, and floatstone with few grainstone.
5. Lagoon facies, skeletal peloids wackestone, wackepackstone, and packstone structure characterized these environment progressions.
6. Tidal flat facies, this environment facies exhibited the shallowest water depositional region in this Formation.

Mishrif Formation is composed of rudist, algal, foraminifera, bivalves, coral, gastropods, and echinoderms. Facies are changing gradually from the mid-ramp to the lagoon facies and the formation is divided into five units: Cap Rock I, Upper Mishrif (mA), Cap Rock II, and Lower Mishrif. (mB1 and mB2, respectively). The heterogeneity

Fig. 4 Stratigraphic column for southern Iraq (Mahdi and Aqrabi, 2014)

Age		Group	Formation	Lith.	Description	Thickness m	AP	Super seq.	
period	epoch								
Tertiary	L. Miocene - Recent	Kuwait	Q. deposits		Clay and silt	180	AP11	IV	
			Dubbiba		Sand and gravel	240			
	E-M Miocene		Fatha		Marl and limestone	120		III	
			Ghar		Sand and gravel	90			
	M-L Eocene	Hasa	Dammam		dolomite	220	AP10	I	
			Rus		Anhydrite	30			
Paleocene -early Eocene	Umm- Radhuma			dolomite	450				
Cretaceous	Late cretaceous	Aruma	Tayarat		dolomite	260	AP9	IV	
			shiraish		Marly limestone	105			
			Hartha		Limestone and dolomite	190			
			Sadi		Limestone	220		IV	
			Tanuma		Shale	45			
			Khasib		Limestone	60			
	Middle cretaceous	Wasia	Mishrif		Limestone	180	AP8	IV	
			Rumaila		Limestone	80			
			Ahmadi		Limestone	140			
			Mauddud		Limestone	110		III	
			Nhr Umar		Sand and Shale	260			
	Early cretaceous	Thamama	Shuaiba		Limestone and Dolomite	80	II		
			Zubair		Sand and Shale	400			
			Ratawi		Limestone with Shale	260	I		
			Yammama		Limestone	280			
	Jurassic	U-Jurassic		suly		Argillaceous Limestone	240		

of the formation varies from homogeneity in the mA unit to higher anisotropy in the mB1 unit than mB2 unit (Al-Dujaili et al. 2021).

Materials and methods

Materials

The data used in this study have been extracted from 20 wells drilled in Mishrif formation in the West Qurna oilfield

as in Figs. 6, 7, and Appendix 1. The number of plugs is shown in Table 3.

Methods

The coring task provided 4816 preserved cores, which were used in the first step for measuring the permeability and porosity of the samples. The core samples were extracted from Mishrif Formation, and the average rock density of the core was measured to be 2.691 g/cm³. The laboratory measurements (RCA) were conducted.

Fig. 5 Depositional environments for Mishrif Formation in the West Qurna oilfield (Sharland et al., 2001)

Fig. 6 Well locations in Mishrif contour map

The second step in this study was to insulate the plugs stated according to the layers depending on the upper and lower limit of each unit and also on the specified depth that each core has been taken from a certain well. The data have been analyzed and tabulated for each unit of Mishrif Formation Figs. 8 and 9.

Fig. 7 Core handling and a core sample from a well in West Qurna oilfield

Table 3 Plugs numbers used in the study

Mishrif unit	No. of Plugs	Range of ϕ (v/v)	Range of K (mD)
mA	1024	0.010–0.319	0.01–1384
CRII	80	0.021–0.267	0.001–282
mB1	1284	0.010–0.352	0.01–2214
mB2	1528	0.019–0.377	0.01–1350

Results

Core data values for porosity and permeability of 20 wells for Mishrif reservoir in West Qurna oil field were used to determine rocks type, pore throat radius, and flow units for Upper Mishrif (mA), Cap Rock II, and Lower Mishrif. (mB1 and mB2 units, respectively). Techlog software 2015.3 has been used to determine rocks type, pore throat radius, and

Fig. 8 Porosity histogram according for wells lithofacies by Techlog software

flow units. The results are presented and discussed for all units in the following:

Rocks type

By using rocks type classification (Lucia 2007), the results for all units are shown in Fig. 9. mA unit shows rocks type in class 1 lower than in mB1, which reflects the rare grainstone. The small grain size makes most of the rocks forming this unit are classes 2 and 3 (pack-wackestone, wackestone, mudstone, and with packstone but in low percentage) (Fig. 10).

