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RESEARCH ARTICLE Open Access

Source Rock Evaluation through Well Logging Data and Pyrolysis Analysis: A Study of the Kurra Chine Formation in Well-6, Peshkhabir Oil Field, Kurdistan, Iraq

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Abstract: The volume of hydrocarbon exists in the reservoir is directly related to the quantity of the hydrocarbon generated and expelled from the source rock. Accurate evaluation of source rock is important for hydrocarbon production planning and subsurface resource prediction. This study evaluates the source rocks of the shale zones within the Kurra Chine Formation using well-logging data and Rock-Eval pyrolysis analysis for Well-6 in the Peshkhabir Oil Field, located at Zakho, Northern Iraq. Comprehensive well logging data of Well-6 in the Peshkhabir Oil Field, and sixteen cutting samples were selected for this study. The result indicates that the total organic carbon wt.% of Well-6 ranges from 0.39 - 1.62 %, classifying the Kurra Chine as a good source rock in the shale zones. The Generation potential ranges from 1.02 – 6.562, additionally confirming the source rock potentiality through wireline logs. The S1 value for most samples ranged between 2.68 – 3.16, indicating favourable hydrocarbon presence and suggesting a good quality source rock. The level of maturity, represented by thermal maturity, ranges between 400 °C – 420 °C for most samples, indicating them as immature to marginally mature. Furthermore, the kerogen types predominately fall under type III, based on the relationship between hydrogen index and thermal maturity.

Keywords: *Well Logging Data; Rock-Eval Pyrolysis; Source Rock Evaluation; Peshkhabir Oil Field; Kurra Chine Formation; Northern Iraq*

1. Introduction

The Term Petroleum System, as described by [1], encompasses both process and elements. The Kurra Chine Formation is considered a complete system, comprising the key elements of reservoir, source, and cap rocks. Rock Eval pyrolysis is a cost-effective and time-efficient laboratory method for assessing thermal maturity and hydrocarbon generation potential of the studied sedimentary rock samples [2]. Pyrolysis technique measures many parameters including free hydrocarbon (S1), hydrocarbon generation (S2), carbon dioxide (S3), maximum temperature (Tmax), total organic carbon (TOC), generation potential (GP), petroleum production (PI), hydrogen and oxygen Index (HI and OI), vitrinite reflectance (Ro), The PI is calculated using the equation PI= S1/(S1+S2) to estimate the maturity of the organic matter. This formula approach separates between hydrocarbon already produced from the samples and hydrocarbons yet to be produced [3]. TOC, as emphasized by [4], is a key parameter to identify the amount of organic matter in the samples to estimate the evaluation of the source rock in the studied samples. Organic matter significantly influences the value of PI and GP, with each of the organic matter types producing specific hydrocarbon generation potential [2].

Numerous researchers studied the Kurra Chine Formation, focusing on its lithology, kerogen type, source rock, organic matter and maturation. [5], described the source rock of the Kurra Chine Formation and determined the main lithology of the Formation, that consists of dolomite, limestone, anhydrite and shale. [6], studied the kerogen types and found types II and III. Also studied the level of maturation of the organic matter and found mature organic matter at the Kurra Chine Formation. [7], studied the Kurra Chine Formation and divided the Formation lithological into four units, included two carbonate units and two evaporate units. [8], studied the source rock of the Kurra Chine Formation and described the thermal maturation of the organic matter, and proved that the samples were mature organic matter. [9], categorised the Kurra Chine Formation into three main units, which include the Kurra Chine A, B, and C that based on the sea level and maximum flooding surface.

Further studies include [10], who studied Biomarks of the Kurra Chine Formation, using the pristine (pr) and phytane (ph) Pr/Ph ratio and determined the maturity of the organic matter based on the cutting samples that found mature to early maturity. [11], Who focused on unit A of the Kurra Chine Formation at Shaikhan oil field, and they found mainly dolomite and anhydrite with minor shale (mainly Illite and Chlorite). [12], analyzed the pyrolysis for the Kurra Chine Formation based on the rock eval technique and cutting samples. They found the low generation of hydrocarbon and samples of immature organic matter. [13], studied the petrography and microfacies analysis to determine the depositional environment of the Kurra Chine Formation. [14], studied the Kurra Chine Formation based on the outcrop and well samples to identify the heterogeneity of the shale units in the reservoir. [15], studied the pyrolysis of the Kurra Chine Formation at Tawke Oil field and found a poor to good source rock. [16], studied the porosity and petrography of the Kurra Chine Formation and found high porosity in most parts. [17], studied the reservoir properties of the Kurra Chine Formation in the Sarta Oilfield and found low porosity in most parts. [18], studied the palynofacies analysis of the Kurra Chine Formation and found different types of palynofacies and deep depositional environment.

In Northern Iraq, Jurassic reservoirs frequently rely on hydrocarbon sourced from Triassic Formations like Kurra Chine Formation. The shale volume of the Kura Chine Formation plays a significant in generation of hydrocarbon and migrating to the Jurassic reservoirs. Kurra China is located in the Upper Triassic, and most of the reservoirs are in the Middle Jurassic. This research explores the relationship between source rocks of the drilled wells at the Triassic Formation to the Jurassic Reservoirs, aiming to inform the production rate and drilling developments. Given its substantial thickness in the Upper Triassic, understanding the Kurra Chine Formation is important for assessing its contribution to Jurassic Reservoir Formations.

