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Reservoir Characteristics of the Lower Miocene Carbonate Formations in Kor Mor Gasfield, Kirkuk Area, NE Iraq

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ABSTRACT

This paper presents the evaluations of the reservoir characterization of the Lower Miocene Euphrates, and Jeribe carbonate formations that have been selected for this study in Kor Mor Gasfield in Northeastern Iraq. The Euphrates ranged in thickness between 30 and 65, and Jeribe 30 and 50m in this field, and they are overlain by a thick evaporate cap rock of the Fatha Formation. The two formations are separated by the thin evaporate rock unit of the Dhiban Formation

The full set of log data for the well Km-9 was used in addition to some general data derived from other eight wells (Km-1 to Km-8). The log data have been used in evaluating the reservoir properties of the two rock units. The detected lithologies from the available mud log and well reports showed that the two formations mostly dolostone and dolomitic limestone were dominated. From the log data, different types of reservoir properties (clay content, clay types, porosity, and fracture index,) have been estimated. The average porosity of the Euphrates reservoir is around of 0.15, and the Jeribe 0.10, the secondary porosity makes a significant fraction of porosity in both units.

1. Introduction

The Kor Mor Field is located in the NE part of Iraq. The Field lies 35 Km SE Kirkuk City and about 8 Km SW Qadir- Karam Town (Fig.-1). The structure firstly discovered in 1927 by Iraq Petroleum Company (IPC) during a general geological survey in the northern part of Iraq. This study is based on the importance of the carbonate successions in the upper Oligocene and Lower Miocene since Iraq's Cenozoic sequence has about 16 percent of the country's oil reserves [1]. The Lower Miocene units have been studied by numerous authors in many parts of Iraq, some examples of those during the last decade, who focused on the reservoir characteristics in central and north areas including: (Al-Ameri et al. 2011[2]; Hussein D. O. 2015[2]; Baban et al. 2016[4]; Hussein et al. 2017[5]; Saeed 2017[6]; Abdullah et al. 2019[7]; Fadhil et al. 2020[8]; Abdulrahman et al. 2020[9]; Deabl et al. 2021[10]. The goal of this study is the reservoir characteristic of the Lower Miocene Jeribe and Euphrates Formations in Kor Mor Field

The first exploration well (Km-1) was drilled in 1928, on the middle of the SW flank of the structure by (IPC) to discover the Hydrocarbon potential of the structure to the TD 1971.6 m RT in Jeribe Formation [11]. The well proved the existence of gas in the Jeribe Formation (previously called the Main limestone). The well Km-2 drilled in 1952 at NE flank to the total depth of 1614 m RT in Jeribe Formation. The well-completion test proved the presence of gas in the Jeribe Formation [11]

The wells (3 to 8) were drilled during the period (1980-1990) by (NOC) as a development plane of the field to produced gas with condensates from the field to provide the south Jambur degassing station. The well Km-3 (the deepest exploration and evaluation well in the field) was drilled at the NE flank toward the NW plunge of the field to explore the possibilities of hydrocarbon in Cretaceous formations; the well reached the TD of 2962m in Kometan Formation. The test results proved the Upper Cretaceous reservoirs were dry [11].

In 2008 the structure has been delineated by DanaGas /Crescent Petroleum Company using a (2D) seismic survey by (Tera- Sise Canadian Company). Depending on the seismic results the location of the well Km-9 was drilled, the well had two targets, the primary one to explore the Cretaceous formations, and the second target to produce gas from Tertiary

reservoirs. The drilling was spaded on Jan. 25th /2009, the final TD of the well (3054 m RTKB) in Balambo Formation [12].

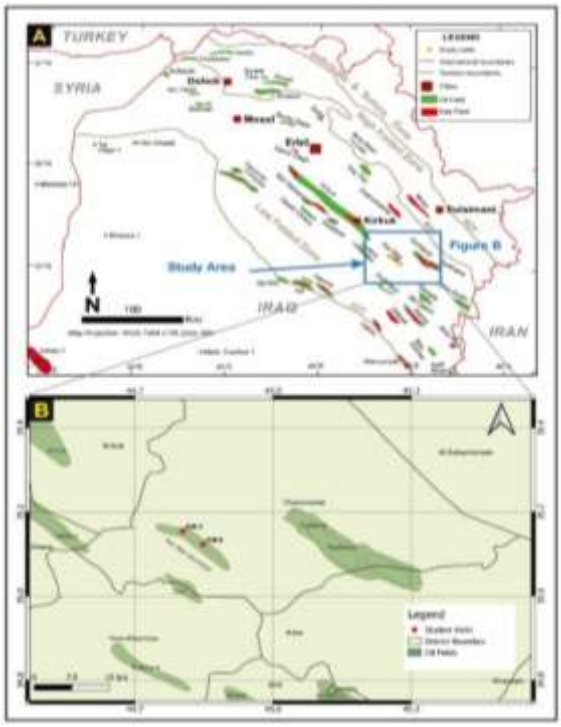

Fig. 1: (A) Map of Iraq showing structural provinces and (B) the location of the Kor Mor Field [13, 14]

2. Materials and Methods

The main tools that are used in this study are different types of logs, namely: Gamma Ray, Gamma Ray Spectrometry, Caliper Log, Neutron Log, Density Log, and Sonic Log, in the well Km-9.

