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EVALUATION OF RESERVOIR POTENTIALITY OF THE SINJAR FORMATION WITHIN THE TAQ –TAQ OIL FIELD, KURDISTAN REGION, IRAQ

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ABSTRACT

The carbonate rocks of Sinjar Formation in the Taq Taq oil field are analysed in three wells (TT-04, TT-05, and TT-06) to indicate reservoir potentiality using wireline well logs, cutting samples and the structural seismic section of the field. The lithology of the Sinjar Formation consists of limestone with an interlayer of sandstone at the lower part which only appeared in well TT-05. Porosity is calculated from three porosity logs and the results show very good magnitudes of porosity with high secondary porosity as revealed from bulk porosity with sonic porosity plot. Two porosity units are recognized in the Sinjar Formation; 0.18 in the upper unit and 0.07 in the lower unit. High shale contents are calculated in the studied interval of the Sinjar Formation, which destroyed pore connectivity and acted as barriers to fluid flow. From petrophysical analyses, it can be illustrated that the Sinjar Formation holds a good secondary porosity but without reserving any hydrocarbons and the formation is not recognized as a potential carbonate oil reservoir in the studied wells.

تقييم إمكانية الخزن لتكوين سنجار ضمن حقل طق طق النفطي في إقليم كردستان، العراق

ديفان عثمان حسين

المستخلص

تم تحليل الصخور الكاربوناتية لتكوين سنجار في حقل نفط طق طق في ثلاثة آبار هي TT-04 و TT-05 و TT-06 لإظهار الصفات المكمنية للتكوين. ولأجل ذلك تم دراسة الجس البئري السلكي ونماذج فتاتية ومقطع زلزالي تركيبي للحقل. تتكون صخارية تكوين سنجار من الحجر الجيري مع تداخل طبقات من الحجر الرملي في الجزء السفلي من التكوين الذي يظهر فقط في بئر TT-05. تم حساب المسامية من خلال ثلاث مجسات للمسامية وقد أظهرت نتائج جيدة جدا للمسامية مع نسبة عالية للمسامية الثانوية كجزء من المسامية الكلية. من خلال المخطط البياني الصوتي تم تمييز وحدتين مساميتين، وحدة مسامية عليا بقيمة 0.18 ووحدة مسامية سفلى بقيمة 0.07. تم حساب محتوى عالي للطَفْل في التكوين مسببا في غلق الإتصالات المسامية بالإضافة الى عمل حواجز لمنع جريان الموائع. تبين من خلال التحليل الصخري الفيزيائي ان الصخور الكاربونيتية في آبار الدراسة ضمن تكوين سنجار ذات مسامية ثانوية عالية غير محتفظة بالهايدروكاربونات لذلك لايمكن اعتبارها ذات مواصفات مكمنية جيدة.

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INTRODUCTION

Structures in the Folded Zone of the Zagros Basin are characterised by NW – SE trending symmetrical anticlines enriched with carbonate rocks that have various hydrocarbon reservoir potentiality and productivity (e.g. Aqrawi *et al*., 2010; Hussein *et al*., 2018; Rashid *et al*., 2020). The dominant reservoir potential has been proved in the Cretaceous Qamchuqa Formation (Al-Qayim and Rashid, 2012; Ghafur and Hasan, 2017) and resulted from the depositional environment and diagenetic modifications, which provided primary porosity and secondary porosity through dolomitization and extensive diagenesis from hydrothermal overprint of the dolomite that caused further dolomitization (Hollies, 2011). Furthermore, the grain dissolution created wide size range of moldic and vuggy pores with integration of fracturing enhancing the pore connectivity and constructed fluid flow in the rock units. Consequently, the limestone beds of the Cretaceous Kometan and Shiranish Formations have very low magnitude of porosity, while fracturing created extensive fracture permeability and eventually improved the fluid productivity (Garland *et al*., 2010; Rashid *et al*., 2015a and b; Rashid *et al*., 2017).

The dominant Tertiary reservoir rocks in the Zagros Folded Belt are represented by heterogenous and fractured rocks of Baba, Anah and Azkand Formations of the Kirkuk Group, Euphrates, Jeribe and PilaSpi formations in the Kirkuk embayment fields (Aqrawi *et al*., 2010; Mackertich and Samarrai, 2015 Hussein *et al*., 2017). Besides enormous carbonate reservoir rocks throughout the region, there are some carbonate rock units that have restricted reservoir qualities including Khurmala Formation in the Taq Taq oil field (Rashid *et al*., 2020). Shalness and entrapment kept the formation in water bearing zone while it has a productive interval in the Khurmala (dome) of Kirkuk oil field. Another massive carbonate rock, which is extended as continuous formation throughout the newly discovered field in the foothill zone of the Zagros Folded Belt field, is Sinjar Formation that acts as an ignorable interval in terms of reservoir productivity and usually classified as a cased zone .The lithology of Sinjar Formation consists of recrystallized limestone (Jassim and Goff, 2006 and Aqrawi *et al*., 2010).

Ahmad (2016) described the Sinjar Formation as thick, massive and highly fossiliferous limestone with occasional beds of dolomitic limestone. This study is conducted to achieve an acceptable explanation for the low consideration and kind of ignorance of this formation as a potential reservoir during hydrocarbon explorations in the Kurdistan Region of Iraq. Different sets of data have been collected from the Sinjar Formation in the Taq Taq oil field to evaluate the reservoir characteristics and reservoir potentiality of the formation.