The objective of this study is to evaluate the hydrocarbon potentiality of the Upper Triassic Kurra Chine Formation at Peshkhabir Oil Field. The result of this study will provide insights into hydrocarbon generation and maturation in the upper Triassic and their contributions to the Lower and Middle Jurassic reservoirs. This finding will help oil companies to understand the volume of hydrocarbon during these periods, supporting the drilling development with detailed source rock maturity and quality assessment.

2. Location and Tectonic Setting of the studied area

Kurra Chine Formation was first described by Wetzel at the Ora Anticline in the Amedy district [19]. The thickness of the Kurra Chine Formation is 834m at this type of locality, and the main lithology includes limestone, thick bedded dolomite and bedded breccia [19]. The studied Well is located in Zakho, within the Peshkhabir Oil Field, Northern Iraq. This study is focusing on analysing the cutting samples from Well-1 of the Peshkhabir Oil Field. The coordinates of the studied well are 37º 05' 04" N and 42º 31' 01" E (Fig. 1a).

Structurally, the studied area lies within the high-folded zone and is part of the Taurus fold and thrust belt (Fig.1b). The tectonic activity in this region is associated with the collision between the Eurasian and Arabian plates, which led to the formation of a foreland basin. This foreland basin corresponds to the Zagros fold belt in Iraq [20]. Tectonically, Iraq is located to the northeast of the Arabian plate, where ongoing convergence between the plates has shaped the region's geological features.

Kurra Chine Formation underlies Baluti Formation and overlies the Galikhana Formation. The lower contact of the Kurra Chine Formation is unconformable, whereas its upper contact is conformable [14].

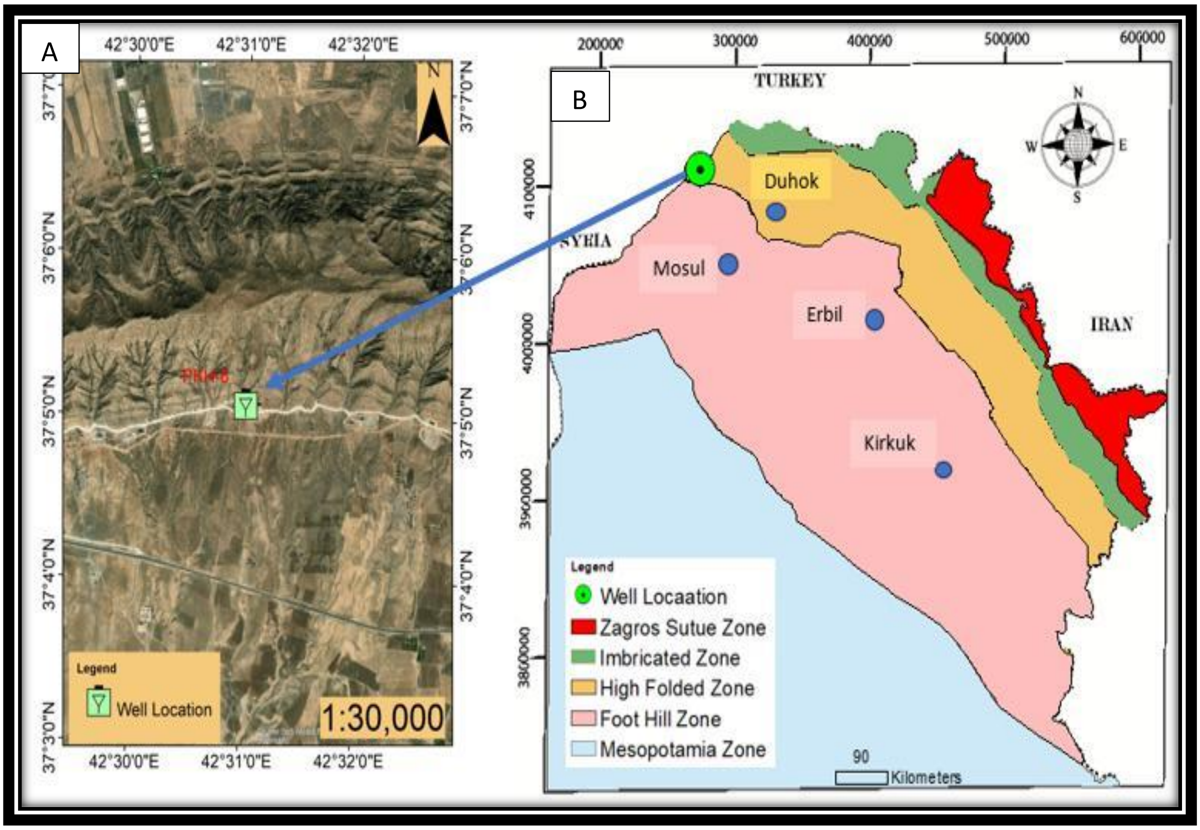

Figure 1: A- The location of the studied drilled Well and The tectonic map of the studied area [8]

3. Materials and Methodology

3.1 Well Logging Date

Well-logging analysis was conducted using Tech-Log software to evaluate the shale volume at various depths. The thickness of the shale zones provides major information about the ratio of the organic matter and hydrocarbon potentiality. The Well Logs determined shale zones, and cutting samples were collected at these intervals.

