RESERVOIR MODELING OF MISHRIF FORMATION IN MAJNOON OIL FIELD, SOUTHERN IRAQ

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ABSTRACT

The Middle Cenomanian-Early Turonian Mishrif Formation includes important carbonate reservoirs in Iraq and some other surrounding countries due to their high reservoir quality and wide geological extension. The 2D models of this study for facies, effective porosity and water saturation indicate the vertical and lateral heterogeneity of the Mishrif Formation reservoir properties in the Majnoon oil field. Construction of 2D reservoir model of the Mishrif Formation to explain the distribution of facies and petrophysical properties (effective porosity and water saturation) by using RockWorks software. The increase of effective porosity is attributed to the presence of shoal facies. The high water saturation is attributed to the existence of restricted marine facies or shallow open marine facies. Maximum values of hydrocarbon saturation are predicted to occur towards the crestal parts of the field.

INTRODUCTION

The Mishrif Formation is the most important carbonate reservoir unit in the south of Iraq and it contains up to 30% of the total Iraqi oil reserves (Aqrawi *et al*., 2010). The reservoir units of the Mishrif Formation in southern Iraq occur at locations where the rudistid facies with appropriate porosity and permeability are developed at different structural elevations of Mesopotamian basin's Oilfields (Mahdi and Aqrawi, 2017). The task of the reservoir geologists is to identify such reservoir units. Therefore, it is essential to model reservoir characteristics to understand inter well-scale heterogeneities of facies and petrophysical properties. This study incorporates well logs data combined with facies data to establish the geological model of the Mishrif Formation in Majnoon Oilfield. In this study RockWorks

(2016) software is used to build static 2D models for facies, porosity and water saturation of the Mishrif Formation in Majnoon Oilfield.

THE STUDY AREA

The study area is located in Majnoon Oilfield, located in southern Iraq, Basrah and Missan Governorate; 70 km to the northwest of Basra city, close to Iraqi-Iranian borders (Fig. 1).
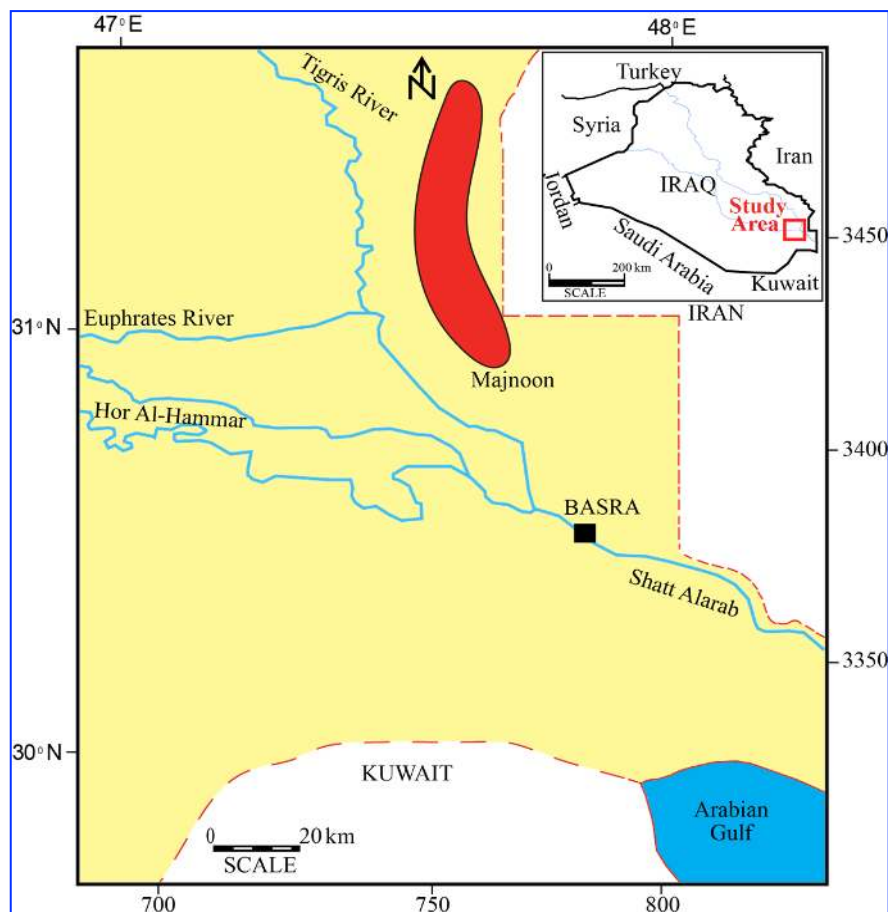
Fig. 1: Location map of the study area (modified from Al-Ameri *et al*., 2012)