Before starting the interpretation, the log data were corrected from shale content, and later the TechLog software has been utilized to adjust the environmental situation and analyze the well logs.

In addition, other available subsurface data from well Km-1 to Km-9 were used [11, 12]; including high pressure zone (Gas Kick), low pressure zone (mud loss), rate of penetration, rock properties; obtained from mud log, and final well reports and they were used in calibrating the outputs of the log analysis.

3. Geological setting

The Kor Mor Field is the SE extension of Kirkuk Structure, which is separated by a saddle about (20) Km in length. This field is a huge Gas field, the production is from the Tertiary reservoirs (Jeribe, and the Euphrates) which are the gas reservoir in many fields in the area (example Jambur, Hamreen), in addition to the documented oil in Lower Fars (Fatha Formation) [11]. According to the tectonic classification of Iraq [13]. The field locates in Foot-Hill Zone, Makhul-Hemrin Subzone (Kirkuk Embayment) that belongs to the Unstable Shelf.

The Kor Mor structure is (35) Km long and (5) Km wide, and consists of an asymmetrical anticline, its northeast flank is less inclined than its southwest one, and the dip on the (SW) Flank is (30^0) while the dip to the (NE) flank is (15^0) (Fig. 2) . According to the seismic investigation of the area which has done by the Iraqi Petroleum Company in 1955, they indicated a subsurface structure plunging toward the northwest, and two major faults intersect the structure to the SE plunge and SW limb, and they had a significant influence on reservoir performance [12].

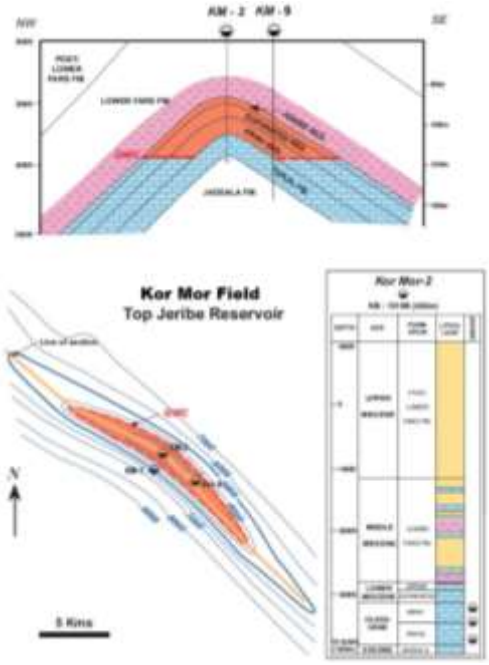

Fig. 2: Schematic cross section of Kor Mor Field, structural map of the tope of Jeribe reservoir and stratigraphic column of the field [15].

3-1 Stratigraphy and lithology:

The Miocene succession in Iraq is represented by the Ghar, Serikagni, Euphrates, Dhiban, and Jeribe Formations in the Lower Miocene and the Fatha, Injana, Mukdadiya, and Bai Hassan Formations of Middle-Upper Miocene times (Buday 1980[13]

The Lower Miocene units in Iraq represent deepwater facies of the Serikagni Formation (basinal) and shallow carbonate and evaporite facies of the Euphrates, Dhiban, and Jeribe Formations [16].

The Lower Miocene Jeribe and Euphrates formations are considered as significant reservoirs, they contain oil and gas in excess of 30 structures in Iraq, and most of the production come from Jeribe and Euphrates formations in most of the fields in Iraq particularly Northern Iraq fields [17].

The Kor Mor area covered by thick layers of Upper Fars (Injanah) and Lower Fars (Fatha) formations before getting the Jeribe, Dhiban, Euphrates, and Anah-Azkand formations.

3-1-1 Jeribe Formation: Bellen defined the Jeribe Limestone in 1957 [18] from the type site near Jaddala village in the Sinjar anticline and it is thought to be of Early Miocene age.

The first who pointed out the formation was Damesin in 1963 in an unpublished report but Bellen in 1957 was defined and described it as of the type locality near Jaddala Village in Jebel Sinjar [18]. The

thickness in the type locality is around 73m which mainly composed of massive recrystallized and dolomitized limestone; with beds of from 1-2m thick [18]. Jeribe Formation is equivalent to the Govanda Limestone Formation in age.

