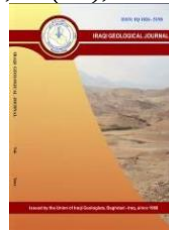




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Organic Matter Characteristics and Hydrocarbon Potential of Jurassic Sargelu Formation in X Well, Northern Iraq

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Abstract

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Sargelu Formation from X Well, northern Iraq was studied to evaluate the hydrocarbon generation potential. To achieve this purpose, 15 rock samples were analyzed for Total Organic Carbon, Rock Eval pyrolysis and biomarkers analysis. The studied samples were classified as poor-excellent source rocks, in which they have Total Organic Carbon content in the range of 0.21% - 5.21 wt.%, with an average of 1.07 wt.%. There is gradually increasing with depth. Based on modified Van Krevelen diagram, most of the samples fall in the Kerogen type II and II/III except two samples which fall in the zone of type III. Unimodal normal alkane distributions, low Terrigenous to Aquatic Ratio values (ranging between 0.06-0.54), higher concentrations of C₂₃ tricyclic terpanes relative to C₁₉ tricyclic terpanes indicating minimal terrestrial input relative to aquatic sources. Pristane/Phytane ratios are in the range of 0.41-0.61 which indicate marine anoxic depositional environment. The C₂₉/C₃₀ ratios ranging between 0.65-1.04, indicated of anoxic marl or carbonate rocks. Tmax values are in the range of 418-440°C, C₂₉SS/SS+RR ratios ranged between 0.45-0.47 whereas C₂₉ββ/ββ + αα ratios are between 0.51 and 0.53. The methyl phenanthrene index for studied sample is in the range of 0.53-0.60. All these results indicate immature-early mature organic matter.

Keywords: Sargelu Formation; Source rocks; Biomarker; Organic Matter; Northern Iraq

1. Introduction

Potential source rock is a rock having well preserved organic matter that has been subjected to sufficient temperature and pressure, to generate petroleum. So, it simply refers to the formation in which oil and gas originate. Thus, it is very important in this regard to be taken under consideration for study to evaluate the organic matter that present in it. Initial screening of the source rocks generally involves determination of Total Organic Carbon (TOC) values and type of organic matter (Peters et al., 2005). The kerogen is the most important part of the source rock and rock eval pyrolysis (RE) plays a key role in determining the kerogen types and potential for hydrocarbon generation. RE analysis gives the certain parameters for the values of which giving further information about hydrocarbons that present in the source rock sediments. But TOC is very important and first step in the source rock screening (Peters and Cassa, 1994). In Iraq, although the hydrocarbon source rocks are recorded from Paleozoic to Tertiary (Al-Hadidy, 2007; Alkhafaji, 2017, 2018; Al-Auqadi et al., 2024), but the richest hydrocarbon source rocks on the Arabian

Plate are Jurassic sediments, (Sharland et al., 2001). These successions represented, in Iraq, by Sargelu, Naokelekan, Najmah formations (Sharland et al., 2001). Due to its relatively high thickness (up to 400 m) and organic richness of TOC up to 20% (Al Habba and Abdulla, 1989), the middle Jurassic Sargelu Formation considered to be the main hydrocarbon source rocks in the northern, northeastern, and southern of Iraq (Alsharhan and Nairn, 1997; Aqrawi et al., 2010); but grade westward into non-source rocks (Muhaiwir Formation). Sargelu Formation is the main source rock for oil reside in Cretaceous and Tertiary reservoirs (Pitman et al., 2004; Abdula, 2015), and for bitumen seeps in northern Iraq (Alkhafaji et al., 2020, 2021). Sargelu Formation consists of bituminous and argillaceous limestone and shale (Jassim and Buday, 2006). Generally, the lower part of Sargelu Formation has higher TOC than the upper part (Al Habba and Abdulla, 1989; Pitman et al., 2004). The maturity of organic matter of Sargelu Formation decrease from east to west. The highest maturity level of Jurassic successions was existed in the Mesopotamian Basin (Pitman et al., 2004). It crops out in northern and northeastern of Iraq and penetrated in several exploratory wells. Its potentiality for hydrocarbon generation widely studied in surface and subsurface section (Al-Ahmed, 2001; Abdula, 2015; 2016; Al-Ameri et al., 2013; Hussein et al., 2013; Gharib et al., 2021; Baban et al., 2023; Fadhil et al., 2023; Mina and Abdula, 2023). This study aims to assess the hydrocarbon potential of Sargelu Formation through measuring its organic richness, identifying the type, characteristics of organic matter and its thermal maturity level.

