PETROLEUM POTENTIALITY AND PETROPHYSICAL EVALUATION OF THE MIDDLE-JURASSIC SARGELU FORMATION, NORTHERN IRAQ

Research Project:

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DEDICATION

We Dedicate Our Research To:

Our great parents, who never stop giving of themselves in countless ways,

Our dearest supervisor, who leads us through the valley of darkness with light of hope and support,

Our beloved brothers and sisters: whom we cannot force our self to stop loving. And all our family, the symbol of love and giving,

Our excellent and very helpful friends who encourage and support us.
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ABSTRACT

This study indicates the source rock evaluation and reservoir properties of the Middle-Jurassic Sargelu Formation in section (well Atrush-3) northern Iraq. The Sargelu Formation in well Atrush-3 which is in the depth interval of 1261- 1301 (40m thick), Tectonically located in the High Folded Zone. which is located 85Km northwest of Erbil City. The subsurface layers of the Atrush block within the Zagros sedimentary basin is intensively folded and thrust. lithologically the formation consists of calcareous bituminous, black shale and limestone. In this study five core samples are analyzed from well Atrush-3 by Rock-Eval Pyrolysis that indicate for us TOC values in the Sargelu Formation ranged from 3.56-5.02 wt% in the well Atrush-3, Consequently, the quantity of organic matter in well Atrush-3 within the black shale of the Sargelu Formation is considered good to very good source material. Due to abundant residual hydrocarbon (S2) in the subsurface beds, the hydrogen index (HI) values surpassed 500 mg HC/g TOC (ranges 512-603). By contrast, values of the oxygen index (OI) is too low ranges from 3-138 mg CO₂/g TOC. The Formation is in the mature stage (oil window) and types of kerogen vary between Type II and II-III. The well log data display that the shale includes 30% of the upper part of the Sargelu Formation. This extraordinary ratio of shale content has negative impacts on the reservoir properties in this part of the formation. The lower part of the formation has a good porosity ratio that reaches 15% as calculated from the log data. The porosity is obtained from analyzed core samples support the same conclusion that obtained in the log data analysis and it is measured at 9-17.5% for interval 1282-1301 m in Atrush-3 well.
1. INTRODUCTION

The Middle-Late Jurassic Megasequence was deposited during a period of isolation of the main intra-shelf basin of Mesopotamia from the neo-Tethyan ocean probably due to renewed rifting along the NE margin of the Arabian plate. The basin was bounded to the W by the N-S trending Rutba uplift of W Iraq. Deposition within the basin occurred in a restricted, relatively deep water environment during middle Jurassic (Jassim and Goff, 2006). Middle Jurassic-Sargelu is the most significant formation in northern Iraq. The formation in well Atrush-3 discovered in depth interval 1261-1301 m between Alan and Barsarin formations, this study is the first collaborative identification of source and reservoir rocks for the formation together. The formation is the basinal representative of the widespread transgression of Middle Jurassic in Iraq. Sargelu was acknowledged and pronounced by Wetzel at Sirdash anticline in northern Iraq’s High Folded Zone (Bellen et al., 1959). The formation's lithological composition is rather uniform; typically it consists of calcareous bituminous and black shale and limestone (Buday, 1980). The thickness of the formation in the zone of outcrops at the High Folded, Imbricated and northern Thrust Zones varies from 20-125m (Jassim and Goff, 2006); the thickness in the current area is 40m in well Atrush-3. As in age-equivalent units throughout the Arabian Shield, the Sargelu Formation is comparable to parts of the Cudi Unit of SE Turkey (Altinli, 1966); in central Syria it is equivalent to the black shale of the uppermost portion of the Dolaa Group (Dubertret, 1966); in both Saudi and southwest Iran it is equivalent to Dhruma and the lower part of the Sarmeh formations respectively.