GEOLOGICAL SETTING

The Taq Taq oil field is located in the Zagros Folded Belt within the Kirkuk Embayment, Kurdistan region of northern Iraq. The Taq Taq structure lies in the folded foothills to the southwest of the mountain front fault, which separates the high Zagros Mountains from the Kirkuk Embayment (Fig.1). The Taq Taq anticline is a NW – SE trending, symmetrical, thrust-related structure, approximately 30 Km long and 10 Km wide. Similar to the other Kirkuk embayment fields, in this field faults and fractures share a sufficient role in hydrocarbon entrapment and production (TTOPCO, 2006).

The geology of the oil field and the surrounding area shows that the Injana Formation (Upper Miocene) and the Mukdadiya Formation (Pliocene) are exposed close to the Taq Taq anticline. These young stratigraphic successions pass to older Eocene, Paleocene and Upper Cretaceous rocks toward the north of the field including Pilaspi, Gercus, Sinjar, Kolosh and

Tanjero formations. The first exploration well (number 1) penetrated the three different petroleum systems starting from the top to the bottom as Tertiary, Cretaceous and Jurassic petroleum systems.

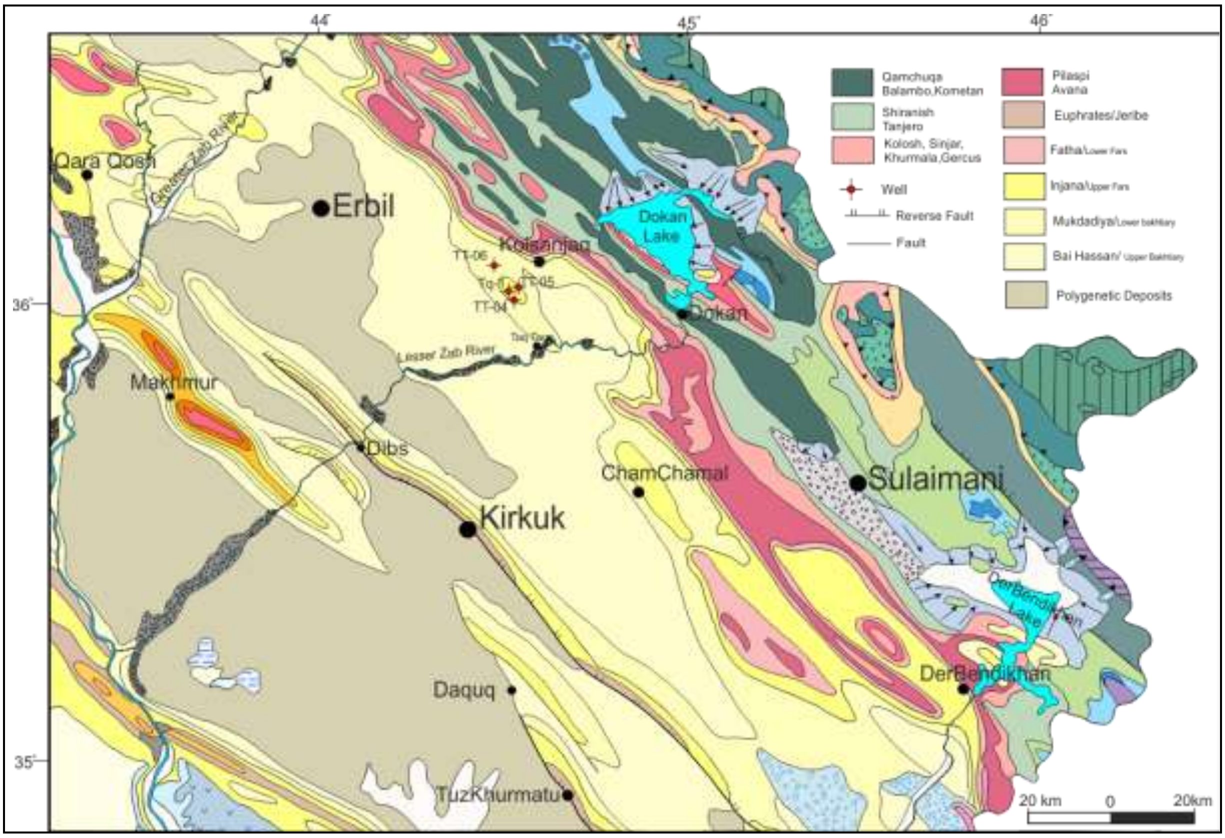

Fig.1: Geological map of Kurdistan Region and north of Iraq shows location of the Taq Taq oil field and the three studied wells (TT-04, TT-05 and TT-06) (Sissakian, 2000)

In this study three wells (TT-04, TT-05, TT-06) are chosen to evaluate the reservoir characteristics and potentiality of the Eocene Sinjar Formation (Fig.1). The TT-04 well is the first well in the new Taq Taq operation program. The well penetrated the defined targets and had production of 15000 bbl/day from the Cretaceous reservoirs (TTOPCO, 2006). The TT-05 well was the second well in the new Taq Taq development program. The well achieved most of the objectives and production was 26.500 bbl/d of light oil with measured gravity ranging from 44 to 50 degrees API (TTOPCO, 2006). Finally, the TT-06 planned as an appraisal and development well on the northern flank of the Taq Taq anticline, and it was located 4 Km northwest of the TT-01 along the axis of the anticline. The well was flowed at an aggregate rate of 18,900 bbl/d of light (48 degrees API) oil (TTOPCO, 2007).

MATERIALS AND METHODS

Three drilled wells (TT-04, TT-05 and TT-06) from the Taq Taq oil field were selected for this study. The wells reached all the targets in the field and successfully drilled to the Cretaceous Upper Qamchuqa Formation during the development program of the field. The TT-04 well drilled vertically to a target 600 m SE of well Tq-1, and TT-05 located 500 m of the NE side of Tq-1, was drilled on the crest of the anticline. Well TT-06 was planned as an appraisal and development well on the northern flank of the Taq Taq anticline, 4 Km NW of the well Tq-1.

