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Hydrocarbon source rock potential of the late paleocene Patala formation, Kohat basin, Pakistan

Tausif Javed[1,2], Syed Mamoon Siyar[1,3]*, Syed Muhammad Wasim Sajjad[1,4], Fayaz Ali[1], Fawad Raziq[1], Saeed Ullah Shah[1], Nasar Khan[1], Izaz Ali[1]

[1]*Department of Geology, University of Malakand, Chakdara, Dir (Lower), Pakistan.*
[2]*Department of Earth Science, Quaid-e-Azam University Islamabad, Pakistan.*
[3]*Department of Geology, University of Peshawar, Pakistan.*
[4]*Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Italy.*

*__Corresponding author:__ mamoon@uom.edu.pk

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Abstract:
The Late Paleocene Patala Formation shales exposed at Tarkhobi Nala, Kohat Basin, Pakistan were geochemically studied in detail for hydrocarbon evaluation. A total of 09 shale samples of the studied formation were analyzed in G & R Labs, Oil & Gas Development Company Limited (OGDCL), Islamabad, Pakistan for TOC and Rock-Eval pyrolysis. The TOC results were low ranging from 0.36 wt. % to 1.25 wt. % indicating poor to fair petroleum potential except a sample falling in the good source rock category. The generating potential values ($<$ 2 mg HC/ g. rock) also show poor ability for hydrocarbon production. The different cross plots between Rock-Eval pyrolysis parameters (HI vs OI; HI vs Tmax; S_2 vs TOC) were used to describe the types of kerogen and thermal maturity of the evaluated samples. All these plots confirmed the presence of type IV kerogen which has no capability to generate hydrocarbon except minor gas upon thermal maturation. The thermal maturity of the organic matter was assessed by Tmax (444 °C to 459 °C) which shows that the studied formation is falling in the oil window but due to the presence of type IV (oxidized & reworked) organic matter not able to generate commercial hydrocarbons.

Keywords: Organic geochemical analyses; Patala Formation; Kohat Basin; Pakistan

1. Introduction

A source rock can be defined as a type of fine-grained sedimentary rock possessing an adequate amount of organic matter with the capability to produce and release abundant hydrocarbons to form a commercial accumulation of oil and gas (Wang et al., 2020). Hydrocarbon production and their expulsion are the two basic properties of source rock. Shale and lime mudstone containing a substantial amount of organic matter is generally considered a good source rock (Tissot, 1984). Based on hydrocarbon generation potential, source rock is distinguished into three different categories which include immature, mature and postmature source rock (Hunt et al., 1995). Immature source rocks can't generate any hydrocarbon yet while mature source rocks are those which are currently in the hydrocarbon generation stage. Post mature source rock previously generated all types of hydrocarbons (Hunt et al., 1995).

Pakistan is divided into two major sedimentary basins i.e Indus Basin to the east and Baluchistan Basin to the west. The Indus basin represents part of the Indian plate and is further divided into Upper, Middle and Lower Indus Basin. The Upper Indus Basin is divided into Potwar and Kohat Sub Basins. The Upper Indus Basin is one of the most significant sedimentary basins in Pakistan and contains formations that are important from a hydrocarbon point of view i.e. the Paleocene Patala Formation (Kadri, 1995; Fazeelat et al., 2010). The Patala Formation is a part of the Makarwal group which is well developed all over the Kohat-Potwar Sub-Basin. Previously, several authors suggest different names for the Patala Formation like Tarkhobi Shales of Eames and Evelyn (1952), Nummulitic Formation of Wynne (1873) and Patala Shales of Davies (1937). The Stratigraphy Committee of Pakistan (SCP) then dignified the name Patala Formation in 1977. Lithologically, the studied section of the Patala Formation which is exposed in the Tarkhobi Nala is comprised of dark grey shale, carbonaceous shale and light grey argillaceous limestone beds. The Patala Formation is of the Late-Paleocene age and is well distributed in Upper Indus Basin, Hazara Basin and Kala Chitta Ranges.

