RESEARCH ARTICLE

Source Rock Evaluation and Lateral Changes in Thermal Maturity of the Sargelu Formation (Middle Jurassic) in Kurdistan Region-Northern Iraq

Ayad N. F. Edilbi[1]*, Ali J. Ali[1], Bahjat E. Abdullah[1] and Stephen A. Bowden[2]

[1]Department of Petroleum Geosciences, Soran University, Soran, Kurdistan Region, Iraq
[2]Department of Geology and Petroleum Geology, School of Geosciences, University of Aberdeen, Aberdeen AB24 3UE, UK

*Corresponding author's email: ayad.faqi@soran.edu.iq

ABSTRACT

In this study, source rock characteristics and lateral changes in thermal maturity of the Sargelu Formation (Middle Jurassic) in three outcrops were studied. The formation's outcrops can be found in the High Folded and Imbricated Zones of Iraqi Tectonic Division. To achieve the main goals of this study, the gas chromatography-mass spectrometry and Rock-Eval pyrolysis were performed on the organic matter (OM) of the Sargelu sediments. Pristane/Phytane ratios for analyzed samples indicate reducing conditions (anoxic) during sedimentation. Moreover, based on C_{29}/C_{30} hopanes ratios the sediments of the Sargelu Formation associated with clay-rich source rock. Biomarker thermal maturity parameters display that all samples are thermally in Oil Window at least. The biomarker findings reveal that the samples of Walasmt and Barsarin are seem more mature than Banik section. The values for total organic carbon percentage of the Sargelu Formation may show Excellent, Very Good, and Poor quality source rock. The pyrolysis executed for studied samples revealed the kerogen in Banik section belongs to Types II and III (Probably Oil/Gas- prone), while Barsarin and Wala simt sections obtained Types III-IV Kerogen (Gas-prone). Pyrolysis parameters suggested Early Mature Stage in Banik, While Overmature in Barsarin and Wala simt. The data also show that OM of the Sargelu Formation in Banik section is in Oil Widow, while in Barsarin and Wala simt are in Gas Window.

Keywords: Biomarkers, Kurdistan, Rock-Eval, Sargelu Formation, Thermal Maturity.

1. INTRODUCTION

The Sargelu Formation was first described by Wetzel in Bellen *et al.*, 1959 at Surdash Anticline, Sulaimaniyah district, located in northern Iraq, in High Folded Zone area. The age of the formation determined most Upper Liassic to the Bathonian age (Bellen *et al.*, 1959). The formation is well-known as potential source rock and is the main hydrocarbon charge for the Jurassic and Cretaceous reservoirs (Jassim and Al-Gailani, 2006, Aqrawi *et al.*, 2010). The Sargelu Formation has rather uniform lithological setting that encountered and consists of streaks of thin black chert within black papery shale, dolomitic limestone and thin-bedded black bituminous limestone (Bellen *et al.*, 1959). The lithological composition of the Sargelu Formation is nearly same composition in the outcrops and subsurface (wells) along the whole area (Buday, 1980). The thickness of the formation in the outcrops can be 20–125 m in the High Folded and Imbricated Zones (115 m in its type locality section). However, in the subsurface sections, it is between 250 and 500 m in the Foothill and Mesopotamian Zones (Unstable Shelf) (Ditmar *et al.*, 1971).

The Late Triassic - Early Jurassic was the time of opening the Neo-Tethys (Dercourt *et al.*, 1986). Iraqi Unstable Shelf changed to a deep-sea environment due to the Neo-Tethys

opening and subsidence of the Unstable Arabian Shield (Numan, 1997). Marouf (1999) believes that due to the cooling of the adjacent oceanic crust that results crustal under loading, there was increasing in the deepening and subsidence of the basin to Eastward. There was a major change in depositional setting, and climate pattern occurred during the Middle Jurassic. There were rare evaporates deposition and more humid climate (Murris, 1980). Liassic sedimentary basins had changed to euxinic basins, and the sedimentation setting became more uniform (Buday, 1980).

In Iraq, the Sargelu and Muhaiwir formations represent the Middle Jurassic [Figure 1]. The Sargelu Formation has a broad geological distribution in Iraq, and the depositional basin was NW-SE trends (Balaky, 2004). The western edge shoreline of the basin was represented by the Rutba-Jazeera Zone, and the eastern shoreline with the zone of western Iran, Sanandaj-Sirjan Block (Jassim and Karim, 1984). The Sargelu Formation geographic distribution extends toward southeastern Iraq, Kuwait, and southwestern Iran in Lurestan zone and partly Khuzestan region from Geosyncline of Zagros (Darvichzada, 1992). The main aim of this study is to address the source rock potential and lateral changes in thermal maturity of organic matter (OM) of the Sargelu Formation in the selected sections as following: (1) Banik village near Zakho Town, (2) Barsarin village near Rowanduz, Balak, and (3) Walasimt village near Said Sadiq Town. According to the Iraqi Tectonic Division (Jassim and Buday, 2006), these sections are within the Imbricated (Balambo - Tanjero) and High Folded Zones [Figure 2].

2. PREVIOUS STUDIES

Al-Barzanji (1989) though that the Sargelu Formation was deposited in the euxinic marine basin. The generation and migration of hydrocarbons of the Sargelu Formation were studied by Othman (1990), he concluded that the OM of the Sargelu Formation belongs to Type II and Type III kerogen. Beydoun (1993) evaluated the formation as a potential source rock that had entered into oil generation stage in the Late Eocene and entered into condensate and gas generation at present day. Pitman *et al.* (2004) believed that the common source rock for hydrocarbon generation in Folded Belt and Zagros Thrust Zone is the carbonate and shale rock units of the Jurassic (mainly the Sargelu Formation). The lower part of the Surmeh Formation in Iran and Dhruma Formation in Saudi Arabia is the age equivalent to the Sargelu Formation (Jassim and Buday, 2006). Abdula (2010; 2014) in his study on the Sargelu Formation concluded that the OM of the

Figure 1. Stratigraphic correlation of Jurassic formations in Kurdistan Region and North Iraq (compiled from Dunnington, 1958, Bellen *et al.*, 1959, Buday, 1980, Al-Sayyab *et al.*, 1982, and Jassim and Goff, 2006). The dark belts at the end of Early and Middle Jurassic in the figure refer to Hiatus. (Figure is taken from Al-Badry, 2012)

Sargelu can be Type II and III kerogen. The most recent study on the Sargelu Formation in Miran Oil Field by Fatah and Mohialdeen (2016) reveal that the main kerogen type of the Sargelu Formation is a mixed Type II/III kerogen and is thermally post mature and in the gas generation zone.

3. MATERIALS AND METHODS

3.1. Field Work
To obtain rock samples, a detail field-work was carried out in one session, August 2016. During fieldwork the sections were logged with a detail description of the outcrops, for examples, the thickness of formation, lithology, and optical properties such as color were recorded in the logs. Due to some official difficulties, no well data were used in this study.

