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Source Rock Characteristic of Sargelu and Kurrachine Formations from the Selected Wells in Northern Iraq

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Abstract

A total of 56 cuttings samples of Sargelu and Kurrachine formations from different wells (Ain Zalah, Baiji, and Jabal Kand) in northern Iraq have been investigated in this study. Both the Sargelu and Kurrachine formations were examined using Rock-Eval pyrolysis to assess the richness of organic matter and thermal maturity level. The Sargelu Formation have Total Organic Carbon wt.% ranged from 0.22–2.52 wt.%, average 1.26 wt.% in Ain Zalah Well, and between 0.57–8.90 wt.%, average 2.95 wt.% in Baiji Well, and between 0.81–11.80 wt.%, average 5.01 wt.% in for Kand Well. It is considered a potential source rock based on total organic carbon content. total organic carbon wt. % in Ain Zalah and Kand in the Kurrachine Formation is considered poor source rock with a total organic carbon content of 0.17, 0.39 wt. %, respectively, while in Baiji Well is considered moderate source rock with total organic carbon content 0.53 wt. %. The Rock-Eval data are not always sufficient to define the kind of organic matter through the use of the van Krevelen diagram because HI and OI are affected by both matrix mineralogy and the kerogen mixture. For accurate assessments of the source rocks, gas chromatography has been relied on, which provides a direct indication of the kerogen type as well as the type of hydrocarbons that kerogen can generate during maturity. Gas chromatography analysis indicates that all selected samples contained type II kerogen. The highest value of the TAS/ (MAS+TAS) ratio was found in Ain Zalah samples (Sargelu Formation), and this result indicates the occurrence of an aromatization process with increasing thermal maturation.

Keywords: Sargelu; Kurrachine; Source rock; Organic matter; Maturity; Aromatic

1. Introduction

Petroleum source layers are fine-grained, silicate rocks rich in clay (mudstone, shales) or dark-colored carbonate rocks (marlstones, limestone) that have generated and expelled hydrocarbon effectively (Leythaeuser, 2005). The source rocks contain great quantities of organic material consequent from the death of different species, including animals and plants, entombed and to different processes of heat and pressure for millions of years and is capable to produce significant amounts of hydrocarbons which can produce oil and gas. Peters et al. (2012) distinguished the petroleum source

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rock into effective, active, and inactive potential as follow; Effective: Currently it is generating or has been generated and expelled; Potential: Containing organic matter in sufficient quantities but not yet expelled; Active: Petroleum is generated subjected and expelled at the critical moment; Inactive: Stopped generating due to uplift and/or reduced thermal stress, despite petroleum potential remains.