2. Geological settings

The Indo-Pakistan sub-continent signifies complex tectonic history. The northern and southern boundary of the sub-continent is marked by Himalaya Thrust and Fold Belt and the Indian Ocean respectively. Continental drifting, sea-floor spreading and continental collision are the major tectonic evolutionary events that cause the Indo-Pakistan Sub-Continent accretion with Eurasia and the ultimate Himalaya orogeny (Johnson et al., 1977; Coward et al., 1986). Initially, the Pangaea which is surrounded by a universal ocean called as "Panthalassa Ocean" is split into two, the northern Laurasia and southern Gondwana supercontinent about 300-200 million years ago along with the creation of an intervention "Tethys Ocean" separating the northern Laurasia Continent from the southern Gondwana Continent. The Laurasia Continent is primarily composed of Northern Europe and most of Asia excluding India, while the Gondwana Continent comprises five sub continents i.e., South America, Africa, India, Australia and Antarctica. The Indian Plate was originally a part of Gondwana where its break up from the Gondwana Continent followed by its northward journey started in the Late Jurassic. During its northward movement, the Indian Plate first collides with Kohistan-Island-Arc during Eocene with the termination of "Neo-Tethys" (Tahirkheli, 1979). The sliding of the Indian Plate underneath the Eurasian Plate in the North is yet active (Seeber, 1981) and this subduction results in considerable tectonic trust in Pakistan that primarily comprises the Main Karakorum Thrust (MKT), Main Mantle Thrust (MMT), Main Boundary Thrust (MBT) and Salt Range Thrust (SRT). The Kohat Sub-Basin is one of the geologically complex and tilted plateaus of northern Pakistan. The Kohat Basin comprises deformed Paleocene to Pleistocene sedimentary rocks that were originally deposited on the northern Indian Plate. The Kohat sub-basin is situated between latitude 32°-34′N and longitude 70°-74′E (Fig. 1). Its northern boundary is with the Main Boundary Thrust (MBT) while toward the south it is bounded by the Surghar Range. Toward the west, the Kurram-Parachinar Ranges lie while the River Indus divides the Kohat-Potwar Plateau into the Potwar area on the east and the Kohat area on the west. The Stratigraphy of Kohat Sub-Basin ranges from Jurassic to Plio-Pleistocene. The overall stratigraphic record of the Kohat Sub-Basin is shown in Table 1.

3. Materials & Methods

Detailed fieldwork was conducted to Tarkhobi Nala, Kohat Basin and collected 14 shale samples (bottom to top) from the Late Paleocene Patala Formation. Of these samples, only 09 samples were analyzed and processed. The sample preparations and geochemical analyses were carried out in the G & R labs, OGDCL, Islamabad, Pakistan. The geochemical analyses include total organic carbon (TOC) determined by using ELTRA *HELIOS* C/S-Analyzer autosampler and