For the cap rock II unit, it has been seen that the variation in rock type is very noticeable in the unit which covers all classes.

Rocks type of mB1 unit enhances rock properties as compared with unit mB2. Rocks type of facies continues to be consists of classes 2 and 3 while in some wells the grainstone increased noticeably.

For the mB2 unit, class 2 wackestone and packstone were the main rocks of this reservoir unit when correlated with core description and microfacies thin section and the result was the same microfacies. The mB2 environment graded from mid-ram environments at the lower section to

Fig. 9 Permeability histogram according for wells lithofacies by Techlog software 2015.3

Fig. 10 Rocks Type for all units of Mishrif units

Fig. 11 Pore Throat Radius for all units of Mishrif

shoal and rudest bioherm at the upper section of the unit. Class1 grainstone has been noticeable rarely in this unit.

Pore throat radius

Pore throat radius of unit mA were macropores and mesopores correlated wackestone, packstone, and low percentage of grainstone microfacies in the northern part of the formation. While the pore throat radius was mesopores with a rare percentage as macropores and micropores in the southern part of the unit (Fig. 11).

According to Fig. 11, the CRII unit is composed generally of nanopores and micropores in the south of the formation and it will transfer to mesopores in the northern part of the unit.

For the mB1 unit, it enhanced as rocks type, megapores noticed as the major distribution in this unit with some

macropores. Macropores correlated the grainstone when correlated with microfacies. Rudist, benthic foraminifera, coral, and echinoderms microfacies. On the other hand, mesopores equivalent packstone when the bioclast grains decrease in microfacies.

The mB2 unit was better in the north of the formation also where pores throat radius type was mesoporous and some points were micropores, while southern part points distributed between microporous and mesopores as shown in (Fig. 11).

Flow units

The upper Mishrif (mA)

In this part, three flow units are observed as in Figs. 12, 13 with moderate regression of about 0.7.

Fig. 12 Flow units for the upper Mishrif (mA) and the lower Mishrif (mB1, mB2)

The lower Mishrif (mB1, mB2)

The lower Mishrif which consists of mB1, mB2 units has eight flow units as in Figs. 12, 13 with a good regression of about 0.9.

Discussion

Many previous studies dealt with rocks type, pore throat radius, and flow units but the determination of these characterizations was done either from electrofacies or limited lithofacies data. This study tried to be more accurate by using lithofacies data from many locations in the field. By using bigger project area with bigger number of the wells could provide broader picture of the reservoir description.

According to the rocks type and pore throat radius results, the study diagnosed the following:

High porosity, high permeability rock

Reservoir flow units correspond to skeletal-dominated grainstone/ rudstone facies (class1). Dominant pore types include inter-particle and moldic porosity types. Pore throat sizes average around 4–15 microns. High flow zones within the mB1 lagoonal system. High flow zones (grainstone) within the upper part of the mA unit are best developed in the upper mA higher permeability flow units and finally, the high flow zone in the upper mB2 shoal facies with pore throat sizes average around 4–10 microns.

Fig. 13 Flow units for the upper Mishrif (mA) and the lower Mishrif (mB1, mB2) by Techlog software 2015.3

High porosity, low permeability rock (high storage, low flow potential)

Rocks types 2 and 3 correspond to facies with packstone/wackestone textures and are dominated by microporosity. Pore throat sizes average around 2–0.5 microns. This rocks type includes the lower part of mB2 which is marked as mid-ramp facies and the lower part of the mA unit.