The Sinjar Formation is recorded from depth 827 m to 900 m in the TT-04, from 799 m to 869 m in TT-05, and from 885 m to 941 m in TT-06 well. The gathered data set for these wells includes wireline logs of the drilled Sinjar Formation intervals. The log data comprises porosity logs (sonic, density, and neutron), gamma ray logs, and resistivity logs. In addition, drilling stem test, mud log, lithologs, and cutting samples have been analysed to support and achieve the aims of this research in the assessment of reservoir quality of the Sinjar carbonate rocks in this field. The gathered data are summarized in Table 1. The inflection raw data of the wireline logs were operated to investigate the lithology, mineralogical components, shale volume, porosity calculation, and fluid movability prediction in the Sinjar Formation using Interactive Petrophysics (IP) software, where the wireline logs have digitized and converted to LAS format, then they were loaded to the software to evaluate petrophysical properties including shale volume, lithology, porosity and fluid saturation. The petrophysical analysis of the log data were mainly produced from the common mathematical equations and some standard (Schlumberger) charts that have been applied to wireline log studies (Schlumberger, 1997; Rider and Kennedy, 2011).

Table 1: Collected data set from the selected drilled wells in the Taq Taq oil field

Data	TT-04	TT-05	TT-06
Wireline Log	Gamma ray (GR), Sonic (DT), Compensated Density Log (CDL), Compensated Neutron Log (CNL)	Gamma ray (GR), Sonic (DT), Compensated Density Log (CDL), Compensated Neutron Log (CNL)	Gamma ray (GR), Sonic (DT), Compensated Density Log (CDL), Compensated Neutron Log (CNL)
Cutting samples	39	35	38

- ***Lithology***

Lithological investigation of the collected cutting samples with the combination of the wireline well logs were used to indicate interval lithology of the Sinjar Formation based on related literature (Ellis and Singer, 2007; Asquith and Krygowski, 2004; Wiley and Pachett, 1990; and Dahlberg, 1989) and for the density-neutron cross plot (Rider and Kennedy, 2011; Krygowski, 2003; and Schlumberger, 1997). The combination of these well logs is used for lithological description especially porosity logs, which depend on porosity amounts, matrix variation and drilling fluids. The neutron-density logs crossover and are overlapping the main log method for the lithological study. In addition, this cross-plot determines continuous lithological variations in the logged interval as well as providing single lithology component or a mixture of two types of rocks such as limestone, dolostone or dolomitic limestone.

- ***Clay volume (Shale volume)***

In this study, gamma ray log is used to calculate the volume of shale in the studied interval. The mathematical calculation of the shale volume (V_{sh}) comes from the gamma ray index (I_{GR}) as the first step of the shale volume calculation using Equation (1), using shale base line where gamma ray log records maximum reading 100 API and for clean sand line the gamma reading is equal to 0.0 with the gamma ray log reading from the logged interval (Bhuyan and Passey, 1994). The calculated gamma ray index (I_{GR}) then could be converted to shale volume. The shale volume is usually displayed as a percentage or a decimal fraction. The amount of shale in carbonate rocks is influenced by amount of organic matter present.

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

$$V_{sh} = 0.083(2^{3.7 I_{GR}} - 1) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

I_{GR}: gamma ray index.

GR_{log}: gamma ray reading from log, API.

GR_{min}: minimum gamma ray reading (clean sand or carbonate), API.

GR_{max}: maximum gamma ray reading (shale), API.

V_{sh}: shale volume

- ***Porosity***

Porosity assessments and petrophysical analysis are derived from the three main porosity logs including sonic, density and neutron logs. Sonic slowness is converted to porosity using Wiely time average Equation (3), (Wiley and Pachett, 1990; Asquith and Krygowski, 2004). The matrix density from the density log with known fluid density filling the pores and by applying Equation (4) the result comes as density porosity. Furthermore, the third porosity log directly measures hydrogen concentration that is comparable with porosity (Rider and Kennedy, 2011; Schlumberger, 2012).

$$\phi_s = \frac{(\Delta_{t\,bulk} - \Delta_{t\,ma})}{(\Delta_{t\,fl} - \Delta_{t\,ma})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Φ_s: sonic porosity, fraction.

$\Delta_{t\,bulk}$: sonic log reading, µs/ft.

$\Delta_{t\,ma}$: transit time of matrix, µs/m.

$\Delta_{t\,fl}$: transit time of the mud filtrate, µs/m.

$$\phi_\rho = \frac{(\rho_{ma} - \rho_{bulk})}{(\rho_{ma} - \rho_{fl})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Φ_ρ: density porosity, fraction.

ρ_{ma}: matrix density, g/cm^3.

ρ_{bulk}: log reading density, g/cm^3.

ρ_{fl}: fluid density, g/cm^3.

Density and neutron log porosities are determined from the nuclear records, while the sonic porosity is calculated from acoustic properties of the studied formation (Rider and Kennedy, 2011). Calculation of porosity from the three logs gives an accurate value of porosity for the targeted reservoir interval after applying some corrections for shale and environmental impact.

RESULTS

- ***Lithology***

Limestone is the main lithology of the studied formation; white limestone is dominant with dolomitic limestone especially in wells TT-04 and TT-06 (Figs.2 and Fig.3), while in well TT-05, the white limestone is inter-layered with moderate to dark brown, very fine sandstone.

The homogeneous lithology of the Sinjar Formation is investigated all through studied wells (TT-0-4 and TT-06) where 73 m and 56 m of limestone are recorded, respectively. However in well TT-05, being a little different, where 5 m of sandstone bands appeared between 835 m – 840 m (Fig.3) within 70 m of limestone. The limestone description from cutting samples is characterized by white to very pale grey, pale to medium grey, commonly micritic to occasionally microcrystalline, chalky texture with no visual porosity. The sandstone layer is characterized by dark brownish grey, friable, quartz, grading to very fine sandstone with argillaceous matrix and carbonate cement with no visual porosity.

