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## Estimation of Total Organic Carbon and Depositional Model of Paleocene Patala Formation Western Salt Range, Pakistan

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### Abstract

*In this research, we estimated the total organic carbon and presented a paleo depositional model of the Paleocene Patala Formation from the western Salt Range of Pakistan. Results shows, during the Paleocene period, the Patala Formation was settled in barrier-island or in back-barrier depositional environments. This evidence is supported by lithofacies analysis and TOC determination data collated from the studied stratigraphic sections. According to lithofacies analysis and the TOC estimation of the Patala Formation, the carbonaceous shale deposits of Western Salt Range at Khairabad, Chitta Wahan, and the Kalri area were deposited in back-barrier marshes. In the study area, the Patala Formation 16 meter thick. Based on detailed outcrop investigation, we have divided the Patala Formation into five different lithofacies, i.e., grey shale, carbonaceous shale, sandstone, limestone, and a mixture of sandstone and shale facies. The TOC was measured with the help of a wet combustion titration method. Carbonaceous shale and grey shale lithofacies contain an average of 3.64 % and 1.39 % of TOC value, respectively. Results show moderate to very good TOC values in the shales of Patala Formation, which indicates that Patala Formation in the Western Salt Range has a good source rock potential to generate hydrocarbon.*

**Keywords:** Patala Formation-Total Organic Carbon- Lithofacies-Western Salt Range

### 1. Introduction:

Hydrocarbons are being produced in Pakistan, but still, the production rate is lower than its predicted quantity. To accomplish the need for energy, Pakistan chiefly relies on oil and gas resources. Indigenous resources of oil are not enough to quench the energy thirst of the growing economy. In order to explore the more reserves of hydrocarbon, detailed geological studies of source and reservoir rocks are needed, such as, construction of lithofacies, analysis of the depositional environment, TOC evaluation, permeability estimations, hydrocarbon saturation, and total

hydrocarbon reserves assessments. Significant work on Patala formation has been carried out in Eastern Salt Range. Detailed data is available on Patala Formation in most of the areas of Eastern Salt Range. Still, inadequate information about the depositional environments and TOC evaluation of Patala Formation from Western Salt Range have been produced in the recent past. Patala Formation holds great importance when it comes to source rocks, as described by various scientists. Kadri, (1995) suggested that the Patala Formation of Paleocene age appears to be the primary source rock in the Potwar Basin to the east. The Patala

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Formation contains carbonaceous shale deposits in the Salt Range [2]. Various rock types were observed, cataloged, and sampled from Patala Formation during field studies, which are described in this paper with a primary emphasis on lithofacies and TOC determination. The results of this study will be helpful in developing a better understanding of Patala Formation characteristics as a source rock in the western Salt Range, Pakistan. The main objectives of the present research are as follow:

1. To determine the total organic richness of Patala Formation from the western Salt Range.
2. To present different lithofacies of Patala Formation from Khairabad and its adjoining areas, in Western Salt Range of Pakistan.
3. To present a paleodepositional environment of Patala Formation during the Paleocene period.



**Figure 1:** Location map of the study area, District Mianwali, Western Salt Range, Pakistan.

## 2. Regional Geological Setting:

Due to collision between Indian and Eurasian Plate, the crust was deformed results in the arc-type convergent region naming Himalayan orogenic belt [3]. Presently, on the northern side, Indian Plate is moving at a degree of 45mm/y, illustrating an active tectonic zone, that has been endured numerous major earthquakes, e.g., the magnitude of 7.9 in 2005. [4]. Due to the convergence, different N-dipping thrust fault was developed, naming MKT, MMT, and MBT [5], [6]. These faults isolate the