2. Materials and Methods

The total thickness of Sargelu Formation in the studied well is 417 m. Sargelu Formation in this Well consists of shale beds in the lowermost part and limestone and marly limestone in other parts (Fig. 1). Fifteen cutting samples were collected for Sargelu Formation from this (X) well, located in the western part of the Low Folded Zone as shown in (Fig. 2), were grinded and then analyzed for total organic carbon (TOC) by using LECO CS-300 and Rock-Eval pyrolysis using Rock-Eval pyrolysis 6. Then bitumen was extracted from three samples using Soxhlet extraction procedure and adding di-chloromethane (DCM) as solvent. After precipitation of asphaltenes by adding pentane, the de-asphalted fraction fractionated into three fractions (saturated hydrocarbons, aromatic hydrocarbons and NSO-compounds) on silica gel column chromatography after adding n-hexane for saturated fraction and (DCM) for aromatic fraction from polar compounds. The GC-FID configuration included split/splitless injector onto a 30m x 0.32mm x 0.25 μ m silica column. The equipment used for biomarker analysis is GC coupled with a mass spectrometer.

3. Result and Discussion

3.1. Organic Richness

The TOC content of rock samples was found to be ranged from 0.21% to 5.21% with an average of 1.07 wt.%, where gradually increasing with depth. For instance, at depth from (2967 m and 2987 m) the samples exhibited high TOC values range between 2.96% and 5.21% respectively. This result is expected where the TOC of the lower part of the formation is higher than the upper part (Al Habba and Abdula, 1989). According to (Peters and Cassa, 1994); the studied samples of Sargelu Formation can be classified

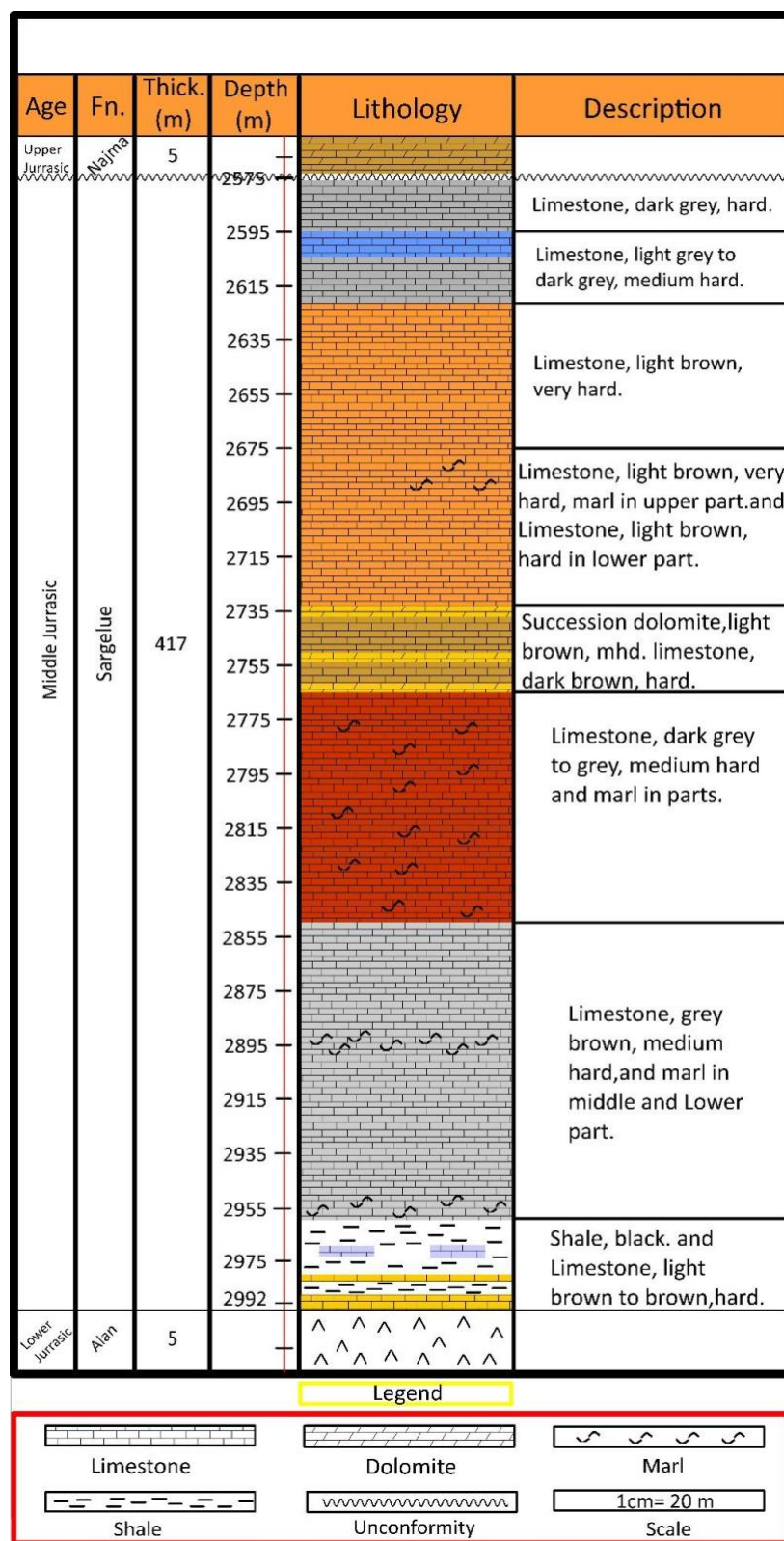


Fig. 1. Lithology of Sargelu Formation in the studied Well



Fig. 2. Main tectonic zones of northern Iraq and location of the studied Well (Red circle)