3.2. Lab Works
Rock-Eval pyrolysis was done in the Soran University (Scientific Research Center). The gas chromatography-mass Spectrometry (GC-MS) samples were analyzed in the Department of the Geology and Petroleum Geology in University of Aberdeen- Scotland/UK.
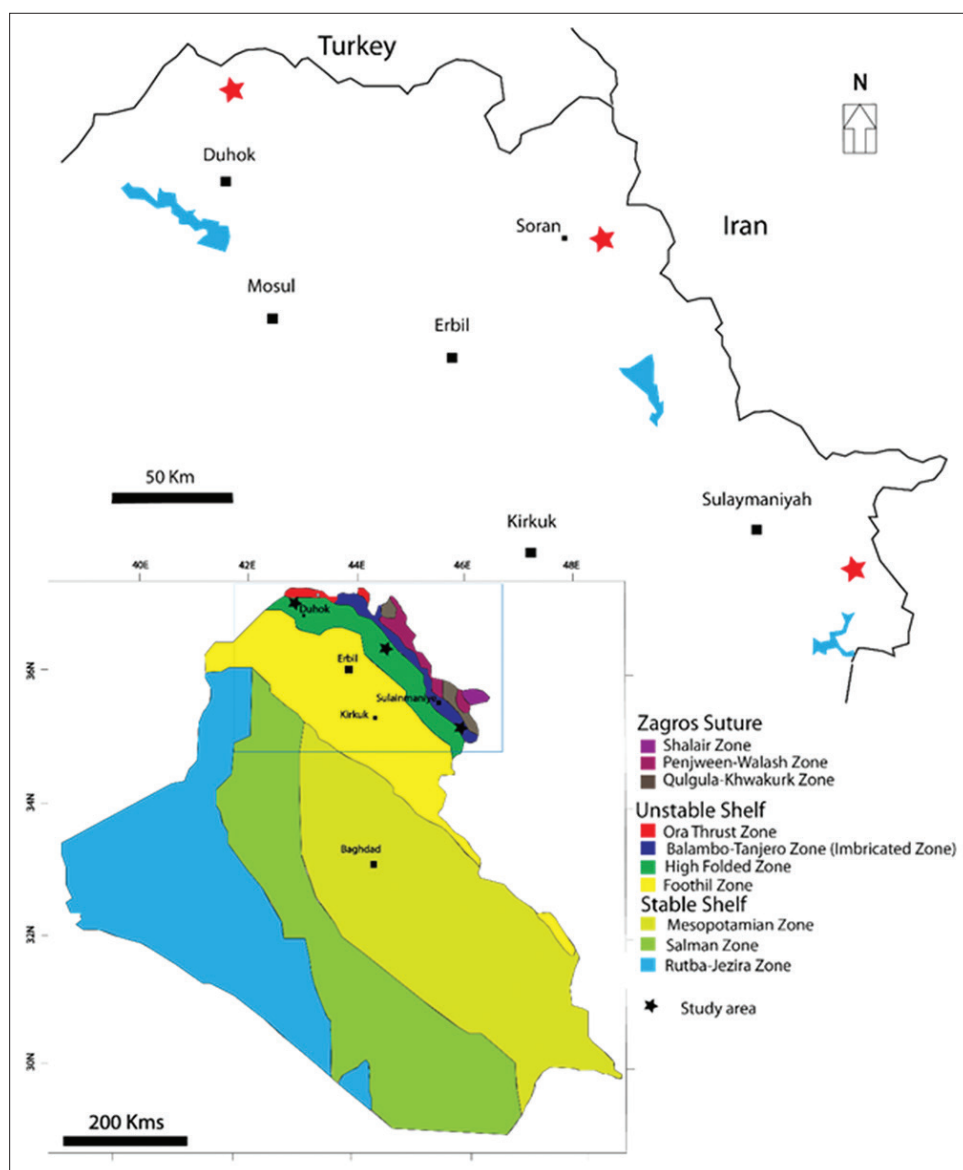
Figure 2. Main tectonic zones of Iraq and approximate locations of the studied areas (Maps are modified from Numan, 2000, Jassim and Buday, 2006, Sissakian and Al-Jiburi, 2014, and google map 2017)

3.3. Rock-Eval Pyrolysis

One of the most important techniques in organic geochemistry for source rock appraisal is using Rock-Eval Pyrolysis (Espitalie *et al.*, 1997; Whelan and Thompson-Rizer, 1993). The Rock-Eval pyrolysis method consists of a programmed temperature heating (in a pyrolysis oven) in an inert atmosphere (helium) of a small sample to quantitatively and selectively determine: (1) The amount of free hydrocarbons (S_1), (2) the amount of hydrocarbons generated through thermal cracking of nonvolatile OM (S_2), (3) the amount of CO_2 produced during pyrolysis of kerogen(S_3), and (4) the temperature at which the maximum

release of hydrocarbons from cracking of kerogen occurs during pyrolysis (Tmax), it is an indicator of OM maturity stages.

3.4. GC-MS Analysis

GC-MS analysis was carried out with an Agilent Technologies (AT) 6890N Network GC (pulsed splitless) system fitted with a 30.0 m×250.0 μm i.d film thickness 0.25 μm fused silica DB-5 column coupled to an AT 5975 quadrupole mass selector detector (electron energy 70 eV, source 250°C) with He as carrier gas, normal initial flow: 1.3 mL/min. The GC temperature program for saturated hydrocarbons was hold

at 60°C for 2 min, rising at 20°C/min–120°C, and then rising at 4°C/min–290°C and then holding for 23 min. Data acquisition was controlled by CHEMSTATION software in ion selection monitoring for saturated.

4. RESULTS AND DISCUSSION

4.1. Biomarkers Characteristics of the Sargelu's extractable organic matter

The biomarkers indicate the specific OM input and the condition of its depositional environment, and can be linked back to the natural precursors of algae, bacteria, and other plants from that they are derived (Hunt, 1996). Biomarkers are used to determine the depositional environment, OM input, thermal maturity, oil-source, and oil-oil correlation (Peters *et al.*, 2005). Aliphatic fractions in biomarker analyze for the compound are focused on four groups; isoprenoid, n-alkanes, steranes, and terpenes.

4.2. Acyclic Alkanes and Isoprenoids

Hydrocarbons of n-alkanes and isoprenoids can be identified and described from their mass spectra in the total ion chromatogram (TIC), and the m/z 85 ion chromatogram [Figure 3]. Elevated m/z 183 fragments and their molecular ion (M⁺) were used to identify the isoprenoids typically in the mass spectra.