Source rock is one of the essential elements for generating hydrocarbon, and the capacity of source rocks for petroleum generation is based on the (quantity, quality) of organic matter and thermal maturity (Peters and Cassa, 1994). Different studies were done on the Sargelu Formation (Middle Jurassic) and Kurrachine Formation (Upper Triassic) source rocks. They have been studied from outcrops and well cuttings by many researchers e.g. Jassim and Al-Gailani (2006) studied petroleum systems in the Triassic and Jurassic; Al-Ameri et al. (2009) in their study on the palynofacies of the upper units of Kurrachine and Baluti formations concluded that the organic matter within the Kurrachine Formation consists of thermally mature mixed kerogen types II and III; Abdula (2010 and 2015) identified two types of kerogen (II and III) in the Sargelu Formation and he showed through the pyrolysis analysis that complete organic carbon is decreasing towards the north and northeast areas of Iraq; Al-Badry investigated geochemistry and stratigraphy of Jurassic formations in northern Iraq in 2012 and concluded that Chia Gara, Naokelekan, and Sargelu formations are all good source rocks for generating and producing hydrocarbons. Furthermore, he stated that the Sargelu Formation characterized by type II with a low contribution by type I; Hussein et al. (2013) evaluated Jurassic source rocks geochemically northern Iraq and concluded that there are two types of kerogen in the Sargelu Formation, I and II, and described the source rocks as good to excellent with an average total organic carbon content is more than 4.69%; Al-Ameri et al. (2013) reported that the generation and expulsion of petroleum in the Sargelu Formation started and ended in the Miocene; Aqrabi and Badics (2015) assessed potentiality and volumetric capability of shale oil/gas of the middle Jurassic-lower Cretaceous and they concluded that the Naokelekan, Sargelu and Najmah formations could be the best plays of shale-gas/shale-oil in Iraq, Iran, and Kuwait due to their organic richness; Fatah and Mohialdeen (2016) determined the mixture of types II/III kerogen from Sargelu Formation in Miran Oil Field in Sulaymaniyah Governorate and based on the production index (PI), the organic material in the Sargelu is thermally mature; Sargelu Formation samples in Zab-1 Well with production index values ranging from 0.15 to 0.25 (average 0.19) and T_{max} values ranging from 422 °C and 431 °C (average 427 °C), suggesting thermally immature to early mature source (Abdula, 2016); Awdal et al. (2016) concluded that the Kurrachine Formation in the Kurdistan Region is widely fractured and has a good network of fractures; therefore, the production of hydrocarbon comes mainly from secondary porosity within the fractured dolomitized rocks; The petroleum system of Jabal Kand Oil Field shows that the Sargelu Formation is immature and has not generated any oil $Ro < 0.55\%$ (Abdula, 2017); Hakimi et al. (2017) explained through the burial/thermal history model that the source rock of the Sargelu Formation has passed the oil generation window since the late Eocene to late Miocene. The results show that the Sargelu marine type IIS kerogen in Bijel Oil Field is a potential source of hydrocarbon and is thermally mature with relation to the oil window. In the analyzed samples that they studied, carbonate is richer in organic matter and more oil-prone than silty mudstones and carbonaceous shales (Abdula et al., 2017); Edilbi et al. (2019) in their study on the potential of source rocks and basin modeling of the Kurrachine Formation concluded that the formation consists of mixed types III and II-III kerogen, and the values of T_{max} show that the organic matter is mature. The aim of this research is to evaluate the potential of the source rocks by determining the type of kerogen using gas chromatography and to assess the rock maturity in the Sargelu and Kurrachine formations.

2. Study Area

The study area is situated in northern Iraq and includes three oil wells, Kand (Kd-1), Ain Zalah (AZ-29), and Baiji (Bj-1) (Fig. 1).

3. Geological Setting

The Sargelu Formation is one of the most widespread formations in Iraq and neighboring countries. This formation appears in Iraq in several areas, (1) Balambo-Tanjero Zone; (2) Northern Thrust Zone; and (3) Qulqula- Khwakurk Zone. It is located all over Iraq, with the exception of the Rutba Subzone, where it is transformed into Muhaiwir Formation (Jassim and Buday, 2006). The type section is located in the High-Fold Zone in Surdash Area, northeastern Iraq. The type section is identified by Bellen et al. (1959) and they noted that the Sargelu Formation consists of thin-bedded calcareous black, bituminous calcareous, dolomitic calcareous, papery shale, and thin black chert strips. The proportion of clay admixture with sand is higher in subsurface sections (Jassim and Buday, 2006; Buday, 1980). The formation is rich in fossils both in outcrops and boreholes (Abdula et al., 2015). The thickness of the formation varies as it is 115 m in the type locality (Bellen et al., 1959). The contacts are conformable and gradational in the type section in Sargelu Village, but in north-west of Mosul, it overlaid by Cretaceous Sarmord Formation (Jassim and Buday, 2006).

Fig.1. Location map of the studied wells

The Sargelu Formation was deposited in a reduced marine environment except for some parts of the formation that appear to have been deposited in shallow environments or better-aerated conditions in Salman Zone of the Stable Shelf, which represent the Muhaiwir Formation tongues (Jassim and Buday, 2006). The Sargelu Formation was deposited during Late Toarcian-Early Tithonian Megasequence AP7 (Jassim and Buday, 2006). The region of Iraq during the middle Jurassic Period is characterized by the occurrence of many calcareous and argillaceous facies, and according to Jassim and Buday (2006) all facies of this period were located in different regions of Iraq. The Kurrachine Formation is the most widely distributed formation within the Late Triassic sequence. This formation occurs in the central and northern parts of Iraq. The formation in the type section is comprised of dark brown and black limestone, thick and thin-bedded, with occasional layers of thick-bedded, fetid dolomites, with slump

structures, and some papery shale (Bellen et al., 1959). Additionally, they determined the age of the formation to be Late Triassic (Rhaetic at the top).