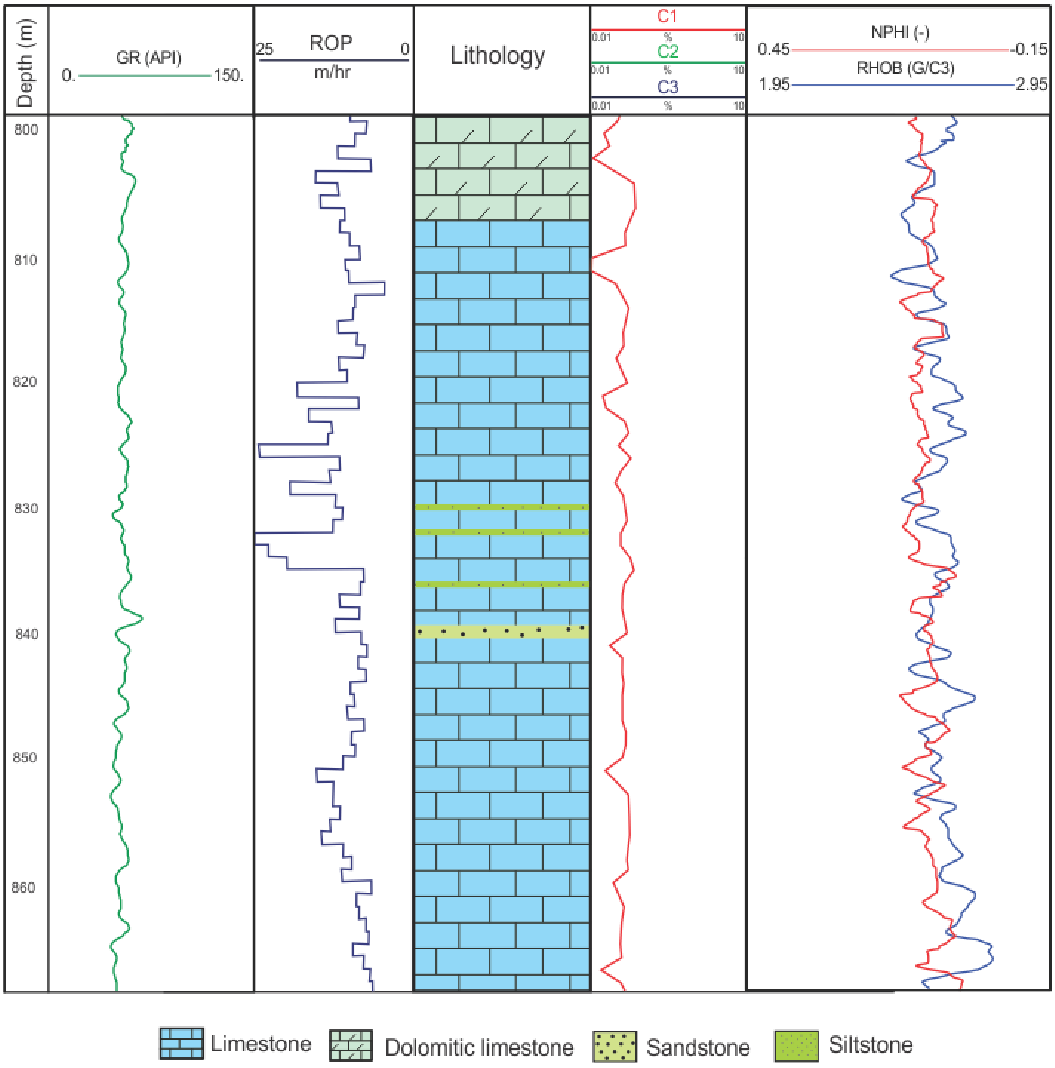

Fig.2: Lithology log of of the Sinjar Formation in well TT-04 - Taq Taq oil field showing the penetrated lithology, wireline well logs, and rate of penetration with C (Gas reference)