3.2 Rock Eval Pyrolysis

Sixteen cutting samples of the Kurra Chine Formation were analysed using Rock Eval pyrolysis. These samples were obtained from Well-6 of the Peshkhabir Oil Field, located in Northern Iraq, through DNO International Oil Company. Samples were analysed at Tehran University. The subsurface samples were crushed and powdered, and a maximum of 90 – 100mg per sample was used for analysis following the calibration process. This method provides detailed data on all pyrolysis parameters, including the volume of each parameter [21]. The detailed lithology descriptions, thickness measurements, sample depth and shale zones from which samples were taken are explained in (Fig.2).

3.3 GIS and Illustrator

GIS software was utilized to create Location and Tectonic maps of the studied area. Additionally, the Geological column was created by Illustrator software (Fig.2).

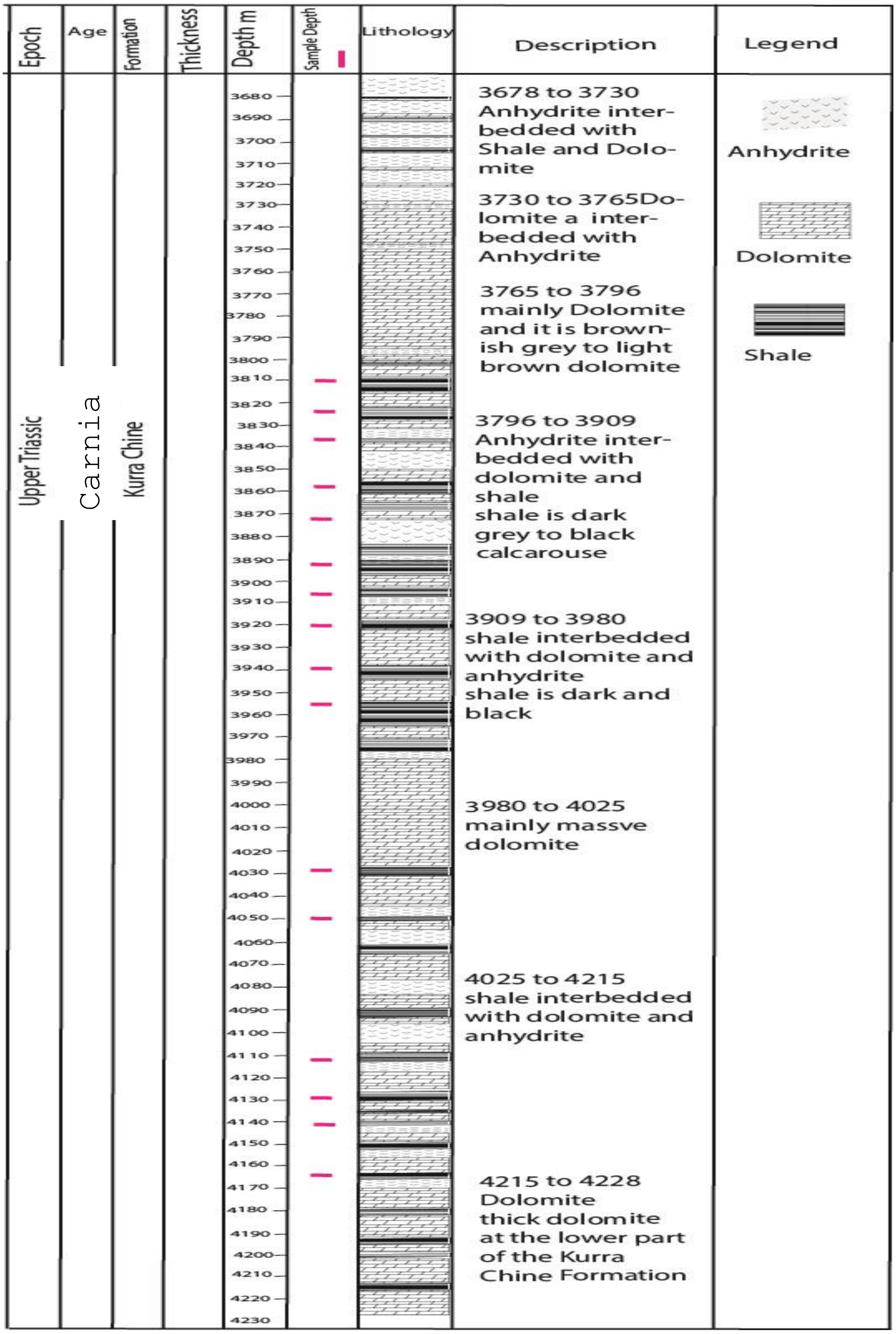

Figure 2: The Lithostratigraphic column of the studied Well of the Kurra Chine Formation at Peshkhabir Oil Field Well-6

4. Results

4.1 Well logging data and analysis

The Kurra Chine Formation presence a significant thickness during the Triassic Period. Shale is one of the essential components's lithology of the Kurra Chine Formation. Shale can be identified based on the Gamma Ray Log (GR) from Tech-Log software. Samples were selected from shale lithology at different depths. As outlined by [22], the Linear GR method gives a rapid and straightforward approach for quantifying shale volume within a porous reservoir. In a petroleum system, Shale provides dual functions as a source rock and a seal rock. According to GR log separation, lithology is classified into clean zones and shale zones, with a high GR value indicating shale zones and a low value representing clean zones. All shale zones and clean zones are shown in Fig. 3.

