

ORGANIC GEOCHEMICAL ASSESSMENT OF JURASSIC POTENTIAL SOURCE ROCK FROM ZAB-1 WELL, IRAQI KURDISTAN

Rzger A. Abdula¹

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ABSTRACT

The studied samples were collected from Butmah, Adaiyah, Mus, and Sargelu formations in Zab-1 Well which lies about 25 Km to the south of Kalak town, Erbil Governorate. The hydrocarbon potential parameters, including type and amount of bitumen and kerogen, and thermal maturity of eight samples were assessed using Rock-Eval pyrolysis techniques. In general, Sargelu Formation samples have PI values of 0.15 – 0.25 (average 0.19) and T_{max} values varying between 422 °C and 431 °C (average 427 °C), indicating thermally immature to early mature oil. They can be considered as poor to fair source, where TOC (Total original Carbon) content ranges from 0.27 to 0.77 of percentage weight (average 0.48). The Mus, Adaiyah, and Butmah formations' samples are considered to be poor source rocks with TOC content of 0.39, 0.64, and 0.44 wt. percentage, respectively.

Samples of Sargelu, Mus, Adaiyah, and Butmah formations contain kerogen types II, III, and mixture of types II and III indicating marine and non-marine organic matter derived mainly from algae and higher plants organisms suggesting oil and gas prone sources.

دراسة جيوكيميائية عضوية للصخور الجوراسية المصدرية المحتملة من بئر زاب-1، كردستان العراق

رزگار عبدالكريم عبدالله

المستخلص

لقد جمعت العينات المدروسة من تكاوين بطمة، عداية، موس، وسرگلو من بئر زاب-1، الواقع حوالي 25 كم الى جنوب مدينة كلك، محافظة أربيل. فدرست عوامل احتمالية تواجد المواد الهيدروكربونية، والتي تشمل نوع ومقدار البتيومين والكيروجين، والنضوج الحراري لثمان عينات بواسطة تقنية Rock-Eval pyrolysis. بصورة عامة، والعامل الإنتاجي للعينات العائدة لتكوين سرگلو يتراوح ما بين 0.15 – 0.25 (المعدل 0.19) وقيمة الحرارة القصوى تنتشر بين 422 درجة مئوية و 431 درجة مئوية (المعدل 427 درجة مئوية)، مما يدل على عدم نضوجية ومرحلة نضوج بدائي حراري للنفط. ويمكن اعتبارها كصخور مصدرية فقيرة الى شبه غنية، حيث يتراوح إجمالي الكربون العضوي بين 0.27 الى 0.77 بالمئة وزناً (المعدل 0.48 بالمئة وزناً).

¹ Soran University, Department of Petroleum Geosciences, Soran, Kurdistan Region, Iraq,
e-mail: rzger.abdula@soran.edu.iq

إن العينات العائدة لتكاوين موس، عداية، وبطمة يمكن اعتبارها صخوراً مصدرية فقيرة، حيث أن النسبة المئوية لإجمالي الكربون العضوي وزنياً للتكاوين المذكورة هي 0.39، 0.64، و 0.44، على التوالي.

وتحتوي العينات العائدة لتكاوين سرگلو، موس، عداية، وبطمة على كيروجين من النوع الثاني، والثالث، وخليط من النوع الثاني والثالث مما تدل على مواد عضوية بحرية وغير بحرية تعود إلى الطحالب والأشجار المثمرة اللتين تدلان على إمكانيتهما في إنتاج النفط والغاز.

INTRODUCTION

The lower Jurassic rocks are much thicker at the subsurface sections than at the outcrops and their organic contents are very low (Dunnington, 1958). All Lower Jurassic formations except Mus were deposited in sabkha environment and dominated by lagoonal evaporitic facies, but Mus Formation was deposited under normal marine condition (Bellen *et al.*, 1959). The Middle Jurassic Period is considered as the major source rocks deposited under euxinic conditions and became one of the major source for generating hydrocarbon in the Middle East (Murriss, 1980; Beydoun, 1986). The Alan and Mus formations in Jabal Kand-1 Well (Fig.1) are thermally mature, but have a low potentiality for generating hydrocarbons (Al-Habba, 1988). In contrast both Alan and Mus formations are the source of the condensate that is produced from the Samawa-1 Well in southern Iraq (Samarrai, 1988, in Sadooni, 1997). The shallow depth of Sargelu Formation makes it unable to generate hydrocarbon due to low maturity in Jabal Kand-1 Well in northern Iraq (Al-Habba, 1988). The Sargelu Formation in Qara Chugh-1 Well in northern Iraq (Fig.1) is enriched with amorphous organic matter of purely marine origin and is thermally mature for generating oil (Sadooni, 1997). The Jurassic formations in various wells in northeastern Iraq are producing mainly gas and their sediments are dominated by spores and pollen assemblages (Ahmed and Al-Gibouri, 1998). These source rocks in the Fold Belt Zone reach peak oil generation at the Late Miocene and Pliocene (Pitman *et al.*, 2004). The richness of Sargelu is related to its lithology which consists of thin to medium bedded, black bituminous limestone, dolomitic limestone, and black shale with black chert beds at the upper part (Balaky, 2004). The Alan, Mus, Adaiyah, and Butmah formations have some reservoir characteristics due to the presence of oil shows in the fractured part. Sargelu Formation also contains heavy oil within the fractured parts, especially where the Gotina seal is absent (Jassim and Al-Gailani, 2006). Mus Formation contains kerogen types II and II/III and Alan and Adaiyah formations contain Type II kerogen oil prone (Mustafa, 2009). The argillaceous sediments were associated with thick evaporates in Adaiyah Formation and might be a source for generating hydrocarbons (Aqrabi *et al.*, 2010). Sargelu is a source for most of the hydrocarbons accumulated at the north including Demir Dag Oil Field (Al-Ameri *et al.*, 2013) (Fig.1). The maturity of Jurassic succession in Sangaw North-1 Well (Fig.1) is high and ranges from 1.34 to 2.10 Ro percentage (Saeed, 2014) and the maturity of Sargelu mainly increases from the west to the east (Abdula, 2015).