The formation, however, was later included into the Middle Miocene Sequence. The presence of the *Orbulina* datum towards the base of the Jeribe Formation indicates a Middle Miocene age [19]. According to the depositional environment study in the Azh Dagh-Qara Wais anticline, the Jeribe Formation was deposited in a hypersaline lagoon to a restricted lagoon [7].

The thickness of the Jeribe Formation in the Kor Mor Field ranged between 30 and 50m all over drilled wells [11], and it is comprised of a series of brown to grey recrystallized dolostone with dolomitic limestone and anhydrite nodules. According to the final well report [12] severe mud losses and gas flow were encountered during the drilling of the formation due to the fractures and vugs. The formation is underlain by Dhiban Anhydrite Formation with a thickness of 3 to 10 m in the drilled wells [11].

3-1-2 Euphrates Formation: It was first described by De Böckh [20] and then revised by Bellen in 1957 [18]. The type site on the Stable Shelf in Wadi Fuhaimi near Anah consists of 8 m of shelly, chalky, and well-bedded recrystallized limestone; nevertheless, it represents only a small section of the formation and does not include the basal conglomerate. Sands and anhydrite were also found in some subsurface layers [18] and are thought to be tongues of the Ghar and Dhiban formations [17].

According to depositional environments study [7] The Euphrates Formation passes up from deposits of restricted lagoon to shoal depositional environments.

The thickness of Euphrates Formation in Kor Mor Field is ranged between 30 and 65m in wells Km-2, 3, 7, and 9 [11]. According to the final report [12] this formation consists of a thin sequence of brown dolomitic limestone, marly limestone that was affected by the diagenesis with secondary anhydrite nodules. Also, oil-stained and bitumen in addition to the gas show was recorded along the upper part of the formation, also mud losses were recorded during the drilling [12].

4. Results and Discussion

4.1 Shale Volume Calculation

Gamma ray logging is often regarded as the most effective method for finding shales within logged intervals. That is why gamma ray log is occasionally referred to as "shale log"[21].

Due to the fact that radiation strength is proportional to the amount of radioactive materials present, the gamma ray recorded by the tool's detector in API units can be converted to shale volume as a fraction or percentage.

Shale volume was computed for the Jeribe and Euphrates Formations using data from the Gamma Ray Log and the equations for the Gamma Ray Index (Eq. 1) [22], shale volume calculation for Tertiary equation rocks (Eq. 2), [23].

$$IGR=\frac{GRlog-GRmin}{GRmax-GRmin} \quad \ldots\ldots\ldots \text{Eq. 1.}$$

Where:

IGR: Index Gamma Ray

GR_{log}: gamma ray recorded value at any depth (in API)

GR_{min}: minimum gamma ray recorded value at clean (non-shale) zone (in API) GR_{max}: maximum gamma ray recorded value at shale zone (in API)

$$Vsh = 0.083[2^{3.7.IGR} - 1] \quad \ldots\ldots\ldots \text{Eq. 2.}$$

According to [24], reservoir rocks classified on the basis of percentage of shale or shale volume (V_{sh}) into: Clean zone (V_{sh}<10 %), Shaly zone (V_{sh}10 – 35%), and Shale zone(V_{sh}> 35 %).

The determined volume of shale as seen in the upper part of the Jeribe Formation (Fig.3) contains a higher shale contents than the other parts; especially some intervals of its upper part (1241-1249m and 1256-1260m) are mostly shaly dominants, while its lower part from the depth 1260 to1276m, to the lower boundary with Dhiban Formation is clean zone.

Dhiban Formation (interval 1276 to 1279.5m.) is anhydrite, and it is excluded from further analysis. Regarding the Euphrates Formation its upper part is characterized by lower shale contained except two beds in the depths 1282 and1285.5m (Fig.3), while the lower part (1301-1311) is characterized by high shale contents.

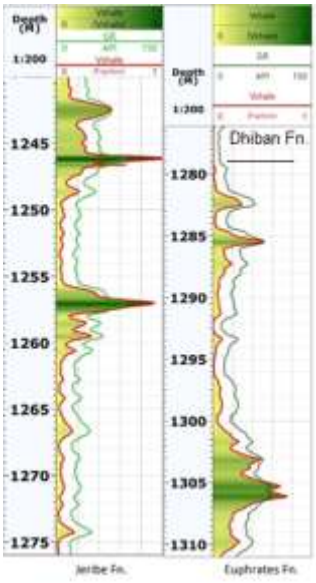

Fig. 3: Gamma ray log and the calculated shale volume for the Jeribe and Euphrates Formation at the studied well.