2. GEOLOGICAL SETTING

The Middle-Late Jurassic megasequence starts with the Muhaiwar Neritic Formation in the Rutba Subzone and the Sargelu Basinal Formation elsewhere in Iraq (Jassim and Goff, 2006). The study region is currently considered to be a significant hydrocarbon province. Indeed, the wide and box-shaped anticlines in the region are systems for hosting hydrocarbons. In such layers, the sealing ability of the corresponding thrusts must be carefully regarded. Several supplementary faults in the adjacent anticlines to the study area (in Atrush field) reveal trapping efficiency in the Triassic and Jurassic systems (Shamaran petroleum corporator, 2013). The selected section is located inside the Zagros belt which formed by subduction between two plates that are the Arabian and the Eurasian plates. The belt is located within the Arabian Plate's northeastern margin. In Atrush block, the well Atrush-3 which is located 85 Km northwest of Erbil city in the High Folded Zone has been selected. The subsurface layers of the Atrush block within the Zagros sedimentary basin is intensively folded and thrusted, “Figure 1”. The region is a narrow belt that encompasses areas of High Folded Zone north and northeast. It is folded and thrusted violently. Anticlines are broken into imbricates by thrusts and bypass synclines. The sedimentary
cover in the High Folded Zone typically consists of rock units of Paleozoic (1.5-5 Km thick), Triassic (1.5-2 Km thick), Jurassic (1.1 Km thick), Cretaceous (1.05-2 Km thick), Palaeogene (1-1.5 Km thick) and Neogene sediments which fill other synclines in the area with variable thickness (Jassim and Goff, 2006). In the middle of the anticlines the uncovered rocks are mostly Cretaceous, while Jurassic and Triassic rock units crop out in anticlines that are close to the Imbricated Zone.

![Location map for the northeast Arabian Platform in Iraq, which shows Zagros Thrust-Fold Belt, including studied section (Aqrawi et al., 2010)](image)

**Figure 1.** Location map for the northeast Arabian Platform in Iraq, which shows Zagros Thrust-Fold Belt, including studied section (Aqrawi et al., 2010)

### 3. AIM OF THE STUDY

The main aims of this study are determined petrophysical characteristic of the formation based on well log data and core samples, in addition to potentiality of Sargelu Formation to hydrocarbon generation.
4. DATA AND METHODS

4.1. Petrophysical evaluation

The most common types of well logs such as gamma ray, neutron porosity, bulk density and resistivity that are taken at depth intervals of 1261-1301 m in well Atrush-3 using interactive petrophysics (IP) software to identify the formation's most critical reservoir characteristics such as shale thickness, porosity and saturation. The gamma ray log (GR) is used to determine the volume of shale within the studied formation. The formation resistivity for its fluids and matrix (water and hydrocarbon) in the pores is true resistivity (Rt), which is typically gotten from deep resistivity log, however the resistivity of the flushing zone (Rxo) are measured by micro spherical focused logs (MSFL); both are used to estimate the type and amount of the liquids (HCs and water) between the pores. Basically the formation water resistivity (Rw), with Archie parameters such as cementation factor (m) and saturation exponent (n) are calculated from well log data via Pickett plot method, which is relationship between effective porosity and true resistivity.

The porosity (Φ) can be estimated from neutron (NPHI) and bulk density (RHOB). Finally water saturation (Sw) is calculated by Archie equation.

4.2. Rock-Eval Pyrolysis

Five core samples from well Atrush-3 are analyzed, using Rock-Eval pyrolysis-6 to obtain total organic carbon (TOC) and pyrolysis parameters (S1, S2, S3 and T_max). The analysis has been done at scientific research center (Soran University). The artificial temperature in the laboratory gives the crashed samples, beginning at 300 °C and increasing to 650 °C in about 3 and 25 minutes, and then the temperature rises to 850 °C to get (S3). The hydrogen index ((HI=100×S2/TOC, mg HC/g TOC) and the oxygen index (OI=100×S3/TOC, mg CO₂/g TOC) are expected when TOC is paired with S2 and S3; Free hydrocarbon (S1) as opposed to overall generative capacity (GP = S1+S2) to achieve production index (PI), all the results are “shown in Table 1”.