The Zab-1 Well in Erbil Governorate has been selected to perform the present assessment on the hydrocarbon potential. Zab-1 is situated in the north of Iraqi, about 25 Km to the south of Kalak town. The studied section (Fig.2) lies at latitude 36° 05' 45.45" N and longitude 43° 37' 49.88" E, nearly 500 m to the west of Zeigawra Well (Fig.1). Zab-1 was drilled in 1990 and was completed in 2003. This paper reports the results of hydrocarbon source rock characterization of four formations of interest, namely, Sargelu, Mus, Adaiyah, and Butmah and their hydrocarbon potential.

The Jurassic rocks are commonly exposed as isolated patches at some eroded cores and limbs of anticlines in the High Folded, Imbricate and Thrust zones of Iraq. Zab-1 is located in the Low Folded Zone of the Unstable Shelf of Iraq (Buday, 1980). It was drilled in a rugged

terrain where the Tertiary rocks crop out. The studied formations from old to young are Butmah, Adaiyah, Mus, and Sargelu formations.

Butmah Formation (Liassic) is heterogeneous and its upper part is composed mainly of oolitic, pseudo-oolitic and detrital limestone with beds of argillaceous limestone, shale and anhydrite. The lower part of the formation is composed of limestone with beds of anhydrite (it is a cyclic deposition) (Jassim and Buday, 2006). The total thickness of the formation is 190 meters in Zab-1. Based on lithofacies and fossils content, Butmah Formation was deposited in a shallow water lagoonal and sabkha environment (Jassim and Buday, 2006). Adaiyah Formation (Upper Liassic) is 199 m thick in Zab-1. It consists mainly of nodular anhydrites with limestone and shales (Bellen *et al.*, 1959). Adaiyah Formation was deposited under sabkha environment (Jassim and Buday, 2006). Mus Formation (Late Liassic) is dominated by dolomitic peloidal limestone with marly limestone, shale and subordinate anhydrite and it is relatively uniform throughout the area (Aqrawi *et al.*, 2010). The total thickness of Mus Formation in Zab-1 is 41 m. Mus Formation was deposited in normal marine environment (Alsharhan and Nairn., 2003), which is an indicator of a short period of freshening cycle between two intervals dominated by the evaporitic environments of Alan Anhydrite and Adaiyah Anhydrite formations. Sargelu Formation (Late Toarcian-Bathonian) consists of thin bedded, black bituminous limestone, dolomitic limestone, and black shale with streaks of thin black chert in the upper parts (Bellen *et al.*, 1959). The thickness of Sargelu Formation in Zab-1 is about 419 m in which the limestone rocks are mostly dolomitized. The depositional history offers an indication that the environment of Sargelu had initiated and terminated as deep, quiet marine, interrupted by some relatively shallow intervals but still remains in the basinal realm and represents deeper ramp (Balaky, 2004; Abdula *et al.*, 2015).