The thickness of the formation in the type area is up to 850 m (Buday, 1980). The lower contact of the formation is characterized by an erosional break determined by haematization and leaching of the underlying Geli Khana Formation. According to Bellen et al. (1959), the contact with overlying Baluti Formation is gradational and conformable. The environmental conditions of Kurrachine Formation are characterized by lagoonal, occasionally euxinic in the Mesopotamian and Foothill zones (Buday, 1980). Upper Triassic in north Iraq is part of an Upper Triassic-Middle Jurassic Cycle, which began with a regional transgression marking the beginning of the spreading sedimentary basins in the region (Buday, 1980).

4. Material and Methods

A total of 56 cuttings samples of shale from Sargelu and Kurrachine formations in different wells have been taken from the North Oil Company in Kirkuk, Iraq. The samples have been tested in the stratochem laboratory, Cairo, Egypt. Various methods have been applied to achieve the request of organic geochemical analyses such as total organic carbon by LECO analyzer, Rock-Eval pyrolysis, gas chromatography, and gas chromatography-mass spectrometry.

4.1 Total Organic Carbon Analysis (TOC)

The richness of organic matter is defined by the steps begins with weighing the samples in an Erlenmeyer flask and reacting with HCl to remove the carbonates. With a Millipore filter device, the sample is filtered into a microfiber filter paper and then washed by distilled water to slough traces of hydrochloric acid and placed in an oven for drying. The filter paper is transferred in a LECO crucible with the sample, which is then incinerated in the combustion oven. The amount of CO₂ resulting from the combustion of organic matter is also detected with an infrared detector. This quantification is expressed as a weight percentage of TOC.

4.2 The Rock-Eval Method

Pyrolysis can be used to estimate the petroleum potential of source rock samples by using a heating program. The emitted hydrocarbons are observed by a flame ionization detector (FID), to generate two parameters (S1, S2). The temperature at which the highest amount of S2 formed is called Tmax, which gives an indication of the maturity of kerogen. In addition, the infrared IR can monitor the CO₂ emitted during pyrolysis in real time, providing information on the kerogen oxidation state.

4.3 Bitumen Extraction

Extraction is the process of separating the adsorbed compounds from the rock matrix by repeatedly rinsing the sample (continuous extraction) with a suitable solvent. Soxhlet bitumen extraction was performed from sedimentary rocks with dichloromethane (DCM) for 72 h. DCM is a very effective polar solvent for extracting and dissolving oils.

4.4 Gas Chromatography (GC)

Diluted samples were injected into chromatographic column and programmed from 60°C-350°C at a rate of 12°C/min with an Agilent 7890A GC and Helium was used as carrier gas. Following the determination of the <C15 fraction by evaporation in a stream of N₂ for 30 minutes and precipitation of asphaltene with excess n-hexane, the C15+ deasphalted are isolated into saturated, aromatic, and NSO fractions by gravity-flow column using a silica gel activated at 400°C before employing. Hexane was

used to remove the saturated, dichloromethane to remove the aromatic and the NSO fractions, dichloromethane/methanol (50:50) was used. After the solvent has evaporated, the recovered fractions are measured by gravity method to concentrate the branched/cyclic biomarker fraction. The C15+ saturate fraction undergoes molecular sieve filtration based on West et al., (1990) technology.

4.5 Gas Chromatography-Mass Spectrometry (GCMS)

GC/MS technical of C15+ branch/cyclic and aromatic hydrocarbons was used with Agilent 7890A GC connected to a 5975C MS. During the analysis, helium is held at a steady flux rate. The J & W DB5 column is a temperature scheduled to range from 150 to 325°C at 2°C/min (branched/cyclic) and from 100 to 325°C at 3°C/min (aromatic). The spectrometer is set to selected ion mode (SIM), which monitors ions with m/z 177, 191, 205, 217, 218, 221, 231, and 259 amu (branched/cyclic) and 156, 170, 178, 184, 192, 198, 231, 239 or 245 and 253 (aromatics). To assess absolute biomarker concentrations, a deuterated internal standard was applied to the C15+ branched/cyclic fraction. The aromatic hydrocarbon fraction was supplemented with a deuterated anthracene standard.