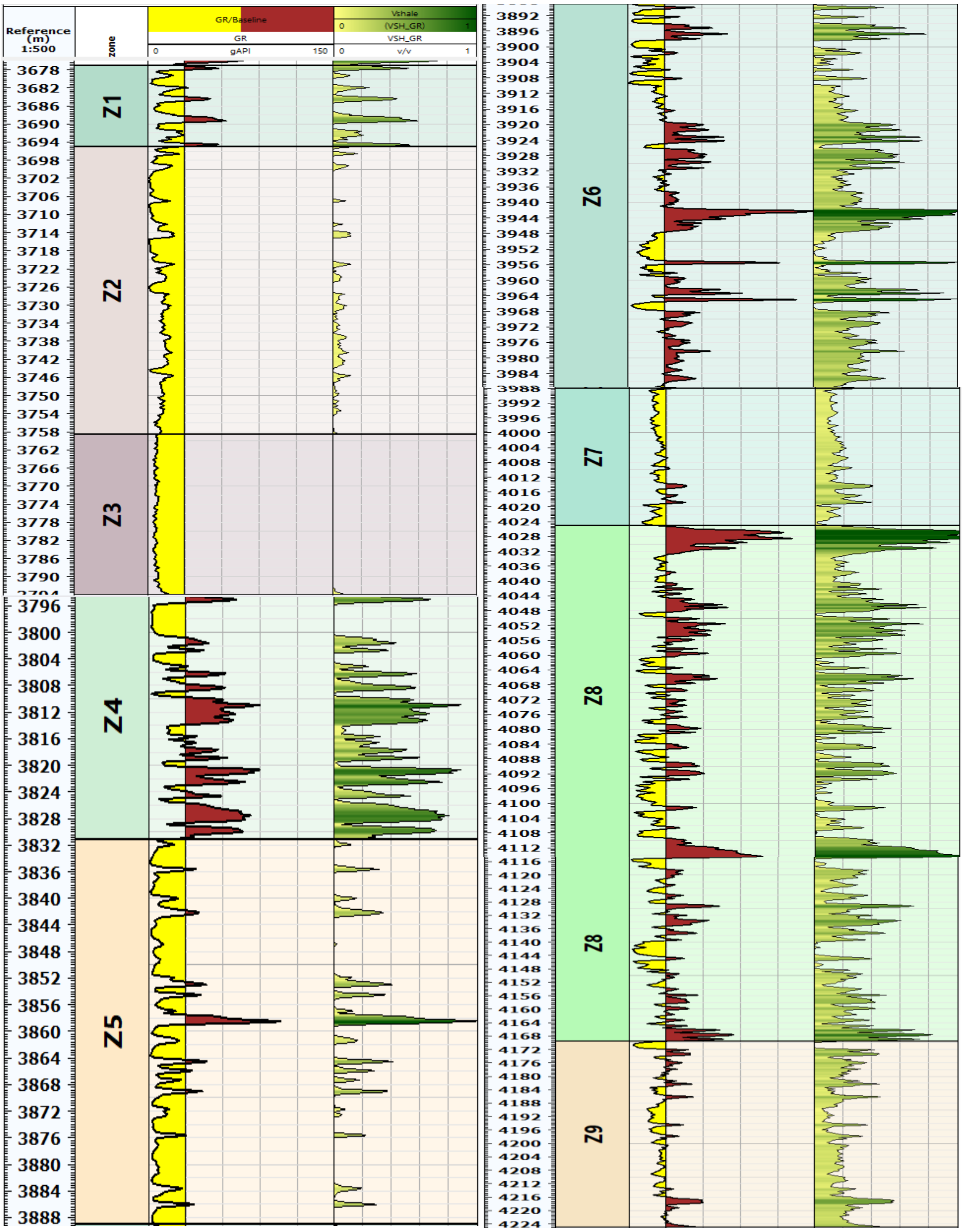

Figure 3: The Kurra Chine Formation shale zones at Well-6 of Peshkhabir Oil Field.

4.2 Pyrolysis parameters

4.2.1 Main Parameters

The result of the pyrolysis analysis for the Kurra Chine Formation at Peshkhabir Oil Field, Well-6, is shown in Table 1. The data were analysed using Rock-Eval pyrolysis at Tehran University.

Table 1: The presents key pyrolysis parameters analysed using Rock-Eval

Section	Sample Depths	Rock-Eval pyrolysis									
		S1 mg/g	S2 mg/g	S3 mg/g	T_{max} °C	TOC Wt%	HI	OI	PP	PP	Ro%
Peshkhabir Well-6	3810	2.68	3.67	1.26	424	1.62	226	78	6.35	0.42	0.47
	3825	2.8	3.64	1.27	420	1.5	285	88	6.44	0.43	0.40
	3836	2.93	3.22	1.28	400	1.2	315	120	6.15	0.48	0.04
	3858	3.16	3.12	1.29	410	0.98	318	132	6.28	0.50	0.22
	3874	3.2	3.16	1.33	415	1.1	330	140	6.36	0.50	0.31
	3892	3.26	3.18	1.44	420	1.5	340	145	6.44	0.51	0.40
	3908	3.19	3.43	1.48	415	1.39	350	112	6.62	0.48	0.31
	3920	0.41	0.61	1.33	215	0.69	98	192	1.02	0.40	-3.29
	3938	0.18	0.62	0.96	419	0.39	159	248	0.80	0.23	0.38
	3956	0.12	0.51	1.04	404	0.42	123	251	0.63	0.19	0.11
	4028	2.91	3.91	1.21	435	1.42	300	250	6.82	0.43	0.67
	4050	1.87	3.1	1.24	405	1.54	250	240	4.97	0.376	0.13
	4112	2.81	3.89	1.44	432	1.46	280	270	6.7	0.419	0.616
	4128	2.71	3.59	1.39	428	1.32	290	295	6.3	0.43	0.544
	4144	2.31	3.43	1.31	445	1.26	300	310	5.74	0.402	0.85
	4166	2.22	3.24	1.29	437	1.21	305	320	5.46	0.407	0.706

4.2.2 Secondary Parameters

The calculation for the production index, hydrocarbon index, generation potential and thermal index is presented in Table 2.