Himalaya orogenic belt into divers geologic and structural units [7]. There are three critical zones in the northern fold and thrusts belt of Pakistan, e.g., Kohat and Surghar ranges, Potwar and Salt ranges, and Khisor ranges or Bannu Basin. Our research area is located in the Salt range area that has been experienced transpressional deformed structures, e.g., Main Frontal thrust and Kalabagh dextral fault. The western boundary of the Potwar Basin is delineated by a Kalabagh fault. Current studies demonstrated the Kalabagh fault is still an active fault with a slip degree of 5.3 mm/y [8]. Recent research deciphers the Salt Range experiencing uplifting at a rate of 15mm/y [9]. Yeats & Hussain, (1987) and others did work on the structural style of the Salt Range. According to their interpretation, the Salt Range structure is made up of a thin zone of extremely folded, faulted, and uplifted rocks, which is dissimilar with the open folds of low-structural relief of the Potwar Plateau. The sedimentary rocks which are present in the south of the Salt Range thrust (SRT) have no structural deformation. Fatmi & AN, (1973) evaluated that organic material was found in Paleocene Patala Formation that was likely deposited in the early Paleocene age. The deposits of carbonaceous shale commonly occur as isolated beds (more or less 1 m thick), which are mostly composed of dark grey shale or thin bands of quartzose sandstone, which are about 0.25 m thick as reported by [12]. Warwick & Wardlaw, (1992), while working in Salt Ranges established that, "in central and Western Salt Range the carbonaceous shale deposits are more uninterrupted at oblique sides and superior in quality as compare to deposits in Eastern Salt Range." Warwick & Shakoor, (1988) worked on the lithofacies of marginal marine Paleocene formations of the Salt Range. [2] did a study to understand the depositional environment of the carbonaceous shales in central and western Salt range and concluded in their research that these are back barriers and near marine deposits. In a study on the Paleocene source rock, Kadri, (1995) suggested that the rocks of the Paleocene age act as the key source rock for hydrocarbons production in Potwar Plateau.

## 3. Materials and Methods:

In this research, we have arranged a geological field of the Chitta Wahan section, Khairabad section and

the Kalri section of the Western Salt Range, Pakistan. The purpose of this field was to construct the lithofacies, and to evaluate the Total Organic Carbon content of the Paleocene Patala Formation from the Salt Range.

### 3.1 Field investigation:

Three stratigraphic sections Khairabad, Chitta Wahan, and the Kalri sections from the western part of the Salt Range, Pakistan were selected for detailed field investigation. The top and bottom of the Patala Formations were established, and sections were categorized into different lithofacies based on rock colour, lithology, and texture. Information about physical characters was recorded on the field datasheet. Samples were collected and preserved for each lithofacies.

### 3.2 Laboratory examination:

The wet combustion titration technique was carried out as applied by Fazeelat, (2004) on the collected samples. These experiments were performed in the Department of the Chemistry University of Sargodha. The solution of 10 ml chromic acid was added in a flask with 100 mg of the finely crushed sediments. Then the flask was heated at a temperature of 175 °C (for three minutes). After heating the sample, distilled water was added, making a solution volume of 100 ml. Then it was cooled down. Later on, the was added (5 drops). After that, the solution was titrated compared to ferrous-ammonium sulfate (0.2N) until the green endpoint was reached. A blank titration was also carried out containing the acid solution only (i.e., without the sample). For each specimen, a total of three titrations were carried out for better assessment of TOC of Patala Formation. TOC was calculated by using the following equation.

$$\text{TOC (wt. \%)} = \frac{2.16(\text{Blank titer} - \text{Sample titer})}{(\text{Blank Titer} \times \text{Sample weight})}$$

## 4. Results and Discussion:

### 4.1 Lithofacies Analysis:

In this study, Patala Formation at Khairabad, Chitta Wahan, and the Kalri sections is divided into five lithofacies: i. grey shale, ii. carbonaceous shale,

iii. sandstone, iv. sandy shale, v. limestone lithofacies (Fig 3a, 3b, 3c).