5. Results and Discussion

Rock-Eval pyrolysis is a rapid analysis that provides important information about the source rock's maturity; petroleum production capacity and the type of hydrocarbon produced (Peters, 1986). It is estimated the total amount of petroleum formed during the thermal decomposition of kerogen by Rock-Eval pyrolysis. The parameters obtained by Rock-Eval pyrolysis include S₁ (free hydrocarbon exists in the rock sample before analysis), S₂ (Hydrocarbon compound generated by the cracking of Kerogen during pyrolysis, S₃ (Carbon dioxide released during the thermal cracking of kerogen), and Tmax (Maximum temperature at highest amount of S₂ generation). From these measured values, a number of additional parameters like oxygen index (OI=S₃/TOC*100), hydrogen index (HI=S₂/TOC*100) and production index (PI=S₁/(S₁+S₂)) are determined and shown in Table 1. Interpretations of biomarker data and their derivatives such as the pristane/phytane ratio, and isoprenoid/n-alkanes ratio have been performed (Table2). While aromatic biomarker and Ts/(Ts+Tm) trisnorhopanes are shown in Table 3.

Table 1. Analysis of TOC and Rock-Eval for cuttings samples selected from Sargelu and Kurrachine formations at different wells in northern Iraq

Samples	Formation	Depth M	TOC Wt. %	S1 mg/g	S2 mg/g	S3 mg/g	Tmax C°	HI mg HC / g TOC	OI mg CO ₂ / g TOC	PI	S1/ TOC
AZS 1	SARGELU	2556	0.29								
AZS 2	SARGELU	2585	0.22								
AZS 3	SARGELU	2625	0.58	0.19	0.99	0.41	434	170	71	0.16	0.33
AZS 4	SARGELU	2644	1.38	0.26	2.13	0.54	441	154	39	0.11	0.19
AZS 5	SARGELU	2664	1.30	0.19	1.55	0.51	442	119	39	0.11	0.15
AZS 6	SARGELU	2689	0.75	0.18	0.86	0.49	441	115	66	0.17	0.24
AZS 7	SARGELU	2714	1.73	0.23	1.87	0.77	441	108	45	0.11	0.13
AZS 8	SARGELU	2730	2.52	0.55	3.37	0.52	444	134	21	0.14	0.22
AZS 9	SARGELU	2750	1.23	0.24	1.35	0.51	443	110	41	0.15	0.20
AZS 10	SARGELU	2779	1.64	0.41	2.12	0.54	442	129	33	0.16	0.25
AZS 11	SARGELU	2799	2.17	0.29	1.64	0.88	446	76	41	0.15	0.13
AZK 1	KURRA CHINE	3526	0.12								
AZK 2	KURRA CHINE	3608	0.11								
AZK 3	KURRA CHINE	3631	0.10								
AZK 4	KURRA CHINE	3736	0.16								
AZK 5	KURRA CHINE	3785	0.09								
AZK 6	KURRA CHINE	3821	0.13								
AZK 7	KURRA CHINE	3852	0.19								
AZK 8	KURRA CHINE	3901	0.16								
AZK 9	KURRA CHINE	3926	0.30								