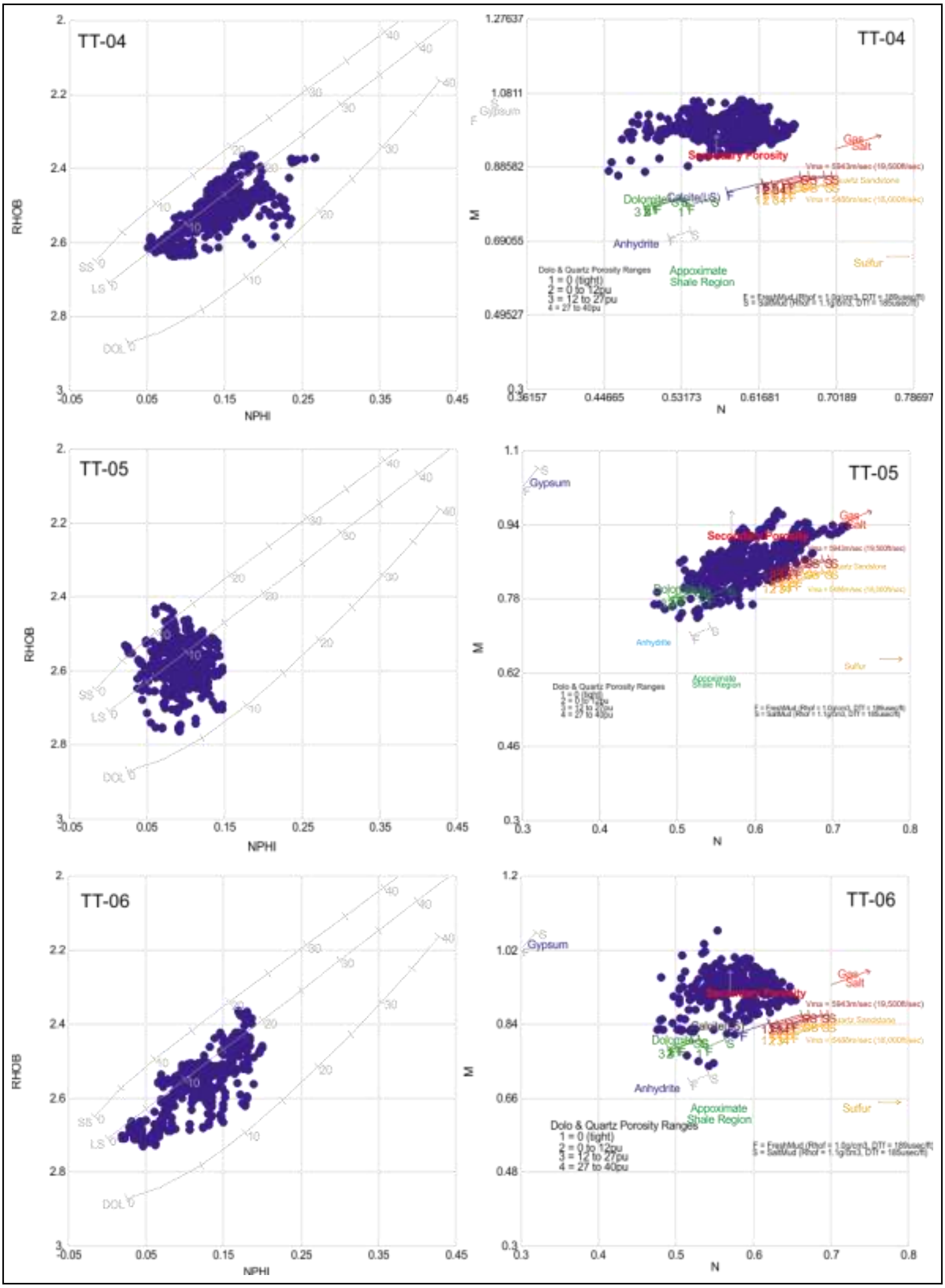

Fig.3: The Density-Neutron cross, and the M-N plots of the Sinjar Formation in the three drilled wells (TT-04, TT-05, and TT-06) illustrating nearly homogeneous lithology with secondary porosity within the formation

- ***Clay volume***

Gamma ray log is selected to calculate shale volume, where different percentage of shale is observed from the top to the bottom of the Sinjar Formation. In general, the percentage of shale volume in the formation is high reaching up to 35% in well TT-04; 25% in well TT-05 and 45% in well TT-06 (Fig.4). The GR readings for clay (shale) volume calculations range from 5 to 95 in the studied wells.