4.2 Natural Gamma Ray Spectroscopy

In this study, the data of the natural gamma ray spectroscopy was available for Jeribe, Dhiban, and Euphrates formations at the well Km-9. Natural Gamma Ray Spectroscopy measures the mass concentrations of uranium (U), thorium (Th), and potassium (K) independently. This tool is used to clay mineral identification in reservoir rocks which is

helpful to reservoir evaluation through applying special crossplots and graphs established to be used for such a purpose. The Th/K crossplot (Fig.4) shows that most of the clay minerals formed the shale content consist of Glauconite, Illite, and Micas with a little contribution from other kinds of clay minerals like Montmorillonite; this indicates the effect of the basinal depositional environments on the Jeribe and Euphrates formations [25].

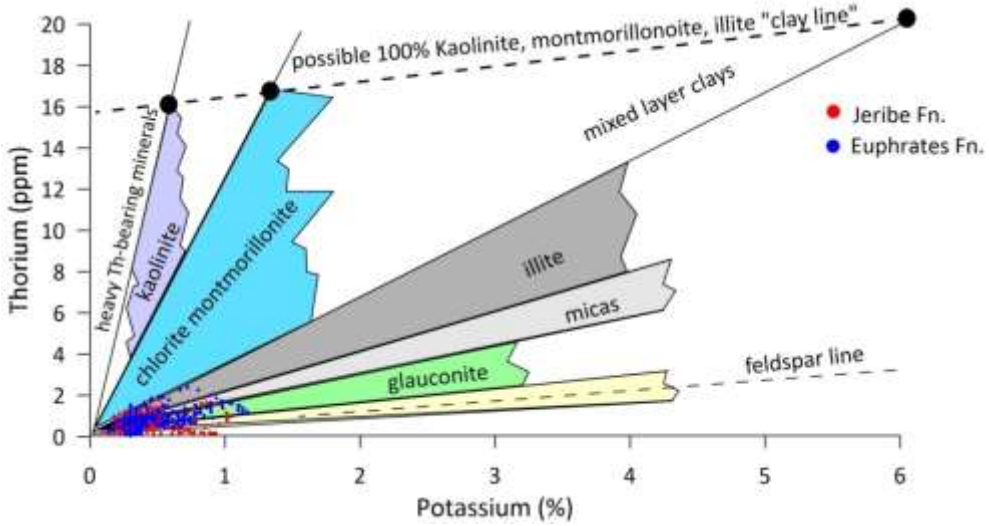

Fig. 4: The Th/K chart showing clay types in Jeribe and Euphrates Formation [26].

4.3 Measurement of Porosity (Φ)

The porosity of reservoir rocks is often determined using porosity logs (Sonic, Density, and Neutron logs).

4.3.1 Sonic Log

Sonic logging is a critical technique for evaluating formations. The sonic tool measures the interval transit time (Δt), or the time in microseconds for an acoustic compressional wave to travel through one foot or meter (μs/ft or μs/m) of formation, along a path parallel to the borehole (reciprocal of velocity). The interval transit time (Δt) is related to primary porosity; with increasing the Δt, also primary Φ increases (if other things are constant).

The borehole-compensated (BHC) devices were used in Kor Mor Field and the Wyllie time-average equation [23], was utilized: (Eq. 3).

$$\Phi_S = \frac{\Delta t\ \log\ -\ \Delta tma}{\Delta tfl\ -\ \Delta tma} \quad \text{.....Eq. 3.}$$

Where:

Φ_S = Sonic derived porosity.

Δt_{ma} = interval transit time in the matrix (Δt limestone or dolomite used, accordingly)

Δt_{log} = interval transit time in the formation (measured by log)

Δt_{fl} = interval transit time in the fluid in the formation (salt mud = 185 μsec/ft; used in this study)

Both plots of the Δt and Φs curves show almost a gradational increasing porosity from the top of the Jeribe Formation toward the bottom, the porosity at the top of the formation does not exceed 8% and become more than 18% at the bottom due to increasing of dolomitization downward [12]. While the upper part of Euphrates Formation has higher sonic porosity exceeding 20%, (except a few meters on the top characterized by low porosity), and the porosity of the lower part is around 10% (Fig. 5), also the upper part of the Euphrates more dolomitized than its lower part [12].

4.3.2 Density Log

The Density Log is a continuous record of bulk density of the formations. The bulk density (ρb) is the density of the entire formation as measured by the logging tool. The formula for calculating density porosity is to determine the density porosity of a formation, either visually or numerically, the matrix density and the type of fluid in the formation must be determined [23].

$$\Phi_D = \frac{pma\ -\ pb}{pma\ -\ pfl} \quad \text{.....} \quad \text{Eq. 4.}$$

Where:

Φ_D = density derived porosity

ρ_{ma} = matrix density (in this study 2.71 – 2.88 g/cm^3 were used according to the changes of the lithology from limestone to dolostone)

ρb = formation bulk density (the log reading)

ρ_{fl} = fluid density (salt drilling mud; 1.1 g/cm^{3}used for this study)

The density porosity from the both Jeribe and Euphrates formations are very variable due to the dolomitized heterogeneity [12] , it is ranged between 1% to 30%, as the same sonic porosity; the upper part of Jeribe has lower porosity than its lower part, while in the Euphrates the density porosity increased upward (Fig. 5).