AZK 10	KURRA CHINE	4002	0.29								
BJS 1	SARGELU	2414	5.53	1.02	29.61	1.29	433	535	23	0.03	0.18
BJS 2	SARGELU	2422	8.90	1.65	44.23	1.38	434	497	16	0.04	0.19
BJS 3	SARGELU	2426	3.54	0.55	9.63	1.90	429	272	54	0.05	0.16
BJS 4	SARGELU	2449	0.68	0.26	2.77	0.55	429	408	81	0.09	0.38
BJS 5	SARGELU	2465	0.77	0.31	2.76	0.63	423	359	82	0.10	0.40
BJS 6	SARGELU	2483	0.65	0.28	2.72	0.53	424	420	82	0.09	0.43
BJS 7	SARGELU	2492	0.57	0.15	2.12	0.83	421	374	146	0.07	0.26
BJK 1	KURRA CHINE	3378	0.60	0.13	1.31	0.85	433	217	141	0.09	0.22
BJK 2	KURRA CHINE	3390	0.50	0.06	0.70	0.96	429	140	192	0.08	0.12
BJK 3	KURRA CHINE	3413	0.22								
BJK 4	KURRA CHINE	3550	0.38								
BJK 5	KURRA CHINE	3583	0.97	0.42	2.44	1.14	425	251	117	0.15	0.43
BJK 6	KURRA CHINE	3636	0.54	0.17	1.59	0.84	436	293	155	0.10	0.31
BJK 7	KURRA CHINE	3644	0.47								
JKS 1	SARGELU	2115	3.83	2.88	22.52	0.79	428	588	21	0.11	0.75
JKS 2	SARGELU	2130	11.30	1.14	43.94	3.26	434	389	29	0.03	0.10
JKS 3	SARGELU	2145	11.80	5.78	56.01	1.32	435	475	11	0.09	0.49
JKS 4	SARGELU	2163	2.71	0.99	14.54	0.99	429	537	37	0.06	0.37
JKS 5	SARGELU	2188	0.81	0.32	3.76	0.51	425	462	63	0.08	0.40
JKS 6	SARGELU	2202	1.25	0.47	5.15	0.86	427	412	69	0.08	0.38
JKS 7	SARGELU	2230	3.38	1.02	14.25	0.90	435	422	27	0.07	0.30
JKS 8	SARGELU	2248	4.73	2.08	25.36	0.88	432	536	19	0.08	0.44
JKS 9	SARGELU	2267	2.05	3.54	12.15	0.66	422	593	32	0.23	1.73
JKS 10	SARGELU	2271	8.23	1.16	39.52	0.76	436	480	9	0.03	0.14
JKK 1	KURRA CHINE	2963	0.30								
JKK 2	KURRA CHINE	3000	0.42								
JKK 3	KURRA CHINE	3135	0.28								
JKK 4	KURRA CHINE	3206	0.50	0.34	1.38	0.65	418	274	129	0.20	0.68
JKK 5	KURRA CHINE	3396	0.54	0.13	0.92	0.53	422	171	99	0.12	0.24
JKK 6	KURRA CHINE	3455	0.66	0.22	1.29	0.55	421	196	84	0.15	0.33
JKK 7	KURRA CHINE	3605	0.65	0.15	1.08	0.53	433	165	81	0.12	0.23
JKK 8	KURRA CHINE	3750	0.21								
JKK 9	KURRA CHINE	3840	0.18								
JKK 10	KURRA CHINE	3958	0.32								
JKK 11	KURRA CHINE	4060	0.27								

Table 2. Ratios of Pristane/Phytane, Pristane/nC₁₇, and Phytane/nC₁₈ for the analyzed samples

Formation	Sample	Depth (m)	Pr/Ph	Pr/nC ₁₇	Ph/nC ₁₈
Sargelu	AZS3	2625	0.77	0.29	0.32
	AZS8	2730	1.09	0.18	0.21
	BJS2	2422	0.62	0.21	0.27
	JKS3	2145	0.35	0.19	0.34
	BJK1	3378	0.65	0.25	0.30
Kurrachine	BJK5	3583	0.33	0.62	1.70
	JKK4	3206	0.52	0.37	0.46
	JKK7	3605	0.59	0.28	0.45

Table 3. Aromatic biomarkers for selected samples

Formation	Sample Name	Depth (m)	C ₂₇ % MAS	C ₂₈ % MAS	C ₂₉ % MAS	TAS/ (MAS+TAS)	(C ₂₀ +C ₂₁)/ Σ TAS	Ts/(Ts+Tm) trisnorhopanes
Sargelu	AZS3	2625	-	-	-	1.0	0.55	0.74
	AZS8	2730	-	-	-	1.0	0.30	0.80
	BJS2	2422	37.7	31.9	30.4	0.33	0.46	0.10
	JKS3	2145	36.0	25.6	38.4	0.15	0.40	0.21
	BJK1	3378	32.8	29.8	37.4	0.55	0.22	0.19
	BJK5	3583	13.0	15.7	71.2	0.96	0.08	0.26
Kurrachine	JKK4	3206	32.0	23.1	44.9	0.93	0.08	0.31
	JKK7	3605	32.5	26.8	40.6	0.81	0.52	0.63