4.3. N-alkane Ratios (Pristane/Phytane)

The Pr/Ph ratios are commonly used to deduce the oxic/anoxic nature of the source of OM and depositional environments (Peters and Moldowan, 1993). The high Pr/Ph ratios are thought to be associated with OM which subjected

by oxidation to the phytol side chain of chlorophyll since this oxidation leads to the formation of the pristane (Peters and Moldowan, 1993). It is also believed that both pristane and phytane were derived from the phytol side chain of chlorophyll (Powell and Makirday, 1973). It is difficult to obtain a conclusive interpretation of redox conditions in the depositional environments using Pr/Ph ratio; therefore, these ratios should be used with caution. However, it is recommended that Pr/Ph >3.0 indicates oxic depositional environments, while between 1.25 and 2.13 could show anoxic to suboxic and a Pr/Ph <0.6 could indicate anoxic water column during the sediment depositional (Peters and Moldowan, 1993). All analyzed samples show Pristane/Phytane value <1.0 (the values range between 0.49 and 0.84), except one sample (1.0) [Table 1]. These values may show that the sediments of the Sargelu Formation deposited in an anoxic environment.

4.4. Steranes

The distributions of regular steranes (C_{27}, C_{28}, and C_{29}) can be obtained by the m/z 217 ion chromatograms [Figure 4]. The steranes are considered as significant biomarkers. It is believed that they are derived from sterols that are found in higher plants and algae, but rare or absent in prokaryotic organisms (Volkman, 1986). Distribution of the steranes could be used to identify source, type, and thermal maturity of OM (Seifert and Moldowan, 1979; Peters *et al.*, 2005).

4.5. Thermal Maturity Parameters of the Steranes

The C_{29} sterane ratios (20S/(20S+20R) and ββ/(ββ+αα)) are frequently used as thermal maturity indicator for OM because C_{29} sterane ratios increase with increasing thermal maturity
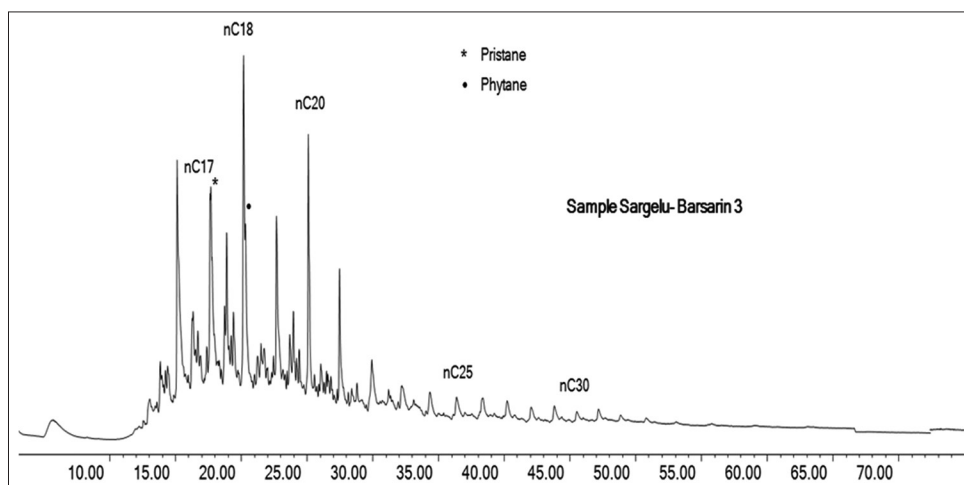

Figure 3. Chromatograph of the n-alkanes and isoprenoids distribution (m/z 85) in sample No. 3 of the Sargelu in Barsarin section

Table 1. Biomarkers parameters that are used in this study

Formation	Sample no.	Pristane/Phytane (Pr/Ph)	C_{29}/C_{30} Hopanes	22S/(22S+22R) C_{32} Hopanes	20S/(20S+20 R) C_{29} Steranes	$\beta\beta/(\beta\beta+\alpha\alpha)$ C_{29} Steranes
Sargelu	Banik 2	0.68	1.93	0.60	0.40	0.53
Sargelu	Banik 7	1.00	0.79	0.56	0.42	0.56
Sargelu	Barsarin 3	0.83	0.95	0.57	0.48	0.57
Sargelu	Barsarin 11	0.54	0.71	0.59	0.48	0.56
Sargelu	Wala simt 2	0.50	0.98	0.60	0.47	0.54
Sargelu	Wala simt 26	0.57	0.96	0.61	0.44	0.55
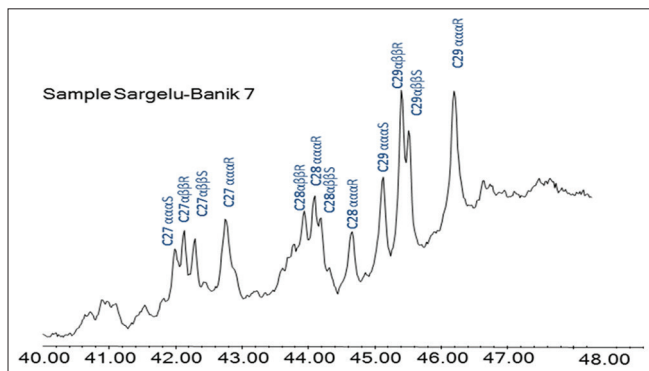
Figure 4. Chromatographs (GC-MS) show distribution (m/z 217) of sterane of the Sargelu Formation in Banik area

(Peters *et al.*, 2005). The ratio of steranes isomerization 20S/(20S+20R) ranges from 0 to 0.5 with increasing thermal maturity (Peters *et al.*, 2005). Likewise, due to isomerization at C-14 and C-17 in the C_{29} 20S and 20R regular steranes, the ratios of $\beta\beta/(\beta\beta+\alpha\alpha)$ tend to increase from 0 to 0.7 value (Peters *et al.*, 2005). The C_{29} 20S/(20S+20R) sterane ratios of 0.35 and 0.5 can be corresponded with Ro=0.6% and 0.8%, respectively (Waples and Machihara 1991; Peters and Moldowan 1993; Peters and Moldowan 1991). As shown in Figure 5 and Table 1, all samples are in Peak Oil Window at least, but the samples of the Wala simt and Barsarin areas are seem more mature than Banik area.

4.6. Terpanes (Hopanes)

The distribution and relative abundances of the terpanes obtained from m/z 191 ion chromatograms (Brooks *et al.*, 1969; Peters *et al.*, 2005) [Figure 6]. There are some terpanes parameters that can be used to assess the depositional environment of the sediments such as tricyclic and tetracyclic terpanes, Ts/Tm ratio, C_{29}/C_{30} ratio, Gammacerane. In this study, only C_{29} hopane/C_{30} hopane ratio was used for assessment of the depositional environment. C_{30} hopane is associated with clay-rich source rock (shale), while the dominance of C_{29} hopane indicates carbonate and evaporate sediments (Waples and Machihara, 1991). As shown in Table 1, the samples of the

Sargelu Formation seem to be associated with clay-rich source rock.