4.3.3 Neutron Log:

The Neutron log is used to determine the porosity directly, its value is proportional to the amount of hydrogen in the formation, which comes from either hydrocarbons or water trapped in the formation's pores [27].

Figure (6) shows the neutron porosity for Jeribe and Euphrates formations, since the field is a gas field, the effect of the gas is very clear on both the density and neutron porosities. Gas makes the density porosity overestimated and the neutron porosity underestimated, and this effect is treated by calculating the average porosity from the both logs, and this is what will be addressed later through the combination of neutron-density average porosity.

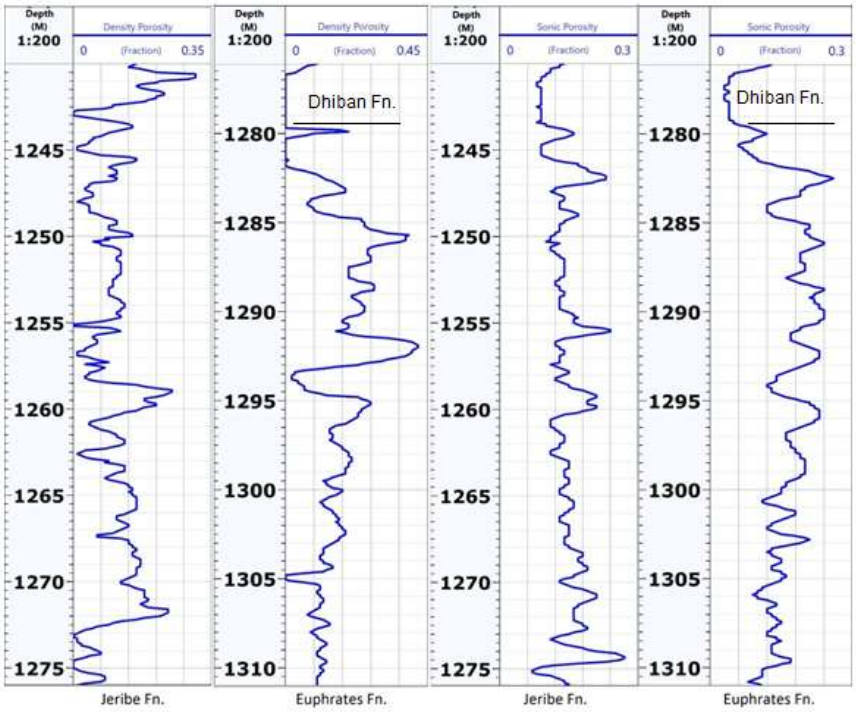

Fig. 5: Sonic and Density porosity for Jeribe and Euphrates formations.

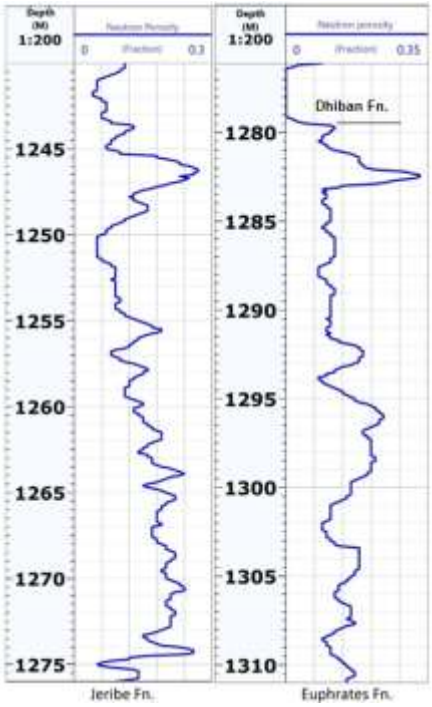

Fig. 6: Neutron porosity for Jeribe and Euphrates formations.

4.4 Correction of Porosity from Shale Impact

The presence of shale within the formation affects interpretation of the porosity calculation due to the various properties of shales and the variable reactions of each porosity tool to shale content [28].

All porosity tools (Neutron, Sonic, and Density) will overestimate porosity values in the presence of shale in a formation, and this is true for all common reservoir types (sandstone, limestone, and dolomite reservoirs) [29].