5. 1 Organic Matter Richness

The amount of organic matter in the source rock is measured by the content of the TOC . Determination of TOC can be considered as a first step to provide primary geochemical information for the evaluation of source rocks for Sargelu and Kurrachine formations (Table 1). According to Peters and Cassa (1994), the TOC wt. % content of more than 1 wt. % is considered a good source rock. The Sargelu Formation in Ain Zalah Well can be rated as having a good hydrocarbon potential (0.22%-2.52% averaging 1.26%), and Baiji Well as very good potential (0.57%-8.90% averaging 2.95%) whereas Jabal Kand Well can be considered an excellent hydrocarbon potential (0.81% to 11.80%, averaging 5.01%). The TOC content of the Kurrachine Formation in Baiji Well range from 0.22%-0.97% averaging 0.53% and can be considered as fair source rock, while Ain Zalah and Kand wells can be rated as having poor hydrocarbon potential (average of 0.17% and 0.39%) for Ain Zalah and Kand, respectively (Table 1). This variation in TOC% values between the wells as well as the variation within one well depends on several factors including sedimentation rate, proximity and distance from the beach, and sedimentary environment (Tyson, 1995).

5. 2 Quality of Organic Matter

The ability to produce petroleum and the type of hydrocarbons generated depend on the quality of organic matter because various types of organic matter have various hydrocarbon generation prone (Tissot and Welte, 1984; Tyson, 1995). Kerogen is an insoluble sedimentary organic material capable of generating petroleum (Vandenbroucke, 2003). In petroleum studies, kerogen is classified into three main types I, II, and III based on the ratio between contents C, H, and O. The organic facies with thermal maturity define the timing and the type (oil or gas) of the hydrocarbon that is produced and expelled from the source rock (Peters et al., 2005a). For example, source rocks containing organic matter type III kerogen from higher plants produce gaseous compounds as the main hydrocarbon phase, while those containing type I and II kerogen from bacteria and algae mainly produce oil. The potential of the source rock is reflected by the hydrogen index, and this is the distinguishing tool for identifying kerogen. Type I (HI >600 mg HC/g TOC) and type II (300-600 mg HC/g TOC) have great hydrocarbon generation capabilities, while the type III kerogen which has low HI, the ability to generate petroleum is limited. Thus, understanding the diversity of organic facies helps to explain why some sediments are both oil-and-gas prone, some are barren, and others produce only dry gas (Rogers, 1979). The hydrogen index can be plotted versus the oxygen index on a modified Van Krevelen scheme (Tissot and Welte, 1984). It is noticed from Fig. 2A, the organic matter in the Sargelu Formation is represented by Type II in the wells Baiji and Kand, and Type III in the Ain Zalah Well. As for the Kurrachine Formation, the type of kerogen is II/III in the wells Kand, and Baiji (Fig.2B). Tmax versus HI is commonly used to determine the type of Kerogen (Hunt, 1996). Determination of kerogen type using Tmax versus HI appears to be more accurate than HI versus OI. Some discrepancies between the results would be expected due to the carbonates affecting OI. In Sargelu Formation the majority of the samples of Kand fall under the type II kerogen and samples of Baiji fall under types II, as well as a mixture of types II-III, while all samples of Ain Zalah represented by the type III kerogen (Fig. 3A). The Kurrachine Formation's organic matter in wells Kand and Baiji belong to the type III kerogen and a mixture of types II-III (Fig. 3B).

It is essential to keep track of what happens when the source rocks mature. As the source rock generated and expels hydrocarbon the TOC content of source rocks can be reduced (Daly and Edman, 1987). This means that the TOC will decrease as the amount of reactive kerogen is consumed (Dembicki, 2009). The amount of hydrogen will also decrease which leads to a decrease in S₂. The lowest average value of the S₂ (1.76 mg HC/g rock) was found in the samples of the Ain Zalah Well (Sargelu Formation) compared to the samples of Jabal Kand and Baiji Wells, where the average value of

the S₂ reached 23.72 mg HC/g rock and 13.41 mg HC/g rock in both wells, respectively. The decrease in the S₂ value of the samples of the Ain Zala well may be due to maturity of its source rocks.

However, Rock-Eval data by itself are not always sufficient to determine the type of organic matter when mixtures of kerogen are present (Dembicki, 1993). The TOC content of rocks can decrease significantly during thermal maturation. Losses are great in type I and II kerogens as approximately 70% and 50%, respectively of the organic carbon content are liberated during generation and expulsion of hydrocarbon. In comparison, the carbon loss in type III kerogen is not significant with decrease estimates ranging from 12-20% (Daly and Edmann, 1987). In addition, the mineral matrix in the source rock can affect the Rock-Eval parameters. In sediments with a TOC content (< 2.0%), the retention of hydrocarbons on mineral grain can lead to a significant reduction in hydrogen index (Katz, 1983), while present carbonate minerals can increase the oxygen index (Dembick, 1993).