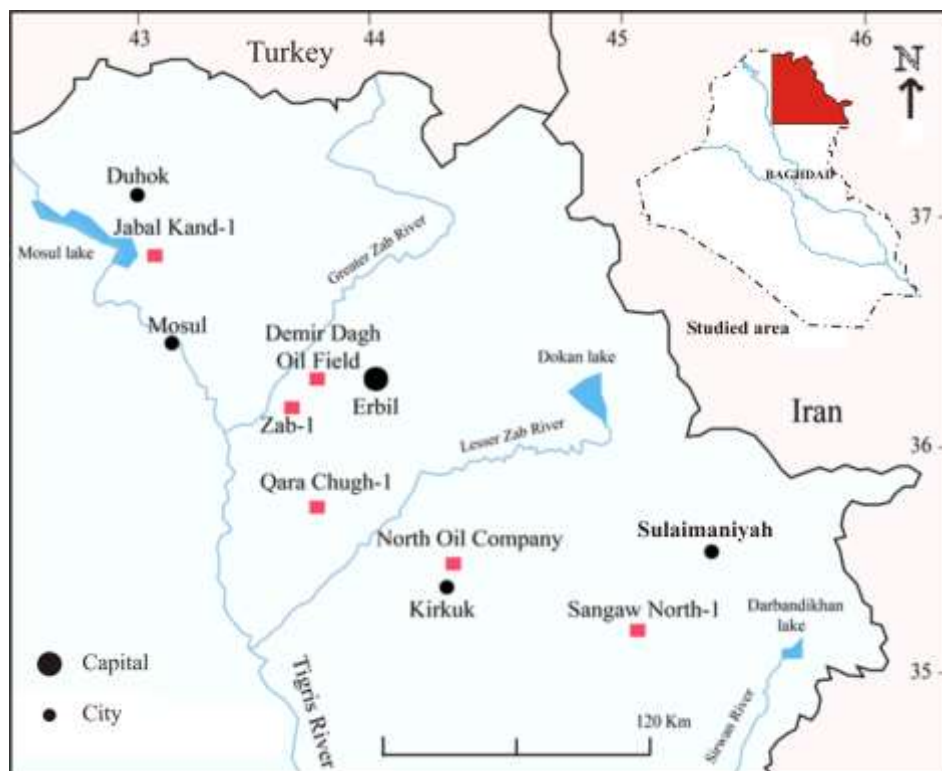


Fig.1: Location of the study area (Zab-1)