as good-excellent source rocks in the lower part and poor-moderate in the middle even upper parts as shown in Fig. 3. The generated hydrocarbons (S_1) parameter falls within the range of 0.07 to 0.98 mg HC/g rock, or <1 mg HC/g rock (Table. 1), which indicating poor to fair source rock potential. The remaining potential (S_2) parameter, on the other hand, ranges from 0.37 to 22.38 mg HC/g rock, with most of samples that falling between 0.37 to 3.95 mg HC/g rock, or <5 mg HC/g rock, showing poor to fair source rock potential. However, two samples from the deepest part, specifically at 2568 m and 2587 m, exhibited S_2 values of 8.63 mg HC/g rock and 22.38 mg HC/g rock, respectively; which then indicate good-excellent source rock potential. Based on genetic potential (GP) (S_1+S_2), the studied samples indicate poor to good source rocks, so most samples were fall in the good source rock category (Fig. 3) in which samples were fall in the range of 0.44-23.36 mg HC/g rock, as shown in (Table. 1) (Ahmed et al., 2023). Finally, S_1/TOC values of all samples are <1.5, Table. 1, indicating they are indigenous and not contaminated (Amoak et al., 2024).

Table. 1. TOC and Rock Eval Results of Sargelu Formation in X Well

No.	Depth (m)	TOC (%)	S_1 (mg HC/g rock)	S_2 (mg HC/g rock)	S_3 (mg CO ₂ /g rock)	G.P (mg HC/g rock)	T- max (°C)	HI (mg HC/g TOC)	OI (mg CO ₂ /g TOC)	PI	S_1/TOC
1	2588	0.21	0.07	0.37	0.13	0.44	418	176.1	61.9	0.16	0.33
2	2653	0.45	0.07	0.74	0.04	0.81	422	164.4	8.88	0.08	0.16
3	2757	0.31	0.09	1.21	0.24	1.3	424	387	77.4	0.06	0.29
4	2788	0.87	0.21	3.12	0.66	3.43	425	358.6	75.86	0.06	0.24
5	2804	0.55	0.12	1.58	0.23	1.7	429	287.2	41.8	0.07	0.22
6	2835	0.93	0.15	3.95	0.05	4.1	429	424.7	5.37	0.03	0.16

7	2856	0.39	0.11	1.22	0.04	1.33	429	312.8	10.25	0.08	0.28
8	2877	0.53	0.11	1.5	0.09	1.61	428	283	16.98	0.07	0.21
9	2891	0.61	0.12	1.97	0.01	2.09	430	322.9	1.63	0.06	0.20
10	2916	0.64	0.12	1.78	0.02	1.9	431	278.1	3.12	0.06	0.19
11	2935	0.46	0.11	1.11	0.04	1.22	429	241.3	8.69	0.09	0.24
12	2945	0.65	0.24	1.9	0.01	2.14	428	292.3	1.54	0.11	0.37
13	2955	1.26	0.17	3.1	0.13	3.27	434	246	10.32	0.052	0.13
14	2968	2.96	0.41	8.63	0.44	9.04	435	291.5	14.86	0.045	0.14
15	2987	5.21	0.98	22.38	0.13	23.36	440	429.5	2.5	0.042	0.19