Fig.2. The HI/OI plot for various kerogen types. A) Sargelu Formation. B) Kurrachine Formation

Fig. 3 Determination of kerogen type for source rock. A) Sargelu Formation. B) Kurrachine Formation

The methods and concepts were updated in 1980's and 1990's as additional methods were developed for the back-calculation of the original organic carbon, including the use of well logs to determine the TOC content. For example, the structural density of kerogen varies from 1.6 g/cc for low-mature kerogen to up to 1.6 g/cc for high-mature kerogen.

Usually, Rock-Eval data is insufficient alone to characterize the types of kerogen present and the type of hydrocarbons it might generate (Dembicki, 2009). So, the Rock-Eval data needs other organic geochemical data to obtain accurate assessments of kerogen type. The plot of $Pr/n-C_{17}$ against $Ph/n-C_{18}$ (Fig.4) was used to evaluate the type of kerogen (Ghori, 2002) and it was shown that all samples fall within the type II kerogen. The pristane/ $n-C_{17}$ versus phytane / $n-C_{18}$ (Fig.5) also shows variations in source input, organic matter alterations, and sedimentary environments (Shanmugam, 1985). The extract samples are located in the reducing field, suggesting a more marine organic matter-rich source rock (Type II). Al-Atroshi et al. (2020) and Al-Dolaimy et al. (2021) both conclude that organic matter in Sargelu Formation derived from the marine depositional environment.

Fig. 4. Pristane/ nC_{17} versus Phytane/ nC_{18} plot of Sargelu and Kurrachine samples to identify the type of kerogen

Fig. 5. Pristane/ nC_{17} versus Phytane/ nC_{18} plot of Sargelu and Kurrachine samples

5.3. Maturity

Maturity refers to the amount of thermal change that organic matter undergoes as a result of heating (Peters and Cassa, 1994). Maturation of source rock happens in three stages: diagenesis, catagenesis, and metagenesis. The thermal maturity level of various types of organic matter can be evaluated from the Tmax range. Peters and Cassa (1994) mentioned that the beginning and end of the oil window are about 435-470 °C, 0.1-0.4 for Tmax and PI, respectively. Tmax depends on the organic matter type and the matrix which surrounds the organic matter. The relationship between HI and Tmax is explained in Figs. 3A and 3B. It determines the types of organic matter in the rock. Likewise, it is used to determine maturity (Madukwe, 2014; El-Nady et al., 2015), and it has been observed that all samples of Ain Zalah well (Sargelu) are within the maturity range (oil window) while the samples of wells Baiji and Kand fall within the immature zone and graded to the mature zone. In the formation of Kurrachine in the Baiji well two samples fall within the maturity zone and two samples within the immature zone, while in K and Well, three samples within the immature zone and only one sample within the maturity zone.

Production index can be used to describe the level of organic matter maturity evaluation by plotting Tmax against PI for analyzed samples (Fig. 6A), it can be concluded that Ain Zalah source rock in the Sargelu Formation have PI values in the range 0.11-0.17 (Table 1), indicating that most of the source rocks of Ain Zalah within the main stage of hydrocarbon generation. While the Baiji and Jabel Kand samples are immature-early mature for hydrocarbon generation, also Baiji and Jabel Kand samples in Kurrachine Formation are immature-early mature, (Fig. 6B).

Fig. 6. Cross plot of pyrolysis PI versus Tmax, showing nature of the hydrocarbon product and maturation. A)Sargelu Formation. B)Kurrachine Formation