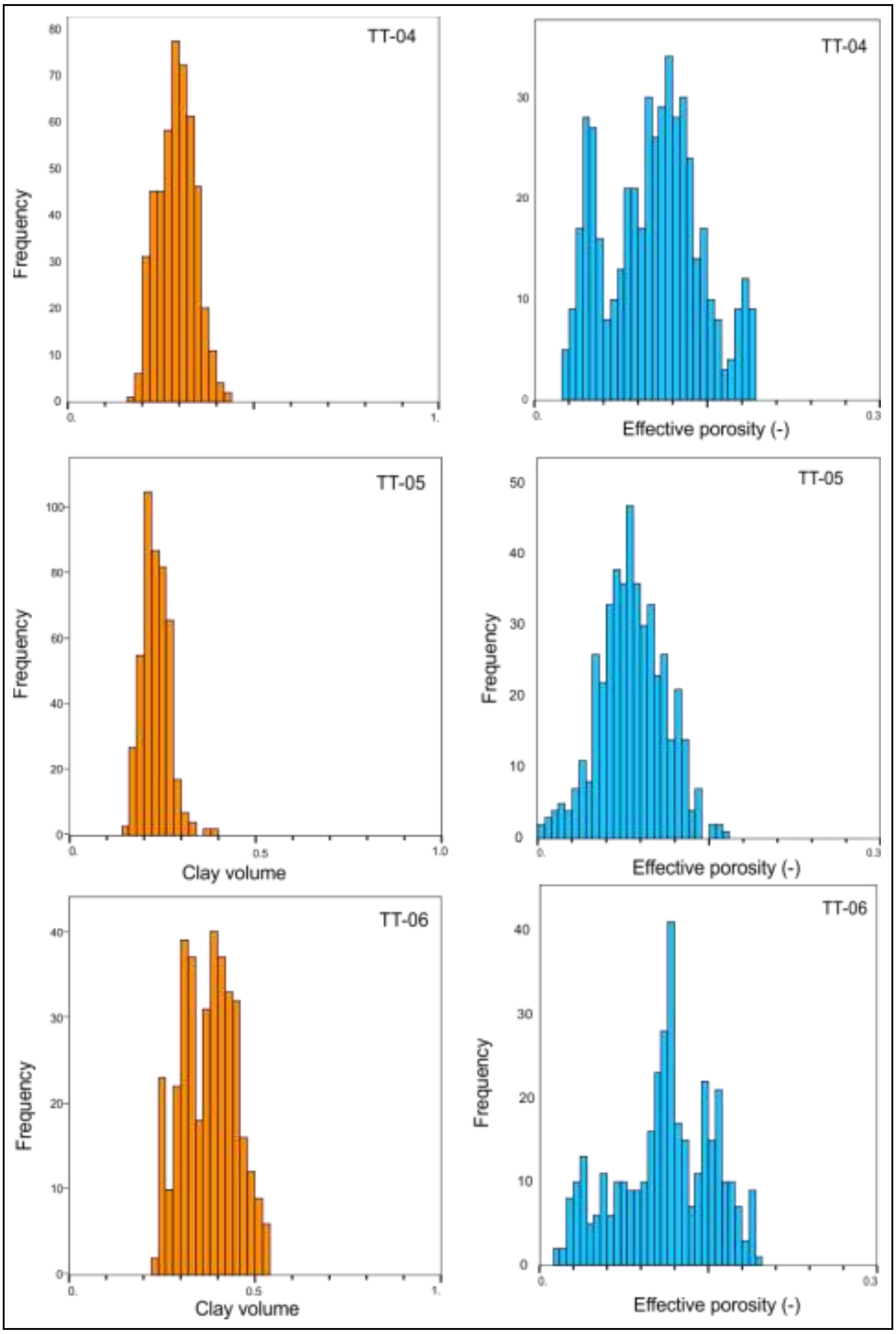

Fig.4: Histograms of the calculated clay (shale) volume and total porosity after shale correction in the selected wells (TT-04, TT-05 and TT-06)

- ***Porosity calculation***

The porosity calculation is derived from porosity logs. Average porosity (Bulk porosity) is achieved from density log derived porosity and the neutron derived porosity, whereas, the primary porosity is calculated from interval transit time of sonic log (Asiquith and Graybowski, 2004; Rider and Kennedy, 2011). The total porosity distribution with the primary porosity throughout the studied wells is presented in Figure (5).

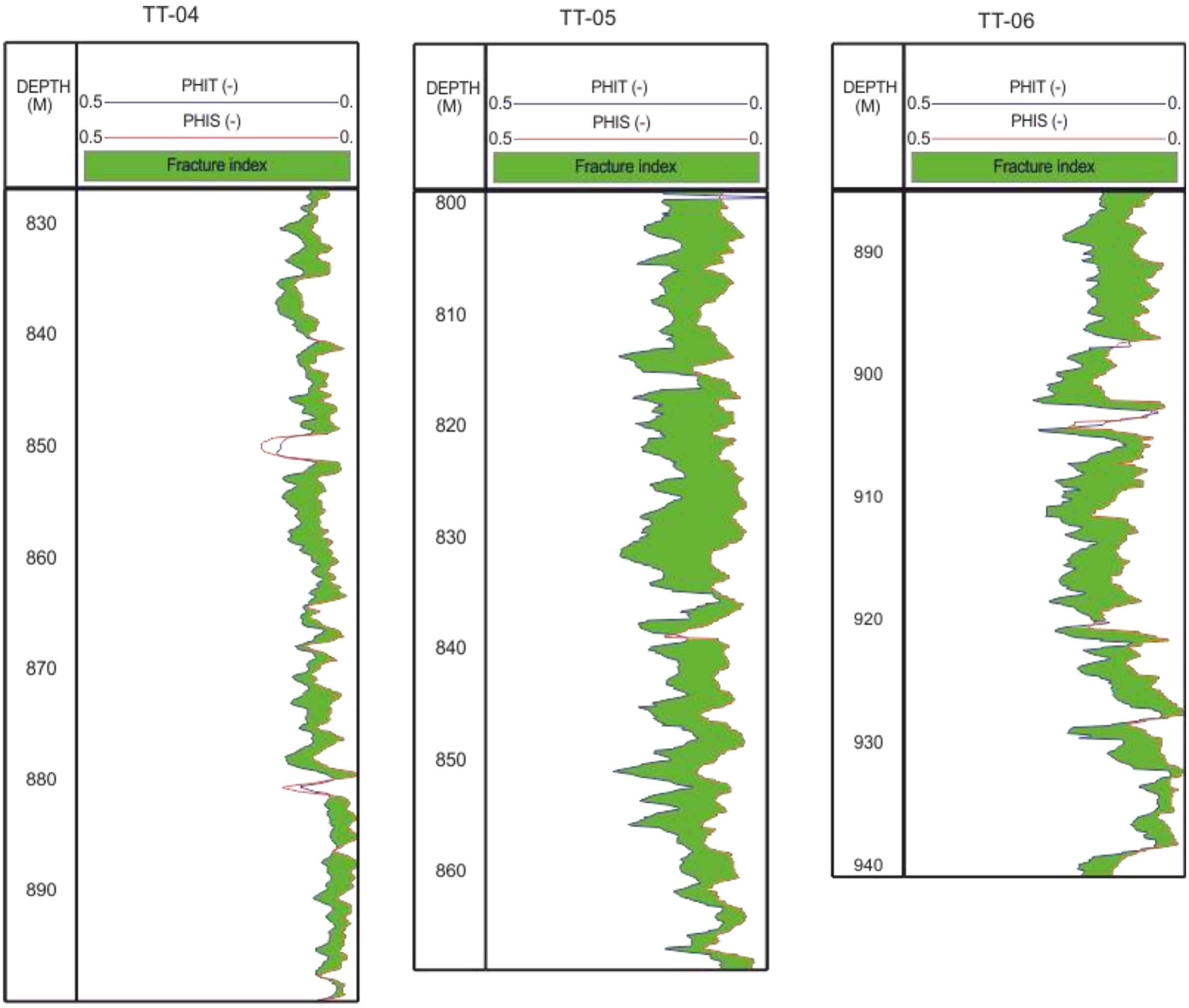

Fig.5: Porosity logs showing bulk porosity (PHIT) and sonic porosity (PHIS) distribution throughout the Sinjar Formation. The green area shows the separation between bulk porosity and sonic porosity which in turn indicate secondary porosity or it can be recognized as a fractured index

The porosity distribution of the Sinjar Formation from porosity logs illustrate that the upper part of the formation has a higher porosity than the lower part. The upper part exhibits (0.18) total porosity while the lower part has (0.07) porosity. Therefore, this study suggests a rather homogeneous porosity and it cannot be divided into different units of porosity. Based on Figure (3), the M-N plot show that all investigated porosities belong to secondary porosity, furthermore, clear separation observed where a plot of total porosity (PHT) vs. SPHI is presented for these wells and interpreted as fracture index.