GEOLOGICAL SETTING

The study area is located in Zubair Subzone, which considered the most prolific petroleum region in Iraq (Jassim and Goff, 2006). This subzone forms the southernmost unit of Mesopotamian Zone and has a uniform structural style by the underlying basement. It incorporates prominent N-S trending structures (Fig. 2), which continue hundreds of kilometers southwards (Jassim and Goff, 2006). Figure (2) shows the limited change in the structural attitude of Majnoon Oilfield during the deposition of the Mishrif Formation as indicated by shifting of structural closure towards north and south directions.

The type section of Mishrif Formation was described as a heterogeneous succession of organic detrital limestone, with algal beds, rudist, and limestone of coral-reef, capped by limonitic fresh water limestone (van Bellen *et al*., 1959-2005). This description was given by Rabanit (1952), who first described the formation in the Zubair area of southern Iraq (Buday, 1980). The contact between the Mishrif and Rumaila formations is gradational as is the contact between the Mishrif and Kifil Formations. However, in many oilfields the Mishrif Formation is unconformably overlain by the Khasib Formation where the Kifil Formation is absent in the study area (Aqrawi *et al*., 1998).

The formation was deposited as rudist shoals and patch of reefs over growing subtle structural highs developing in an otherwise relatively deeper shelf on which open marine sediments of the Rumaila Formation were deposited (Jassim and Goff, 2006) (Fig. 3).
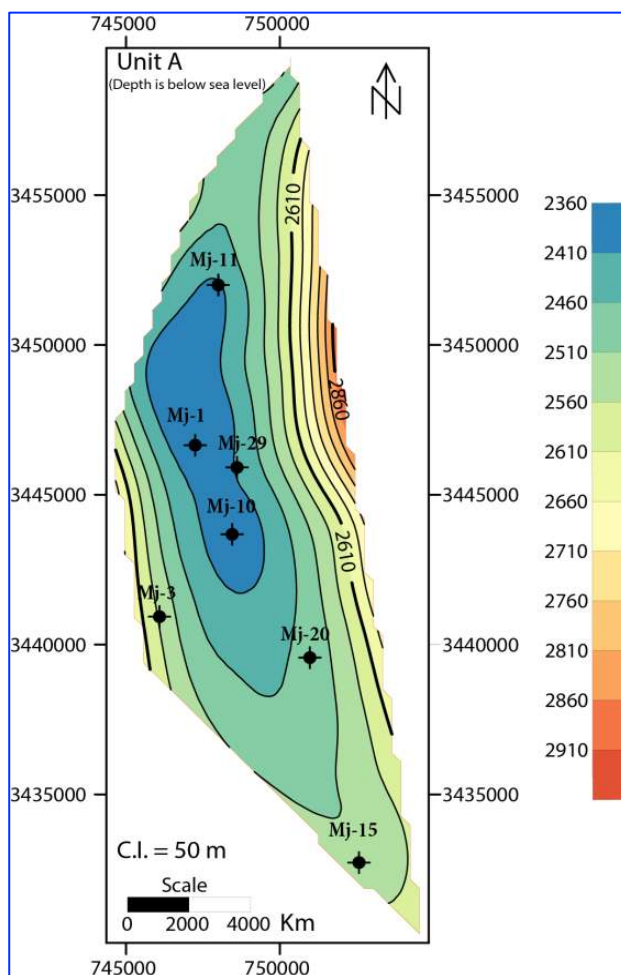

Fig. 2: Structure contour map at the top of Mishrif Formation in Majnoon Oilfield