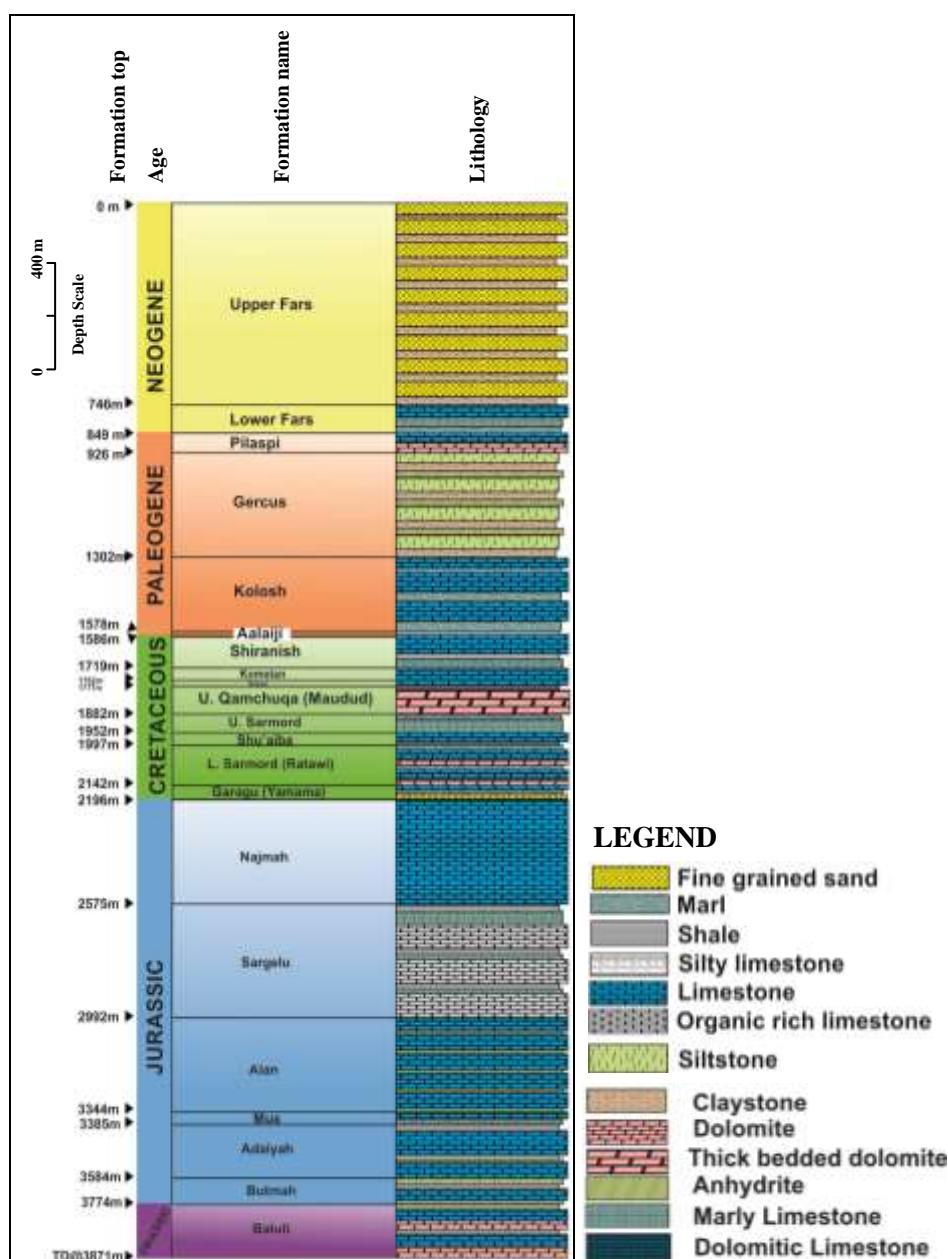


Fig.2: Stratigraphic column of Zab-1 with a summary of the lithology and depth

METHODOLOGY

Eight samples were collected from Zab-1 at different depths and different spacing including the shale intervals. The samples were stored at the North Oil Company in Kirkuk (Fig.1). The collected samples represent the different lithologies of the Sargelu, Mus, Adaiyah, and Butmah formations. These lithologies are commonly limestone and shale. Analyses were conducted at Kurdistan Institution for Strategic Studies and Scientific Research (KISSR), in Sulaimaniyah. The representative eight samples were analyzed by Rock Eval pyrolysis. The measured parameters include S_1 (mg HC/g rock), S_2 (mg HC/g rock), S_3 (mg CO_2 /g rock), T_{max} ($^{\circ}C$), and TOC (wt.%) are quoted in Table 1. Several additional parameters such as Hydrogen Index ($HI = S_2/TOC \times 100$), Oxygen Index ($OI = S_3/TOC \times 100$), and Production Index $\{PI = S_1 / (S_1 + S_2)\}$ are calculated from these measured values and are also shown in Table 1.

Table 1: Total organic carbon and Rock-Eval pyrolysis data on samples selected from different formations in well Zab-1 in Iraqi Kurdistan

Sample No.	Depth (m)	Formation	TOC (wt.%)	S1 (mg HC/g TOC)	S2 (mg HC/g TOC)	S3 (mg CO ₂ /g TOC)	T _{max} (°C)	HI (mg HC/g TOC)	OI (mg HC/g TOC)	GP (mg HC/g TOC)	PI	PCI (mg HC/g TOC)	S1/TOC	Ro%	S ₂ /S ₃
Zb-1	2577	Sargelu	0.58	0.34	1.63	1.11	428	281	191	1.97	0.2	1.64	0.59	0.54	1.47
Zb-2	2625	Sargelu	0.27	0.20	0.62	0.46	429	230	170	0.82	0.3	0.68	0.74	0.56	1.35
Zb-3	2676	Sargelu	0.30	0.23	1.10	0.50	427	367	167	1.33	0.2	1.10	0.77	0.53	2.20
Zb-4	2685	Sargelu	0.77	0.21	0.73	1.33	422	95	173	0.94	0.2	0.78	0.27	0.44	0.55
Zb-5	2856	Sargelu	0.50	0.32	1.83	0.73	431	366	146	2.15	0.2	1.78	0.64	0.60	2.51
Zb-6	3350	Mus	0.39	0.79	0.77	0.93	425	197	238	1.56	0.5	1.29	2.03	0.49	0.83
Zb-7	3430	Adayah	0.64	1.76	1.35	1.09	425	211	170	3.11	0.6	2.58	2.75	0.49	1.24
Zb-8	3700	Butmah	0.44	0.23	0.64	0.73	428	145	166	0.87	0.3	0.72	0.52	0.54	0.88

RESULTS AND DISCUSSION

Pyrolysis techniques were used to assess the hydrocarbon potentiality and the likely hydrocarbon products or source type.

▪ Quantity of organic matter

The TOC content of the sediments can be considered as a straight expression of kerogen and bitumen abundance. The TOC ranges in Sargelu Formation from 0.27 wt.% to 0.77 wt.%, averaging 0.48 wt.%. The TOC wt.% is 0.39, 0.64, and 0.44 in Mus, Adayah, and Butmah formations, respectively. According to Peters and Cassa, 1994, the sediments from the Sargelu, Mus, Adayah, and Butmah formations can be rated as having poor to fair hydrocarbon potential (0.27 to 0.77 wt.%, averaging 0.49 wt.%) (Table 1 and Fig.3).