Grey shale facies is abundantly found and make most of the Patala Formation in all three measured sections with a thickness of 12 to 13 m at Khairabad section, 10 to 11 m at Chitta Wahan section, and 7 to 8 m at Kalri section, Western Salt Range (Fig 2a). The average thickness of a single bed at all these sections ranges from 2 to 3 m. Grey is determined as fresh colour, and weathered colours are yellow, maroon, and brown. The presence of yellowish colour in shale beds represents the presence of sulphur contents and, in turn, indicates a reducing environment (Fig 2f). At places, intercalation of silt inside grey shale facies was also observed. The grey shale facies have existed at the base of the Patala Formation, which overlies Hangu Formation's sandstone and overlying by limestone and carbonaceous-shale facies at all three localities. The existence of sulphur and the presence of carbonaceous shale facies in close association, indicates the grey shale facies were deposited in a Lagoonal environment.

Carbonaceous shale facies in the study area are generally present in the central portion of the Patala Formation. The single bed ranges from 1.0 to 1.5 m thick on average in all three measured sections (Fig 2b). The thickness of the carbonaceous shale facies at the Khairabad, Chitta Wahan, and the Kalri section are 1.0 2.0 m, 2.0 3.0 m, and 3.0 4.0, respectively. The fresh colour of this facies is dark grey to black, and the weathered colour is also dark grey and black. In some places, yellowish maroon was also noted. The blackish colour of this facies is owing to the occurrence of a high content of organic content. Due to the presence of high organic content, carbonaceous shale facies contain coal seams at other geographic locations, but at the study area, no coal contents were observed. The carbonaceous shale facies with a close association with sandstone and fine-grained facies, specifies the carbonaceous shales were likely to be deposited in back-barrier environments in deep marshes or swamp horizons.

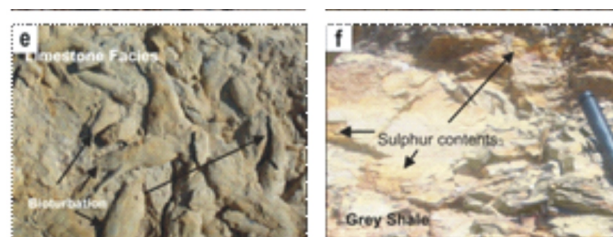
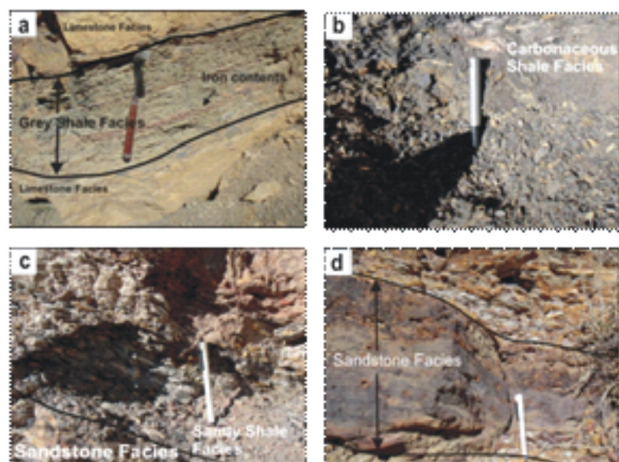
The Sandstone facies was only observed at the Kalri section, which is overlain by carbonaceous shale



facies, and at the bottom, grey shale and sandy shale facies are present. Sandstone was found medium to coarse-grained with light grey as fresh and maroon weathered colour (Fig 2d). The thickness of sandstone lithofacies is ranged from 1.0 - 2.0 m at the Kalri section with a mean bed thickness of 0.5 m. The lower surface of sandstone facies was found usually uneven. The association of sandstone facies with carbonaceous shale facies designates that sandstone facies were likely to be deposited in the barrier setting.