Age	Formation	Depth (m)	Lithologic Succession	Lithologic Description
U.Turonian-Coniancian	Khasib	2500		Shale, calciferous, fissle, pyritic, grading to marl, plastic. calcarenite, poor porosity, argillaceous, at the base, conglomerate, calcilutite pebbles, marly
		2515		Unconformity Surface
Middle- Cenomanian- Early Turonian	Mishrif	2530		Calcarenite, fair to good apparent porosity, detrital, bioclastic, vuggy, partly calcilutite
		2545		
		2560		Calcilutite, fossiliferous, vuggy, fractures, some recrystallized, argillaceous and pyritic
		2575		Calcarenite, low to fair porosity, detrital, bioclastic, intraformational conglomerate, calcilutite, fossiliferous
		2590		
		2605		Calcarenite, fair to low porosity, detrital, fossiliferous and calcilutite
		2620		
		2635		Calcilutite, poor porosity, argillaceous, fossiliferous, vugs and shale, carbonaceous material
		2650		Calcarenite, fair to good porosity, calcilutite, poor porosity, some vugs and fractures
		2665		
		2680		Calcilutite, poor porosity, fossiliferous
		2695		Calcarenite, some calcirudite, fair to good porosity, fossiliferous, vugs, some recrystallised, calcilutite beds, poor porosity, fossiliferous, vugs
		2710		
		2725		Calcilutite, chalky, fossiliferous, vugs
		2740		
		2755		Calcarenite, fossiliferous, vuggy, recrystallized, grading to calcilutite, chalky, vuggy, argillaceous, fossiliferous
Cenomanian-Early Turonian	Rumaila	2770		Calcilutite, recrystalized, fossiliferous, argillaceous, marly

Fig. 3: Stratigraphic succession of Mishrif Formation in well Mj-2 (lithologic description is adapted from Braspetro, 1978)

MATERIALS AND METHODS

Microfacies analysis of the thin section of cuttings and core samples. Well logs analysis and the calculation of the petrophysical properties by using IP software. Construction 2D reservoir

models of Mishrif Formation in two directions along the studied wells to explain the facies and petrophysical properties distribution by using RockWorks (2016) software. Where two types of data were imported to RockWorks (2016) for simulation. These are I-data and P-data where I-data includes facies association and P-data includes the petrophysical properties (effective porosity and water saturation) that derived from well logs analysis. The porosity model shows the distribution of effective porosity values calculated from analysis of porosity logs in IP software. Effective porosity values imported from IP to RockWorks (2016) software as a data point. The data point is used to enter measured values which are sampled at single depth points (as opposed to depth intervals) down the boreholes. The following formula was used to calculate effective porosity:

$$\phi_e = \phi_t \times (1 - V_{sh})$$

Where: ϕ_e= effective porosity, ϕ_t= total porosity ($\phi_{N.D}$) calculated from the averaged porosity of the neutron and porosity that calculated from the density log, Vsh = volume of shale that calculated from Dresser Atlas (1979) used to determine the volume of shale for older rocks by using the following equation:

$$V_{sh} = 0.33 \times [2^{(2 \times I_{GR})} - 1]$$

Where: Vsh = volume of shale, IGR= gamma ray index.

The water saturation model considers the water saturation values that were calculated by IP software. Water saturation values were imported to RockWorks as a data point (P-Data). The following formula was used to determine water saturation of the uninvaded zone:

$$Sw = \left(\frac{a \times R_w}{\phi^m \times R_t} \right)^{\frac{1}{n}}$$

Where: S_w = water saturation of the uninvaded zone, R_w = resistivity of formation water at formation temperature (0.020@ 120° F), R_t = true formation resistivity (i.e., deep induction or deep laterolog), ϕ= porosity, a = tortuosity factor (a=1.3), m = cementation exponent (m=1.62), n = saturation exponent (n=2.15).

RESULTS AND DISCUSSION

The static reservoir model is applied in the present study by using Rock Works software. It is usually referred to as the geological model (often abbreviated "geomodel"), and is a digital

numerical model describing the initial state of the reservoir before any production of hydrocarbons has taken place, i.e. representing the spatial distribution of rock types with different reservoir properties. The petrophysical calculations can be performed for an entire reservoir or individually for any layers or fault segments that have been defined during model construction (Bjørlykke, 2015). The petrophysical heterogeneity of the reservoir units within the Mishrif Formation is due to variations in porosity, water saturation and fluid volume (Mahdi and Aqrawi, 2017). 2D models of facies and petrophysical properties are constructed for the Mishrif Formation in Majnoon Oilfield. It reflects the distribution of facies and petrophysical properties of the Mishrif Formation.

Microfacies Analysis

Four facies associations were distinguished, each of which represents a distinct depositional environment and includes several microfacies, and these are (1) Shallow open marine, (2) Shoal, (3) Back-Shoal, (4) Restricted marine.

Shallow Open Marine

Shallow open marine facies are common in Mishrif Formation in Majnoon Oilfield. The facies association includes mud-and grain-supported microfacies such as Foraminifera-bioclastic wackestone-packstone (Pl.1-A), Bioclastic wackestone (Pl.1-B), and Echinoderm packstone (Pl.1-C). The shallow open marine environment is thought to have extended from shoal and reef areas into the very low energy environments of the outer shelf (Taghavi *et al.,* 2006).