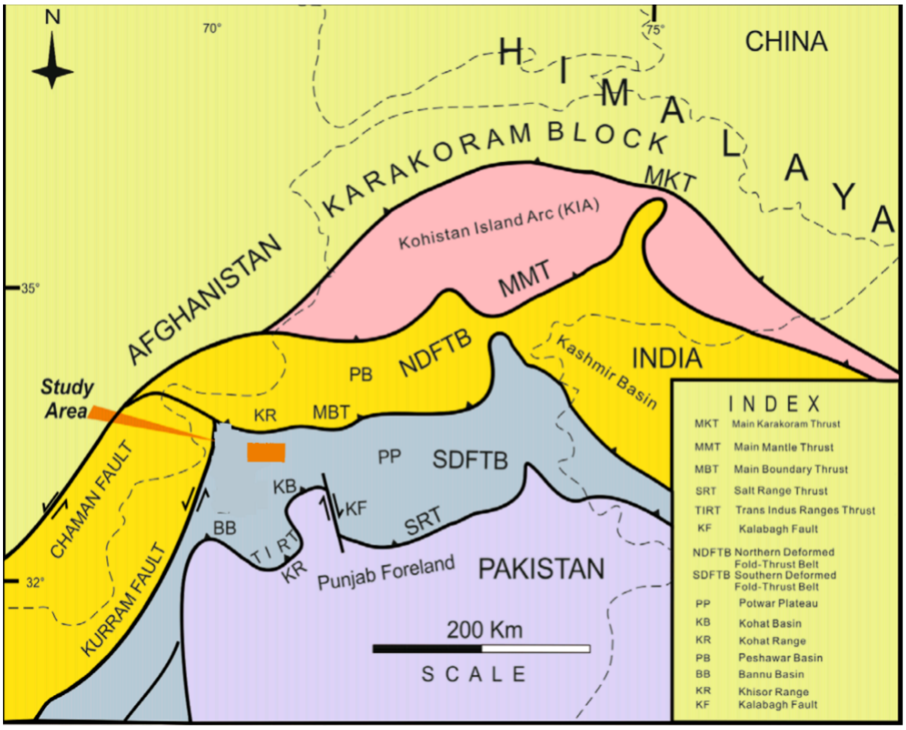

Figure 1. Structural map of North Pakistan (**Kazmi1982**).

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Rock-Eval pyrolysis using the Rock Eval-6 instrument. The organic richness and hydrocarbon generation perspective was evaluated by TOC analysis and Rock-Eval pyrolysis parameter genetic potential (GP). The types of kerogen and thermal maturity of the organic matter were assessed by Rock-Eval pyrolysis parameters including hydrogen index (HI), oxygen index (OI) and maximum temperature (T_{max}) at which maximum cracking of organic matter occurs.

4. Results & Discussions

4.1 Organic richness

TOC is a measure of the total amount of organic carbon found in sedimentary rock or in a geological formation expressed in percentage.
The TOC results of analyzed samples from the Patala Formation at the Tarkhobi Nala are listed in Table 2, it demonstrates that these observed values are generally less than 0.5%. The TOC values range from 0.36% to 1.25% wt.% with an average value of 0.59%. These TOC values and genetic potential of 0.01 to 0.33 mg HC/kg rock suggest poor to fair source rock potential except one sample has good potential (Peter and Moldowan, 1994; Tissot, 1984) as shown in Table 2 and Figure 2 & 3.

4.2 Rock-Eval pyrolysis

Rock-Eval pyrolysis is a conventional analytical technique widely used in oil industries and many research institutes for the estimation of thermal maturity of organic matter, types of kerogen and hydrocarbon generation potential of source rock (Peter, 1986). This technique is primarily devel-

Table 1. Generalized stratigraphy of the Kohat Plateau (**Meissner1974**).