There are some parameters of terpanes can also provide significant information on thermal maturity of the EMO and oils. Thermal maturity of the oils and extracted OM can be evaluated using the following biomarker parameters: Hopane isomerization C_{32} $\alpha\beta$ 22S/(22S+22R), C_{27} Ts/(Ts+Tm) hopanes, and C_{30} $\beta\alpha$-moretane/C_{30} $\alpha\beta$ hopane ratio (Seifert and Moldowan, 1978; Mackenzie *et al.*, 1980; Moldowan *et al.*, 1985; Peters and Moldowan, 1993; Peters *et al.*, 2005). The equilibrium value of the C_{32} 22S/(22S+22R) hopanes epimerization ranges from 0.55 value to 0.6 (0.57–0.62 equilibrium) (Waples and Machihara, 1991). The samples that have 22S/(22R+22S) ratios in the range 0.50–0.54 are in Early Oil Window (low mature), whereas samples with ratios in the range 0.57–0.62 show that they have reached to Peak Oil Window at least (Peters *et al.*, 2005). In current study, the 22S/(22R+22S) ratios show that all samples are in Peak Oil Window [Table 1 and Figure 7]. Due to lithological influence on the C_{27} Ts/(Ts+Tm) ratio, it was not used in the assessment of the thermal maturity of OM in this study. All thermal maturity parameters of steranes and hopanes show that the extracted OM of the Sargelu Formation has been reached Peak Oil Window. The notable point is that the samples from the east of Kurdistan Region seem to be more mature than west [Table 1 and Figures 5 and 7].

5. SOURCE ROCK EVALUATION

Those sedimentary rocks which may have been able or it becomes to generate petroleum are called source rocks (Tissot and Welte, 1984). Qualitative source rock is a rich organic compound which generated the petroleum in appropriate condition under influence of temperature and time (Rullkötter, 1987). The Rock-Eval Pyrolysis technique provides information about thermal maturation and type of the organic from prospective potential source rocks (Peters, 1986).

5.1. Total Organic Carbon (TOC)

The quantity of organic carbon in a source rock which contains kerogen and bitumen are called TOC that represents by percentage of weight (TOC and weight %), (Peters and Cassa, 1994). The values of the TOC from pyrolyzed samples are shown in Table 2. The TOC values
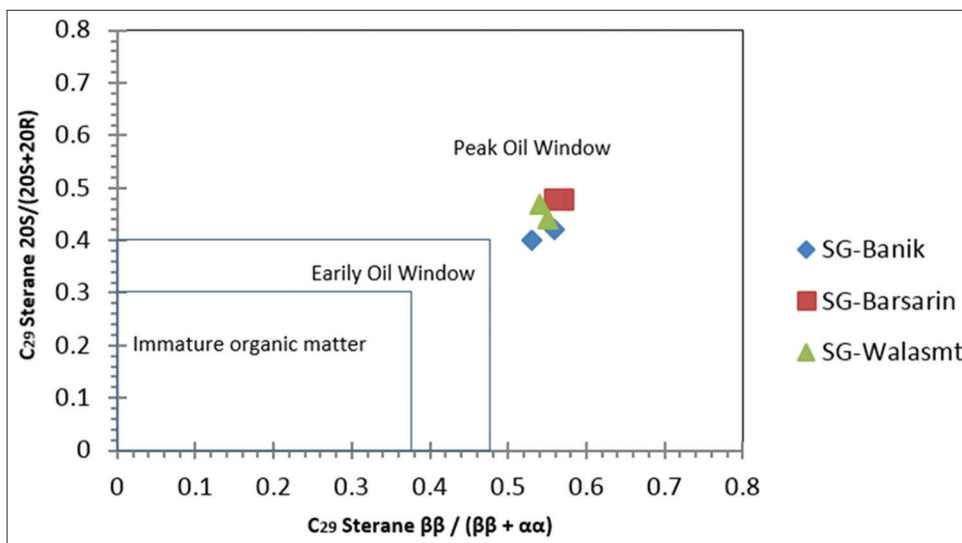

Figure 5. The plot of C29 steranes $\beta\beta/(\beta\beta+\alpha\alpha)$ versus C29 steranes 20S/(20S+20R) for determining thermal maturity of extractable organic matter
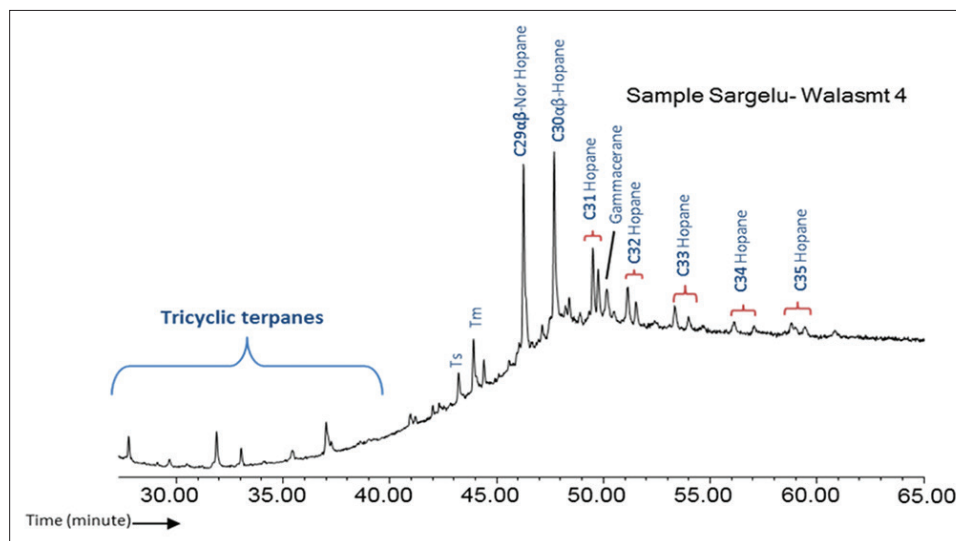

Figure 6. Chromatographs gas chromatography-mass spectrometry of hopane (m/z 191) for sample No. 4 of the Sargelu in Wala simt

Table 2. The values of Rock-Eval Pyrolysis parameters for the sample of the Sargelu Formation

Samples	TOC Wt. %	S_1 mg/g rock	S_2 mg/g rock	S_3 mg/g rock	HI mg/g TOC	OI mg/g TOC	Genetic Potential mg/g rock	PI	HI (S_2/S_3)	T max °C
Bank 2	1.32	0.05	3.18	1.51	241	114	3.23	0.01	2.10	438
Bank 7	12.07	0.25	48.24	2.43	400	20	48.49	0.01	19.85	442
Barsarin 3	0.6	0.08	0.33	0.74	55	123	0.41	0.19	0.44	577
Barsarin 11	2.18	0.01	0.26	3.33	12	153	0.27	0.04	0.07	527
Wala simt 2	0.05	0.01	0.05	0.25	100	500	0.06	0.2	0.20	504
Wala simt 26	0.13	0.03	0.08	0.21	62	162	0.11	0.27	0.38	574