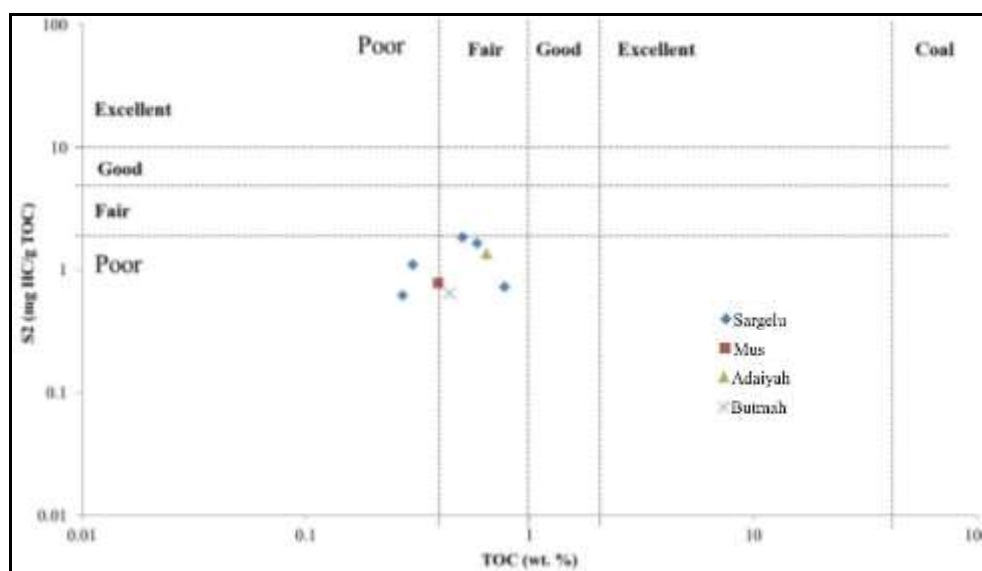


Fig.3: Cross plot of total organic carbon (TOC) weight percent (wt.%) versus S₂ (mg HC/g TOC) shows the quality of organic matter in Lower Butmah, Adayah, Mus and Middle Jurassic Sargelu formations in well Zab-1 (adapted from Dembicki, 2009)

▪ Types of organic matter

It is necessary to recognize, that the quantitative aspects of kerogen evolution vary from one type to another as a result of differences in the original composition of kerogen. These generalizations may not reflect the true nature of the chemistry that occurs during the maturation process (Speight, 2007). So, the types of organic matter must be distinguished and identified because different types of organic matter have different hydrocarbon generation potential and products (Brooks, 1981; Tissot and Welte, 1984; Tyson, 1995). Most of the samples of the Jurassic formations are shown plotted in the field of kerogen types II, III, and mixture of types II and III (Figs.3 and 4). These kerogen types suggest common terrestrial and marine depositional environments. The organic matter is derived mostly from marine algae and vascular plant organisms which can be considered as an "oil and gas prone source" (Dahl *et al.*, 2004). HI versus T_{max} is commonly used to avoid influence of the OI for determining kerogen type (Hunt, 1996). Determining kerogen type using T_{max} versus HI appears to be more accurate than that of OI versus HI. The difference between the results is expected because the Lower and Middle Jurassic formations are dominated by carbonates which affect the OI. The cross plot of HI versus T_{max} indicates dominance of kerogen Type II and mixed types of II – III in all formations (Fig.5). The pyrolyzable carbon index (PCI) is an extreme amount of hydrocarbon that a sample is capable of generating during the analysis, and mathematically, can be expressed as $PCI = 0.83 \times (S_1 + S_2)$ (Reed and Ewan, 1986; Geologic Materials Center, 1990; Pimmel and Claypool, 2001; Shaaban *et al.*, 2006). The PCI can be used to evaluate the kerogen type and its hydrocarbon potential (Shaaban *et al.*, 2006). The PCI values: ≥ 75 indicates type I; 40 – 50 represents type II; and < 15 indicates type III (Fig.6). Thus all samples are Type III.

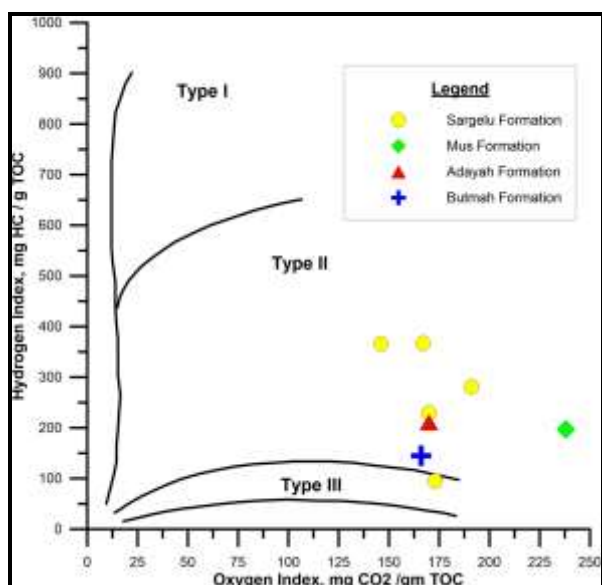


Fig.4: Hydrogen index (HI) versus oxygen index (OI) plot for different kerogen types in the Jurassic formations in Zab-1 (adapted from Espitalié *et al.*, 1977)