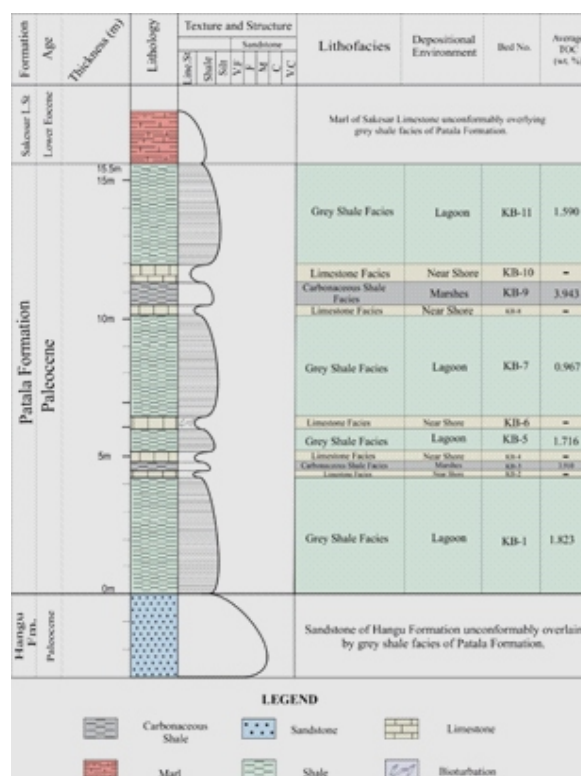
The limestone facies are present throughout the Patala Formation in the form of thin beds less than 0.5 m thick with a total thickness of 1.5 to 2.0 m at the Khairabad section, 1.5 to 2.0 m at Chitta Wahan and 0.5 to 1.0 m at the Kalri section. The fresh colour of the limestone facies of the Patala Formation is light grey, while the weathered colour is yellowish. Bioturbation was also documented in limestone at the Chitta Wahan section (Fig 2e). Limestone facies has an excellent linkage with the grey shale lithofacies. Due to the presence of extensive bioturbation in limestone, it can be inferred the limestone in the studied sections were deposited in the near-shore marine environmental conditions.

Dark grey colour Sandy Shale facies were mapped in the top segment of the Patala Formation at the Kalri section. The thickness of the dark grey colour Sandy Shale facies is 3.4 m at Kalri section (Fig 2c). The sandy shale facies is carbonaceous shale, and the sandy content is due to the wave fluctuation pattern. The presence of carbonaceous contents in the shale indicates that the depositional environment of sandy shale is the marshes

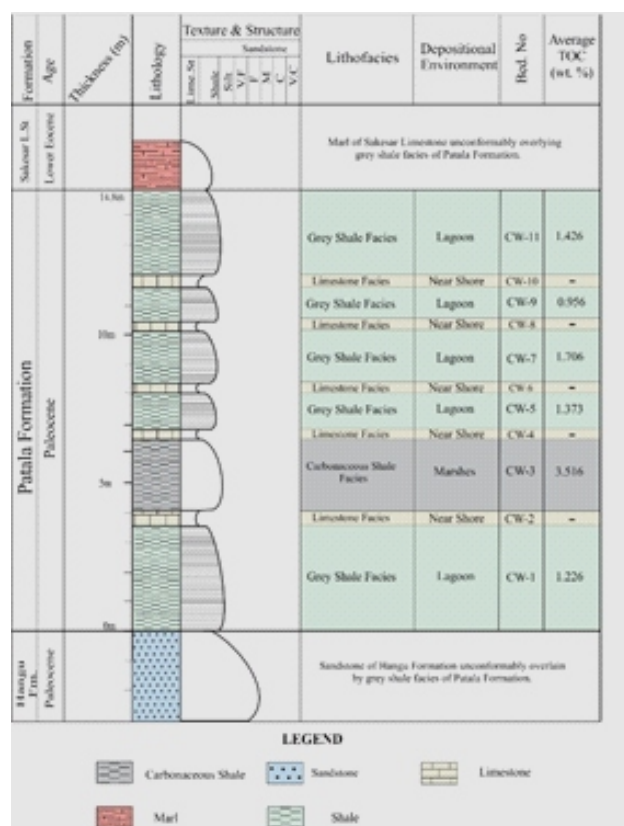


**Figure 2:** The diverse lithofacies of the Patala Formation from the outcrop section of the Khairabad and its surrounding areas of the western Salt Range.