Table 2: The calculation of the Secondary pyrolysis parameters, which are derived through specific computations.

(PI = S1/ (S1 + S2)	TI=(S1/TOC)	S2/S3 HC Index	GP=(S1+S2)
0.42	1.65	2.91	6.35
0.43	1.87	2.87	6.44
0.48	2.44	2.52	6.15
0.50	3.22	2.42	6.28
0.50	2.91	2.38	6.36
0.51	2.17	2.21	6.44
0.48	2.29	2.32	6.62
0.40	0.59	0.46	1.02
0.23	0.46	0.65	0.8
0.19	0.29	0.49	0.63
0.43	2.05	3.23	6.82
0.38	1.21	2.50	4.97
0.42	1.92	2.70	6.7
0.43	2.05	2.58	6.3
0.40	1.83	2.62	5.74
0.41	1.83	2.51	5.46

4.3 Quantity of Organic Matter and Hydrocarbon Potential

TOC is the primary parameter used to determine the organic matter content in the samples. TOC represents the volume of organic matter present in the samples. TOC wt.% values range between (0.39 - 1.62) for the studied samples (Fig. 4)

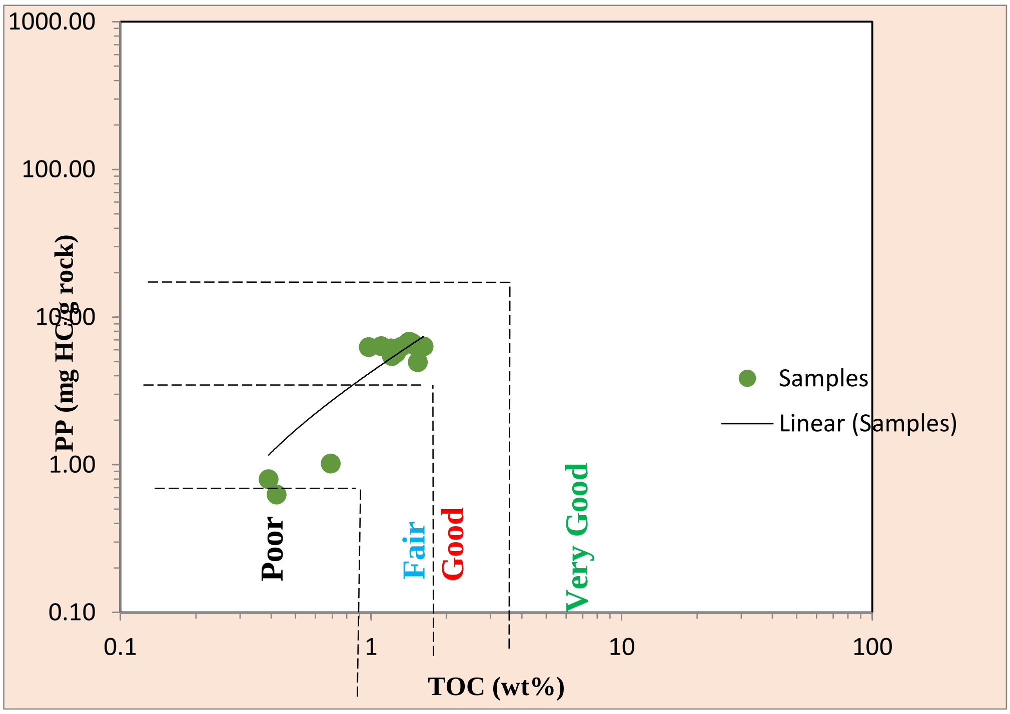

Figure 4: The quality of the organic matter is identified based on the petroleum potential (PP) and total organic carbon (TOC%) for the studied samples.

4.4 Types of Organic Matter

The relationship between the Oxygen index (OI) and the Hydrogen index (HI) is useful for determining the organic matter types. The studied samples predominately indicate oil and gas-prone type II-III organic matter sources (Fig. 5).