The primary components of these microfacies are bioclasts that have different sizes such as echinoderm (Pl.2-B), and rudist (Pl.1-C). Other important components include planktonic foraminifera. The secondary skeletal grains in this facies association include benthic foraminifera, algae, sponge spicules, and shell fragments.

Shoal

The shoal facies association is most important in the Mishrif Formation due to their high reservoir quality related to the dominance of the grain-supported microfacies that are affected by dissolution (Mahdi *et al*., 2013). This facies association consists of Bioclastic-foraminiferal packstone-grainstone (Pl.1-D), Bioclastic grainstone (Pl.1-E), and Rudist grainstone (Pl.1-F). The microfacies are rich in bioclasts, in addition to cemented grains that have micritic envelopes (Pl.1-E).

The observed shoal microfacies in this study are equivalent to MFT-10, MFT-11, MFT-12, and MFT-13 recognized by Mahdi *et al*., (2013) that reflect a high energy shoal environment.

Back-Shoal

The back-shoal facies association is represented by Foraminiferal- bioclastic wackestone-packstone and Peloidal-foraminiferal packstone. The microfacies are rich in bioclasts (rudist, echinoderm), benthic foraminifera, peloids, in addition to gastropod (Pl.2-G). Back-Shoal facies are interpreted to have been deposited in shallow water, low energy settings in a photic environment.

Restricted Marine

The restricted marine facies association is characterized by mud-supported facies. It includes Benthic foraminiferal wackestone and Bioclastic-foraminiferal wackestone-packstone (Pl.1-H). The main constituents are large and small benthic foraminifera (Miliolid, Nezzazata, Praealveolina), bioclasts, peloids, in addition to algae and Ostracoda.

The depositional condition is characterized by low energy as indicated by the mud-supported texture associated with the dominance of benthic foraminifera. A similar interpretation is recorded by Sherwani (1983, 1998) and Mahdi *et al.*, (2013).

**Facies Associations Model**

A facies model captures the reservoir variability based on the sedimentological analysis of the core and wireline data, combined into a conceptual model of the reservoir depositional environment (Cannon, 2018). The 2D facies associations model of Mishrif Formation is built along two directions. The first pass through wells Mj-1, Mj-10, Mj-20 and Mj-15, and the second passes through Mj-11, Mj-29, Mj-10 and Mj-3 (Fig. 4).