DISCUSSION

- **Sinjar Formation compared to other reservoir rocks in the Taq Taq oil field**

The petrophysical analysis in this study reveals that this carbonate formation holds a good reservoir quality to be considered as a potential reservoir. The limestone lithologies, good bulk porosity with high secondary porosity are considered the main parameters to call the Sinjar Formation as a reservoir rock. However, the main question arises from this study is why it cannot hold and transmit hydrocarbon and to be introduced as a potential reservoir.

The main reservoirs in the Taq Taq oil field are documented to be in Cretaceous reservoirs such as Qamchuqa, Kometan and Shiranish Formations (e.g. Rashid *et al*., 2015a and b; Rashid *et al*., 2017) and also from the Tertiary reservoir such as Pilaspi Formation (Al-Qayim and Othman, 2012). These formations are characterized by high dolomitization, highly fractured and well inter-connected pore systems that provide good permeability to store hydrocarbon in their porous medium. While based on final well reports (TTOPCO, 2006 and 2007), very limited oil shows were observed throughout the Sinjar Formation in the studied wells and during drilling the wells and the flow rate tests implied water bearing zones throughout the tested intervals.

- **Interpretation based on Resistivity logs**

The Sinjar Formation in the selected wells is overlain by the non-reservoir rocks of the Khurmala Formation in the Taq Taq oil field (Rashid *et al*., 2020). The result of the present study is consistent with a recent study conducted by Rashid *et al*. (2020). Additional considerations to show further evidence for lack of hydrocarbon in the Sinjar Formation were taken by analyzing resistivity logs. The resistivity logs of the wells include Micro Spherically focused log, shallow resistivity and deep resistivity logs and show low inflections or response in the Sinjar Formation (Fig.6), which indicate lack of hydrocarbons. Low separation between LLS and LLD is an indicator to low matrix permeability throughout the Sinjar Formation. High deflection of the MSFL is an effective evidence for fracture distribution which provided a sufficient permeability to the logged intervals. However, fracture creation and growing is the key control for hydrocarbon migration.

- **Interpretation of the seismic section**

The seismic section (Fig.7) shows numbers of extensive through-going fractures including continuous faults that crossed the Sinjar Formation and other Tertiary rocks in the Taq Taq Field (Mackertich and Samarrai, 2015). As a result, fault and fracture extensions could provide sufficient fluid flow pathways for transformation of hydrocarbons to the porous media which have been formed. However, commercial hydrocarbon accumulation from tests and show observations has not been recorded in the drilled interval of the Sinjar Formation. In addition, the Khurmala Formation is also described as dry unit in terms of hydrocarbon saturation (Rashid *et al*., 2020). Meanwhile, the upper rocks of the Pilaspi Formation in the Taq Taq oil field has been chosen as a potential reservoir and to be the main target in the future development plan of this oil field alongside the Cretaceous reservoirs without consideration the Sinjar Formation as a potential petroleum reservoir.

- **Interpretation based on porosity logs and (M-N) plots**

Based on the (M-N) plot with porosity logs (PHIT and PHIS), the Sinjar Formation can be characterized by high secondary porosity with no hydrocarbons due to high clay content. The high clay volume has reduced the pore connectivity within the formation. The same characteristic has been addressed for the Khurmala Formation in the Taq Taq oil field (Rashid *et al*., 2020). The secondary porosity does not resemble primary porosity, where, in secondary porosity the pore connection must have other influencing factors in order to create pore connectivity such as dissolution and dolomitization. This is not the case in the Sinjar Formation which limit its chances be a future reservoir target for hydrocarbon bearing store in this field.