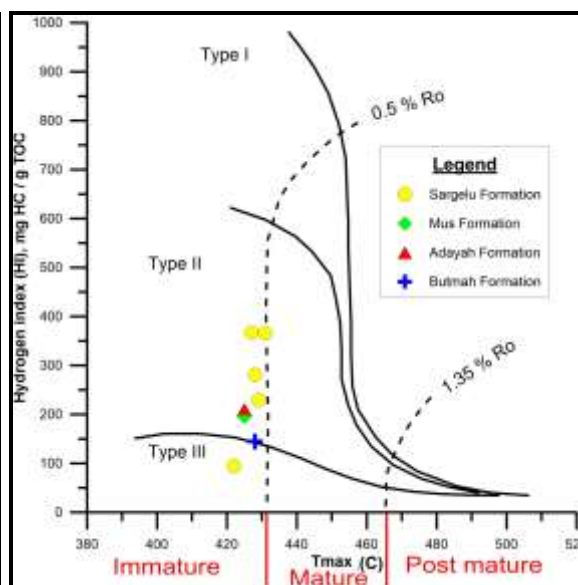


Fig.5: Hydrogen index versus T_{max} for samples the Jurassic in well Zab-1 (adapted from Espitalié *et al.*, 1985)

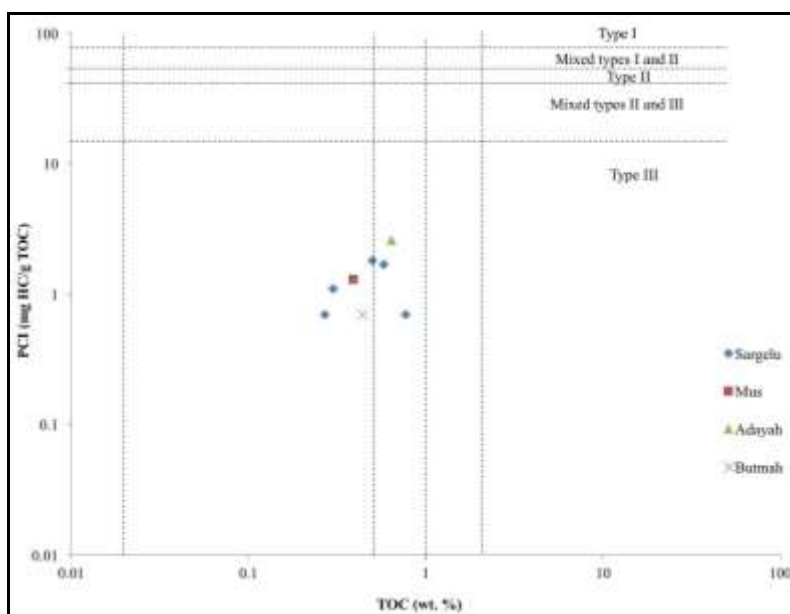


Fig.6: Total organic carbon (TOC) wt.% versus pyrolyzable carbon index (PCI) indicates the quality of organic matter in Butmah, Adaiyah, Mus, and Sargelu formations in studied well Zab-1 in Iraqi Kurdistan (adapted from Shaaban *et al.*, 2006)

▪ Thermal Maturity

The maturity levels for the oil window depend on the type of organic matter (Bacon *et al.*, 2000), and encompass a vitrinite reflectance (R_o) ranges from 0.55 to 1.00% (Sweeney and Burnham, 1990) and temperature at maximum rate of hydrocarbon generation during S_2 evolution (T_{max}) from 435 to 470 °C. The production index (PI) parameter is another measure of maturity, with values ranging from 0.15 to 0.40 normally associated with oil generation. The level of thermal maturity can roughly be estimated from the HI versus T_{max} plot (Fig.5). The figure shows that the majority of the samples are thermally immature to very early stage of maturation, where pyrolysis T_{max} ranges from 422 – 431 °C and PI is ≥ 0.15 . The high PI indicates that the organic matters are within oil window but these conflicts with low T_{max} values. This discrepancy could be related to the presence of kerogen Type II – S which breaks down at lower temperature than regular Type-II kerogen (Orr, 1986).

▪ Migrated Hydrocarbons

The high S_1 values could be normal, which indicate potential source rocks or anomalous, resulting from mixing with migrated oil, or coming from drilling additives (Peters and Cassa, 1994). When S_1 is high and the TOC is low, nonindigenous hydrocarbons can be identified (Hunt, 1996). Figure 7 separates migrated from non-migrated hydrocarbons for the samples from Butmah, Adaiyah, Mus, and Sargelu formations. The dividing line on the plot is where $S_1/TOC = 1.5$. Values belonging to nonindigenous hydrocarbons appear above this line while indigenous hydrocarbon values emerge below it (Hunt, 1996). Thus all the samples analyzed indicate indigenous hydrocarbons presence (Fig.7).