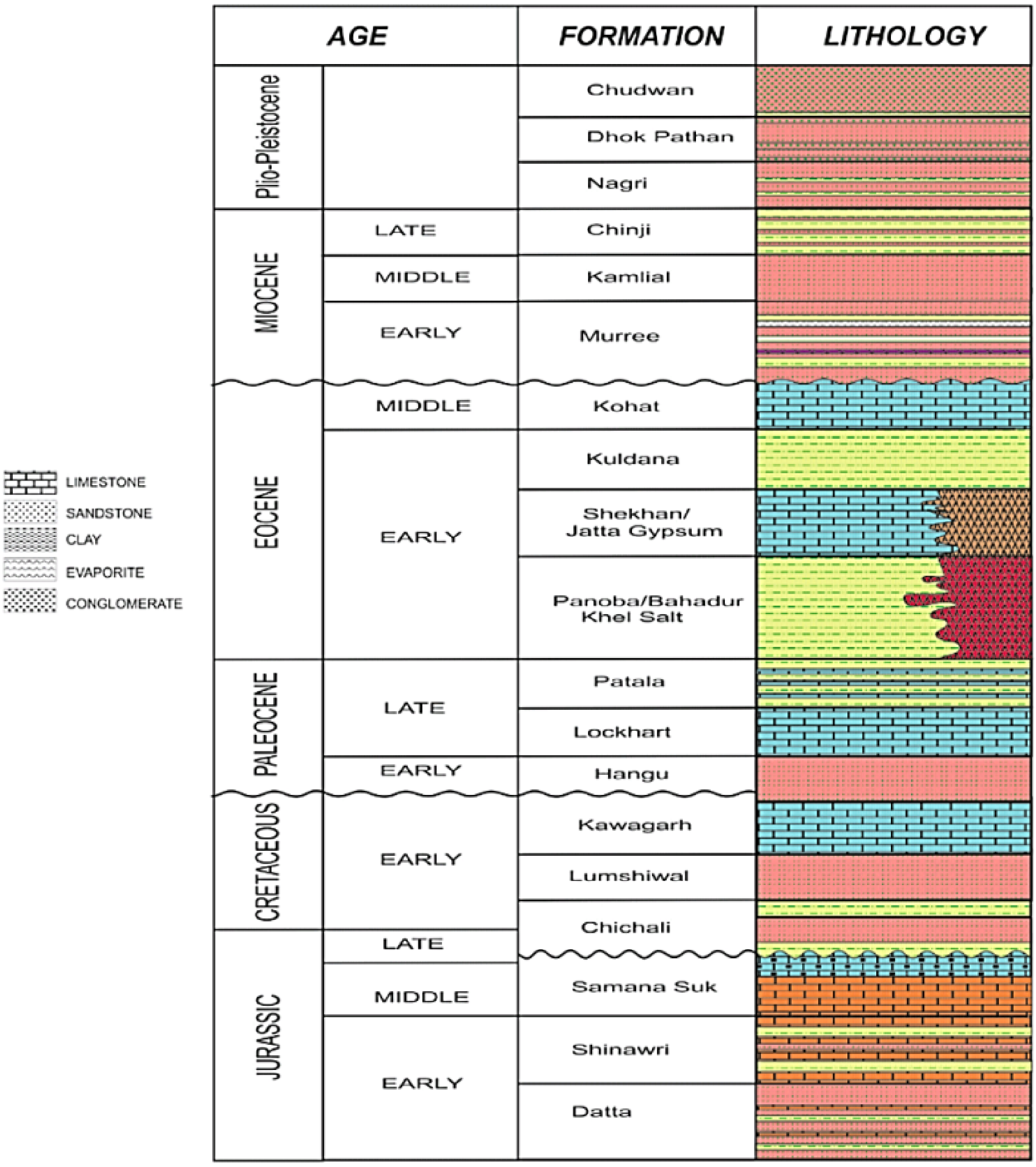

Figure 2. Field photos showing the outcrop features of the studied formation.

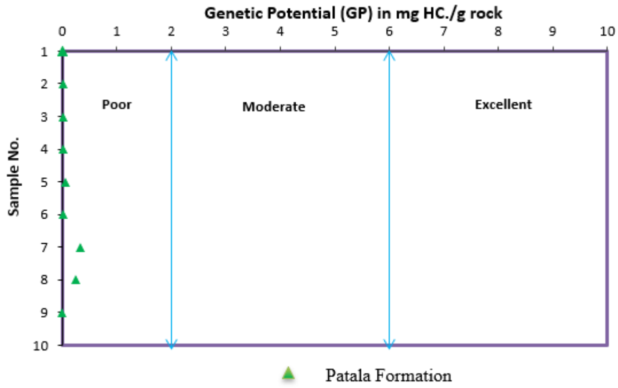

Figure 4. Generation potential of the Patala sediments in the studied section.