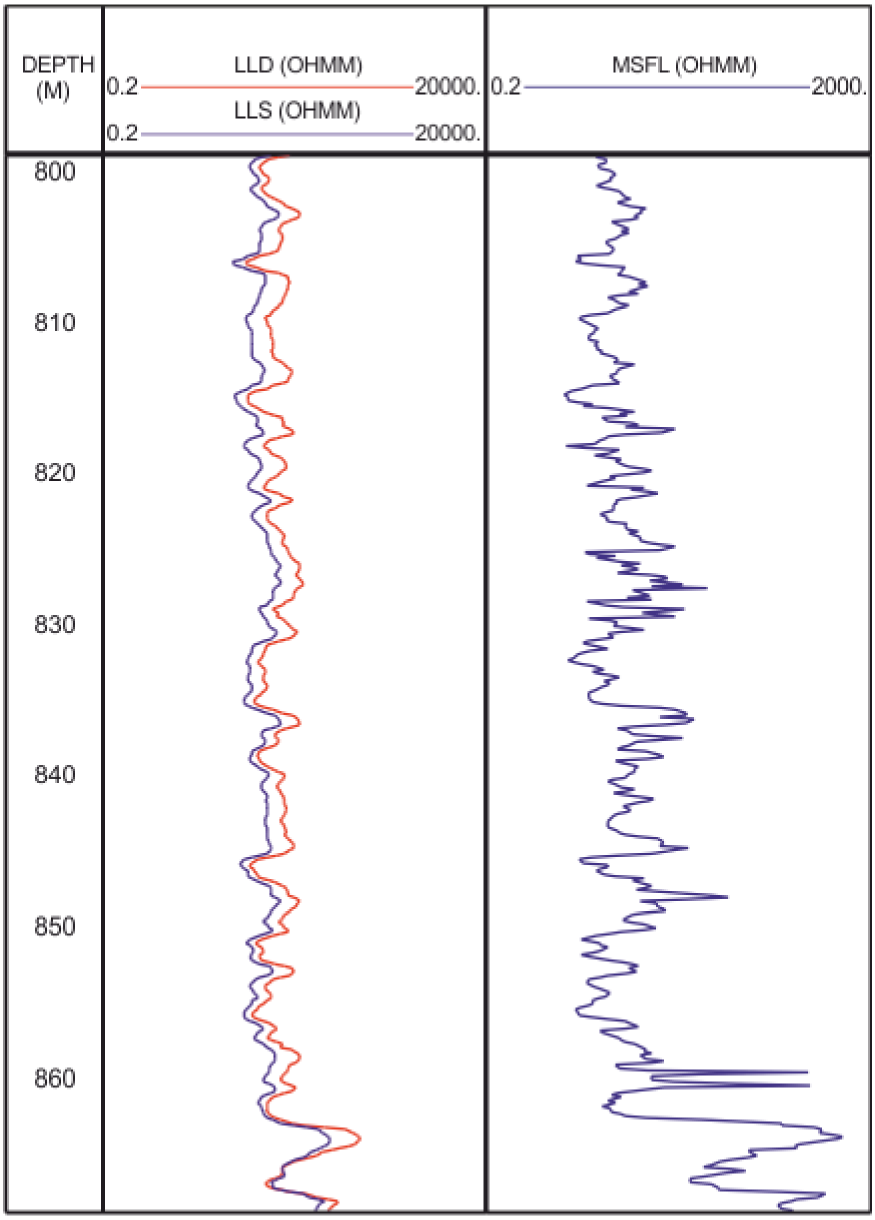

Fig.6: Resistivity logs of the penetrated intervals of the Sinjar Formation including deep resistivity LLD, shallow resistivity LLS and microspherical focused log MSFL

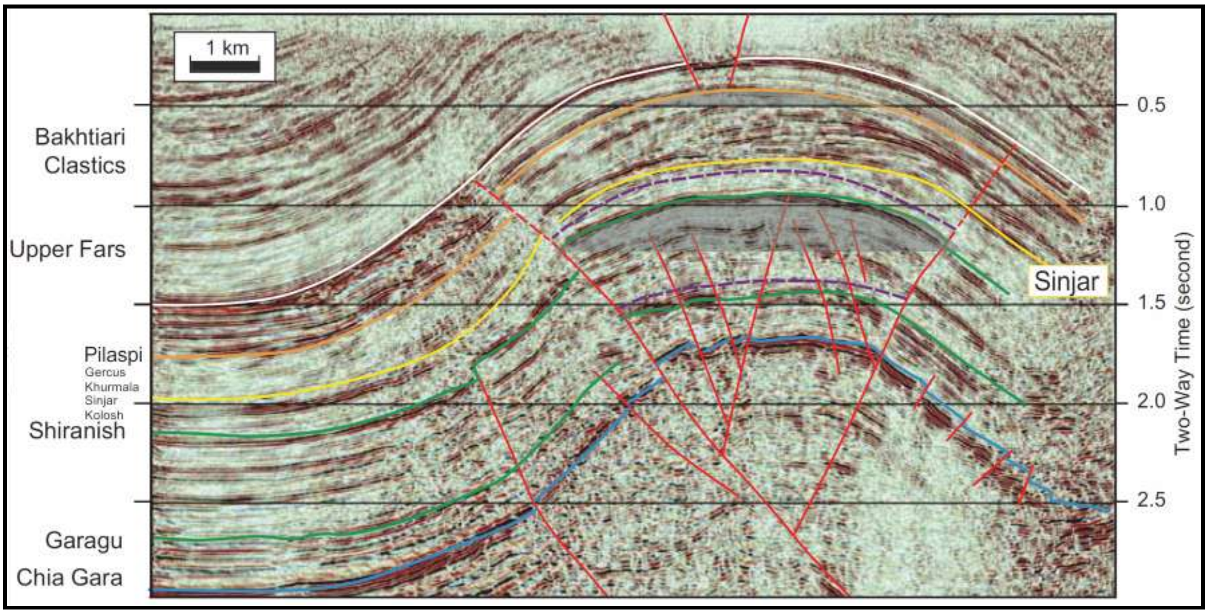

Fig.7: Seismic cross section across the Taq Taq oil field showing field structure and number of faults with stratigraphic succession (modified from Mackertich and Samarrai, 2015)

CONCLUSIONS

The reservoir potentiality of the Sinjar Formation, one of the several carbonate formations in the Taq Taq oil field is assessed from log data of three wells and the conclusions are summarized in the following points:

- The Sinjar Formation in the Taq Taq oil field consists of limestone in wells TT-04 and TT-06 with no interlayering of sandstone, whereas in well TT-05 the limestone is interbedded with sandstone at the lower part of the formation.
- The shale volume within the Sinjar Formation is high, being greater than 10% in the three wells; reaching 35% in well TT-04, 25% in well TT-05 and up to 45% in well TT-06. The high shale volume is one of the main reasons that destroyed the reservoir quality by decreasing the effective porosity.
- The bulk porosity, calculated from density log and neutron log, is 0.18 and 0.07, respectively, and the resulted curve, when compared to the sonic derived porosity, exhibits separation between them which suggests high secondary porosity of the Formation.
- The combined results from the wireline well logs, cutting samples, structural-seismic cross section indicate that the Sinjar Formation in the Taq Taq field cannot be recognized as a potential reservoir because of high clay content which has reduced the permeability magnitude.

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