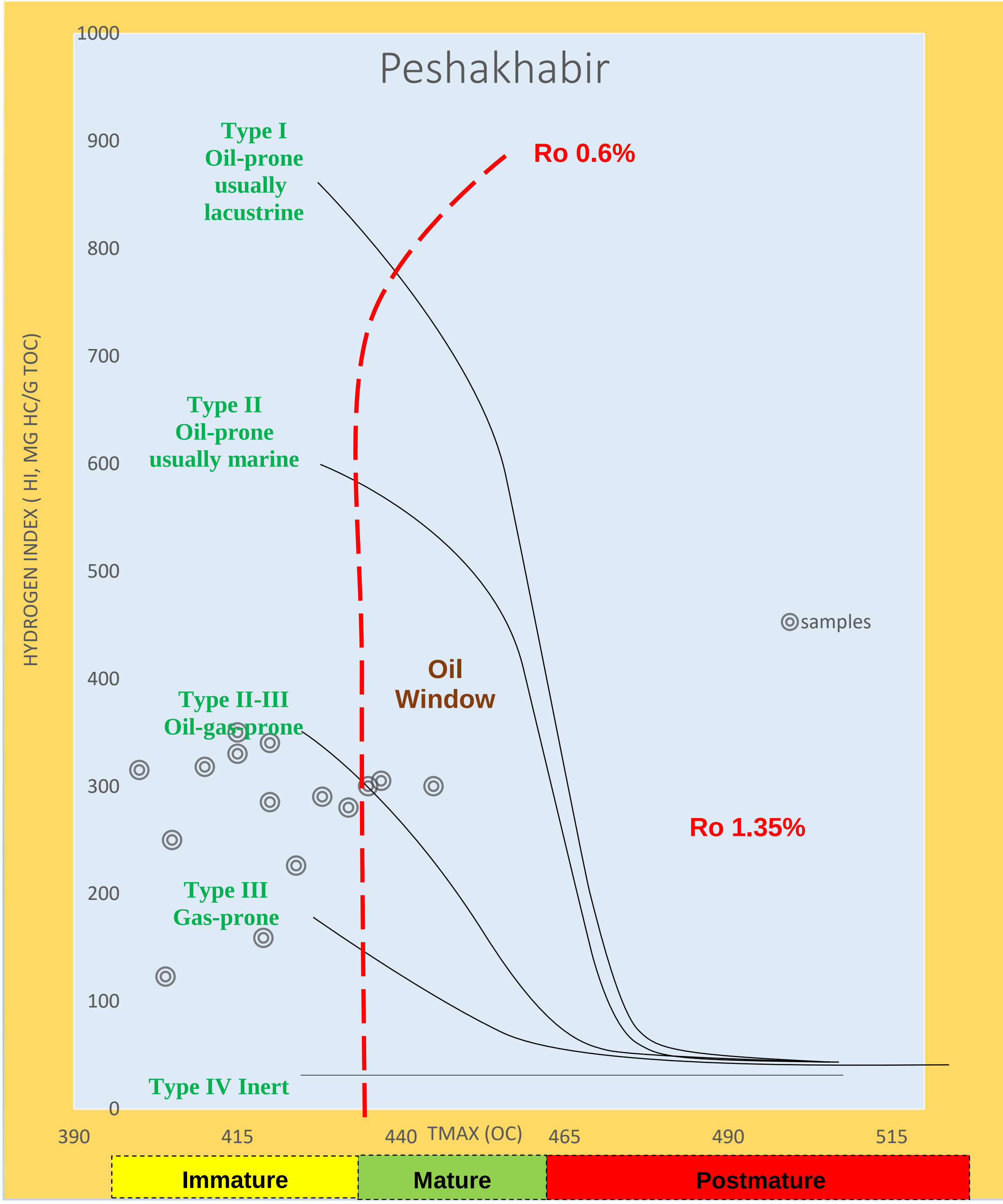

Figure 5: Organic matter types identified based on HI and Tmax plots for the studied samples

4.5 Maturity of the Organic Matter

The maturity of the organic matter is determined by the relationship between petroleum production (PI) and thermal maturity (Tmax). The PI for studied samples ranges from 0.19 to 0.51, while the Tmax ranges from 400°C to 445°C. The samples show a maturity progression from immature to mature, with the majority of samples located within the mature part of the studied section (Fig.6).

