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HYDROCARBON GENERATION POTENTIAL AND PALYNOLOGICAL STUDY OF THE EARLY JURASSIC SUCCESSION (ALAN, MUS, AND ADAIYAH FORMATIONS) IN WELL MIRAN-2, SULAIMANIYAH, KURDISTAN REGION, IRAQ

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ABSTRACT

The Early Jurassic sediments from Alan, Mus and Adaiyah formations have been studied in oil exploratory well M-2, Miran Oil field, Sulaimaniyah Governorate, Kurdistan Region, Iraq. Three techniques were used for determining hydrocarbon generation potentiality for these rock units; Rock-Eval Pyrolysis, microscopic study, and Infrared spectrometry. The Alan Formation has high TOC wt.% content, ranging between 1.47 and 1.82 (average 1.63), and Mus Formation with 0.85 and 1.75 (average 1.3), while the Adaiyah Formation samples are totally with low TOC wt.% ranging between 0.08 and 0.47 (average 0.30). Although the Rock-Eval Pyrolysis data show good genetic potential of the Alan and Mus formations, the potentiality of dry gas generation is only the chance for generating hydrocarbons if the organic matter reaches the mature stage. Also the Rock-Eval data reveal the type of kerogen is mostly type III and IV and the organic matters are still in immature stage except one sample from Adaiyah Formation. The organic matter within these sediments is amorphous and there are neither palynomorphs nor phytoclasts. These organic matters also are very small and have no fluorescence, which mostly of gas-prone type with no possibility for oil generating. Five kerogen samples were selected and analyzed by Infrared Spectrometer. The results from these samples show small variation outcomes with Rock-Eval data as the kerogen type of Alan and Mus formations are mostly type II, while samples of Adaiyah Formation are type IV kerogen, as determined by Rock-Eval pyrolysis. However the Infrared spectrometers also show vitrinite reflectance around 0.3% and less ($Ro \leq 0.3\%$) hence immature sediments, this result is coincides with the data of Rock-Eval pyrolysis. The results of all mentioned techniques were not exactly the same, and show some discrepancies, but mostly indicating to no potentiality for generating any oil and may be some gas generated from Alan and Mus formations. The Adaiyah Formation is inert and has no potentiality for generating any hydrocarbons in this well.

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دراسة بالينولوجية وقدرة انتاجية الهايدروكاربونات لتتابع الجوراسيك المبكر (تكاوين علان وموس وعداية) في بئر ميران-2، السليمانية، أقليم كوردستان، العراق

أبراهيم محمد جزا محي الدين

المستخلص

ترسبات الجوراسيك المبكر من تكاوين علان وموس وعداية تمت دراستها في بئر ميران-2 في حقل ميران النفطي في محافظة السليمانية، إقليم كردستان العراق. تم استخدام ثلاث تقنيات مختلفة من أجل تحديد قدرة إنتاجية للهايدروكاربونات لهذه الوحدات الصخارية. هذه التقنيات هي: الانحلال الحرارى (Rock-Eval Pyrolysis) لصخر المصدر والدراسة المجهرية للحفريات النباتية الدقيقة ودراسة طيف الأشعة تحت الحمراء. النسبة المئوية لإجمالي الكاربون العضوى في تكوين علان تراوحت بين 1.47 و 1.82% (بمعدل 1.63%)، وفي تكوين موس تراوحت بين 0.85 و 1.75% (بمعدل 1.3%) أما في تكوين عداية فكانت النسبة قليلة جدا حيث تراوحت بين 0.08 و 0.47% (بمعدل 0.3). أظهرت نتائج الانحلال الحرارى لصخر المصدر بأن تكوينى علان وموس لهما قدرة إنتاجية جيدة ولكن فقط للغاز الجاف إذا وصلت المواد العضوية لمرحلة النضوج. كذلك نتائج الإنحلال الحرارى لصخر المصدر بينت بأن نوع الكيروجين معضمه من النوع الثالث والرابع والترسبات لاتزال غير ناضجة ماعدا نموذج واحد من تكوين عداية. الدراسة المجهرية أظهرت بأن المواد العضوية فى هذه الترسبات هى عديمة الشكل والأوجه ولم يلاحظ أي تواجد للبالينولات (أحافير نباتية دقيقة) ولا للفايتوكلاست. هذه المواد العضوية صغيرة الحجم ولايوجد فيها فلوريسنس مما يؤكد قدرة إنتاج الغاز وعدم إمكانية إنتاج النفط.

تم أختيار خمسة نماذج للتحليل بواسطة طيف الأشعة تحت الحمراء، وقد أظهرت النتائج لتكوينى علان وموس بأن الكيروجين هو من النوع الثانى وفي تكوين عداية هو من النوع الرابع مطابقا لما تم تحديده بواسطة نتائج الانحلال الحراري لصخر المصدر. تم تحديد درجة النضوجية بواسطة نتائج طيف الأشعة تحت الحمراء وتبين ان إنعكاسية الفيترينايت هي 0.3% والتي تدل على عدم نضوج هذه الترسبات وهي متطابقة مع نتائج الانحلال الحرارى لصخر المصدر.

نتائج التقنيات الثلاثة المستخدمة في هذه الدراسة لم تكن متطابقة ولكن بشكل عام تؤشر الى عدم قدرة إنتاجية النفط لتكوينى علان وموس أما بالنسبة لتكوين عداية فليس له القدرة على إنتاج أي نوع من الهايدروكاربونات في هذا البئر.

INTRODUCTION

The new explorations and drilling processes during the last decade in Kurdistan Region, Iraq has been done by many international oil companies under supervision of Natural Resources Ministry of Kurdistan Government. A huge amount of data and rock samples have been collected from the studied areas and preserved in stores of the Ministry in Erbil. One of these new oil and gas fields in Sulaimaniyah Region is Miran Oil Field, within Miran Block. Miran Block situates in the High Folded Zone of Iraq, and occupies about 70 Km length and 15 Km width, elongated in the Northwest-Southeast direction (Al-Hakari, 2011; Fatah, 2014). The Miran oil field is an Iraqi natural gas field that was discovered in 2011 by Heritage Oil Company.

Field mapping and seismic data indicate the presence of a large anticlinorium in this block, formed by two sub-parallel anticlines known as Miran East and Miran West (Heritage report, 2012). Tasluja Ridge with the NNW – SSE trending is separating the two anticlines, which has a noticeable topographic expression down to the center of the block. The Miran structure was formed by Middle Tertiary compression, which was terminated during late stage of thrusting in the Late Miocene (Al-Hakari, 2011; Heritage report, 2012; Fatah, 2014).

This field is locating about 30 Km NW of Sulaimaniyah city, and geologically as mentioned, it is within High Folded Zone of Iraq (Fig.1). One of the wells in the field is

Miran-2 well (M-2), from which the studied samples were taken. The coordinates of M-2 are: 45° 03' 13.695" E and 35° 40' 19.177" N.