▪ Oil or Gas Prone

The oil and gas-prone source rock intervals are characterized by potential to generate oil and/ or gas as indicated by their hydrogen indices (pyrolysis S_2 yields from 0.62 to 1.83 mg HC/g TOC; and HI mostly ≥ 95 with an average 237 mg HC/g TOC) for all samples (Fig.8). The mixed-prone Sargelu source rock intervals are characterized by intermediate to high

potential to generate oil and gas as indicated by their hydrogen indices (pyrolysis S_2 yields 0.62 – 1.83 mg HC/g rock; and HI ranges from 95 to 367 with an average 268 mg HC/g TOC). The Mus, Adaiyah, and Butmah formations is characterized by having the capacity for gas generation. The gas-prone source rocks are characterized by potential to generate gas as indicated by their hydrogen indices (pyrolysis S_2 yields 0.77, 1.35, and 0.64 mg HC/g rock; HI 238, 170, and 166 mg HC/g TOC, respectively) (Fig.8). The Rock-Eval parameters enable one to predict the type of hydrocarbon that could be generated (Peters, 1986). The gas prone has HI between 0 and 150 mg HC/g TOC and S_2/S_3 is between 0 and 3, oil prone has HI greater than 300 mg HC/g TOC and S_2/S_3 is more than 5. Thus all samples are gas prone (Table 1). The constituents of different organic matter can be identified by plotting S_2 versus TOC (Erik *et al.*, 2006) (Fig.9).

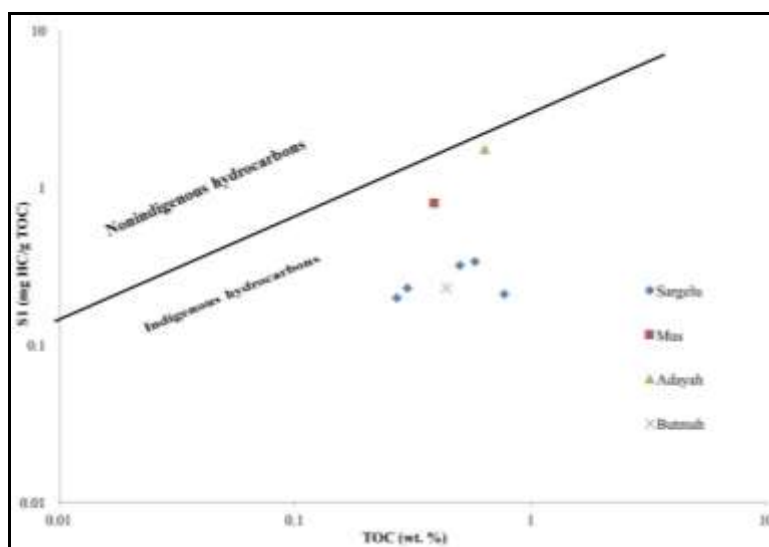


Fig.7: (TOC) versus S_1 for identifying migrated hydrocarbons for Lower and Middle Jurassic Butmah, Adaiyah, Mus, and Sargelu formation's samples in Zab-1 (adapted from Hunt, 1996)

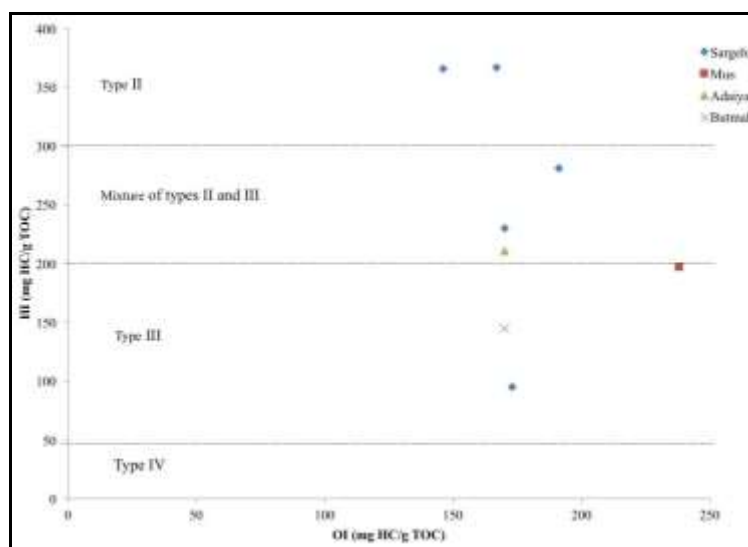


Fig.8: (HI) versus oxygen index (OI) showing kerogen types of Butmah, Adaiyah, Mus, and Sargelu formations in Zab-1

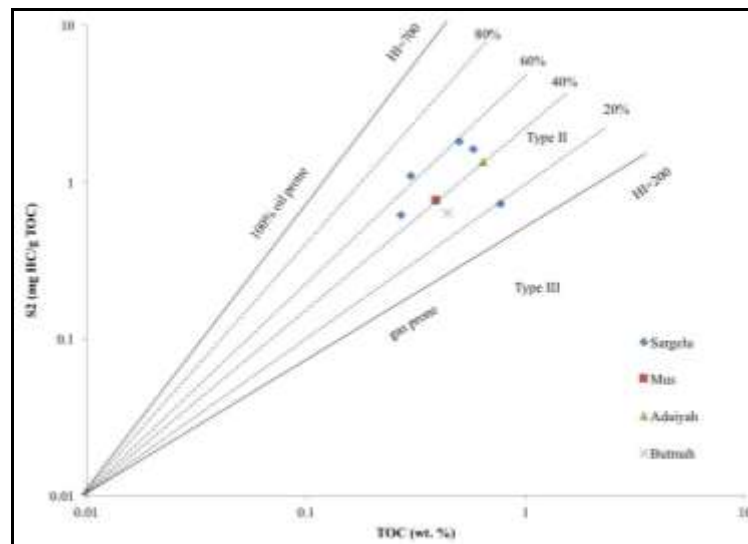


Fig.9: Plot (TOC) versus Rock-Eval pyrolysis S_2 shows the kerogen type for samples from the Jurassic formations in well Zab-1. The plot also indicates whether kerogen is oil or gas prone (modified from Dahl *et al.*, 2004; Allen *et al.*, 2008)