4.4.1 Correcting Sonic porosity:

4.4.1.1 Correcting Sonic porosity from shale impact:

$$\Phi S_{corr} = \frac{\Delta tlog - \Delta tma}{\Delta tfl - \Delta tma} - \left(Vsh * \frac{\Delta tsh - \Delta tma}{\Delta tfl - \Delta tma}\right) \quad \text{..... Eq. 5. [30]}$$

Where:

ΦS_{corr}: Corrected sonic porosity from shale effect

Δt_{log}: Interval transit time at any depth

Δt_{ma}: Interval transit time of formation's matrix (43.5 to 47.6 µsec/ft for dolomite to limestone used)

Δt_{f}l: Interval transit time of fluid (185µsec/ft for salt mud, the case of this study)

V_{sh}: Volume of shale at any depth

Δt_{sh}: Interval transit time of the adjacent shale (65µs/ft at the depth 1238.3m)

4.4.1.2 Correcting Sonic porosity from gas impact:

Also, the sonic porosity has corrected from the gas effect; the interval transit time (Δt) of a formation is increased due to the presence of gas. If the effect of the gas is not corrected as in the case of Kor Mor gas Field, the sonic-derived porosity is too high. Hilchie 1978 in [23] suggests the following empirical corrections for the gas effect:

$\Phi S_{corr} = \Phi S * 0.7$

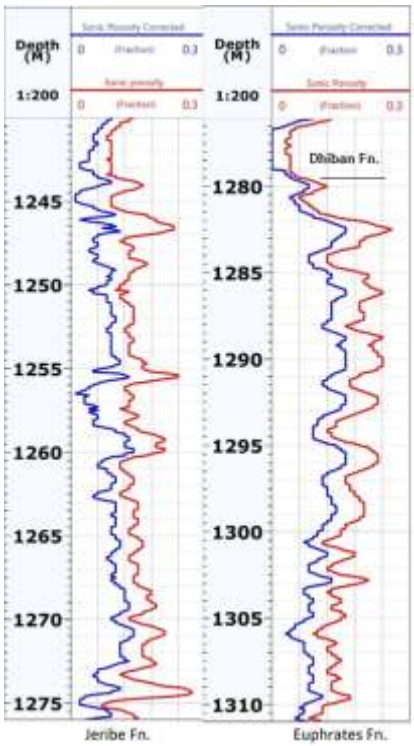

Fig. 7: Corrected Sonic porosity from the both shale and gas effects for Jeribe and Euphrates formations.

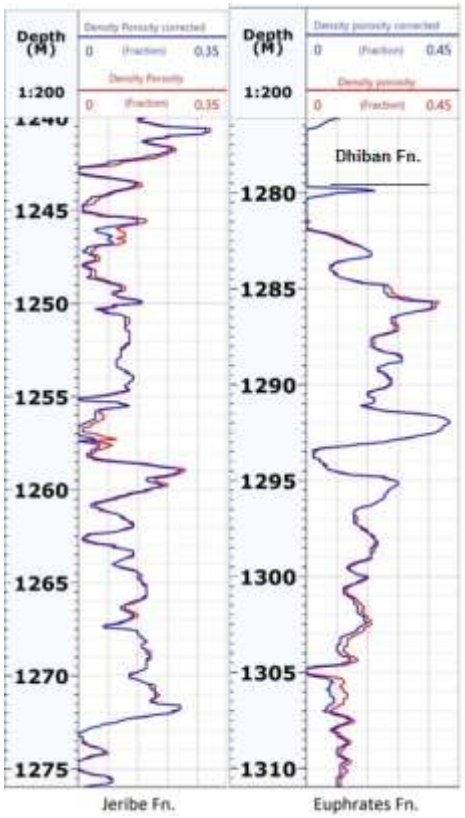

Fig. 8: Corrected Density porosity for Jeribe and Euphrates formations.

4.4.2 Correcting Density porosity:

$\Phi D_{corr} = \frac{\rho ma-\rho b}{\rho ma-\rho fl} - \left(Vsh * \frac{\rho ma-\rho sh}{\rho ma-\rho fl}\right)$ ……. Eq. 6. [31].

Where:
ΦD_{corr}: Corrected density porosity from shale effect
ρ_{ma}: Matrix density of the formation
ρ_b: Bulk density at any depth
ρ_{fl}: Fluid density (1.1 gm/cm³ for salt mud, the case of this study)
V_{sh}: Volume of shale at any depth
ρ_{sh}: Bulk density of the adjacent shale (2.55g/c^3 at the depth 1238.3m)

4.4.3 Correcting Neutron porosity:

$\Phi_{Ncorr} = \Phi N - (Vsh * \Phi Nsh)$ …… (Eq.7)
Where:
Φ_{Ncorr}: Corrected neutron porosity from shale effect
Φ_N: Neutron log reading at any depth
V_{sh}: Volume of shale at any depth
Φ_{Nsh}: Neutron porosity for the adjacent shale (0.22 at the depth 1238.3m)