Restricted marine facies occur in the uppermost part of Mishrif Formation at most wells Mj-10, Mj-20 and Mj-15 except Mj-1 well where the uppermost part consists of shallow open marine facies (Fig. 5). The high thickness of shoal environment occurs in the Mj-20 well middle part. While the lower part is predominantly consisting of the shallow open marine environment with thin intervals of shoal facies (Fig. 5). The uppermost part of Mishrif Formation at second section B-B′ consists of restricted environment except Mj-29 well it where it starts with back-shoal facies. The high thickness of shoal facies occurs at Mj-11, Mj-10 and Mj-3 wells (Fig. 6). In Mj-29 well shoal facies association also occurs at the upper part of the Mishrif Formation but as discrete intervals and interbedded with back-shoal and restricted facies (Fig. 6). Shallow open marine facies exist at the lower part of (Mj-11, Mj-29, Mj-10 and Mj-3) wells.
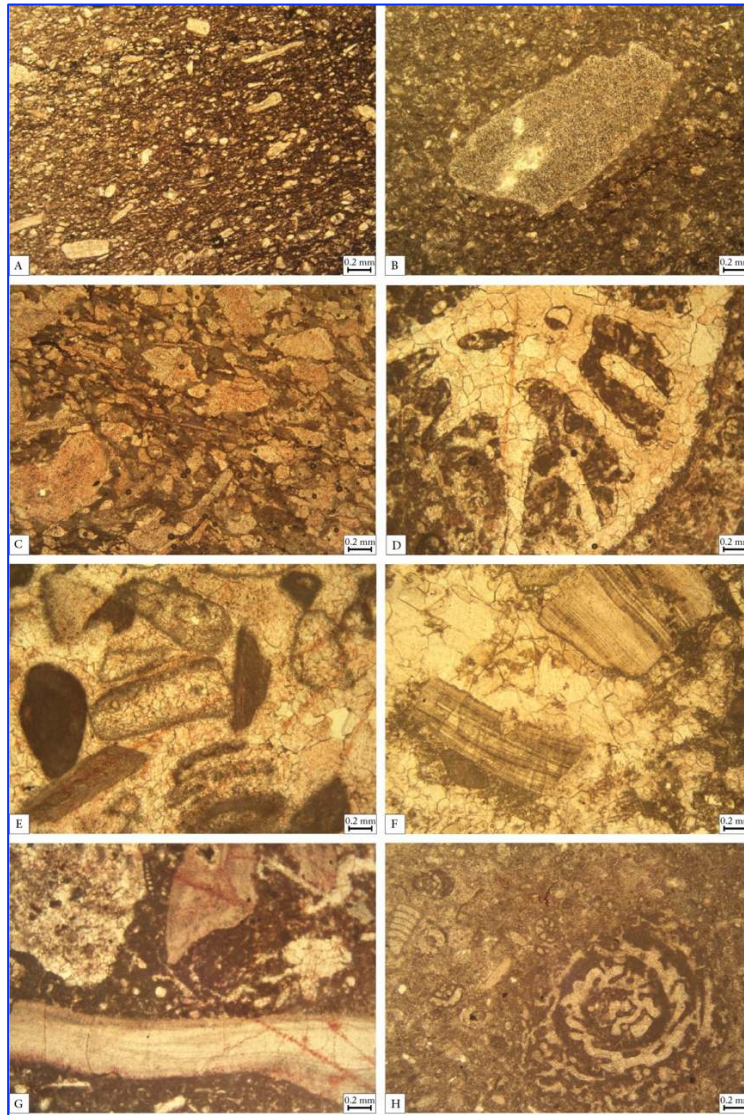
Plate 1: Microfacies, A. Foraminiferal-bioclastic wackestone-packstone, Shallow open marine facies associations (Mj-29, 2490m). B. Bioclastic wackestone showing echinoderm fragment, Shallow open marine facies associations (Mj-29, 2497.5m). C. Bioclastic packstone with compacted echinoderm bioclasts, Shallow open marine facies associations (Mj-29, 2534.25m). D. Bioclastic-foraminiferal packstone-grainstone, Shoal facies associations (Mj-29, 2536m). E. Rudist bioclasts and micritic envelops embadded in calcite cement matrix. Bioclastic grainstone, Shoal facies associations (Mj-29, 2520.5m). F. Rudist bioclasts, Rudistid grainstone, Shoal facies associations (Mj-29, 2570m). G. Rudist and Gastropod shell fragment in Foraminiferal-bioclastic wackestone-packstone, Back-shoal facies associations (Mj-29, 2560m). H. Large benthic foraminifera and bioclasts. Bioclastic-foraminiferal wackestone-packstone, Restricted marine facies associations (Mj-1, 2450).
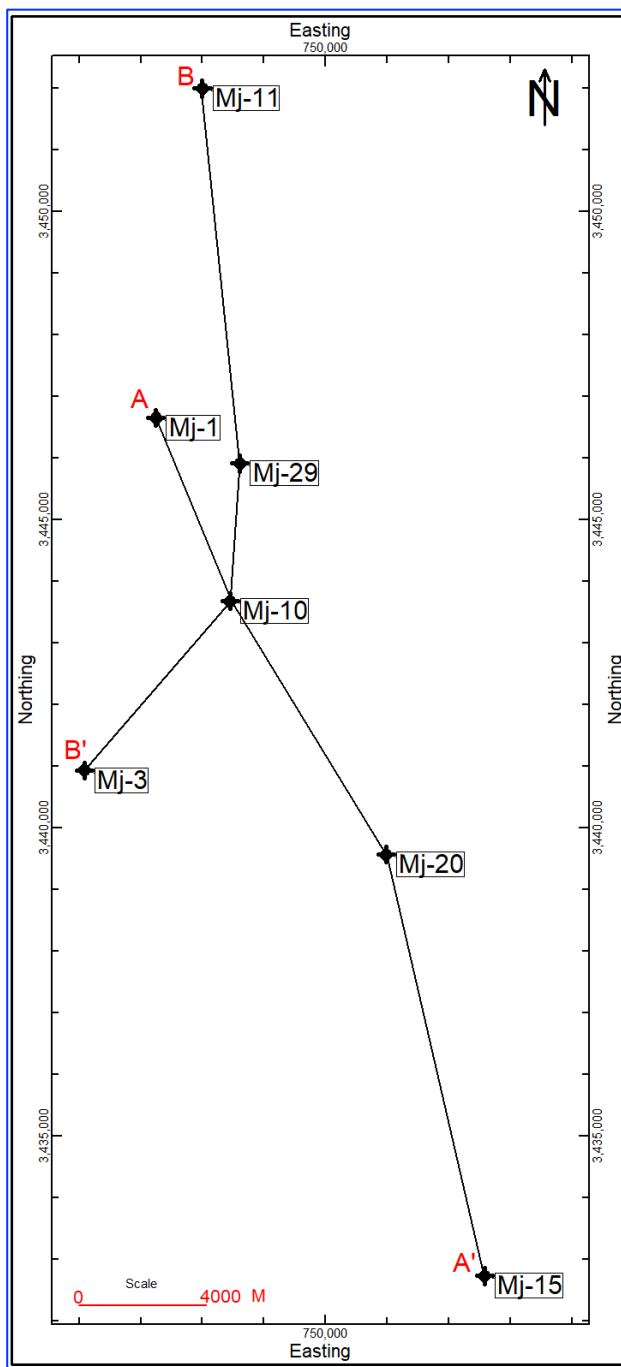
Fig.4: Location map shows the section's directions along where modeling study is done