TOC: Total organic carbon, PI: Production index, HI: Hydrocarbon index, OI: Oxygen index

are between 0.05 and 12.07. Wala simt samples show the lowest values. However, the Banik samples display the highest values of TOC. The Wala simt and Barsarin samples indicate Poor to Fair source rock quality, respectively, but samples of the Sargelu Formation in Banik area can be considered as Good to Excellent source rock quality. Very low TOC values in the Wala simt may be resulted of the contamination. S_1 (mg/g of rock) peak is the total amount of free hydrocarbon measured during the first stage of pyrolysis analyze at the fixed temperature of 300°C.
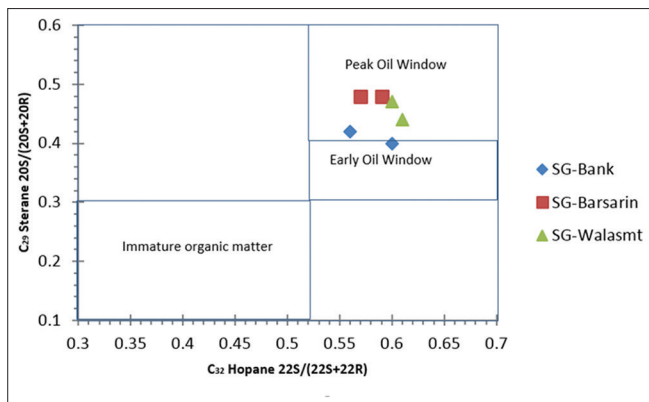
Analyzed samples show the values are ranging from 0.01 to 0.25. The lowest value is from the Wala simt area (0.01 mg HC/g rock), while the highest value can be seen in Banik area (0.25 mg HC/g rock) [Table 2]. All analyzed samples show poor quality for the source rock petroleum potential. S_2 (mg/g of rock) indicates the amount of hydrocarbon that generated from cracking of kerogen from source rock in the second stage of pyrolysis. As shown in Table 2, the S_2 values for the Sargelu Formation in Banik area show the highest values (3.18 and 48.24 mg HC/g rock) in which the OM can be considered as Fair and Excellent quality for petroleum potential. On the other hand, the samples of the Wala simt and Barsarin sections indicate poor petroleum potential quality. By plotting S_2 versus TOC, OM of the Sargelu Formation can be lean OM in Barsarin and Wala simt, while it can be considered as Type II and IV in Banik area [Figure 8]. Production Index (PI) $[S_1/(S_1+S_2)]$ also called Transformation Ratio which is referring to the amount of hydrocarbon which has been produced relative to the total amount of hydrocarbon from a rock sample (Nunez-Betelu and Baceta, 1994, Tissot and Welte, 1984). By plot PI versus Tmax, it can be deduced that the OM of the Sargelu Formation in Banik area is in Oil Window and early stage of hydrocarbon generation. However, in Barsarin and Wala simt area, it seems to be in Gas Window and higher level of hydrocarbon conversation (overmature) [Figure 9].
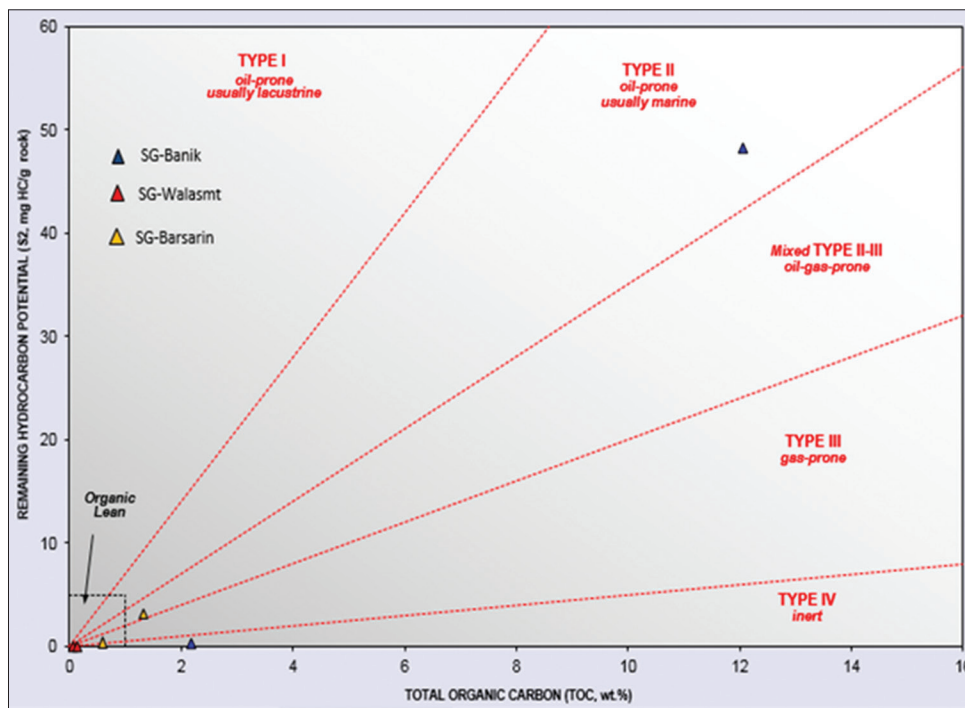

Figure 7. The Plot of C32 Hopanes 20S (20S+20R) versus C29 Steranes 20S (20S+20R), indicating the level of thermal maturity of organic matter

Figure 8. Total organic carbon (total organic carbon wt.) versus remaining hydrocarbon potential for the studied sections
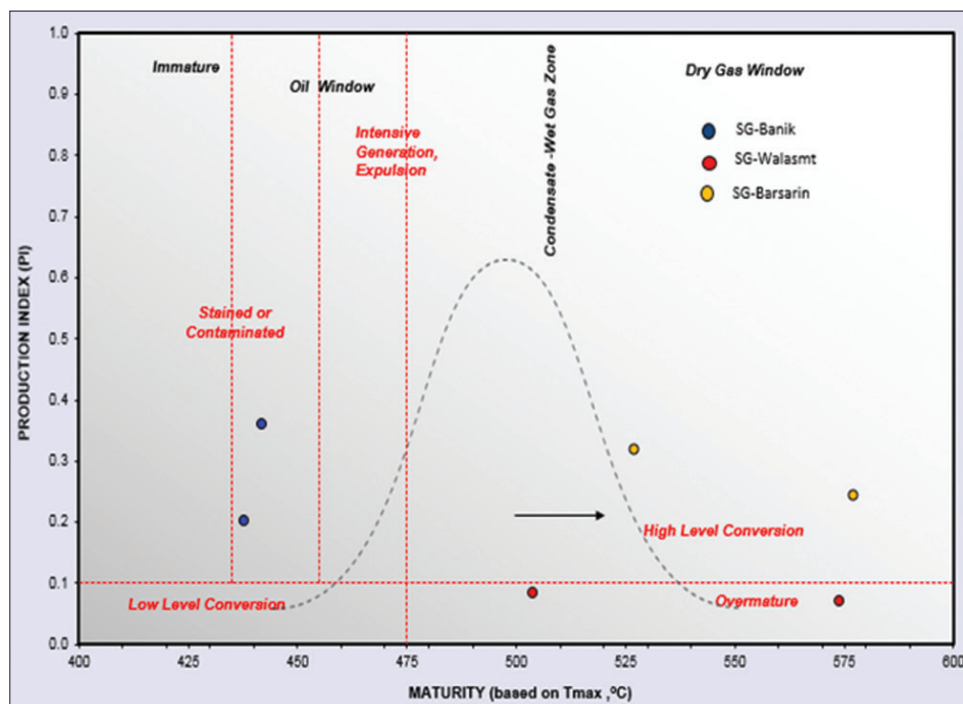
Figure 9. Tmax versus production index for the samples from (Banik, Wala simt, and Barsarin). The samples in Banik area are in the early oil window, while the samples of the Barsarin and Wala simt sections are in overmature zone