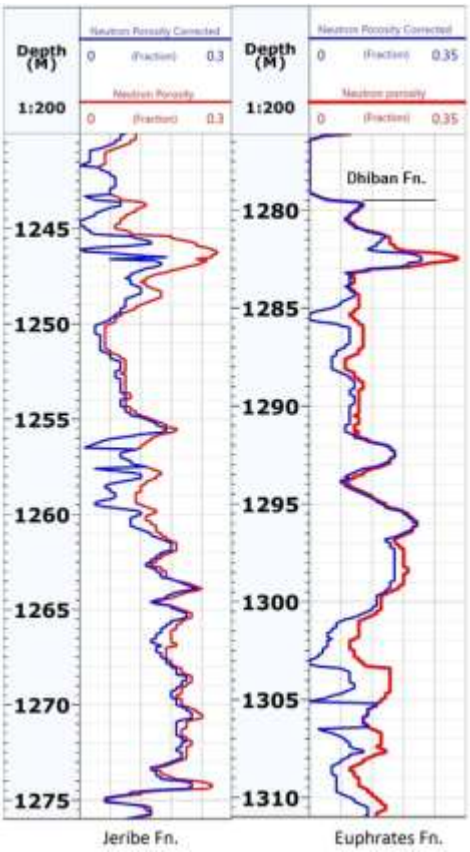

Fig. 9: Corrected Neutron porosities for Jeribe and Euphrates formations.

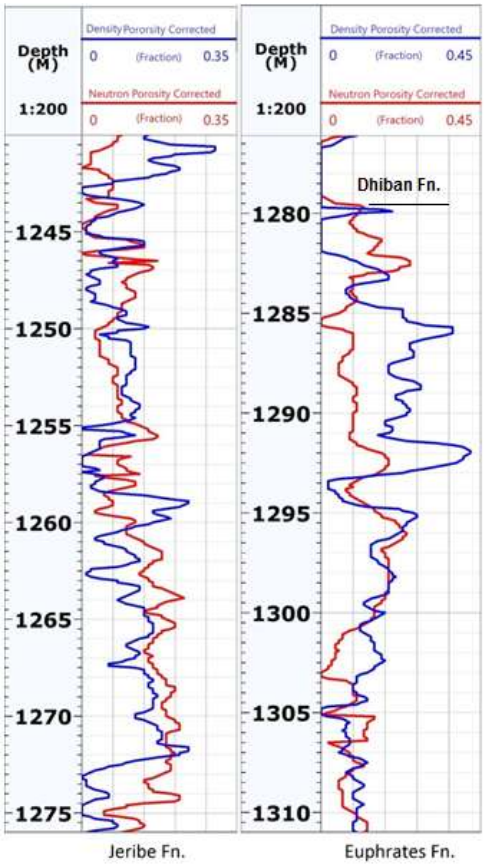

Fig. 10: Corrected Neutron- Density porosity for Jeribe and Euphrates formations.

4.5 Combination of Neutron-Density Porosity Logs (Φ_{ND})

As density and neutron logging tools are typically influenced in different directions by lithological and fluid characteristics, the rate of Φ_D and Φ_N values (referred to as Combination of Neutron-Density Porosity, Φ_{ND}) will be the most dependable and representative recorded porosity at any depth, the porosity of a gas-bearing formation can be estimated by the following equation: [23].

$$\Phi_{ND}gas = \frac{2}{3}\Phi_D + \frac{1}{3}\Phi_N \quad \ldots\ldots\ldots \text{Eq.8.}$$

Where:

Φ_{ND}gas = porosity of the gas-bearing formation

Φ_N = neutron porosity

Φ_D = density porosity

The effect of gas the is evident in the entire reservoir (Fig. 10), where the density porosity is greater than the neutron porosity, with the exception of some intervals this effect is unobserved due to the predominance of dolomite

4.6 Secondary Porosity (Fracture Index) Detection from Log Data

Within reservoir rocks, two distinct forms of porosity can be identified; primary and secondary. Primary porosity refers to the initial and unique porosity that exists prior to deposition [32].

Secondary porosity is a type of porosity that is generated as a result of the interaction of tectonic forces with formation water.

In general, secondary porosity is greater in carbonate rocks than in siliciclastic sediments [33].

The fractures have the great role to improve the reservoir properties (Porosity and permeability) especially in carbonate rocks, so the important portion of the world's hydrocarbon reserves belongs to the fractured carbonate reservoir, and the description of the fracture system is the essential petrophysical evaluation of the reservoir.

Sonic log measures the uniform inter-particle or inter-crystalline porosity (primary porosity), while the average measured porosity by Neutron-Density log is considered as total porosity. When the sonic porosity (Φ_{Scorr}) are compared with the total neutron and density porosity combination (Φ_{NDcorr}) equation 9; the different between them is the secondary porosity (fractures, cavities, vugs .. etc).

$$\Phi_{Sec} = \Phi_{NDcorr} - \Phi_{Scorr} \quad \ldots\ldots\ldots \text{Eq. 9.}$$

Where:

Φ_{Sec}: Secondary porosity

Φ_{NDcorr}: Combination neutron-density porosity (corrected from shale impact and gas)
Φ_{Scorr}: Sonic porosity (corrected from shale impact and gas)
The Jeribe and Euphrates reservoirs in Kor Mor Field shows the reasonable high secondary porosity (Fig. 11, green color) which makes a significant fraction in both Jeribe and Euphrates units represents from 20% to 27% of the total porosities respectively.