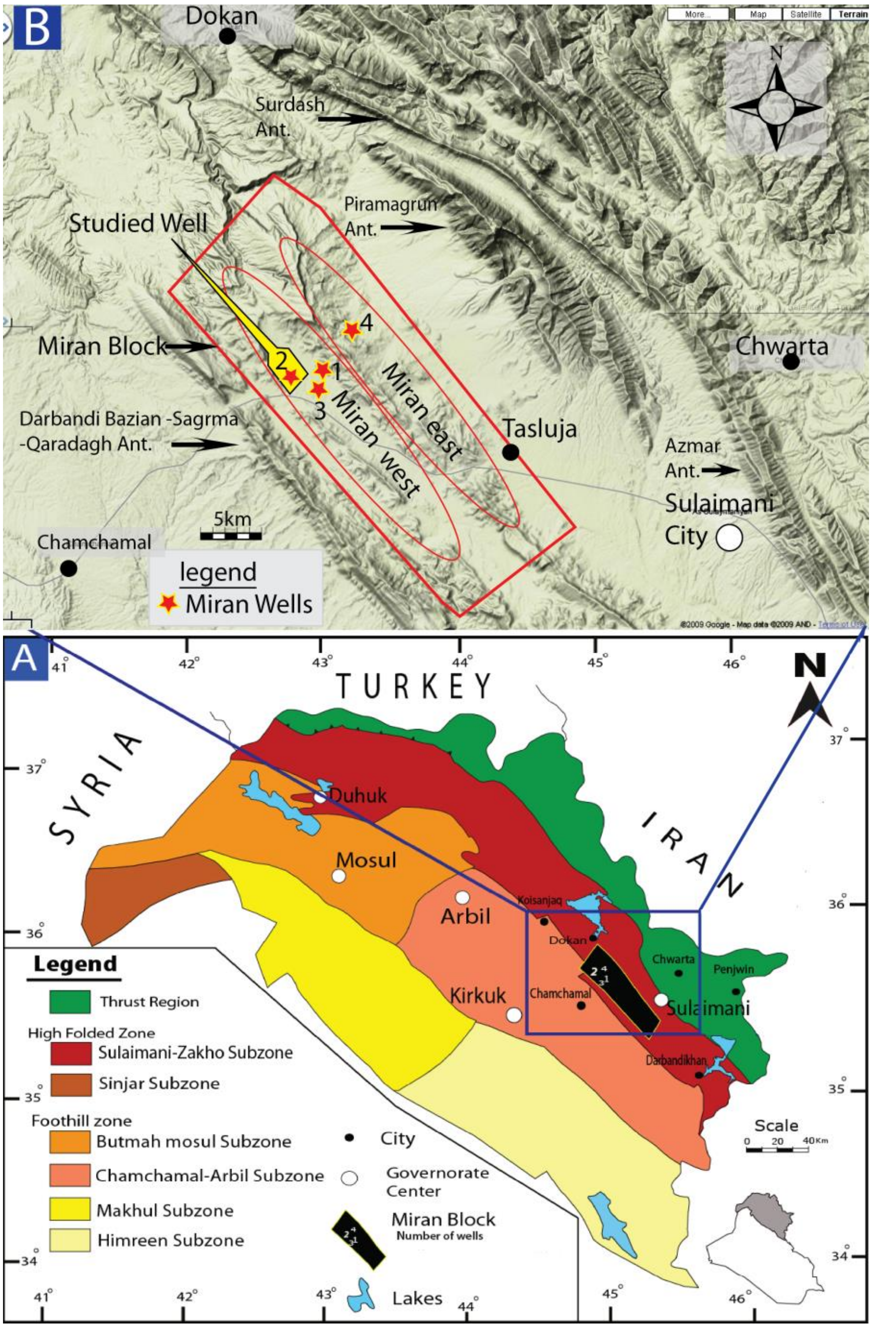


Fig.1: Location map; (**A**) Miran Oil Field within High Folded Zone in Kurdistan region, Iraq and (**B**) location of well M-2 in the studied field (modified from Al-Hakari, 2011; Fatah and Mohialdeen, 2016)

The Chia Gara Formation within this well was studied from the genetic potentiality for hydrocarbons and organic petrology by Stavros *et al*. (in press-2017). They concluded that the Chia Gara sediments in this well is containing total organic carbon (TOC) more than 7 wt.% in the richest sample. Also the content of total organic matter (TOM) approaches the 16 wt.%. The values of vitrinite reflectance are around 1.0% – 1.1% and the values of bitumen reflectance (solid residual structures of oil in the source rock) are around 0.7 wt.% (ibid). The Naokelekan and Barsarin formations in the same well have been studied from the organic geochemical point of view by Mohialdeen *et al*. (2017-in press). The biomarker studies indicated the presence of small amount of gas potentiality and the organic matter mostly mature, peak oil window (ibid).

The main purpose of this study is to evaluate the Early Jurassic succession (Alan, Mus and Adaiyah formations) in well M-2 from Miran Oil Field, for hydrocarbon potentiality, as well as to study the organic matter within the studied samples, in order to determine the type of prevailed organic matter and the maturity of organic matter.

GEOLOGICAL SETTING

As mentioned in the previous section the Miran Block is located within the High Folded Zone of Iraq. This zone characterized by many rugged anticlines and broad synclines. One of these large structures is Miran, which is composed of two anticlines (Fig.1). The studied well is locating within Miran West anticline. The drilled succession reaches to depth 3544m, and the Early Jurassic formations are within interval 2480 to 2650 m. The Middle Jurassic unit is Sargelu Formation which overlain the Alan Formation conformably. Sharland *et al*. (2001) stated that sea level rise occurred during Middle Jurassic time, and probably reached to the maximum flooding surface (MFS). This phenomenon was lead to the development of deep water and then the *Bositra*-bearing shale of lower part of Sargelu Formation was precipitated (Abdula *et al*., 2015). The lower boundary of Adaiyah Formation is with Butmah Formation (Heritage Report, 2012) (Fig.2). The Early Jurassic succession in well M-2 is characterized by evaporitic-rich sediments with brown to black claystone and several limestone beds.

The equivalents of Early Jurassic Butmah, Adaiyah, Mus, and Alan formations in Kurdistan region are Sarki and Sehkanian (Mustafa, 2009; Al-Hakari, 2011; Al-Qayim *et al*., 2016). This well (M-2) is close to the boundary between the Low Folded Zone and the High Folded zone, hence the Early Jurassic sequence characterized by evaporate-rich layers, which are not present in outcrops of Sarki and Sehkanian formations.

Dunnington (1958) explained the lithologic characteristics of Lower Jurassic rocks, which comprises mainly of upper dolomitic limestone and alteration between limestone, shale and anhydrite beds in the lower part. He also believed that the thicknesses of Liassic formations are much thicker at the subsurface sections than the outcrops and their organic contents are very low. Bellen *et al*. (1959) described the depositional conditions of the Lower Jurassic formations, they concluded that all Lower Jurassic formations except Mus Formation were deposited in Sabkha environments and dominated by lagoonal evaporitic facies, whereas Mus Formation was deposited under normal marine condition and comprised carbonate sediments. Al-Habba (1988, in Sadooni, 1997) described Lower Jurassic sequence (Alan and Mus formations) in Kand-1 well and indicated that, although they are thermally mature, but have a low potentiality for generating hydrocarbons. Samarrai (1988, in Sadooni, 1997) stated that the Liassic sequence (Alan and Mus formations) was the sources of the condensate that produced from the Samawa-1 well in south of Iraq.

Jassim and Al-Gailani (2006) stated that Liassic sequence (Alan-Mus-Adaiyah and Butmah formations) have some reservoir characteristics due to presence of oil shows in the fractured part of the carbonate and anhydrites in northern Iraq. Mustafa (2009) used Rock-Eval pyrolysis to evaluate the organic contents and hydrocarbon potentialities of Liassic formations. He summarized that Mus Formation contain kerogen type II and II/III, Alan and

Adaiyah formations included type II kerogen (Oil prone). The ranges of hydrocarbon potentialities of Alan, Mus and Adaiyah formations are fair to good, good to very good and poor to fair, respectively (ibid). The reservoir characteristic of Butmah Formation that was stated by Jassim and Al-Gailani (2006) was also confirmed by Aqrawi *et al*. (2010). Moreover they recognized Adaiyah Formation to seal rock as well.