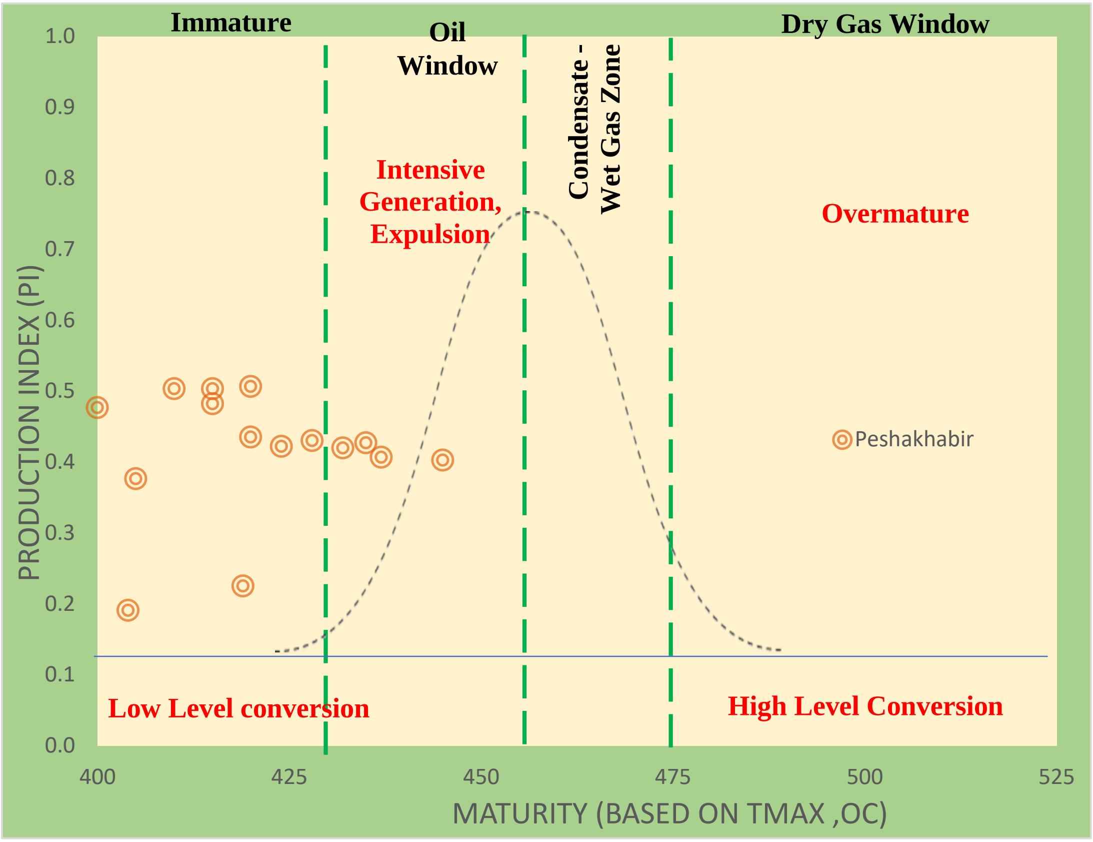

Figure 6: Level maturity is determined based on the relationship between PI and Tmax for the studied samples.

4.6 Kerogen Types

The Van Krevelen diagram is a commonly used method for identifying Kerogen types, based on the relationship between the hydrogen index (HI) and oxygen index (OI) [21]. The studied samples show the HI range of 300-350 and OI range of 190-320 (Fig.7).

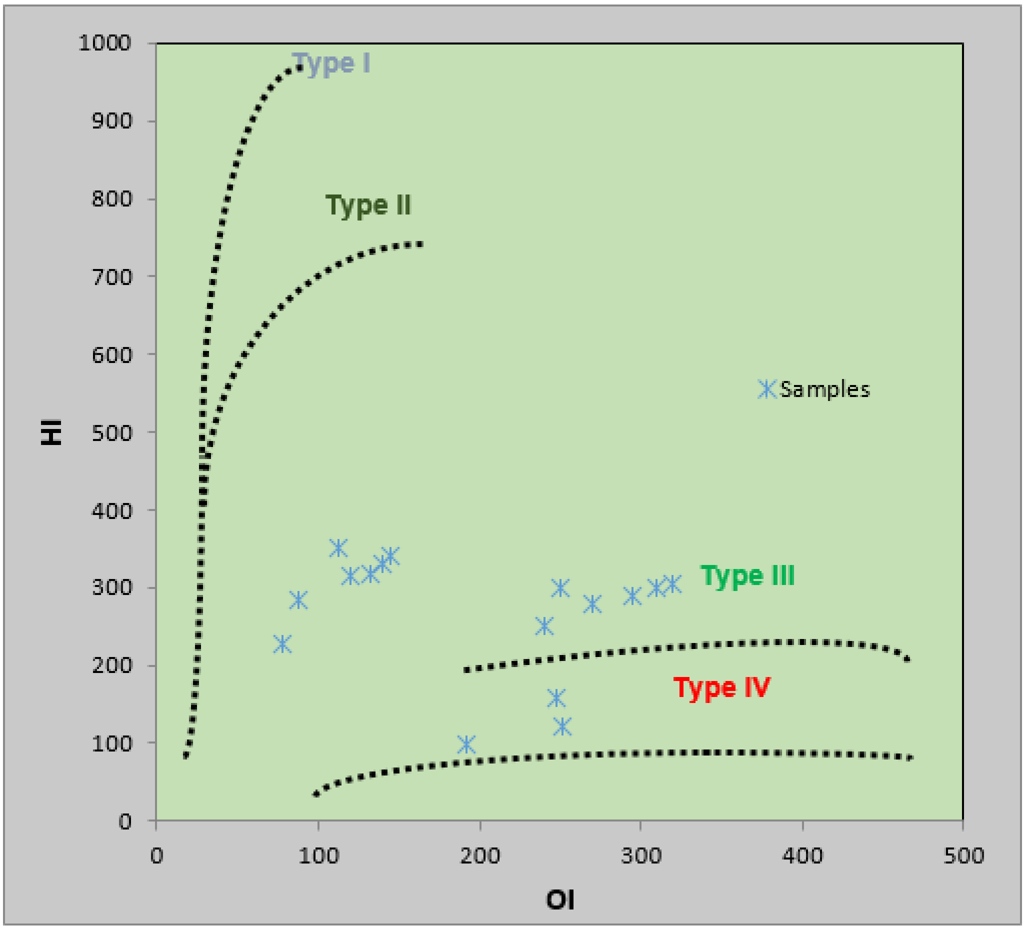

Figure 7: Kerogen types is determined relying on OI and HI relationships for the studied samples

5. Discussion

Source rock evaluation for the Kurra Chine Formation, the potentiality of the source rock evaluation for the Kurra Chine Formation was conducted using logging data and pyrolysis parameters. The Gamma Ray log determined the shale zones at various depths, revealing that most shale zones are deposited in the middle and lower sections of the Kurra Chine Formation. The GR log gives information about the volume of shale and shale-rich intervals. As shown in Figure 3, nine shale zones were identified within the Kurra Chine Formation based on the lithological characteristics. The zones with the highest shale volumes are zone four (3800 -3830 m), zone 6 (3892 -3988 m), and zone 8 (4024 – 4124 m). These three prominent shale zones exhibit significant hydrocarbon generation potential, particularly for the Jurassic and Triassic periods. Shale plays an important role in subsurface hydrocarbon generation. The identification of shale is essential at various depths and distributions. The average shale volume across the three common zones is approximately 50%. These depths indicate that cutting samples from Well-6 could confirm both the hydrocarbon generation potential and evidence of hydrocarbon already produced.