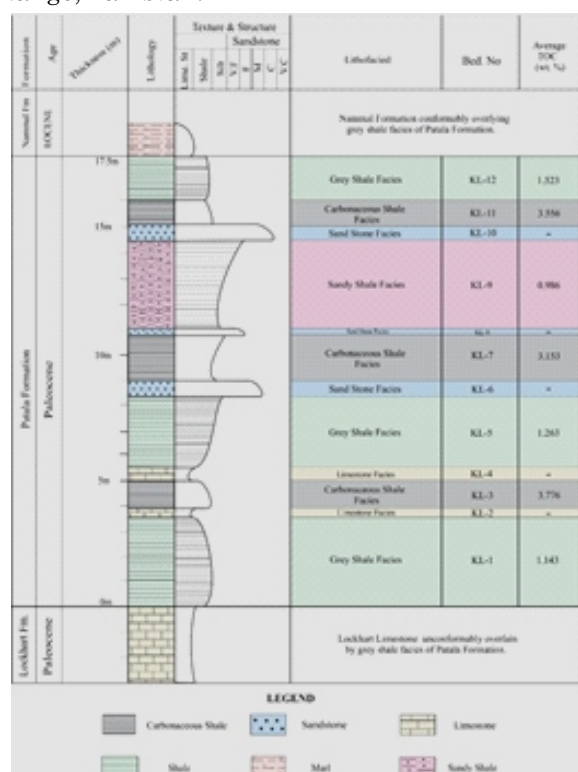
(a). Grey shale facies of the Patala Formation showing iron content which exhibits lagoonal environment of deposition from Khairabad section. (b). Carbonaceous shale facies of the Patala Formation at Kalri section. (c). Sandy shale facies of the Patala Formation at Kalri section. (d). Sandstone facies of the Patala Formation at Kalri section. (e). Limestone facies of the Patala Formation with bioturbation from Chitta Wahan section. (f). Grey shale facies of the Patala Formation from Khairabad section showing sulphur content.



**Figure 3a:** The measured Khairabad section showing the Patala Formation at the western Salt-Range, Pakistan.



**Figure 3b:** The measured Chitta Wahan section revealing Patala Formation in the western Salt Range, Pakistan.



**Figure 3c:** The measured Kalri section deciphering Patala Formation at the western Salt-Range, Pakistan.

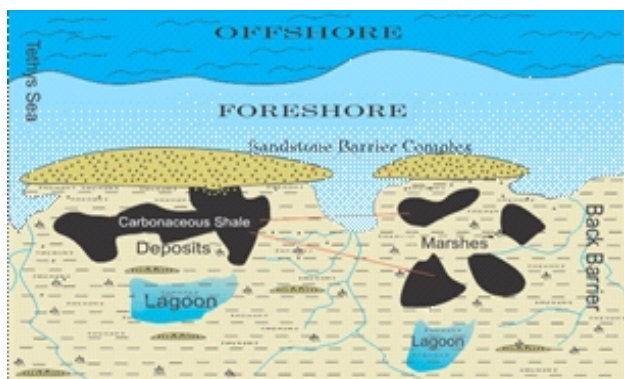
#### 4.2 Depositional Environment :

Five distinct lithofacies have been recognized in the Patala Formation of the western Salt Range. We have differentiated these lithofacies based on variations in lithology and physical characteristics. The predicted model for the deposition of Patala Formation in the study area is presented in Fig 4 (a, b). The in-depth lithofacies examination of Patala Formation for the chosen parts of the western Salt Range, shows that these sediments were deposited in the back-barrier, barrier, and in the shelf environment. Our findings are consistent with the previous studies Warwick, (1995); Warwick & Shakoar, (1988). They proposed the Paleocene Patala Formation was accumulated in the barrier islands and the back-barrier settings through the Salt Range. Alam et al., (1987) carried out work on Patala Formation chiefly on carbonaceous shales from the central part of the western Salt Range. They suggested these shales were deposited in an open marine and back-barrier environment.