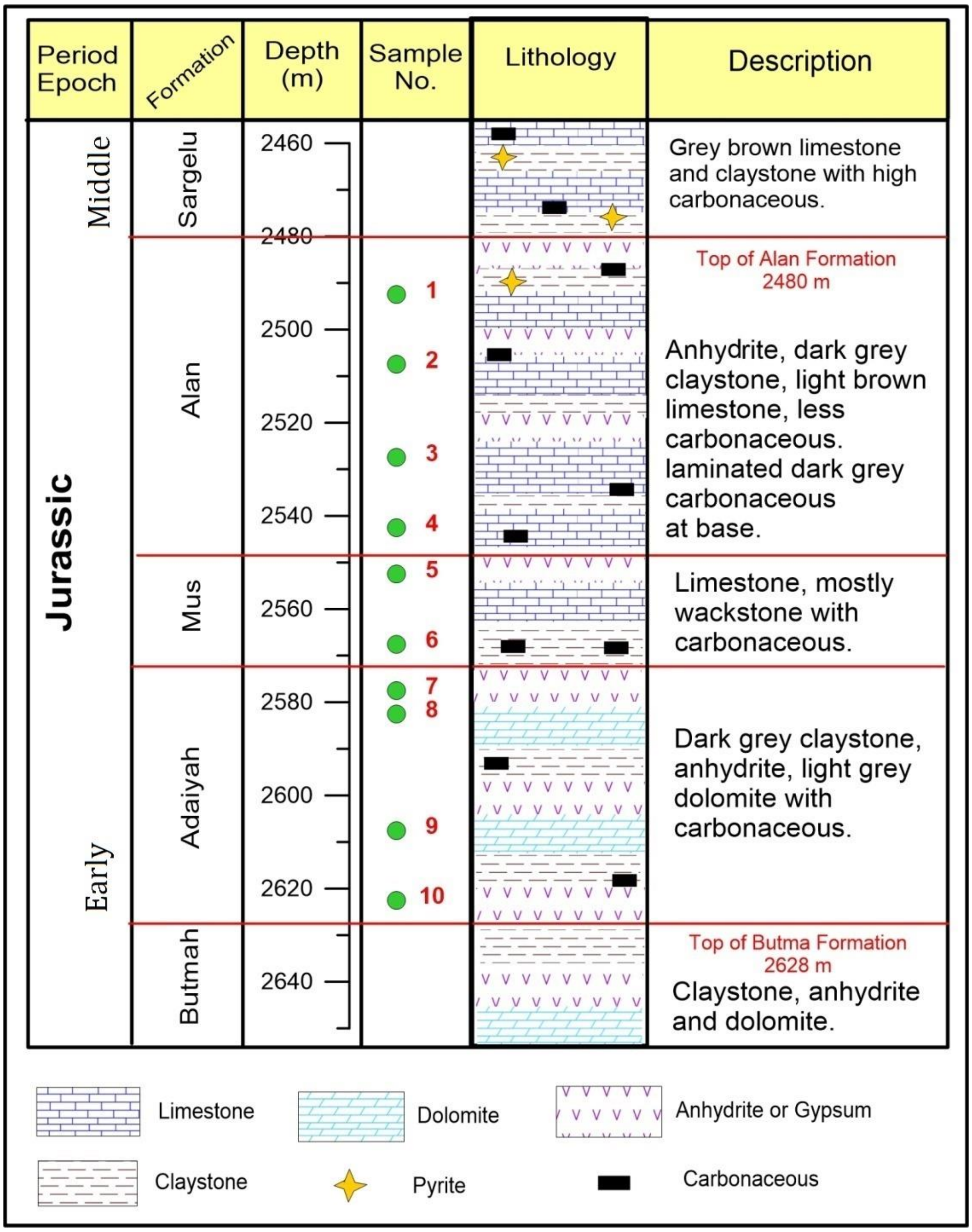


Fig.2: General stratigraphic column for the interval of Early Jurassic succession in well M-2, Miran Oil Field, Sulaimaniyah and the location of studied samples (modified from Master log of the well)

Buday (1980) subdivided the stratigraphic units of Iraq into cycles in accordance with the main stages of the paleogeographic development of the areas. Early – Middle Jurassic sub stage belonged to the Late Triassic – Middle Jurassic cycle. The paleogeographic and paleofacies development during the Early-Middle Jurassic Period starts with a sea transgression over the Stable Shelf. During Early Jurassic (Liassic) period the whole basins were filled by evaporitic facies with decreasing evaporate contribution to the northeast direction.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT

▪ Adaiyah Formation

Dunnington (1953) described Adaiyah Formation for the first time in well Adaiyah no. 1in the north of Foothill Zone, west of Mosul City (Buday, 1980). The total thickness is 90m that consists mainly of nodular anhydrites with limestone and shales (Aqrawi *et al*., 2010). The maximum thickness of the formation was in the wells Sufaya-2A and Kifl-1 according to Jassim *et al*. (2006). The thickness of Adaiyah Formation in Sangaw North-1 (SN-1) well is 136 m which is coincide with concept that the thickness of the formation increases from west and northwest Iraq towards the Mesopotamian basin and Foothill zones (Saeed, 2014). Fossil assemblages within Adaiyah Formation is scarce and not sufficient to measure the exact age, hence the age have been defined based on the regional correlation and estimated to be deposited in Late Liassic (Bellen *et al*., 1959).

The upper contact is with Mus Formation, while the lower contact is with Butmah Formation, and both are gradational and conformable according to Buday (1980). In Iraqi Kurdistan region, the Adaiyah Formation has been replaced by Sehkaniyan Formation due to lateral facies change (Jassim *et al*., 2006; Mustafa, 2009). Adaiyah Formation is dominated by anhydrite sediments unit with pure lagoonal facies and was deposited under sabkha environment (Jassim and Buday, 2006). Abdula (2016) studied one sample of Adaiyah Formation in well Zab-1, and he concluded that the formation is immature.

▪ Mus Formation

The Mus Formation was defined for the first time in well Butmah-2 by Dunnington (1953 in Bellen *et al*., 1959). Well Butmah-2 is situated on the Foothill Zone of Unstable Shelf north of Iraq (Jassim and Buday, 2006). It is comprises 50m of thick limestone beds. Lithologically Mus Formation dominated by dolomitic peloidal limestone with marly limestone, shale and subordinate anhydrite and its relatively uniform throughout the area that exists (Aqrawi *et al*., 2010). The total thickness of Mus Formation in SN-1 well is 42 m (Saeed, 2014). The age of the formation according to relatively abundant fauna, is considered as a Late Liassic (Jassim *et al.*, 2006). Both contacts of Mus Formation, with overlying Alan Formation and underlying Adaiyah Formation are appeared to be gradational and conformable (Jassim and Buday, 2006). Mus Formation deposited in normal marine environment (Alsharhan *et al*., 2003), which is an indicator of short period of freshening cycle between two intervals dominated evaporitic lagoons environment (i.e Alan Formation above and Adaiyah Formation below). One sample of Mus Formation in well Zab-1 was studied by Abdula (2016). He considered the formation as poor source rock and immature.

▪ Alan Formation

Alan Formation was first described by Dunnington (1953) in well Alan-1 which is locating in the north of Mosul, and the total thickness was 87 m (Jassim *et al*., 2006). Alan Formation is composed of anhydrites with subordinate pseudo-oolitic limestone (Buday, 1980). The fossil assemblages are absent, However, the age of the formation was estimated based on its position in the stratigraphic column, which is located between Middle Jurassic Sargelu Formation and the Liassic Mus Formation, assumed to be a Liassic age.