Kerogen is high molecular-weight of compound which consists of OM within sediments (Whelan and Thompson-Rizer, 1993). Kerogen is insoluble in aqueous alkane solvents and solvents of common organic (Tissot and Welte, 1984). Due to variation in chemical structure, a different type of OM has different kerogen type (Tissot and Welte, 1984).

The hydrocarbon index (HI) $[S_2/S_3]$ is the ratio of the amount of hydrocarbon which a source rock can produce (S_2) relative to the amount of organic CO_2 that release during temperature programming (Nunez-Betelu and Baceta, 1994). The samples of the Sargelu Formation show the values of 0.36–19.58. Based on the HI, the samples of the Sargelu in Banik area are considered as type I and III kerogen. However, samples of the Sargelu Formation from Barsarin and Wala simt indicate type IV kerogen. Type I kerogen displays highly oil-prone, type II kerogen oil-gas prone, type III kerogen gas prone, and type IV kerogen no hydrocarbon. Hydrogen Index and Oxygen index (OI) can be also obtained from the values of S_2 and S_3. HI value shows the amount of hydrocarbon from S_2 or pyrolysable organic compound relative to the TOC that mathematically expressed as $(S_2 \times 100/TOC)$. However, OI is determined as the quantity of CO_2 from S_3 value relative to the TOC, and it measured in milligram of carbon dioxide per each

gram of TOC (mg CO_2/g TOC). It can be calculated by the $(S_3 \times 100/TOC)$ formula. The origin of hydrocarbon can be determined using these parameters; for example, HI shows the potential of source rock to generate petroleum (Tissot and Welte, 1984; Peters, 1986; Hunt 1996). Type I kerogen usually contains HI values >600 mg HC/g TOC; Type II kerogen normally has HI values 300–600 mg HC/g TOC; a mixture of Type II and Type III has a low Hydrogen Index 200–300 mg HC/g TOC; type III kerogen generally contains HI values 50–200 mg HC/g TOC, and Type IV kerogen commonly has HI values of <50 mg HC/g TOC (Tissot and Welte, 1984; Peters and Cassa, 1994). Based on the HI values, the Banik's samples can be considered as Types II–III kerogen, and Barsarin and Wala simt samples are more likely Type III and mixed III–IV kerogen [Table 2]. By plotting the values of HI versus OI four main types of kerogen can be determined, but in some cases, such as coal rock and gas-prone coal may give anomaly of high HI value (Peters and Cassa, 1994). As shown in Figure 10, the kerogen type of OM for analyzed samples can be mixed Types II–III and III–IV. Thus, OM of the Sargelu Formation in Banik is more likely Oil-Gas prone, while in Barsarin and Wala simt it seems Gas-prone or inert. A high value of the OI is usually associated with rocks that containing remarkable quantities of primary carbonate minerals such as calcite, dolomite, and
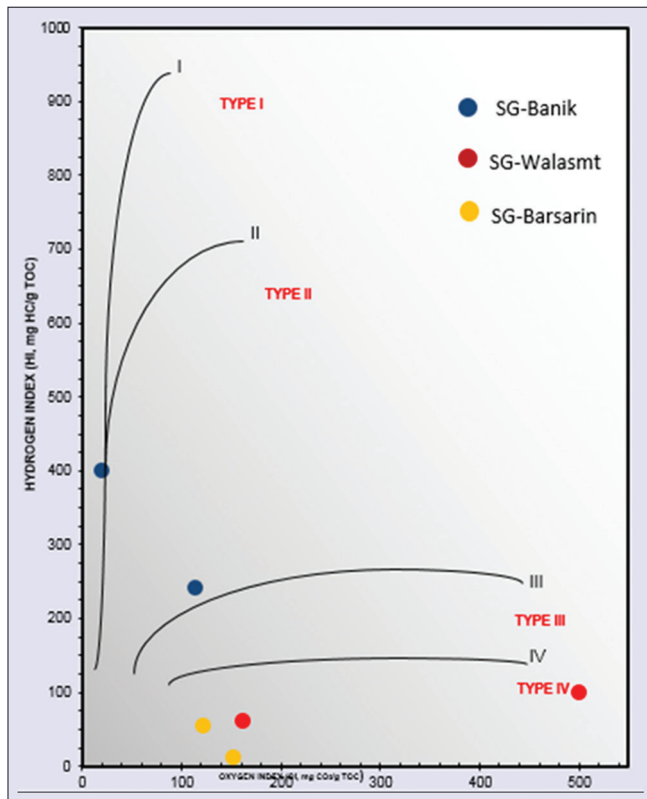
Figure 10. Hydrogen index (mg HC/g total organic carbon [TOC]) versus oxygen index (mg CO2/g TOC) show that kerogen type for the Sargelu sediments is belonging to mixed Types II–III kerogen for Banik area, and Type IV kerogen for Barsarin and Wala simt. Note; the OI value more than 250 may not reliable

Figure 11. The plot of Tmax versus hydrocarbon index, and the level of maturity and Kerogen type for analyzed samples

siderite (Katz, 1983). This case can be seen in one sample of the Wala simt [Figure 10].

Tmax is the highest temperature which on that temperature the maximum amount of hydrocarbon is degraded during Rock-Eval pyrolysis. The peak of S_2 shows the value of Tmax. The Tmax value does not show the rock's burial temperature; however, it can show the level of thermal maturity of the OM, there is gradually increase in Tmax value by increasing burial depth (Nunez-Betelu and Baceta, 1994).