oped for providing data on the quantity, type, and thermal maturity of the related organic matter present within source rocks. Considering the entire rock sample, the pyrolysis measure of hydrocarbon generation as a function of temperature usually describes two well-defined peaks. During analyses, the free hydrocarbons in a sample were evolved and detected as S_1 first peak by using Flame Ionization Detector (FID), while the second peak (S_2) was obtained by doing thermal cracking of kerogen at 300 °C- 500 °C. Production index (PI) is an estimation of the alteration ratio of kerogen into oil in the absence of migration, represented by $S_1/[S_1 + S_2]$. The temperature T_{max} was recorded which is the highest temperature at which concentrated hydrocarbon (S_2) is generated upon thermal heating. The secondary

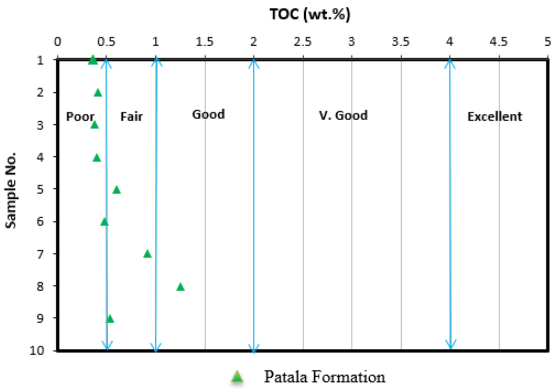

Figure 3. TOC values of the Patala Formation in the studied Tarkhobi section, Kohat Basin.

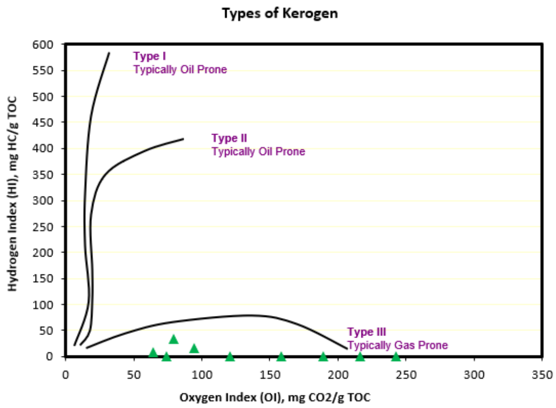

Figure 5. Modified van Krevelen diagram showing types of kerogen in Patala Formation.

Table 2. Geochemical results of the Patala Formation in the studied section, Kohat Basin.

Sr. No.	Sample code	TOC	S_1 mg/g	S_2 mg/g	S_3 mg/g	T max (°C)	G.P mg/g	HI mg/g	OI mg/g	PI mg/g
1	TP-4	0.36	0.01	0.00	0.54		0.01	0	216	1.00
2	TP-5	0.41	0.01	0.00	0.29		0.01	0	121	1.00
3	TP-6	0.38	0.02	0.00	0.34		0.02	0	189	1.00
4	TP-8	0.40	0.02	0.00	0.26		0.02	0	74	0.98
5	TP-10	0.60	0.01	0.04	0.30	459	0.05	9	64	0.24
6	TP-11	0.48	0.01	0.00	0.60		0.01	0	158	1.00
7	TP-12	0.92	0.08	0.25	0.58	451	0.33	34	79	0.23
8	TP-13	1.25	0.03	0.21	1.14	444	0.24	17	94	0.13
9	TP-14	0.53	0.00	0.00	0.90		0.00	0	243	1.00
Average		**0.59**	**0.02**	**0.05**	**0.55**	**451**	**0.076**	**6.66**	**137.5**	**0.73**