Comparative analysis of Figs 2 and 3 highlighted the correlation between well logging data and the lithostratigraphic column for Well-6. The comparison enhances the precision of sample locations and improves the reliability of the results.

Source rock parameters and maturity. Source rock analysis at different depths gives variable results. Following the criteria established by [23, 24], the weight per cent of TOC content greater than 1% indicates a good source rock for hydrocarbon generation potential. Samples from the lower part of the

Kurra Chine Formation (4000 to 4200 m) exhibited TOC values exceeding 1%, indicating that these shale units could serve as an effective source rock. Conversely, TOC values in the middle and upper sections were below 1%, likely due to variations in sedimentation rate and organic matter as described by [3]. Also, the Kurra Chine Formation has different depositional environments based on the lithological content [13]. Samples with S2 less than 0.2 mg HC/g rock typically indicate inaccurate thermal maturity [21]. However, all selected samples exceed this threshold, demonstrating consistent thermal maturity across all zones. The quality of these samples ranged from fair to good, with most classified as good based on the relationship between S2 and TOC.

The maturity level of the samples varied from immature to mature. The middle and upper sections were predominantly immature due to insufficient thermal maturity of the samples, consistent with findings by [12], which suggest limited maturity within the Kurra Chine Formation. the lower sections, however, exhibited greater maturity and hydrocarbon potential.

Kerogen types were determined using the hydrogen index and oxygen index, following the classification proposed by [4]. Most samples were identified as type II or type III kerogen. Figure 8 indicates that the organic matter quality is generally good. When compared to those studied by [8,15], the Kurra Chine Formation samples showed superior quality, with higher TOC and Tmax values.

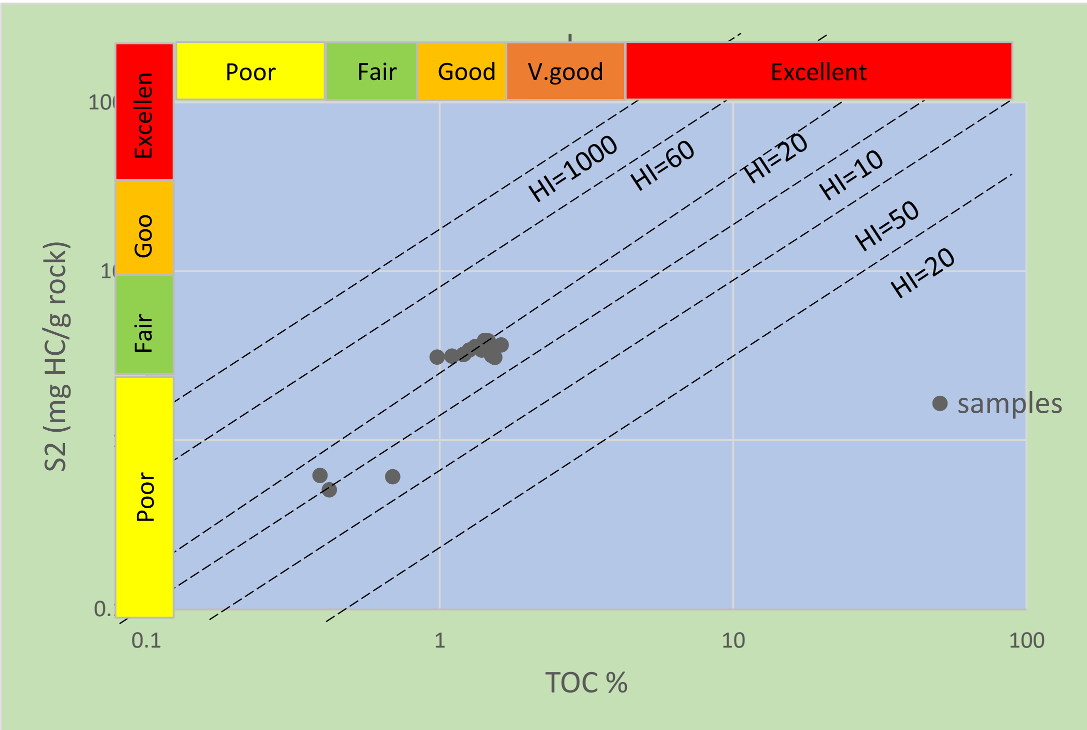

Figure 8: The quality of the organic matter at the studied Well-6

6. Conclusions

The following conclusions were made from the analysis of the studied samples.

- The Kurra Chine Formation is divided into nine zones based on the Well Logging data.
- Gama Ray (GR) logs identified three primary shale-rich zones according to the Gama Ray logs. These three-zones are located predominantly in the middle and lower sections of the Kurra Chine Formation.

- Kurra Chine Formation exhibits high total organic carbon (TOC) content in most samples, except for some samples from the upper part of the Formation.
- Organic matter quality in the Kurra Chine Formation is generally good, with exceptions in certain upper Formation samples.
- The maturity level of the studied samples ranges from immature to mature. The majority of samples from the middle and upper sections remain immature.
- Kerogen types of the studied samples range between type II and type III, with most samples leaning toward type III. However, samples from the lower part of the Formation trend toward type III-IV.

Author's Contribution

"I confirm that all named authors have read and approved the manuscript. I also confirm that each author has the same contribution to the paper. I further confirm that all authors have approved the order of authors listed in the manuscript."

Conflict of Interest

"There is no conflict of interest for this paper."

Aknoledgment

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