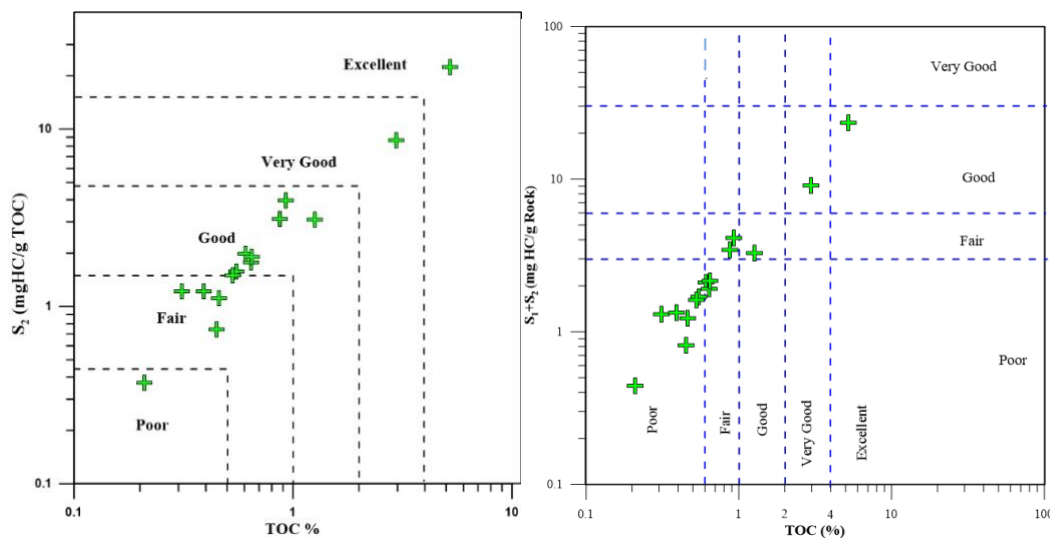


Fig. 3. Remaining potential (S_2) vs. TOC plot (Left) and Genetic Potential vs TOC plot of Sargelu Formation in X Well

3.2. Source of Organic Matter and Depositional Environment

Fig. 4 shows both relationships, as firstly between the Oxygen Index (OI) and the hydrogen Index (HI) (modified VanKrevelen) and secondly, between the Hydrogen Index (HI) and Tmax), it is evident that most of the samples were fall in the kerogen type II and II/III except for two samples which fall in the zone of type III. This interpretation is supported by the plot of (S_2) versus TOC where Fig. 5 shows that most of these samples are predominantly characterized by kerogen types II/III (oil/gas) and II (oil prone).

Gas chromatography fingerprints of two samples from the lower and upper parts of the formation (from depths 2804 and 2987 m) respectively. Fig. 6, showed unimodal distribution of the normal alkanes with short chain dominance; therefore, they have low terrigenous to aquatic ratios (TAR) (0.34-0.06); Table 2, indicating marine organic matter input (Tissot and Welte, 1984; Peters et al., 2005). One sample from the middle part of the formation showed bimodal shape, therefore it has moderate TAR value (0.54), which indicate mixed organic matter input (marine and terrestrial). Generally, the TAR values negatively correlated with TOC values; supporting the marine organic matter dominance. Pr/nC17 and Ph/nC18 ratios ranged between 0.10-0.29 and 0.32-0.55, respectively. These low ratios indicate the non-biodegraded

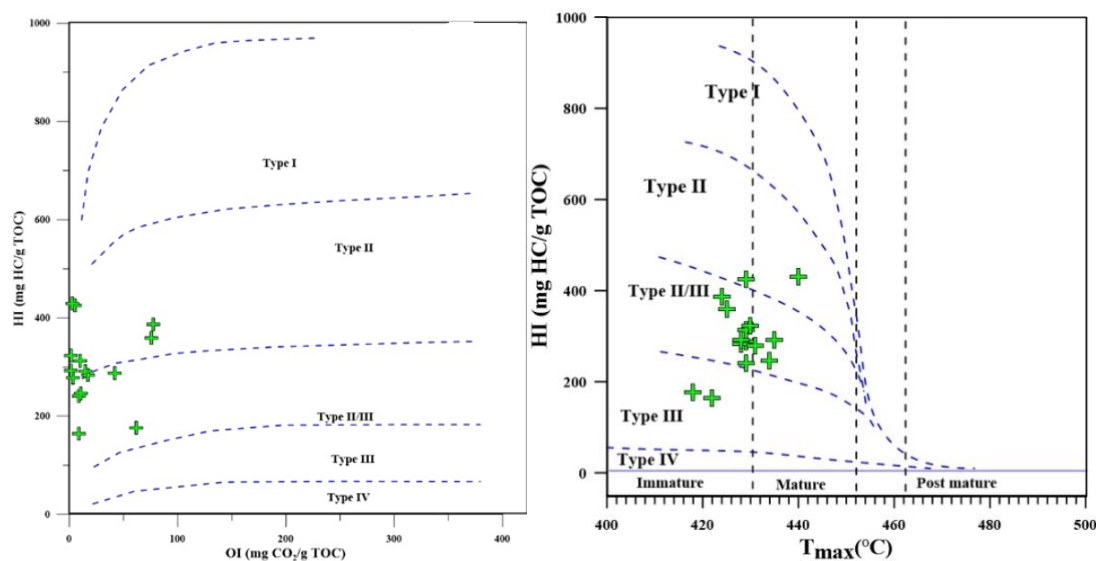


Fig. 4. Hydrogen index versus Oxygen index (Left) and hydrogen Index (HI) versus Tmax plots showing Kerogen type of the Sargelu Formation