In general, a value <435°C shows immature OM (immature zone), Tmax values between 435 and 455°C display mature OM (Oil Window). However, the values between 455 and 470°C show high mature OM (Transition zone-Gas Window). The values >470°C indicate Wet-Gas or the overmature zone (Peters, 1986) [Table 2]. Analyzed samples from studied sections show the value 438–442°C for Banik samples, 504 and 574°C Tmax for Walasimt. The Tmax values for the Barsarin are 577 and 527°C [Table 2]. All samples of

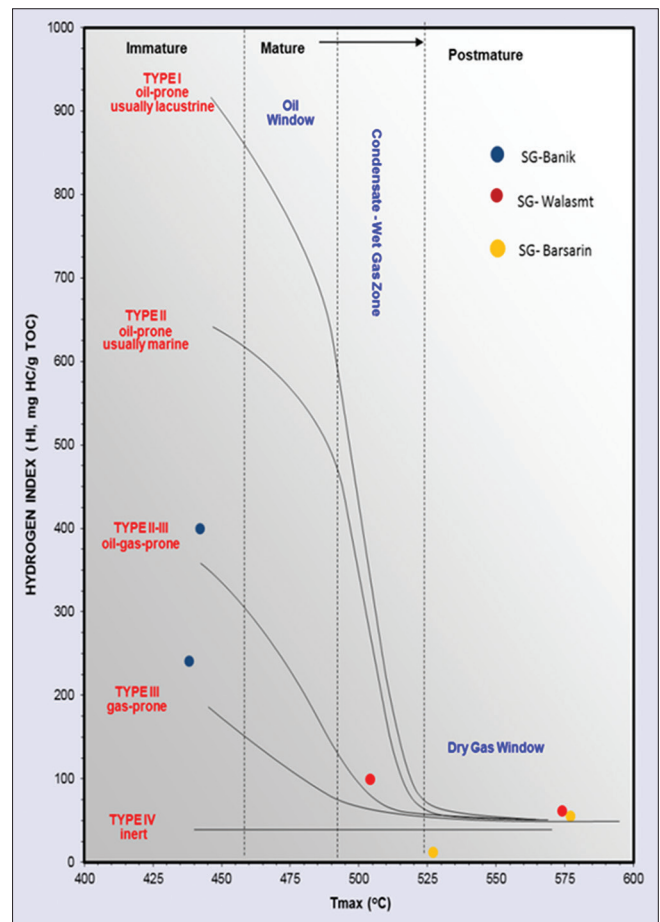Barsarin and Wala simt indicate the Post-Mature stage for the source rock, but the samples of Banik are in the Mature stage. The Tmax values of the Barsarin and Wala simt areas are abnormal and may be unreliable. Regardless of Tmax anomalous, results are in agreement with biomarkers data for thermal maturity. Moreover, by plotting Tmax versus HI, the samples of the Banik section are in early stage of maturity. However, both Barsarin and Wala simt sections show the post-mature level of thermal maturity [Figure 11].

6. SUMMARY AND CONCLUSIONS

Biomarker parameters such as Pr/Ph, C_{29}/C_{30} terpanes ratios show that the OM of the Sargelu Formation was deposited in an anoxic depositional environment that associated with clay-rich source rock.

The geochemical analyzes (include Rock-Eval Pyrolysis and GC-MS) for six samples from all sections show the values of

TOC wt. % decrease from northwestern (Banik area) toward north and northeastern of Iraq (Wala simt area). The TOC wt. % show the highest value in Banik section (12.07 mg HC/g Rock), and lowest value in Wala simt section (0.05 mg HC/g rock). The free hydrocarbon (S_1) for the samples show poor quality in all sections, the values of S_2 are also low, and the ability of source rock to generate petroleum is poor in Wala simt and Barsarin sections, while in Banik section it is fair.

The analyzed samples show that the OM is characterized by Types II–III kerogen for Banik section (Oil-Gas Prone), and mixed III–IV kerogen for Barsarin and Wala simt areas (gas-prone).

The biomarker parameters for thermal maturity such as steranes C_{29} 20S (20S+20R), steranes C_{29} ββ/(ββ+αα), and C_{32} hopanes 22S/(22S+22R) show that all samples are thermally in Oil Window. However, the samples of Wala simt and Barsarin are thermally more mature than Banik section.

Tmax values for Banik area exhibit that OM is in the early stage of thermal maturity (Oil Window), while it is in Gas-Oil Window (Overmature) in Barsarin and Wala simt areas. The most significant conclusion in this study is finding the changes in thermal maturity from Wala simt to Banik area (from high thermal maturity to low thermal maturity). It was concluded that regardless of abnormal data of Tmax values, the Tmax values are consistent with biomarker parameters for thermal maturity. The differences in thermal maturity from a studied section can be due to the high amount of overburden sediments in the east in comparison to the west of Kurdistan region through geological history of the area.

7. ACKNOWLEDGMENTS

REFERENCES

Abdula, R. (2010). *Petroleum Source Rock Analysis of the Jurassic Sargelu Formation, Northern Iraq.* M.S. Thesis, Colorado School of Mines, Golden, Colorado. p. 106.

Abdula, R. A. (2014). Hydrocarbon potential of Sargelu formation and oil-source correlation, Iraqi Kurdistan. *Arabian Journal of Geoscience,* 8(8), 5845-5868.

Al-Barzanji, S. T. M. (1989). *Facies Analysis for Muhaiwir Formation-W.* Iraq: M.S. Thesis (Unpublished), Science College, University of Baghdad, Baghdad, Iraq. p. 86.

Al-Sayyab, A., Al-Ansari, N., Al-Rawi, D., Al-Omari, F., Al-Shaikh, Z. & Al-Jassim, J. (1982). *Geology of Iraq.* Mosul: University of Al-Mosul. p. 280.

Aqrawi, A. A. M., Goff, J. C. Horbury, A. D. & Sadooni, F. N. I. (2010). *The Petroleum Geology of Iraq: Beaconsfield.* United Kingdom: Scientific Press Ltd. p. 424.

Balaky, S. M. H. (2004). *Stratigraphy and Sedimentology of Sargelu Formation (Middle Jurassic) in Selected Sections in Erbil and Duhuk Governorates–Iraqi Kurdistan.* M.S. Thesis (Unpublished), Science College, University of Salahaddin, Erbil, Iraq. p. 109.

Bellen, R. C., Van Dunnington, H. V., Wetzel, R. & Morton, D. M. (1959). *Lexique Stratigraphique International.* Vol. III. Paris: Asie, Fasc., 10a Iraq. p. 333.

Brooks, J. D., Gould, K. & Smith, J. W. (1969). Isoprenoid hydrocarbons in coal and petroleum. *Nature,* 222, 257-259.

Buday, T. (1980). *The Regional Geology of Iraq. Stratigraphy and Paleogeography.* Vol. 1. Iraq: Dar Al-Kutub Publication University of Mosul. p. 445.

Beydoun, Z. R. (1993). Evolution of the northeastern Arabian plate margin and shelf: Hydrocarbon habitat and conceptual future potential. *Revue de L'Institut Francais du Petrole,* 48, 311-245.