Petrophysical Model

The petrophysical models include several important characteristics such as porosity (ϕ) and permeability (k), formation bulk density (ρb) or sonic p-wave velocity (vp), the volume fraction of shale (Vshale) or fracture density (Fd) (Ringrose and Bentley, 2015). In this study, the focus will be the petrophysical model that includes effective porosity and water saturation.
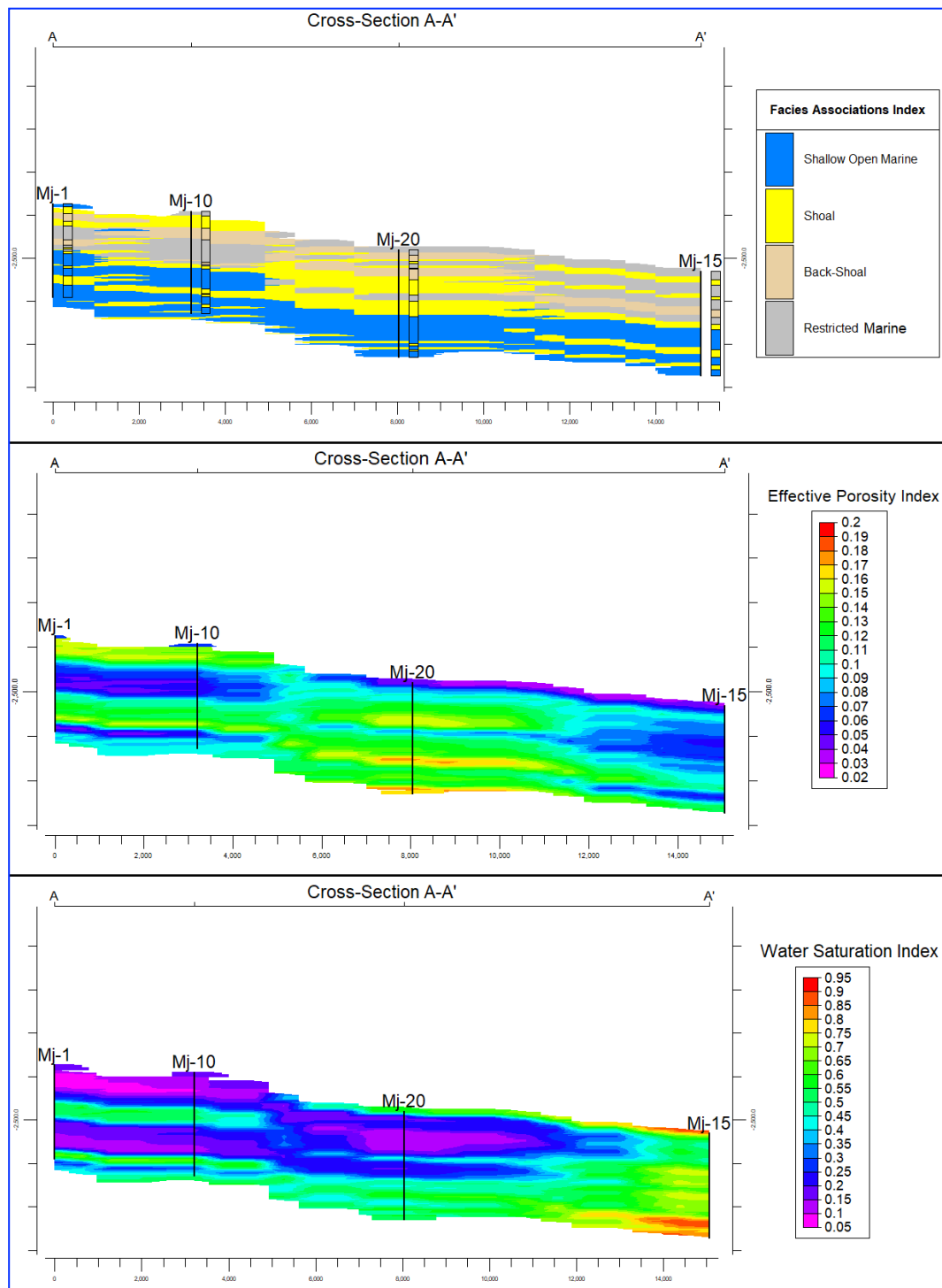
Porosity Model