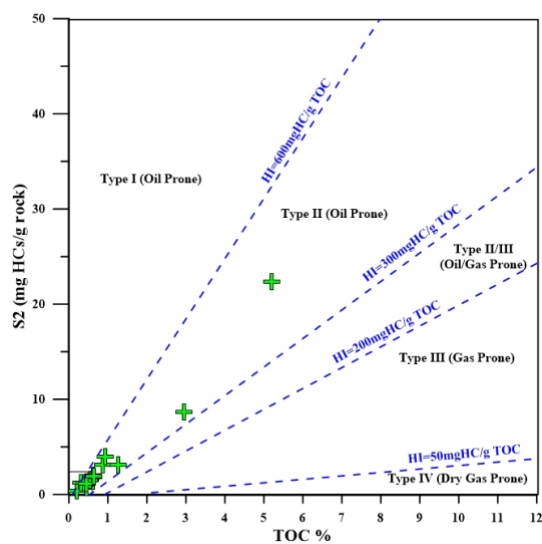
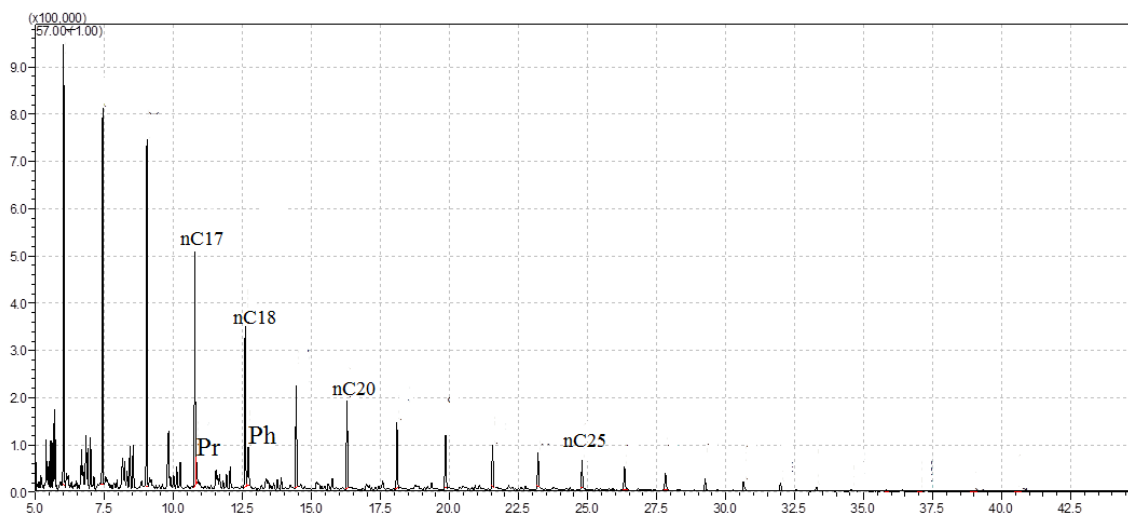


Fig. 5. Remaining potential (S₂) vs TOC plot showing Kerogen type of the studied samples of Sargelu Formation

marine organic matter deposited under reducing conditions (Fig. 7). The anoxic depositional environment of Sargelu Formation is supported by the low Pristane/Phytane ratios (Pr/Ph) (0.41-0.61) (Peters et al., 2005). Carbon Preference Index (CPI) and Odd to Even preference (OEP) are in the range of 0.95-1.12 and 0.92-0.99, respectively; indicating that samples are thermally mature and originated mainly from marine organic matter.

Table. 2. Source and maturity-related biomarker ratios

Parameter	(2804m)	(2891m)	(2987m)
Pr/Ph	0.61	0.48	0.41
Pr/nC ₁₇	0.29	0.29	0.10
Ph/nC ₁₈	0.55	0.53	0.32
Ts/Ts+Tm	0.51	0.61	0.60
C ₁₉ /C ₁₉ +C ₂₃	0.11	0.05	0.08
C ₃₂ S/C ₃₂ S+R	0.59	0.59	0.59
M ₃₀ /C ₃₀	0.07	0.06	0.07
C ₂₉ /C ₃₀	0.65	0.84	1.04
G/C ₃₀	0.15	0.17	0.19
C ₃₅ /C ₃₄	0.70	0.88	0.71
C ₂₉ SS/SS+RR	0.49	0.47	0.45
C ₂₉ ββ/ββ+αα	0.51	0.53	0.52
C ₂₇ /C ₂₇ +C ₂₉	0.47	0.41	0.42
CPI	1.12	1.04	0.95
TAR	0.34	0.54	0.06
OEP ₂₉	0.92	0.99	0.96
MPI-1	0.53	0.58	0.60
DBT/P	0.07	0.17	0.50
Rc	0.72	0.75	0.76
C ₂₇ ββRS %	34	30	31
C ₂₈ ββRS %	20	24	25
C ₂₉ ββRS %	46	47	43