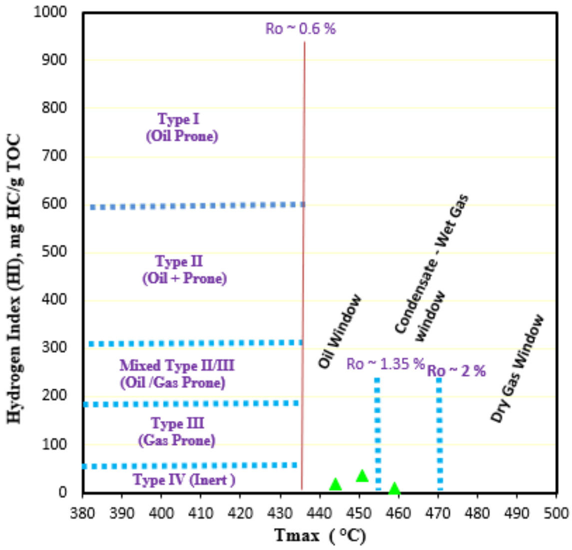

Figure 6. Types of kerogen and its thermal maturity assessment in the Patala Shales in the studied Tarkhobi section, Kohat Basin (Peter and Moldowan, 1994).

parameters like hydrogen index (HI) and oxygen index (OI) are used for the characterization of the type of kerogen and its origination. It is represented by the formula (S_2/Organic carbon * 100). (S_3 /TOC * 100) represents the amount of oxygen-containing compounds.

4.3 Kerogen Types

The kerogen type present is the capability of generating hydrocarbon in a petroleum play (Makky et al., 2014). Various kinds of the kerogen will produce a particular type of hydrocarbons (Hakimi and Abdullah, 2013). It is therefore very important to detect and identify kerogen types and qualities encountered within the formation. HI versus T_{max} plot, and S_2 yield versus TOC contents are widely used to determine and estimate the kerogen types and thermal maturity. Both HI and T_{max} from Rock-Eval pyrolysis data greatly help in the determination of the quality and maturity of kerogen type and hence possible source rock horizons (Makky et al., 2014). Samples containing Type III kerogen have the potential to produce gaseous hydrocarbon with hydrogen index $<$200 mg HC/g TOC, whereas rock samples that contain Type II kerogen and have hydrogen index greater than 200 mg HC/g TOC can produce oil and gas (Hunt et al., 1995). Moreover, rock samples that contain kerogen Type I and have a hydrogen index higher than 300 mg HC/g TOC can generate oil (Khan and Mubarik, 2016).
Different cross plots between Rock-Eval pyrolysis parameters HI vs OI, HI vs T_{max} & S_2 vs TOC were used to evaluate the kerogen types and their thermal maturity in the current study. The hydrogen indices are ranging for the analyzed samples from 0-34 mg HC/g. TOC & oxygen indices are from 64-243 mg CO_2/g. TOC. These two indices show that the studied formation contains type IV organic matter which has no capability to produce hydrocarbon generation except minor gas (Peter, 1986; Tissot, 1984). The T_{max} value varies from 444 °C to 459 °C indicating thermal maturity for oil but as the formation contains negligible hydrogen concentration, so the T_{max} value is not reliable (Peter, 1986).

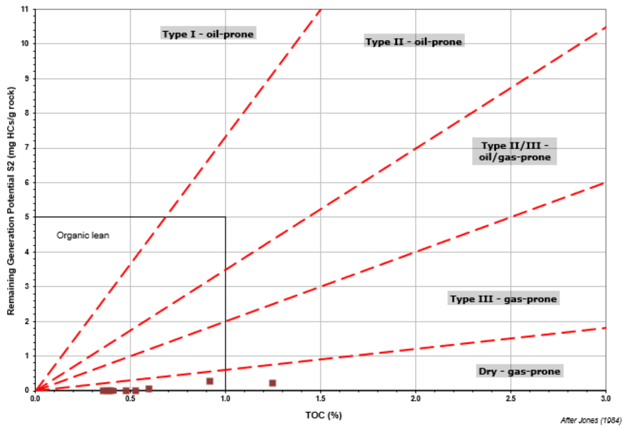

Figure 7. S_2 vs TOC plot showing types of kerogen in the Patala Formation.

5. Conclusions

The studied Paleocene Patala Formation in the Tarkhobi section, Kohat Basin has poor source rock potential containing type IV kerogen. The thermal maturity parameter is not reliable due to type IV kerogen.

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Authors Contributions
All authors have contributed equally to prepare the paper.

Availability of Data and Materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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