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5. RESULTS AND DISCUSSION

5.1 Well log data analysis

Gamma ray log is the most common log used for measuring the volume of shale in the formations. Low reading means low shale content while the reading is high when more shale volume detect. To notify the volume of shale within the Sargelu Formation (Middle Jurassic) Larionov old rock was used. For this purpose gamma ray index determined through the equation (1) then the findings used directly in equation (2). Regarding to, the planned formation is separated into two zones; the average volume of shale in the upper part is 30% whereas this value decrease to 10% for the lower most part of the formation. Shale volume content in any formation more than 20% cannot be considered as a good reservoir for accumulating hydrocarbons (Asquith and Krygowski, 2004).

\[
IGR = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}
\]

……………….. (1)

\[
Vsh = 0.33(2^{2+GR1} - 1)
\]

……………….. (2)

After determine the volume of shale in the formation the relationship between neutron porosity and bulk density has been used to assess the lithology and measure the formations porosity (Darwin and Julian, 2007); according to the crossplot the selected formation in well Atrush-3 consists mainly of limestone with some beds of dolomitic limestone “Figure 2”. On the cited crossplot, the porosity ratios for the lower part of the formation started from 1.7-18%, while it has 0.01-8.9% porosity in the rest parts. Regarding to, the results (based on laboratory and well log tests), only the lower most part of the formation in well Atrush-3 has sufficient porosity and permeability for moving and occupying hydrocarbons. To estimate the saturation of the Sargelu Formation in borehole section, firstly, pickett plot approach used (plotting deep resistivity versus effective porosity, both on logarithmic scales) to calculate water resistivity (Rw), besides Rw Archie’s parameters which are (m) cementation exponent, (a) tortuosity component and (n) saturation exponent were determined which values are a=1, m=1.99 and n=2. The red line going between points that have the lowest deep resistivity and the maximum values of porosity reflect the water area where water concentration is equal to one “Figure 3”. Secondly, the saturations of the formation (Sw, Shc) has been detected; the saturation of the rock fluid reservoir is discussed to as the quantity of pore space occupied with a given fluid, and the total of all pore space fluids is equal to one hundred percent (Dresser, 1975). Water Saturation (Sw) is the sum of pore volume in a rock that has been filled with water since its formation. Water saturation shall be represented as a proportion or decimal fraction (Asquith and
Krygowski, 2004). Archie’s (1942) principle is used to estimate the $S_w$ of the uninvaded zone through equation (3), then the hydrocarbon saturation deduced from water saturation by equation (4)

$$S_w = \left( \frac{a}{\Phi_m} \cdot \frac{R_w}{R_t} \right)^{\frac{1}{n}}$$

............... (3)

$$Shc = 1 - Sw$$

............... (4)

According to, only the lower part of the formation was saturated and it paid 2.75 m from the total 40 m thick. There are two different types of hydrocarbons such as mobile and residual, mobile hydrocarbon signified with a yellow color on computer processing interpretation while residual hydrocarbon with a green color “as shown in Figure4”, the limestone beds include both residual and mobile hydrocarbon.