▪ Depth of Expelled Oil

The expulsion or primary migration from source rock to the migration conduits is the first migration phase for organic material after transformation to petroleum (Durand, 1988). The depth at which a source rock starts to expel oil can be determined by plotting depth against S_1 /TOC (Hunt, 1996). According to Smith (1994) and Hunt (1996), the expulsion of oil starts when the ratio of S_1 to TOC ranges between 0.1 and 0.2. A plot of depth versus S_1 /TOC for samples from Butmah, Adaiyah, Mus, and Sargelu formations in Zab-1 Well indicates that the oil is expelled at a depth shallower than 2500 m below the sea level (Fig.10).

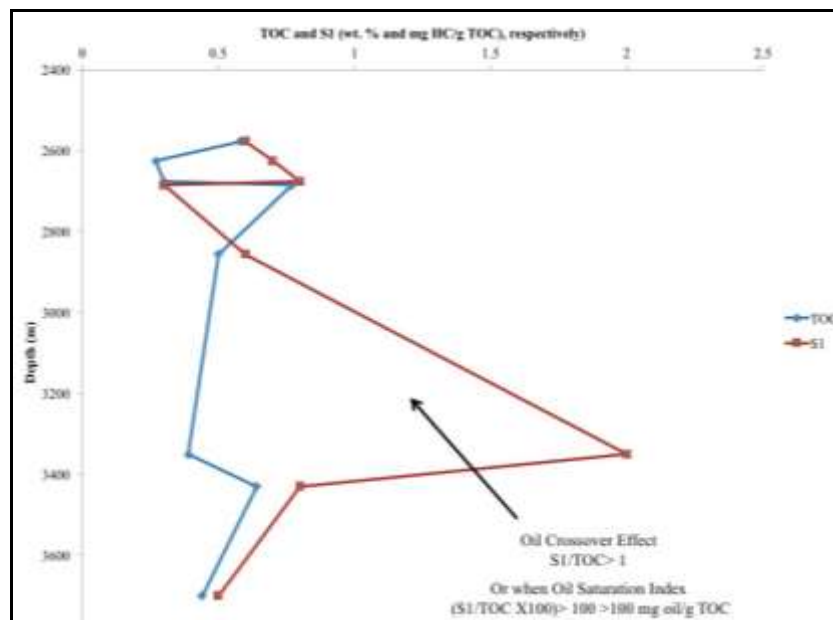


Fig.10: TOC and S_1 versus depth (units in wt. percentage mg oil/ g rock), for Jurassic samples well Zab-1 (adapted from Jarvie, 2012)

The values of S_1/TOC increase with depth due to an increase of thermal maturity assuming no facies change. This increase continues to the top of the oil window and then stays roughly steady for a short distance, such as the case of Zab-1 Well, where the value of S_1/TOC stays the same at depths between 3350 – 3450 m below the sea level. As the depths increase, the value of S_1/TOC decreases as a result of increasing thermal maturity (Fig.10) (Smith, 1994).

CONCLUSIONS

In general, the Lower and Middle Jurassic formations have kerogen types II and II – S in immature to early mature stage of thermal maturity of oil. They can be considered as poor to fair source, where the average of TOC content is less than 0.77 wt.%. The organic matter in the studied formations is within oil window according to their high production index values (0.15 – 0.57 with an average of 0.29). This high production index accompanied with comparatively low T_{max} (422 – 431 with an average of 427 °C) suggests the presence of Type II – S kerogen. The oil starts to be expelled at 3000 m under the surface but the oil crossover appears at depths between 3350 – 3450 m below the sea level.

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About the Author

Mr. Rzger Abdulkarim Abdula, graduated from University of Salahaldin in 1987, with B.Sc. degree in geology; he got his M.Sc. in 2010 from Colorado School of Mines in Geology in U.S.A, and currently he is a Ph.D. student. His prior experience includes 3 years as an Operations Geologist with Talisman-Energy Company and 10 years as a geologist with RMG Engineers Company in United States and Quarry Marble Company in Iraq. He joined Soran University in 2012. He has published four papers on the petroleum geochemistry, Portland cement, and sedimentology and stratigraphy of northern Iraq. Rzger's current research focuses on petroleum system modeling, geochemical oil typing, and organic petrology.



e-mail: rzger.abdula@soran.edu.iq