The 2D models of effective porosity are shown in figures (5 & (6). Due to the high thickness of shoal facies in well Mj-20, the highest effective porosity values are distributed around this well (Fig. 5). The effective porosity values between wells Mj-1 and Mj-10 are nearly similar, where the values increase towards the upper and lower parts of Mishrif Formation. The second section B-B′ (Fig. 6) shows the distribution of maximum effective porosity values along Mj-11 well in the uppermost part of Mishrif Formation. While the porosity increased at the upper and middle part of the Mishrif reservoir at wells Mj-29, Mj-10 and Mj-3 (Fig. 6). The increment of effective porosity at different intervals of these wells is related to the presence of shoal facies (Pl. 2-A, B).
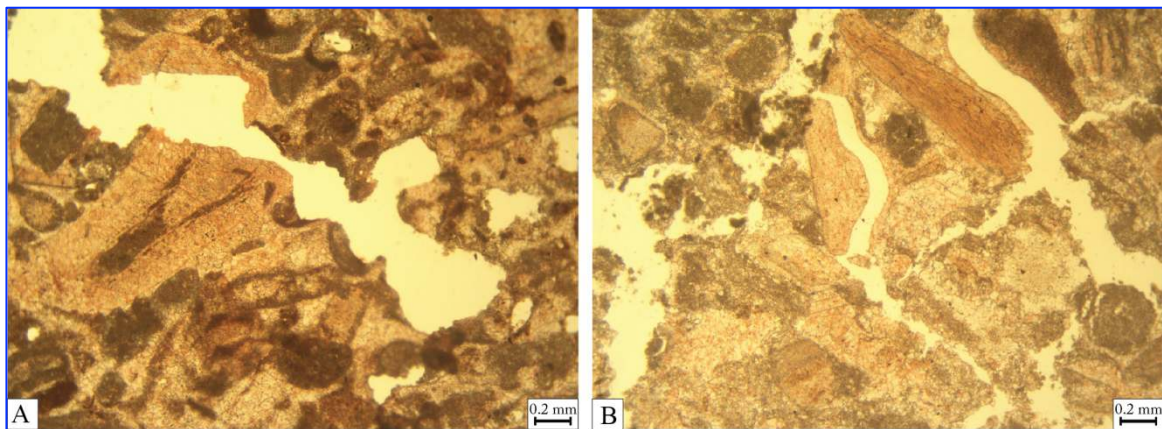

Plate 2: Pore types, (A) Cavern pores cut rudist bioclasts, shoal (Mj-29, 2536.15 m)
(B) Solution enlarged fractures in rudistid facies, shoal (Mj-29, 2517.79 m)

Water Saturation Model

The 2D water saturation models at two sections show increasing values of water saturation at structurally lower parts of Majnoon Oilfield, which are characterized by shallow open marine and resticted facies associations. The highest water saturation at the lowermost part of well Mj-15 is attributed to the existence of restricted marine facies and shallow open marine facies repectively.Therefore, maximum values of hydrocarbon saturation is predicted to occur towards crest parts of the structure of studied field as shown in wells Mj-1, Mj-10, Mj-20 (Figs. 5, 6) which, is characterized by shoal facies.