Low porosity, low permeability rock (barriers and baffles)

This reservoir rock type is characterized by low porosity chalky limestone and class 3 rocks type, low permeability rocks are developed around sequence boundaries and in restricted lagoonal facies in the upper part of the mB1 zone and the lower part of mA. Pore throat sizes average less than 0.2 microns. Low reservoir quality in these rock types is due to cementation correlated with exposure surfaces.

The results of flow units for the upper Mishrif (mA) and the lower Mishrif (mB1, mB2) by (FZI) method showed that among those reservoir units, mB1.4 is considered as one of the most important reservoir unit in Mishrif reservoir in West Qurna oil field.

Units' mA.2, mB1.3, mB2.2, and mB2.4 may be classified as very good to good reservoir.

Units' mA.1 and mB1.1 are of moderate reservoir characteristics, while units' mB1.1, mA.3, and mB2.3 have comparatively poorer reservoir characteristics and may be classified as bad reservoir.

The cap rock is placed at the bottom of the mA.3 reservoir units. This unit has very low porosity and permeability values. The pore type is nanopores and micropores with some mesopores.

Conclusion

This study involved the relationship between petrophysical properties (porosity and permeability), using core data then correlate the result to determine rocks type, pore throat radius, and flow units as follows:

1. The rocks types of unit mB2 were mostly ranged from wackestone to packstone which reflected mid-ramp facies while the upper part of mB2 referred to shoal facies.
2. The rocks type of mB1 unit where mostly range from packstone to grainstone with some points as wackestone marked as shoal and rudist bioherm facies.
3. Unit mA has a variety of rocks types due to facies ranged from rudist bioherm or shoal facies to supratidal facies in the upper part of the mA unit.
4. Megaporous and macroporous referred to rudstone and grainstone when correlated with core data with a high energy environment as shoal or rudist bioherm facies. Mesoporous throwback the medium energy level and packstone microfacies are dominated by microfacies back-shoal facies. Microporous mostly wackestone symbolize lagoon and mid-ramp facies.
5. Pore throat radius of unit mA were macropores and mesopores in the northern part of the formation, while the pore throat radius was mesopores with a rare percentage as macropores and microspores in the southern part of the unit.
6. For the mB1 unit, Megapores are the major distribution with some macropores. Macropores.
7. The mB2 unit was better in the north of formation also where pores throat radius type is mesoporous and some points were microspores, while southern part points distributed between microporous and mesopores.
8. The upper Mishrif (mA) has three flow units while the lower Mishrif which consists of mB1, mB2 units has eight flow units.

Appendix 1: Wells tops for the Mishrif wells in this study in meters

Well	WQ-1	WQ-2	WQ-3	WQ-4	WQ-6	WQ-	WQ-10	WQ-13	WQ-17	WQ-20	WQ-21	WQ-60	WQ-114	WQ-124	WQ-131	WQ-239	WQ-240	WQ-254	WQ-268	WQ-285
Mishrif	2238	2221.1	2297	2290.5	2255.7	2267	2364	2379.5	2369	2220.5	2426	2511.5	2289.5	2343.2	2269	2365.5	2255.8			
mA	2251.5	2238.2	2312.5	2307	2270	2281.8	2383	2412	2378.5	2230	2440	2519	2302	2358	2280	2376.5	2343	2227.5	2228	2231.5
CR II	2300	2275	2342	2339.5	2299	2328	2417	2440	2431.5	2262.5	2487.5	2558	2345.5	2396	2320	2408.5	2374	2266	2262.5	2265.5
mB1	2303.5	2279.5	2347.5	2345.5	2308	2332.7	2421.5	2448.5	2436.7	2269.5	2492.5	2562	2348.5	2399	2324	2417	2382.5	2270	2265.5	2269
mB2	2353	2334.6	2407	2404.5	2355.5	2408.3	2498	2539.3	2496	2333	2545	2634	2401	2464	2387	2475	2452.5	2320	2325	2336
Rumaila	2406	2391	2462	2460	2416	2441		2574.5	2555	2384	2603	2681	2455	2523	2435	2533	2511.2			

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Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics approval We believe the findings in this paper will be of interest to the readers of journal. We declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

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