The total thickness of Alan Formation in SN-1 based on the master log of the well is 141 m (Saeed, 2014). Both contacts of the formation are conformable and gradational with overlying Sargelu Formation and underlying Mus Formation (Jassim *et al*., 2006). In the north and northeast Iraq, top of Alan Formation corresponds with the top of the Sehkaniyan Formation (Bellen *et al.*, 1959). Alan Formation considered as a unique output of an evaporitic phase of deposition at the end of Liassic cycle and was deposited in basin-centered sabkha environment (Jassim *et al*., 2006).

SAMPLES AND METHODS

A total of ten cutting samples were obtained from the Geological Survey Storage in Erbil, Natural Resources Ministry of Kurdistan Region. The samples are belonging to Early Jurassic rock units (Alan, Mus and Adaiyah formations). The samples cleaned from impurities and washed by distilled water to remove dirts. The washed samples were kept in the oven for 24 hours to dry at temperature of 40 °C. Then crushed and grinded to be homogeneous powder for analyzing by Rock-Eval 6. The Rock-Eval instrument is present at Kurdistan Institution for Strategic Studies and Scientific Research, Sulaimaniyah, Kurdistan. The pyrolysis was performed with about 100 mg of crushed samples, which were heated to 600 °C in a helium atmosphere. The oven was hold at 300 °C for 3 min. and then increased at a rate of 25 °C/min. Several parameters such as TOC, S1, S2, S3 and the temperature of maximum pyrolysis yield (T_{max}) were measured (Table 1). This analysis was used to assess the petroleum generative potential and thermal maturity of the organic matter in studied formations.

The preparation of visual kerogen slides (strewn slides) have been done at the Department of Geology, University of Sulaimaniyah, based on Mahdi’s (2015) method. The crushed samples are placed in flasks to which HCl (10%) is added. Then concentrated HCl (37%) is added. After pouring off the acid, distilled water added, and it stands overnight. Then HF acid (52%) is added to the flask. Then the acid poured off and distilled water added and stands overnight. Samples were then washed several times with distilled water until being neutral. The residues are sieved with 10 μm nylon meshes, mounted by cellusize on cover slip and sticker on the slide by a small amount of mounting medium (Canada balsam). The prepared slides studied under transmitted, reflected, and fluorescence light using Leica CTR 6000 microscope (Kurdistan Institution for Strategic Studies and Scientific Research, Sulaimaniyah).

The concentrated kerogens of selected samples were analyzed by Infrared instrument (IR) at Department of Chemistry, University of Sulaimaniyah. The pellets made through mixing with Potassium Bromide (KBr) and pressed under 20Kb pressure. The IR Spectra were recorded on a Perkin-Elmer FT/IR spectrometer using KBr pellets ($v$max in cm^{-1}). The intensity of important peaks at wave numbers such 1630 cm^{-1}, 1710^{-1}, 2860^{-1}, and 2930^{-1} have been measured.

RESULTS AND DISCUSSION

- **Total Organic Carbon (TOC)**

Total organic carbon (TOC wt.%) content and pyrolysis data are shown in table 1 and were used to identify the source generative potential, kerogen type and thermal maturity of organic matter in the Early Jurassic sediments. The TOC, and hydrocarbon yield (S2) generated during pyrolysis were used to determine the amount of organic matter and to evaluate the generative potential (Peters, 1986).

The Alan Formation has high TOC wt.% content, ranging between 1.47 and 1.82 (average 1.63%), and Mus Formation with 0.85 and 1.75% (average 1.3), while the Adaiyah Formation samples are totally with low TOC wt.% ranging between 0.08 and 0.47% (average 0.30%) (Table 1). According to table 2 the TOC wt.% values of Adaiyah Formation are below 0.5%, hence the main parameters such as T_{max}, Hydrogen Index (HI), and Oxygen Index (OI) could not be used in interpretation.

- **Rock-Eval data**

The results of TOC% and other parameters such as S1, S2, S3, and T_{max} are given in table 1.The Rock-Eval data were filtered using different screening parameters (Table 2) to remove non-source samples, and to remove samples that may have been contaminated with bitumen or drilling fluids (Peters and Cassa, 1994; Hunt, 1996; English *et al.*, 2015). The shaded values in Table 1, are rejected according to conditions in Table 2.

Table 1: The bulk geochemical results of Rock-Eval pyrolysis and the calculated parameters data for the Early Jurassic rocks, M-2 well, Miran Oil field, Kurdistan Region, Iraq

Age	Fm.	Sample ID.	Average depth (m)	S1 - (mg/g)	S2 - (mg/g)	S3 - (mg/g)	PI	T_{max} (°C)	HI	OI	TOC (wt.%)	GP (S1+S2)
Early Jurassic	Alan	S.N0.1	2492.5	0.50	0.9	2.06	0.36	350	56	126	1.63	1.41
	Alan	S.N0.2	2507.5	0.32	0.8	2.87	0.29	344	53	195	1.47	1.1
	Alan	S.N0.3	2527.5	0.19	0.2	2.67	0.44	388	13	147	1.82	0.43
	Alan	S.N0.4	2542.5	0.22	0.5	2.16	0.31	303	31	136	1.59	0.72
	Mus	S.N0.5	2552.5	0.12	0.2	2.56	0.44	383	9	146	1.75	0.27
	Mus	S.N0.6	2567.5	0.18	0.4	2.58	0.29	371	51	304	0.85	0.61
	Adaiyah	S.N0.7	2577.5	0.13	0.4	1.03	0.24	425	137	343	0.3	0.54
	Adaiyah	S.N0.8	2582.5	0.15	0.7	0.92	0.18	395	183	256	0.36	0.81
	Adaiyah	S.N0.9	2607.5	0.19	0.8	1.65	0.19	297	168	351	0.47	0.98
	Adaiyah	S.N0.10	2622.5	0.01	0.04	0.26	0.15	495	50	325	0.08	0.05

Table 2: Main Rock-Eval screening parameters
(after Peters and Cassa, 1994; Hunt, 1996; and English *et al.*, 2015)

Condition	Action	Definitions
S2 < 0.5	Reject Tmax	S1: Volatile hydrocarbon (HC) content, mg HC/g rock
Tmax < 395	Reject Tmax	S2: Remaining HC generative potential, mg HC/g rock
S2 < 0.2	Reject PI	S3: Carbon dioxide yield, mg CO_2/g rock
OI > 300	Reject OI	HI: Hydrogen Index, S2 x 100/TOC, mg HC/g
TOC < 0.5	Reject Tmax, HI, and OI	OI: Oxygen Index, S3 x 100/TOC, mg CO_2/g TOC
S1/TOC > 1.5	Reject pyrolysis data	Tmax: Temperature at maximum of S_2 peak
GP < 2	Reject PI	PI: Production Index, S1/(S1 + S2)
Tmax < 435; PI > 0.2	Reject Tmax	TOC: Total Organic Carbon, wt%

The relationship between TOC wt.% content and S2 (Fig.3) as well as TOC wt.% with Genetic Potential (GP) (Fig.4) clearly indicating to poor organic carbon in Adaiyah Formation and poor hydrocarbon potentiality. The Mus Formation is within fair to good TOC wt.%, but with poor genetic potentiality too. Although Alan Formation has a good TOC% content, the hydrocarbon genetic potentiality is also poor.