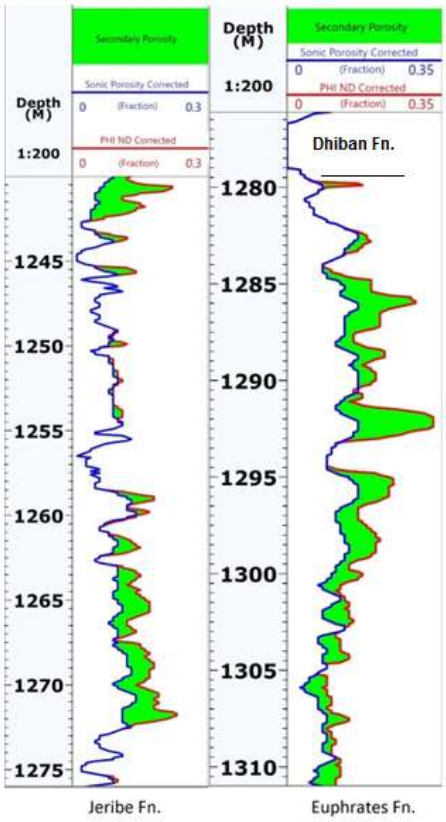

Fig. 11: N-D Combination and Secondary porosity for both Jeribe and Euphrates formations.

The majority of the secondary porosity is related to the Euphrates unit, which it is the range between 0% and 19%, and the upper and lower part of the Jeribe reservoir ranges between 0% and 15%, (Fig. 11). This resulted in a complete mud loss in these two units during the drilling process, hence lost circulation material (LCM) had to be used, along with decreasing the mud weight in order to control the situation [12].

5. Conclusions

From this study about the Reservoir Characteristics of the Kor Mor Gasfield, the following conclusions can be made:

1. Both formations (Euphrates and Jeribe) have different thicknesses all over the field; the thickness of the Euphrates Formation ranged from 30 to 65 m, and Jeribe Formation from 30 to 50m. The two formations were separated by an Anhydrite Dhiban Formation with a thickness of 3 to 10 m in the drilled wells
2. The upper part of the Jeribe Formation mostly limestone and its lower part characterized by dolostone, whereas the dolomitization is more complete in the upper part of the Euphrates Formation.
3. The Jeribe Formation comprises two shaly intervals in its upper and middle part, while the Euphrates includes a shaly interval in the lower part and some bands in the upper part
4. Porosity of the Euphrates reservoir ranges between 0.0 and 0.33 with an average of 0.15, and the Jeribe reservoir ranges between 0.01 and 0.23 with an average of 0.10.
5. The secondary porosity makes a significant fraction of porosity in both units; in Euphrates reservoir ranges between 0 and 0.19 and in Jeribe reservoir ranges between 0 and 0.15, this quantity represents from 0.20 to 0.27 of the total porosities. These fractures resulted in a complete mud loss from some intervals in these two units during the drilling process.

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الخواص المكمنية للتكاوين الجيرية ذات العمرمايوسين الاسفل فى حقل كورمور الغازي، منطقة كركوک، شمال شرق العراق

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الملخص

تم اختيار التقييم المكمني لتكوينين الجيريين؛ الفرات، والجيريبي (الميوسين الاسفل) في حقل كور مور الغازي في شمال شرق العراق. تراوحت سماكة تكوين الفرات بين 30 و 65 و الجريبي بين 30 و 50 مترا في هذا الحقل ، وتعلوهما طبقة غطاء متبخرات سميكة من تكوين الفتحة. وكما تفصل التكوينين بواسطة طبقة رقيقة من صخور المتبخرات لتكوين الذبان

تم استخدام المجموعة الكاملة من بيانات المجسات للبئر (Km-9) بالاضافة الى القراءات المتوفرة لثمان آبار الاخرى من Km-1 الى Km-8، ومن نتائج التحاليل للبيانات فى تقييم خصائص المكمنية للوحدتين، ظهرت ان فى الغالب كلا من دولوستون والحجر الجيري الدولوميتى كانا صخاريتين مهيمنتين فى هذين التكوينين.

و من بيانات المجسات ، تم تقدير أنواع مختلفة من الخصائص المكمنية متمثلا بمحتوى الطين ، أنواع الطين ، المسامية الاولية ، والمسامية الثانوية (الكسور، الشقوق، ولفجوات)