Fig. 5: 2D models of facies associations, effective porosity and water saturation for Mishrif Formation along cross sections A-Aʹ in Majnoon Oilfield
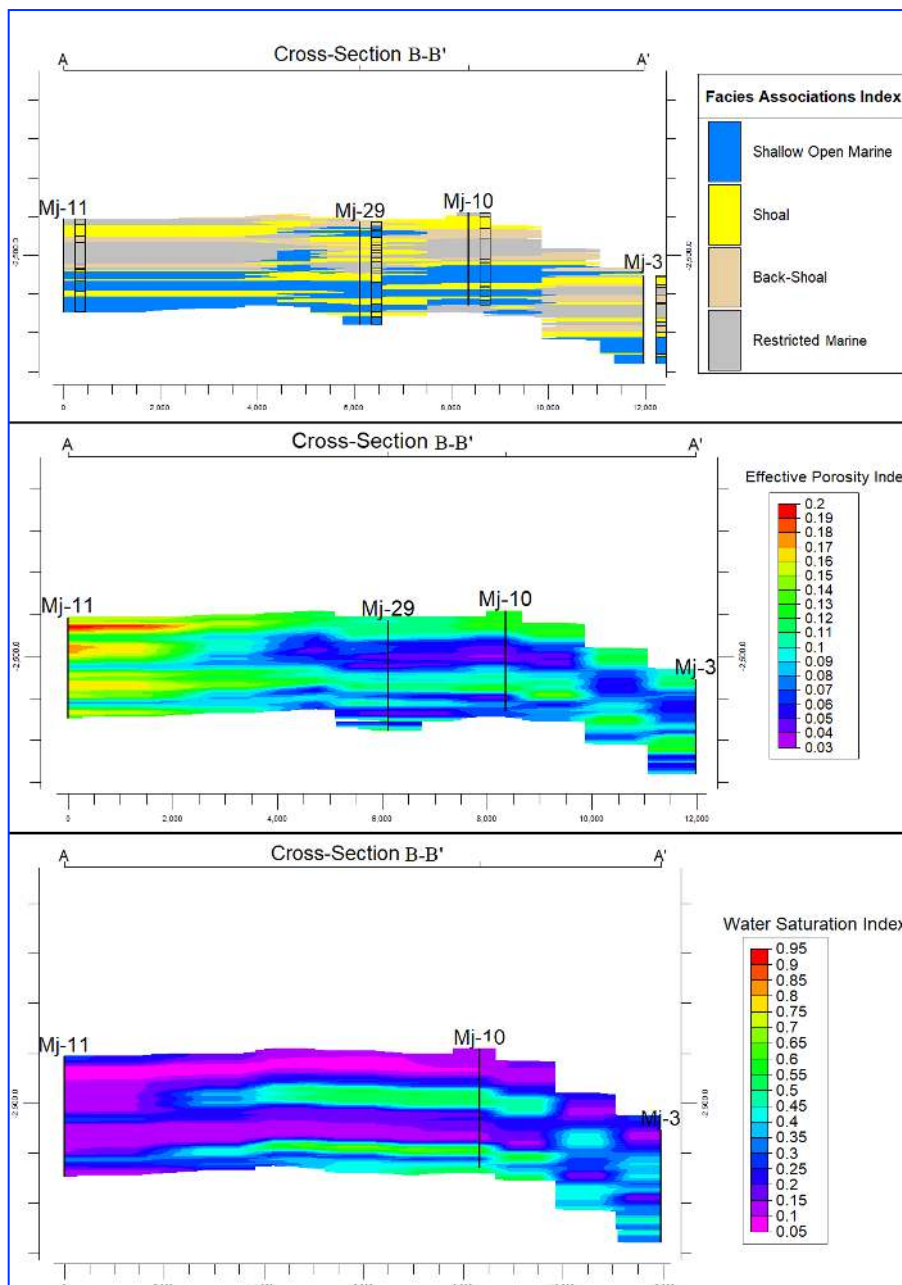
Fig. 6: 2D models of facies associations, effective porosity and water saturation for Mishrif Formation along cross sections B-B' in Majnoon Oilfield

CONCLUSIONS

In this study, the aim was the construction of 2D reservoir model of the Mishrif Formation to explain the distribution of facies and petrophysical properties (effective porosity and water saturation) by using RockWorks (2016) software. The 2D models have shown that the high thickness of shoal environment occurs in the Mj-20 well middle part. Due to the high thickness of shoal facies in well Mj-20, the highest effective porosity values are distributed around the well.

The distribution of maximum effective porosity values along Mj-11 well in the uppermost part of Mishrif Formation. Increasing the effective porosity is accompanied by the presence of shoal facies.

The 2D water saturation models at two sections show increasing values of water saturation at structurally lower parts of Majnoon Oilfield, which are characterized by shallow open marine and resticted facies associations.

The highest water saturation at the uppermost and lowermost parts of well Mj-15 is attributed to the existence of restricted marine facies and shallow open marine facies, respectively. Maximum values of hydrocarbon saturation are predicted to occur towards the crestal parts of the field.

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