**Fig. 6.** Normal alkane distribution of Sargelu Formation (sample depth 2987 m)

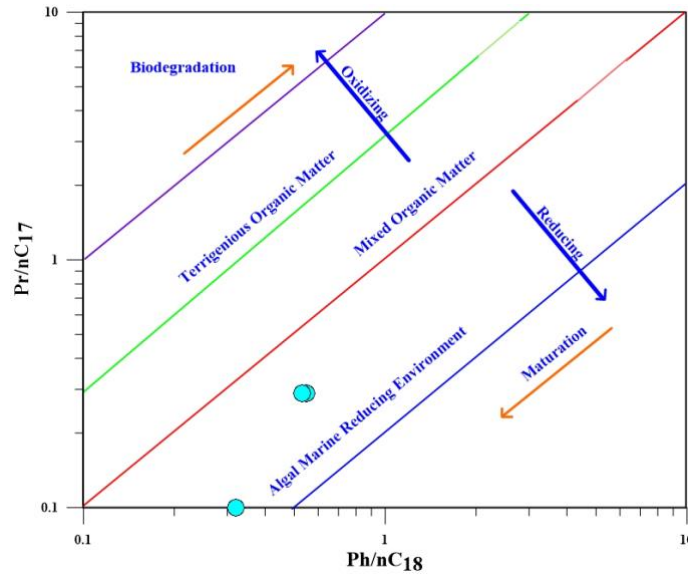


Fig. 7. Cross Plot of Ph/nC_{18} vs Pr/nC_{17} of Sargelu Formation

Terpanes ($m/z=191$) (Fig. 8), is also used to infer type of organic matter, lithology and depositional environment of the source rocks (Peters et al., 2005). C_{23} tricyclic terpanes is higher than C_{19} and C_{20} ; therefore, the studied samples of Sargelu Formation have low values of $\text{C}_{19}/\text{C}_{19}+\text{C}_{23}$ (0.05-0.11), Table 2, indicating marine organic matter (Fig. 9) (Wang et al., 2023; Amoako et al., 2024; Xiao et al., 2024). $\text{Ts}/\text{Ts}+\text{Tm}$ ratios are in the range of 0.51-0.61, the highest value in the middle part of the formation, associated with the high value of TAR; suggesting higher clay content than other samples. Gammacerane Index ($\text{Gammacerane}/\text{C}_{30}\alpha\beta$ hopane, G/C_{30}) is in the range of 0.15-0.19, Table 2, indicate the moderate saline or marine depositional environment (Awadh and Hussien, 2015). High $\text{C}_{29}/\text{C}_{30}$ hopane (C_{29}/H) is typical of anoxic carbonate or marl source rocks and oils (Peter et al., 2005). $\text{C}_{29}/\text{C}_{30}$ ratios are in the range of 0.65-1.04 indicate carbonaceous (carbonaceous shale or varying from marl-carbonates) lithology of the samples. Marine source rocks deposited under anoxic conditions generates oils with high $\text{C}_{29}/\text{C}_{30}$ hopane and $\text{C}_{35}/\text{C}_{34}$ hopane (more than 0.6 and 0.8), respectively, (Peters et al, 2005). The same is the case of the present study samples. $\text{C}_{35}/\text{C}_{34}$ ratio ranged between 0.70-0.88 means high values also lead towards the carbonaceous/marl source rock.

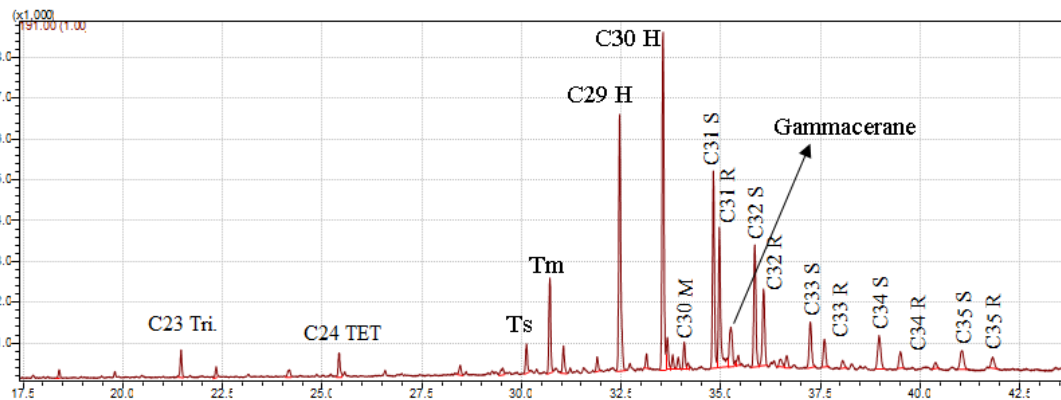


Fig. 8. m/z 191 Chromatograms of rock sample (depth 2804)