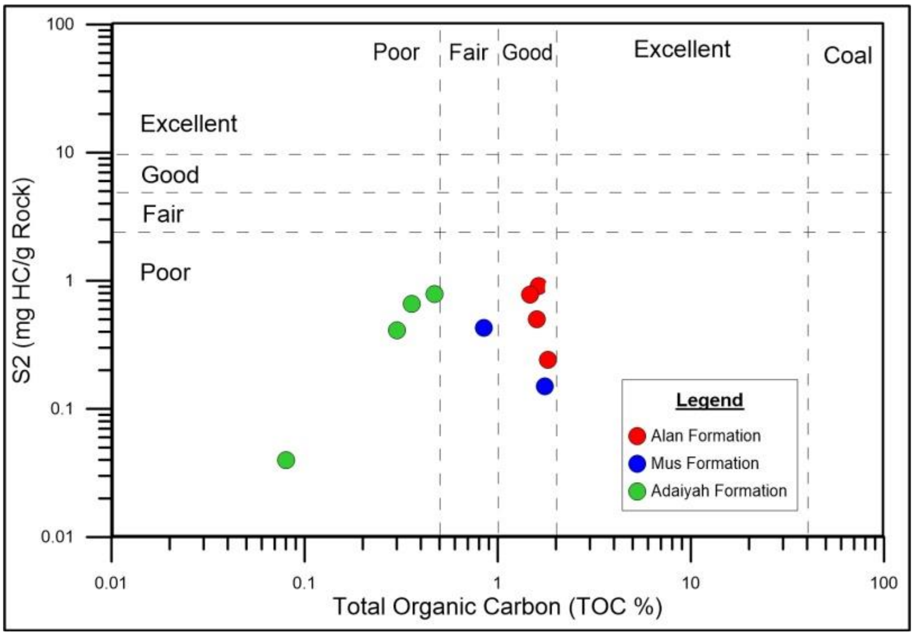


Fig.3: The relationship between TOC wt.% and S2 of the studied samples from Early Jurassic rocks in well M-2, Miran Oil Field, Sulaimaniyah, Kurdistan region, Iraq

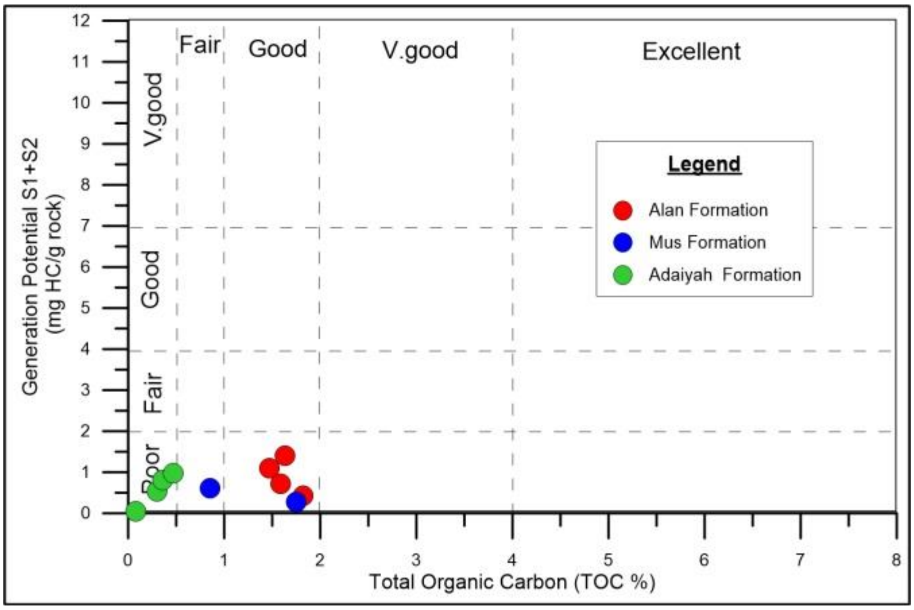


Fig.4: The TOC wt.% and Genetic Potential (GP) cross plot for the studied samples of Early Jurassic rocks, M-2 well, Miran Oil Field, Sulaimaniyah, Kurdistan region, Iraq

Further cross plots could be used for obtaining more information about the type of kerogens. Adaiyah Formation shows kerogen type II and III (Fig.5); however, as mentioned previously the OI data are rejected (Table 1). Mus and Alan formations are containing types III and IV kerogens (Fig.5). The samples have low HI indicating dry gas prone and gas prone rocks (Fig.6).

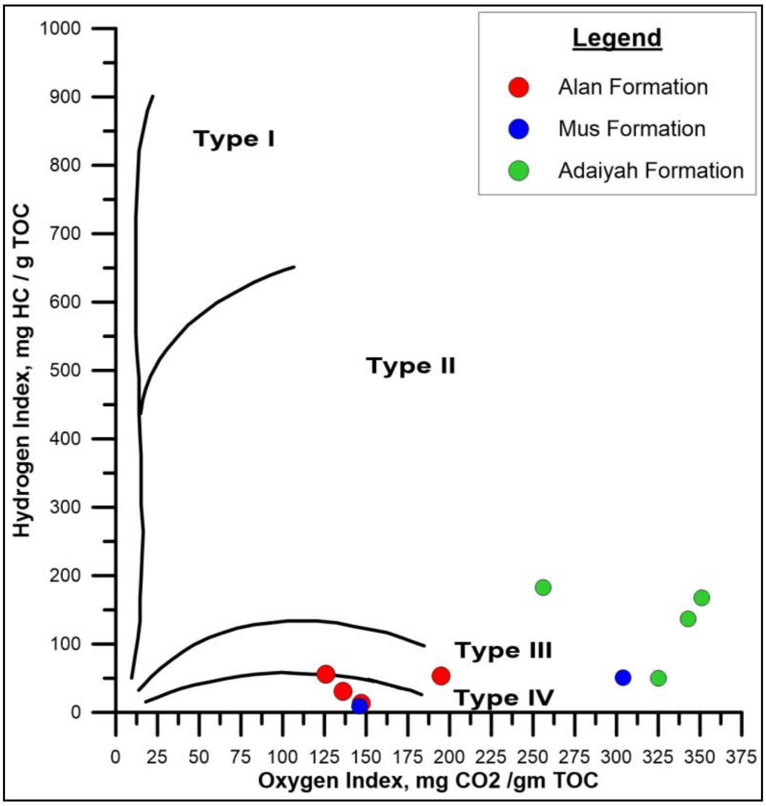


Fig.5: The relationship between HI and OI of the studied samples from M-2 well. The samples from Adaiyah Formation rejected because the values of OI are out of standards according to conditions in Table 2

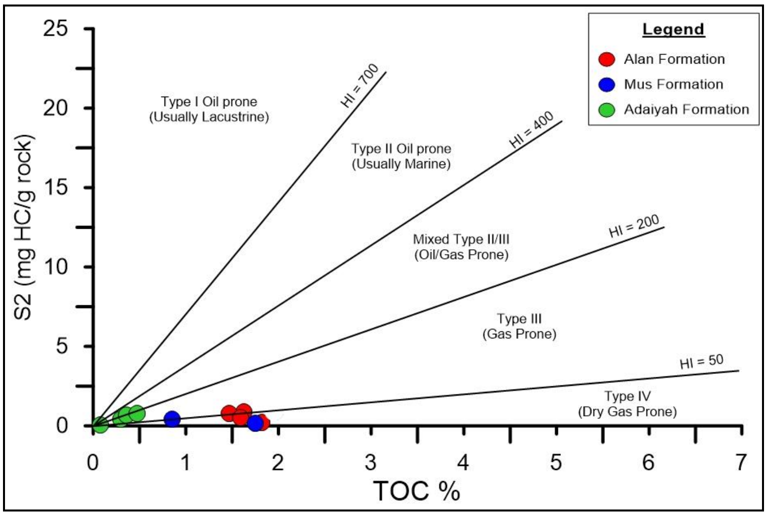


Fig.6: Cross plot of TOC wt.% and S2 (mg HC/g rock) showing that the samples from Early Jurassic rocks in well M-2 are of dry gas prone

Concerning the maturity of the studied samples, all samples are immature, except S.No.10 which is in post mature stage (Fig.7). Based on the guide line of Peters and Cassa (1994) when $T_{max} < 395$ the T_{max} will reject.