Estimates of maturity in this study can be based on aromatic biomarkers. Aromatic steroid hydrocarbons are the main constituents of sediments and crude oils. They are derived from diagenetic processes of biogenic precursors or aromatization of natural products. Therefore, they have been used as indicators of maturity levels of oils and organic-rich sediments (Seifert and Moldowan, 1978; Mackenzie et al., 1981; 1982). Two types of aromatic steroids were identified using GC-MS analysis, mono- and triaromatic steroids characterized by their m/z 253 and 231 mass chromatogram fingerprints. Both showed alteration with increasing burial depth (Mackenzie et al., 1981). Triaromatic steroids are useful for estimating maturation because, with increased thermal maturity, long-chain triaromatic steroids (C_{27} , C_{28} TAS) degrades at a higher rate than the short-chain triaromatic steroids (C_{20} , C_{21} TAS) (Beach et al., 1989). Since long-chain compounds are more vulnerable to thermal cracking than short-chains compounds, the proportion of short-chain components increases with maturity (Riolo et al., 1986). The analyzed samples showed ($C_{20}+C_{21}$)/ Σ TAS ratio from (0.08-0.55) (Table 3), as this ratio was low in Kurrachine formation samples, except JKK7, and an increase in this ratio was observed in the Sargelu Formation samples, to be higher than in sample AZS3(0.55).

The low concentration of monoaromatic was probably due to the maturity-driven aromatization to triaromatic (Mackenzie et al., 1981). Monoaromatic steroid hydrocarbon has been approved by many researchers like Seifert and Moldowan, (1978); Riolo et al. (1986) as potential geochemical parameters. However, it can be recognized that all studied samples contain significant amounts of C_{27} , C_{28} , and C_{29} monoaromatic except Ain Zalah samples (Fig. 7 and Table 3). There was no presence of monoaromatic (C_{27} , C_{28} , and C_{29}) in Ain Zalah samples (Sargelu Formation), this means that diagenetic processes are more advanced than in other wells, and the monoaromatic have started to crack. Monoaromatic steroids are primarily used to evaluate the correlation maturity and aromatization measured by comparing the ratio of TAS to MAS steroids, which is expressed by $TAS/(MAS+TAS)$. It is generally accepted that during the maturation of sediments, the triaromatic are created by aromatization of monoaromatic as indicated in shale extracts (Mackenzie et al., 1981). When the thermal maturity level is increased, it is expected that the ratio of triaromatic/ monoaromatic steroids should increase gradually. The highest value of the $TAS/(MAS+TAS)$ ratio was found in Ain Zalah samples (Sargelu Formation), (Table 3), and this result indicates the occurrence of an aromatization process with increasing thermal maturation at depths 2625, 2720m.

5.4 Ts/Tm Trisnorhopanes

Ts/Tm is commonly used as a saturated hydrocarbon maturity parameter. Ts exhibits greater thermal stability than its regular hopane rival, Tm. The reliability of this ratio, as a source maturity indicator is better when estimating oils from a common source of regular organic facies (Peters et al., 2005b). The value of this ratio alters from low in the immature range to high in the late oil generation stage (Moldowan et al., 1986). Kroon (2011) mentioned that the ratio of $Ts/(Ts+Tm)$ between 0.55-0.88 indicates early to late oil generation. Source rock samples AZS3 (0.74), AZS8 (0.80), and JKK7 (0.63) (Table 3) indicating thermal maturities at the early oil generation stage.

6. Discussion

The source rock of Ain Zalah Well (Sargelu Formation) has T_{max} values ranged from 434°C to 446°C, suggesting that the source rock in Ain Zalah is mature. The relationship between production index and T_{max} data support this, indicating that the source rock in Ain Zalah is located in the main stage of hydrocarbon generation. Another method for determining the thermal maturity of source rock in Ain Zalah is aromatic hydrocarbon. The triaromatic steroids in oils are chiefly from (C_{20} , C_{21}) and (C_{26} - C_{28}) homolog. It is vastly accepted that triaromatic steroids probably formed by aromatization and the loss of a methyl group from monoaromatic (Peters et al., 2005b). Although the mechanism of

poor in Ain zalah and Kand to fair in Baiji wells. The principal kerogen type in Sargelu and Kurrachine formations is II based on the GC-analysis that produces oil and gas. In general, the samples in Sargelu Formation in Ain Zalaz Well have production index values ranging from 0.11–0.17 (average 0.14) and Tmax values ranging from 434 °C to 446 °C (average 442 °C), suggesting that they are in early mature, while both Sargelu and Kurrachine formations are gradient from immature to early mature in wells Baiji and Kand based on Tmax and PI values. The degree of aromatization, measured by comparing the ratio of TAS to MAS steroids represented by $TAS / (MAS + TAS)$, reached the highest value in the samples from Ain Zala Well.

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