![Figure 2. Neutron-density cross plot for the Sargelu Formation in well Atrush-3](image-url)
Figure 3. True formation resistivity versus effective porosity used to calculate formation water resistivity ($R_w$) in well Atrush-3
A petroleum source rock is defined as any rock that has the capability to generate and expel enough hydrocarbons to form an accumulation of oil and gas (Hunt, 1996). Typical source rocks, frequently shales or limestones, contain roughly 1% organic matter and as a minimum 0.5% total organic carbon (TOC), while a rich source rock might have as much as 10% organic matter. Rocks of marine source are inclined to be oil-prone, while terrestrial source rocks in more circumstance produce gas. Protection of organic matter starved of degradation is critical to making a good source rock, and essential for a comprehensive petroleum system (Tissot and Walte, 1984). One of the dominant purposes of organic geochemistry is to classify organic matter from sedimentary rocks. Nowadays, pyrolysis method is commonly used to provide data on the maturity and form of source rocks in different sedimentary basins. The volume of organic matter within the sedimentary rocks as determined by the total organic
carbon (TOC wt%) which is the main quantitative metric to be used when assessing a stratigraphic unit's capacity for petroleum generation (Nunez and Baceta, 1994). Peters (1986) and Leckie et al., (1988) testified that the total organic carbon (TOC) values between 0.5-1.0 wt% specify a decent source of generative potential for rock, and ranging between 1-2 wt% represent strong generative potential, whereas TOC values above 2 wt% indicate very good potentiality. TOC values in the Sargelu Formation ranged from 3.56-5.02 wt% in the well Atrush-3, “Table 1”. Consequently, the quantity of organic matter in well Atrush-3 within the black shale of the Sargelu Formation is good to very good source material “Figure 5”. Due to abundant residual hydrocarbon (S2) in the subsurface beds, the hydrogen index (HI) values surpassed 500 mg HC/g TOC (ranges 512-603). By contrast, values of the oxygen index (OI) is too low ranges from 3-138 mg CO\textsubscript{2}/g TOC. The Formation is in the mature stage (oil window) and types of kerogen vary between Type II and II-III “Figure 6”. The same results have been appealed by Al-Ahmed (2006); Abdula (2015) and Al-Atroshi et al., (2020).

Figure 5. The TOC versus S2 showing type of kerogen for the Sargelu Formation in the studied section
Figure 6. The HI versus $T_{\text{max}}$ showing maturation level in the studied formation
Table 1. Pyrolysis results of the Sargelu Formation in well AT-3

| Formation | Section | Depth (m) | TOC wt% | S1 mg/g | S2 mg/g | S3 | HI | OI | Tmax °C | PI | Ro% |
|-----------|---------|-----------|---------|---------|---------|----|----|----|--------|----|-----|
| Sargelu   | AT-3    | 1262      | 4.07    | 4.9     | 23.99   | 0.35 | 589 | 9  | 443    | 0.17 | 0.66 |
|           |         | 1269      | 4.14    | 3.88    | 22.85   | 0.41 | 552 | 10 | 444    | 0.15 | 0.71 |
|           |         | 1276      | 5.02    | 4.2     | 26.48   | 0.14 | 527 | 3  | 443    | 0.14 | 0.68 |
|           |         | 1279      | 4.99    | 3.1     | 25.56   | 0.31 | 512 | 6  | 441    | 0.11 | 0.72 |
|           |         | 1285      | 3.56    | 3.99    | 21.48   | 0.55 | 603 | 15 | 440    | 0.16 | 0.69 |

Vitrinite reflectance is the most common method. The term (Ro%) relates to the amount of incident light reflected back from the vitrain surface via the microscope. Waples (1988) assumed that the vitrinite reflectance of 0.6% signified the early stage of oil generation, whereas the peak of oil generation was 0.8% and the late stage of oil generation was 1.35 Ro%. The value of the vitrinite reflectance in the studied core samples varies from 0.66-0.72% in well Atrush-3 “Table 1” which indicates for mature and peak oil window, “Figure 7”. Indicating advanced stage and the formation's ability to generate oil in an appropriate situation.
CONCLUSION

The Sargelu Formation in the areas under study (Well Atrush-3) includes both source and reservoir rocks. Based on the geochemical test, the formation has very good potentials to generate enough hydrocarbons (oil and gas). Additionally, the black shales between the limestone beds can be considered as a good source for hydrocarbons’ generation because these shales are rich in organic matter and have reached the level of maturation zone. The limestone units in the subsurface section have adequate porosity and permeability and can sufficiently accommodate mobile hydrocarbons.
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