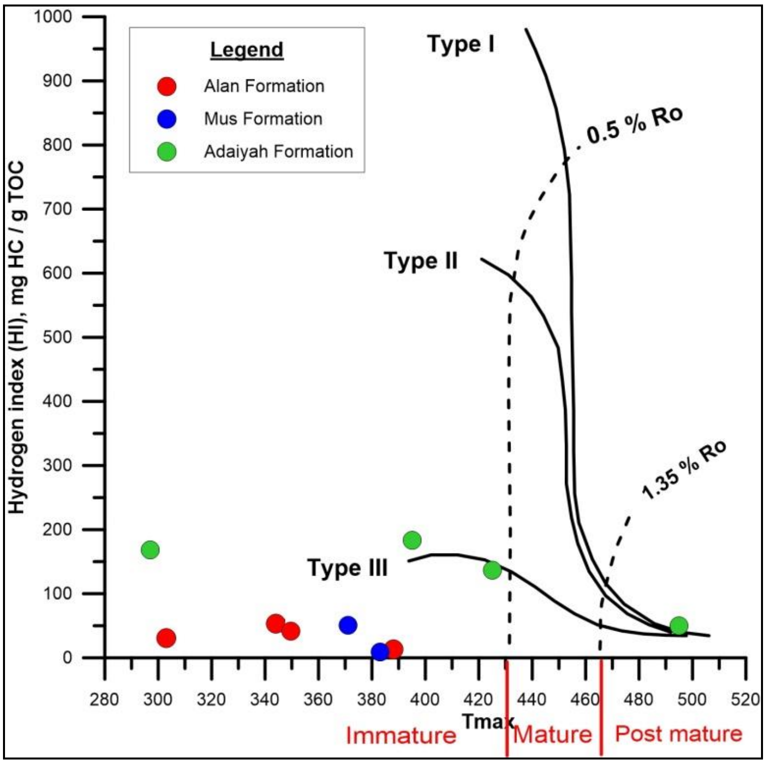


Fig.7: The relationship between HI and T_{max} indicating the stages of maturity for the studied samples of Early Jurassic rocks in well M-2. The samples except one from Adaiyah Formation are in immature stage

- **Visual kerogen**

The prepared strewn slides have been studied under polarizing microscope. Unfortunately, the palynomorphs as well as phytoclasts are totally absent, and only the amorphous kerogen identified and recorded (Fig.8). For this reason the Amorphous Organic Matters (AOM) studied under transmitted, reflected and fluorescence lights using Leica CTR 6000 microscope. The classification of Thompson and Dembicki (1986) used for naming the type of kerogen within the studied samples. This classification has been used successfully in Kurdistan by many authors, such as Mohialdeen (2008), Ranyayi (2009) and Mohialdeen *et al.* (2013). The amorphous organic matter within the studied samples from the Early Jurassic succession classified into two major types as follows: **a)** small and elongated dark grains less than 20 microns in diameter (Type B) and a small amount of very fine rectangular grains (Type D). The both types are dominant in Alan and Mus formations (Fig.8), **b)** the second type represents dark brown grains with large diameters (≈ 200 microns) which is mostly type C, this type seen in Adaiyah Formation (Fig.8). All the studied samples are grey under reflected light and show no fluorescence.

Using the ternary diagram of Tyson (1995) for classification of organic matter within sedimentary rocks, the studied samples are all locating in the corner of AOM (Fig.9). This field (IX) is characterized by sediments belongs to marine, suboxic to anoxic environment. This part has been interpreted to be highly oil prone.

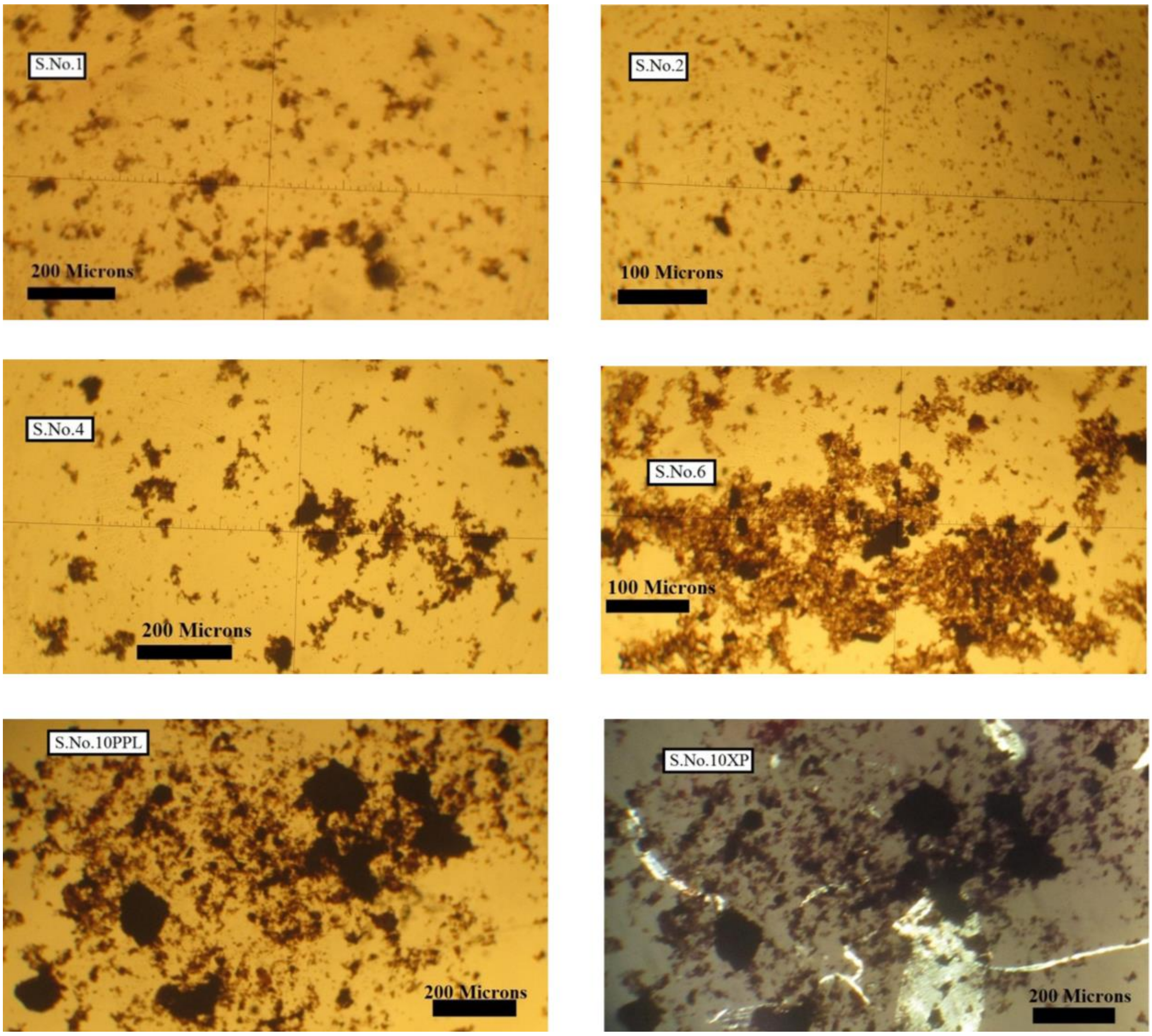
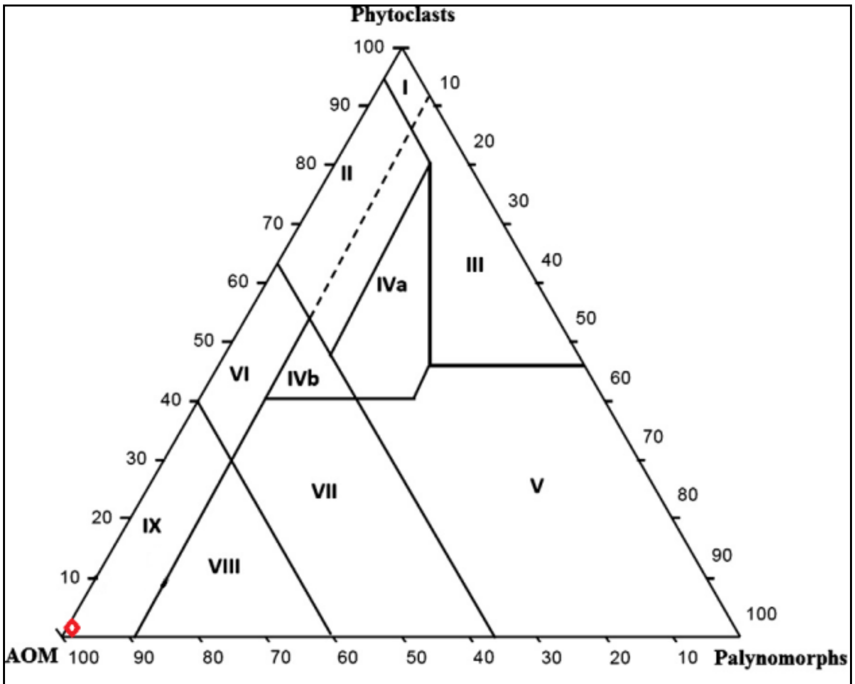