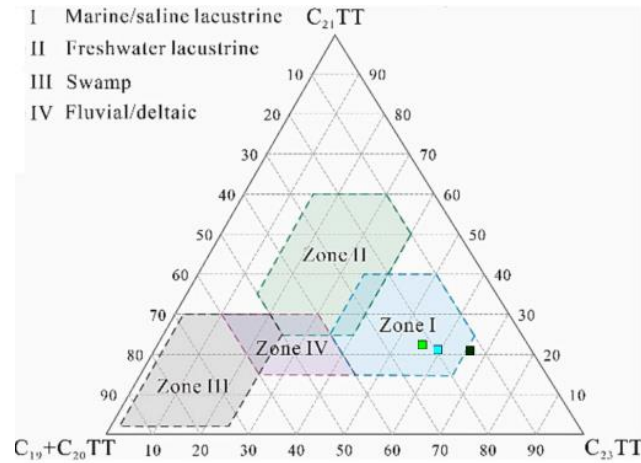


Fig. 9. Ternary diagram of tricyclic terpane ratios of Sargelu Formation showing depositional environments (Xiao et al., 2024)

Regulaersteranes distribution (m/z 217) are shown in (Fig. 10). $C_{27}\%$, C_{28} and C_{29} are 30-34%, 20-25% and 43-47%, respectively. $C_{27}/C_{27}+C_{29}$ steranes ratios ranged between the 0.41-0.47, suggest dominance of marine organic matter. C_{29} -steranes are derived mostly from green and brown algae and higher plants (Volkman, 2003), it recorded with high abundance in oils and rocks of marine origin (Palacas et al., 1984). C_{28} steranes and C_{27} and are derived from phytoplankton. Therefore, high abundance of C_{29} steranes are not necessarily associated with high higher plants input (Grantham, 1986). In the present study samples, there is no clear evidence for high contribution of higher plant input, therefore, the high C_{29} percent may be derived from algae. Most of Iraqi oils which suggested to be generated from Sargelu Formation have high abundance of C_{29} sterane (Al-Ameri et al., 2009 and 2016; Al-Ibrahim and Al-Ameri, 2015; Abdula, 2020; Alkhafaji et al., 2022; 2023;). Regular sterane ternary diagram shown in Fig. 11. support the marine organic matter source.

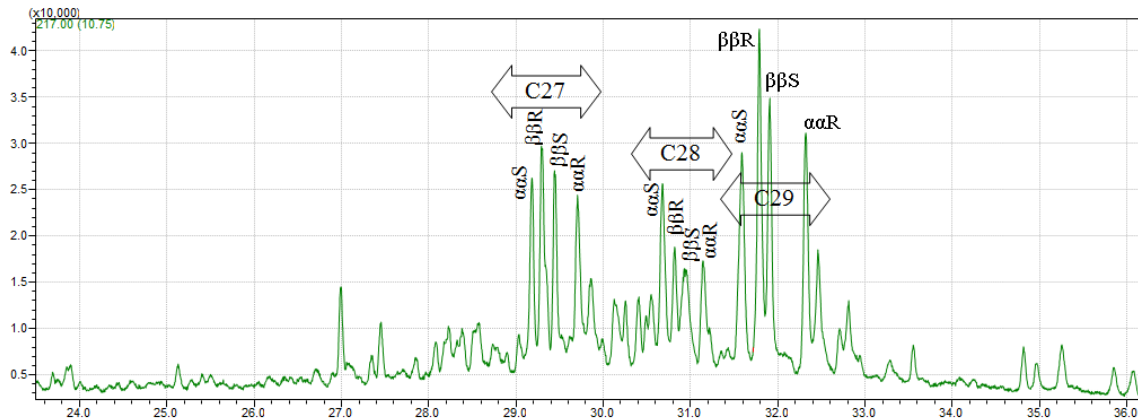


Fig. 10. $m/z=217$ Chromatograms of Sargelu Formation (Sample depth 2891 m)

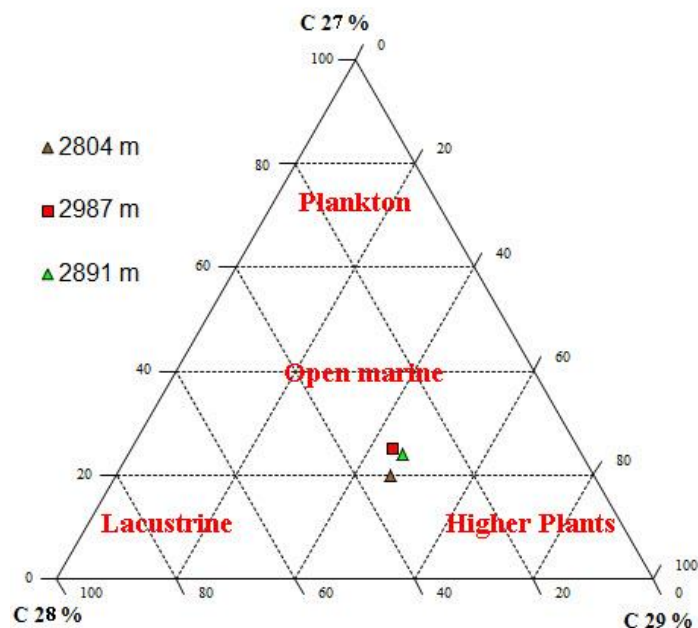


Fig. 11. C_{27} , C_{28} and $C_{29\alpha\alpha\alpha R}$ regular steranes ternary diagram of Sargelu Formation

3.3. Maturity of the Organic Matter

Production index (PI) values are between 0.03 and 0.16 and (T_{max}) values between 418 and 440°C. These values indicate thermally immature to early mature organic matter. From Production Index (PI) vs (T_{max} °C) plot (Fig. 12), it is evident that organic matter of Sargelu Formation are generally marginal mature and not contaminated/stained.