Darvichzada, A. (1992). *Geology of Iran.* Tehran: G.S. of Iran. p. 901.

Dercourt, J., Zonenshain, L. P., Ricou, L. E., Kazmin, V. G., Le Pichon, X., Knipper, A. L., Grandjacquet, C., Sbortshikov, I. M., Geyssant, J., Lepvrier, C., Pechersky, D. H., Boulin, J., Sibuet, J. C., Savostin, L. A., Sorokhtin, O., Westphal, M., Bazhenov, M. L., Lauer, J. P. & Biju-Duval, B. (1986). Geological evolution of the Tethys belt from the Atlantic to the Pamir since the Lias, In: Aubouin, J., Le Pichon, X. & Monin, S., editors. *Evolution of the Tethys.* Vol. 123. Amsterdam: Tectonophysics. pp. 241-315.

Diatmar, V. & Others. (1971). Geological Conditions and Hydrocarbon Prospects of the Republic of Iraq (Northern and Central Parts). Techno Export Report. Baghdad: INOC Library.

Dunnington, H. V. (1958). Generation, migration, accumulation, and dissipation of oil in Northern Iraq. In: Weeks, L.G., editor. *Habitat of Oil, a Symposium*, AAPG Bulletin. p. 1194-1251.

Hunt, J. M. (1996). *Petroleum Geochemistry and Geology.* 2nd ed. San Francisco: W.H. Freeman. p. 707.

Jassim, S. Z. & Buday, T. (2006). Late Toarcian-Early Tithonian (Mid-Late Jurassic) Megasequence AP7, Chapter 10. In: Jassim, S. Z. & Goff, J. C., editors. *Geology of Iraq.* 1st ed. Brno, Czech Republic: Prague and Moravian Museum. pp. 117-123.

Jassim, S. Z. & Al-Gailani, M. (2006). Hydrocarbons, Chapter 18. In: Jassim, S. Z. & Goff, J. C., editors. *Geology of Iraq.* 1st ed. Brno, Czech Republic: Prague and Moravian Museum. pp. 232-250.

Jassim, S. Z. & Karim, S. A. (1984). Final Report on Regional Geology Survey of Iraq: Paleogeography. Vol. 4. Baghdad, Iraq: State Organization for Mineral. p. 69.

Katz, B. J. (1983). Limitations of Rock–Eval' pyrolysis for typing organic matter Org. *Geochem,* 4, 195-199.

Marouf, N. Z. (1999). *Dynamic Evolution of the Sedimentary Basins in Northern Iraq and Hydrocarbon Formation, Migration and Entrapment.* Ph.D. Thesis (Unpub.), University of Baghdad. p. 236.

Murris, R. J. (1980). Middle East–stratigraphic evolution and oil habitat.

AAPG Bulletin, 64(5), 597-618.

Numan, N. M. S. (1997). A plate tectonic scenario for the Phanerozoic succession in Iraq. *Iraqi Geological Journal*, 30(2), 85-110.

Numan, N. M. S. (2000). Major cretaceous tectonic events in Iraq. *Rafidain Journal of Science,* 11(3), 32-54.

Nunez-Betelu, L. & Baceta, J. I. (1994). *Basics and Application of Rock-Eval/TOC Pyrolysis: An Example from the Uppermost.* Western Pyrenees: Paleocene/lowermost Eocene in The Basque Basin. pp. 5-13.

Othman, R. S. (1990). *Generation, Migration and Maturation of the Hydrocarbons in Northern Iraq (Upper Jurassic-Lower Cretaceous).* M.S. Thesis (Unpublished), Science College, University of Salahaddin, Erbil, Iraq. p. 208.

Peters, K. E. (1986). Guidelines for evaluating petroleum source rock using programmed pyrolysis. *American Association of Petroleum Geologists Bulletin*, 70, 318-329.

Peters, K. E. & Moldowan, J. M. (1991). Effects of source, thermal maturity, and biodegradation on the distribution and isomerization of homohopanes in petroleum. *Organic Geochemistry*, 17(1), 47-61.

Peters, K. E. & Moldowan, J. M. (1993). *The Biomarker Guide-Interpreting Molecular Fossils in Petroleum and Ancient Sediments.* New Jersey: Prentice-Hall, Englewood Cliffs. p. 363.

Peters, K. E. & Cassa, M. R. (1994). Applied Source Rock Geochemistry, Chapter 5. In: Magoon, L.B. & Dow, W. G., editors*. The Petroleum System—from Source to Trap*. Vol. 60. Tulsa: AAPG Memoir. pp. 93-120.

Peters, K. E., Walters, C. C. & Moldowan, J. M. (2005). *The Biomarker Guide. Biomarkers and Isotopes in Petroleum Systems and Earth History*. 2nd ed., Vol. II. United Kingdom: Cambridge University Press. p. 679.

Pitman, J. K., Steinshour, D. & Lewan, M. D. (2004). Petroleum generation and migration in the Mesopotamian basin and Zagros Fold Belt of Iraq, result from a basin modeling study. *GeoArabia*, 9(4), 41-72.

Powell, T. G. & McKirdy, D. M. (1973). Relationship between ratio of pristane to phytane, crude oil composition and geological environment. *Nature*, 243, 37-39.

Rullkötter, J. (1987). Geochemistry, organic. *Encyclopedia of Physical Science and Technology,* 6, 54-77.

Fatah, S. S. & Mohialdeen, I. M. J. (2016). *Hydrocarbon Generation Potential and Thermal Maturity of Middle Jurassic Sargelu Formation in Miran Field*. Sulaimani Area, Kurdistan Region, NE Iraq: JZS Special Issue, GeoKurdistan II. pp. 213-228.

Seifert, W. K. & Moldowan, J. M. (1979), The effect of thermal stress on source-rock quality as measured by hopane stereochemistry. *Physics and Chemistry of the Earth*, 12, 229-237.

Sissakian, V. K. & Al-Jiburi, B. A. M. (2014). Stratigraphy of the high folded zone, Iraqi. *Bulletion Geological Minimum Special Issue*, 6, 73-161.

Tissot, B. P. & Welte, D. H. (1984). *Petroleum Formation and Occurrence*. 2nd ed. Berlin: Springer-Verlag. p. 699.

Waples, D. W. & Machihara, T. (1991). Biomarkers for geologists–a practical guide to the application of steranes and triterpanes in petroleum geology. *AAPG Methods in Exploration*, 9, 91.

Volkman, J. K. (1986). A review of sterol biomarkers for marine and terrigenous organic matter. *Organic Geochemistry*, 9, 83-99.

Whelan, J. K. & Thompson-Rizer, C.L. (1993). Chemical methods for assessing kerogen and protokerogen types and maturity, Chapter 14, In: Engel, M. H. & Macko, S.A., editors. *Principles and Applications: Organic Geochemistry*. New York: Plenum Press. pp. 289-353.