Fig.8: Photomicrographs of Early Jurassic succession depicting different types of organic matter (S.N.1+2 from Alan Formation, S.No.4 + 6 from Mus Formation, and S.No.10 from Adaiyah Formation, Miran Oil Field, Well M-2, Sulaimaniyah, Kurdistan). The organic matter is mostly of gas prone type D depending on Thompson and Dembicki's (1986) classification.



Palynofacies Fields	Environment	Kerogen Type
I	Highly proximal shelf or basin	III (gas prone)
II	Marginal dysoxic –oxic basin	III (gas prone)
III	Heterolithic oxic shelf ("proximal shelf")	III or IV (gas prone)
IV	Shelf to basin transition	III or II (mainly gas prone)
V	Mud-dominated oxic shelf ("distal shelf")	III > IV(gas prone)
VI	Proximal suboxic-anoxic shelf	II (oil prone)
VII	Distal dysoxic-anoxic "shelf"	II (oil prone)
VIII	Distal dysoxic-anoxic shelf	II >> I (oil prone)
IX	Distal suboxic-anoxic basin	II ≥ I (highly oil prone)

Fig.9: Ternary diagram showing AOM, Phytoclasts and palynomorphs (after Tyson, 1995; Hakimi *et al.*, 2012) and the location of studied samples from Early Jurassic sediments. All the studied samples located in the lower left corner of the diagram, exactly on AOM corner as a result of high abundance of AOM, indicating that the Early Jurassic sediments were deposited in marine, suboxic to anoxic environment. This part has been interpreted to be highly oil prone

- **Infrared spectrometry**

One of the old methods in evaluating the organic matter within rocks is using the Infrared Spectroscopy (Thompson and Dembicki, 1986; Ganz and Kalkruth, 1987; Ranyayi, 2009). This technique will give great information about the kerogen type and the maturity stage of organic matter. Of course these data will be used together with other results to evaluate the samples from Early Jurassic rocks in well-2, Kurdistan. The infrared spectroscopy has been done for the selected samples from different rock units (Fig.10). From the spectra in Figure 10, the aliphatic parts ($CH_2 – CH_3$) which appeared in range 2860 to 2930 cm^{-1} are very low in all samples. The aromatic part which appeared in range of 1710 cm^{-1} is totally not present or present in scarce amount (Fig.10). After comparison the spectrographs with those of Thompson and Dembicki (1986), it is clear that the studied samples are belonging to types B and C. These types of kerogen are totally gas-prone sources. The presences of aliphatic and aromatic fractions in the studied samples are calculated using the equations of Ganz and Kalkruth (1987) and plotted on the A and C factors diagram (Fig.11). The samples of Alan and Mus formations are immature and within the type II kerogen; however, samples of Adaiyah Formation are clearly of type IV kerogen.

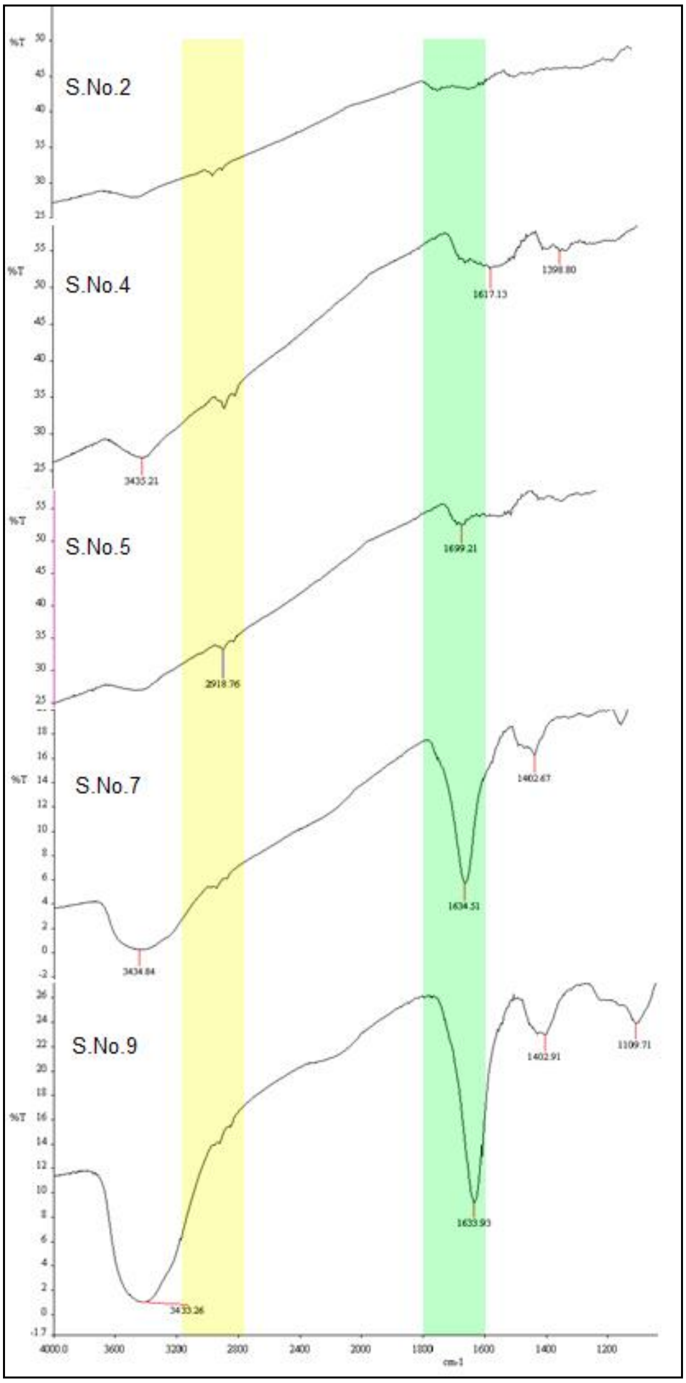


Fig.10: The Infrared spectra (transmittance) for the studied samples. The yellow area indicate the aliphatic ($CH_2 - CH_3$) structures, and the green area represents aromatic (C = C) and carboxyl and carbonyl groups. Samples 2 (type C) and 4 (type B) are from Alan Formation, sample 5 (Type C) from Mus Formation and samples 7 (Type B) and 9 (Type B) are from Adaiyah Formation