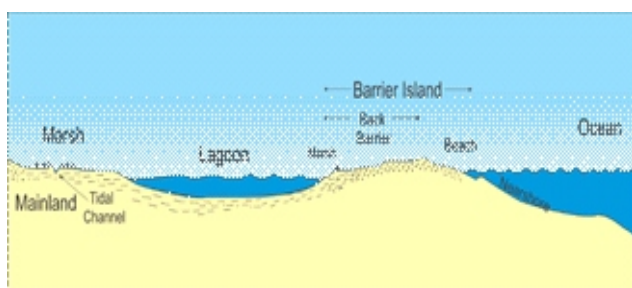
Sandstone bodies observed at studied sections are deposited in the form of the prolonged bodies, which developed barriers laterally to the shoreline. These barrier complexes sheltered a large area from marine invasions, which in turned converted into a back-barrier system where peatlands and marshes were formed. The TOC values in carbonaceous shales indicate that Patala Formation has a good source rock potential in the western Salt-Range. The sandy-shale facies are in a close relationship with carbonaceous-shale facies, which shows that the input of fluvial detrital sediments was most likely to be a fine-grained size. The presence of limestone in the open marine settings and shale is evidence of the subsequent phase of transgression due to which barrier complex, environments of back-barrier marshes and lagoons were submerged Fig 4 (a, b).

The accumulation of organic matter in carbonaceous shale facies is indicating to the back-barrier marshes as a depositional environment. The succession of lithofacies from the Patala Formation unveils the occurrences of diverse environs, and the sub-environments were developed in the barrier and the back barriers structure.





**Figure 4a:** The depositional setting of the Patala Formation from the Western Salt Range, Pakistan.



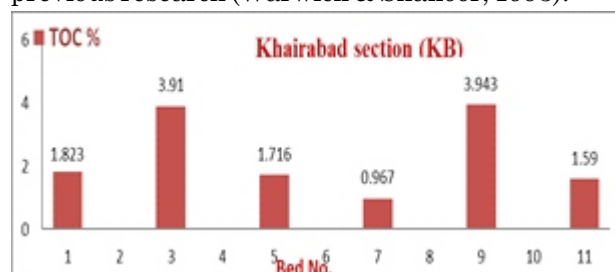
**Figure 4b:** The depositional setting of the Patala Formation (Crosssectional view) from the Western Salt Range, Pakistan.

#### 4.3 Total organic carbon (TOC) Determination

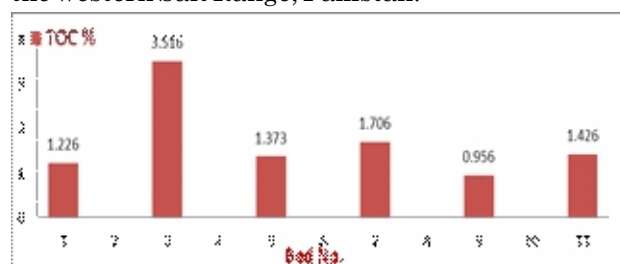
TOC is to measure the quantity of organic carbon in the rock formation [17], [18]. Carbonaceous shales, grey shale and sandy shale samples of the Patala Formation were selected for the determination of TOC. It has been noticed the samples of the carbonaceous shales facies from all three studied sections contains very good organic carbon content ( $>3.0$  wt. %). The specimens of the grey shale facies from the lower part of the Khairabad section relatively contains higher TOC quantities (1.823 wt. %) relative to the middle and the upper parts. However, grey shale facies samples from the lower part of the Chitta Wahan and Kalri section comprised of relatively lower TOC value than to the middle and the upper parts of the section. Only one sample of the sandy shale facie were also utilized from the Kalri section to determine the TOC, which exhibits a good organic carbon potential in these samples.