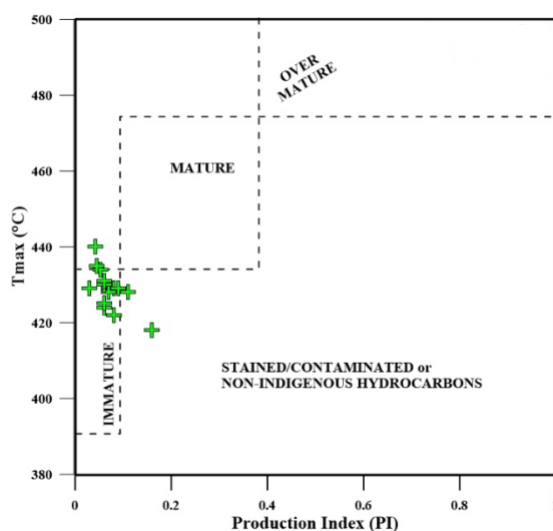


Fig. 12. T_{max} vs PI plot for thermal maturity of Sargelu Formation

Moretane/C₃₀hopane ratios are low ranged between (0.06 and 0.07) indicate thermal maturity of the samples. Low ratio of moretane/hopane indicates increase in thermal maturity of source rocks. This is useful in identifying the early oil window (Peter et al, 2005). C₃₂ 22S/22S+22R homohopanes value is 0.59 in all samples; indicate at least early mature organic matter. C₂₉SS/SS+RR ratios ranged between 0.45-0.47 whereas C₂₉ββ/ββ+αα ratios are in the range of 0.51-0.53; both indicate the mature organic matter (Fig. 13). However, the sterane and hopane biomarker ratios indicate higher maturity level than that deduced from the Tmax. This is because hopanes and maturity ratios are elevated anomalously at low maturities in organic sulfur-rich source rocks (French et al., 2020), which is the same case in the present study samples.

The maturity of oil can also be determined using aromatic compounds. Methyl phenanthrene index (MPI) is a very reliable parameter that is applicable over a wide range of maturity and for the oil window that range between 0.60-1.35 (Radke and Welte, 1983). The MPI for studied sample from Sargelu Formation is in the range of 0.53-0.60, and the calculated equivalent vitrinite reflectance Rc) (0.6 x MPI + 0.4) (Radke and Welte, 1983) values are in the range of 0.72-0.76 (Table. 2). These values indicating that the samples fall in the marginal mature zone (Peters et al., 2005).

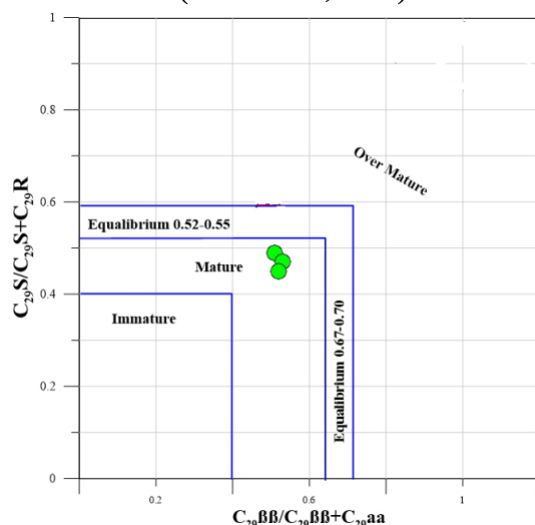


Fig. 13. Cross Plot of C₂₉S/C₂₉S+C₂₉R vs C₂₉ββ/C₂₉ββ+C₂₉αα steranes of Sargelu Formation

4. Conclusions

According to the results mentioned above, the following can be concluded:

- Sargelu Formation from X Well has TOC content ranges from low to high, gradually increasing with depth; categorized into poor-excellent source rock categories.
- HI and OI parameters in the modified Van Krevelen diagram indicate that most of the studied samples are belong to the Kerogen type II and II/III, with two exceptions falling into type III.
- Examination of Tmax values revealed that Sargelu samples are varied from immature in the upper part of the formation to thermally mature in the lower part (Tmax: 418-440°C). The PI vs Tmax plot indicates that the samples are generally classified as marginally mature and not contaminated/stained.
- The gas chromatography and GC-MS analysis revealed that the Sargelu samples are most likely deposited in an anoxic environment, non-biodegraded, appeared thermally mature (early oil window) and dominance of marine organic matter with indications of some contributions from terrestrial organic matter.

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