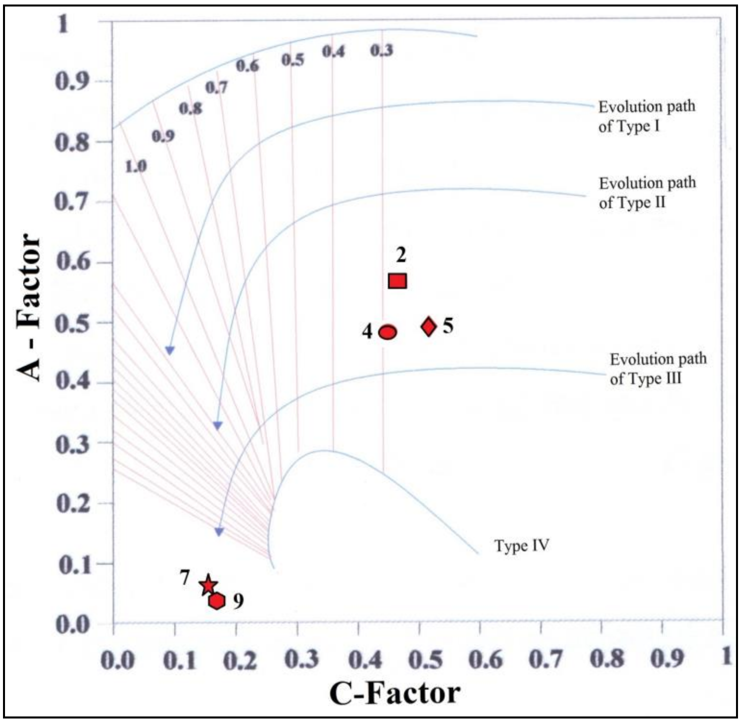


Fig.11: The results of Infrared spectroscopy as plotted on the A-Factor versus C-factor. The samples are mostly type II and immature. Samples 2 and 4 are from Alan Formation, sample 5 from Mus Formation, and samples 7 and 9 are from Adaiyah Formation

DISCUSSION

The studied rock units in this research are mostly known as poor-organic matter sediments (Jassim *et al.*, 2006; Mustafa, 2009; Aqrawi *et al.*, 2010; Abdula, 2016). However, the studied samples from Alan and Mus formations are containing a very good quantity of total organic matter (Table 1), but the Adaiyah Formation clearly contains very poor-organic matter sediments (i.e. mostly be evaporate sediments) as mentioned by previous researchers. Although the Rock-Eval Pyrolysis data show good genetic potential of the Alan and Mus formations (Fig. 4), the potentiality of dry gas generation is only the chance for generating hydrocarbons if the organic matter reaches the mature stage. Also the Rock-Eval data reveal the type of kerogen is mostly type III and IV (Fig.5) and the sediments are still in immature stage except one sample from Adaiyah Formation (Fig.7). The T_{max} and Production Index (PI) parameters of Rock-Eval pyrolysis could be used as indicator for maturity level of source rocks, however depend on types of organic matters (Peters and Cassa, 1994). Tissot and Welte (1984) mentioned to the value of T_{max} to be considered as a maturity indicator, between 420 – 460 °C and 400 – 600 °C for kerogen type II and terrestrial derived type III kerogen, respectively.

The low value of T_{max} for the studied samples (Table 1) is mostly related to the presence of mud additives. Such compounds are affected on the reliability of T_{max} and causing lowering down of the T_{max} values. The values of T_{max} are inconsistence with the PI values, on the other hand the bimodal S2 peak also been noticed during pyrolysis. Hence, the T_{max} value cannot be used for maturity assessment, because it does not represent the real cracking products of kerogen (Hunt, 1996; Fatah, 2014). Therefore, T_{max} values are rejected for maturity assessment. Regarding the values of PI, the results showed nearly all of the samples within the mature zone (oil window) for the studied samples.

The other methods might give better results such as the petrographic study of organic matter (strewn slides) also applied. Unfortunately, all the organic matter within these sediments are amorphous and there are neither palynomorphs nor phytoclasts (Fig.8). These organic matters also are very small and revealing grey under reflected light with no fluorescence. Hence and according to Thompson and Dembicki (1986) these types of organic matter are mostly of gas-prone type with no possibility for oil generating.

The other method, the Infrared spectroscopy, is also used for evaluating these sediments. Five kerogen samples were selected and analyzed by Infrared Spectrometer. The results of these samples show a small different results with Rock-Eval data as the kerogen type of Alan and Mus formations are mostly type II, after plotting the data on the diagram of Ganz and Kalkruth (1987) (Fig.11). Samples of Adaiyah Formation are type IV kerogen as determined from Rock-Eval pyrolysis. However the Infrared spectrometers also show vitrinite reflections around 0.3% and less ($Ro \leq 0.3\%$) hence immature sediments, this result is coincides with the data of Rock-Eval pyrolysis.

Although, the studied samples show some variations in results by analyzing with different techniques, these sediments have no potentiality for generating any oil and may be some gas generate from Alan and Mus formations. Absolutely, the Adaiyah Formation is inert and has no potentiality for generating any hydrocarbons in this well. In order to explain and give better interpretation for the studied samples another study recommended using organic petrological method, i.e. using polished sections and determining the distributed macerals as well as measuring vitrinite reflectance.

CONCLUSIONS

The studied samples from Early Jurassic succession (Alan, Mus and Adaiyah formations) in well M-2, Miran Oil field, indicated to the following points:

- The Alan Formation contains high TOC percentage, and considered as good. The Mus Formation represents poor to good TOC wt.%, while the Adaiyah Formation samples are totally poor in TOC wt.% content.
- The Rock-Eval Pyrolysis results reveal good genetic potential of the Alan and Mus formations, the potentiality of dry gas generation is only the chance for generating hydrocarbons if the organic matter reaches the mature stage. The Rock-Eval data indicate to kerogen types III and IV and the sediments are still in immature stage except one sample from Adaiyah Formation.
- The organic matter is totally amorphous with no indication to any palynomorphs or other phytoclasts. The organic matter is small and has no fluorescence, which mostly of gas-prone type with no possibility for oil generating.
- The studying of prepared pellets by Infrared Spectrometer show a small different results with Rock-Eval data as the kerogen type of Alan and Mus formations are mostly type II, while samples of Adaiyah Formation are type IV kerogen, as determined from Rock-Eval pyrolysis. However, the Infrared spectrometry also shows vitrinite reflections around 0.3% and less ($Ro \leq 0.3\%$), hence immature sediments, this result are coincides with the data of Rock-Eval pyrolysis.

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