In general the amount of TOC in the studied specimens from the Khairabad section is fallen

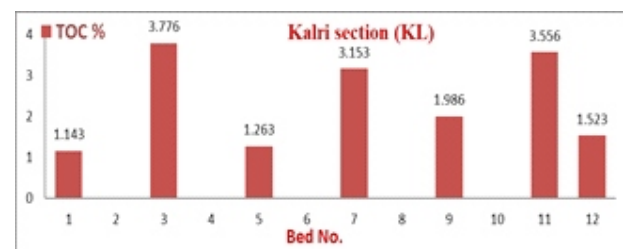
within the range of fair to very good total organic richness. However, only one sample (KB 7) shows relatively lower values of TOC in the the Khairabad section (Fig 5a). The similar TOC range (fair to very good) also observed in the samples of the Chitta Wahan section only, while only samples contain the fair organic potential (CW-09, Fig 5b). In contrast, the TOC values of the Kalri section exhibits good to very good organic carbon content. Three samples contains very good TOC potential (KL-3, KL-7, and KL-11). However, the KL-1, KL-5, KL-9, and KL-12 contains good TOC potential (Fig 5c). The resultant values of TOC in all three sampled section of Patala Formation shows that its shales in the western Salt Range have good to very good quality of source rock to generate hydrocarbon consistent with the previous research (Warwick & Shakoor, 1993).



**Figure 5a:** Graphical presentation of TOC in the Patala Formation from the Khairabad section, of the western Salt Range, Pakistan.



**Figure 5b:** The graphical representation of TOC results at Chitta Wahan section, Patala Formation, in the western Salt Range, Pakistan.



**Figure 5c:** The graphical presentation of the TOC results in the Patala Formation from the Chitta Wahan section, in the western Salt Range, Pakistan.

## 5. Conclusions:

1. In this study, five lithofacies of the Paleocene Patala Formation were established on the basis of three measured outcrop sections at Khairabad, Chitta Wahan, and Kalri area of Western Salt Range, Pakistan wherein carbonaceous shale facies was probably deposited in the marshes (deeply muddy zones) of back-barrier settings.
2. The amount of TOC in the studied specimens decipher 'fair to very good' potential source rock to generate hydrocarbon. However the TOC values of the carbonaceous shales are very good that is due to the high organic matter in the marshes zone.
3. Patala Formation is largely comprised of grey shale facies. This facies was deposited in the reducing environment signposted by sulphur contents and close association with carbonaceous shale facies, which indicates the most likely Lagoonal settings.
4. Sandy shale facies was observed and documented in the Kalri section during field studies. TOC content of moderate range was observed in this lithofacies on lab tests, which indicates that these sandy shales were deposited in the marshy environment.
5. Limestone facies are existing in the form of thin beds with extensive bioturbation at the study area, and the near-shore marine environment was inferred for limestone facies.
6. The sandstone facies at the Kalri section is closely associated with carbonaceous shale facies, which indicates that sandstone facies is of a barrier environment.
7. The TOC values for all three measured sections fall in the range of 1.0 to 3.94 wt.% with few exceptions of TOC less than 1.0 wt.%, which indicates that shales of Patala Formation have TOC in the range of a good to very good source rock designation.
8. Based on these TOC results, it can be suggested that Patala Formation does have attributes to act as good source rock.
9. Based on this research work, it is suggested that further studies should be carried out on these areas of Western Salt Range to evaluate the Kerogen type and maturity with the help of Rock-Eval pyrolysis.

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