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Determination of Total Organic Carbon (TOC) of Chichali Formation through well logs. Case study: Chanda oil & gas fields in KP, Pakistan

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Abstract

Total organic carbon (TOC) present in source rocks can significantly affect the response of various wireline logs. This paper discusses the well logs anomalies caused by TOC in Chichali Formation of Cretaceous age. The open hole well logs (LLD, DT, RHOB, GR, Caliper and CNL) of Chanda-1 well of Kohat Basin, Khyber Pakhtunkhwa (KP) were utilized to determine the organic contents of Chichali Shales. The source rock was distinguished from non-source rock based on low density, high sonic transit time, high porosity and high resistivity. The ΔlogR technique yielded TOC values ranging between 0 to 1.38 % for the formation which is in close agreement with the value obtained by geochemical analysis. This study reveals that TOC of a source rock, using well logs can provide a good estimate of its organic contents before going for detailed geochemical analysis.

Keywords: Well logs data; TOC; Kohat Basin; Shales of Chichali Formation.

1. Introduction

The Kohat Potwar Basin is the most active area for Hydrocarbons exploration. This basin has some famous oil and gas fields like Chanda, Nashpa, Mela, Makori, Manzalai etc. It has prolific elements of petroleum system such as potential source, reservoir and cap rocks reflecting the potential for hydrocarbon exploration in the area. The Kohat Basin consists of overburden of fluvial sediments (~3000 m), providing the burial depth and optimum geothermal gradient for maturation of hydrocarbons (Khan et.al., 1986).The geochemical data, oil to source correlation and lithological characteristics of some rocks in the area confirm that there are multiple source rock horizons of different ages with varying levels of maturity including marine shales of Patala Formation (Paleocene), distal marine shales of Chichali Formation (Lower Cretaceous) , Datta Formation (Jurassic), Mianwali Formation (Triassic) and Sardhai Formation shales (Permian) of marine and deltaic environments.

The well under investigation i.e. Chanda-01 is positioned at latitude 33° 13′ 40.29″N and longitude 71° 30′ 50.93″ E in District Kohat, Khyber Pakhtunkhwa, Pakistan (Fig. 1).

2. Regional geology

The Kohat Basin is restricted by Main Boundary Thrust (MBT) at its northern boundary (Fig. 2). The Surghar Range marks the southeastern periphery of the Kohat Basin where Mesozoic rock units overlie the Kalabagh re-entrant of Indus Foredeep (Ahmad et al., 1999). It is bordered by Kurram Fault in the west, where it is placed alongside the intensely deformed Mesozoic sequence of different ranges including Samana, Darsamand, Tal and North Waziristan agency with Eocene to Miocene rocks of the basin (Ahmad, 2003). The Mesozoic rocks of the Kohat Range are present in the hanging wall and Eocene-Miocene rocks of the Kohat Basin are present in the footwall of MBT, respectively (Yeats and Hussain, 1987). River Indus separates Kohat Plateau from Potwar Basin on the eastern side.

The MBT is a regional fault that has emplaced the shelf sediments of Mesozoic-Cenozoic of Margalla, Kalachitta, Surghar, Kohat, Samana and Safedkoh mountain ranges. The deformation was started in Miocene time along this fault demonstrated by the distortion of Murree Formation (Burbank, 1983; Yeats and Hussain, 1987).

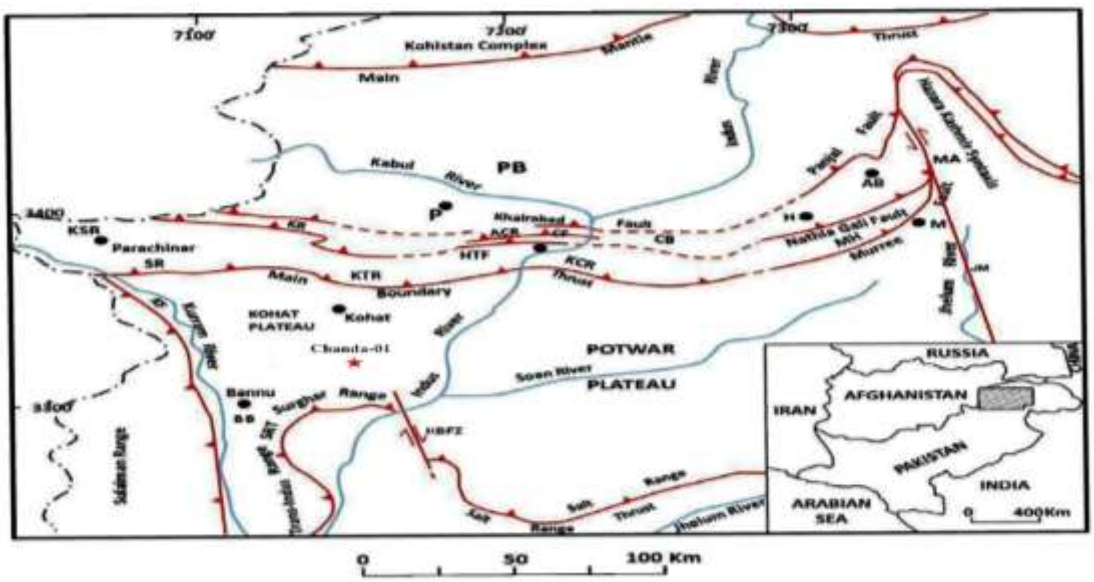

Fig. 1. Tectonic map of Kohat Potwar showing Location of Chanda-01 well (Kazmi and Rana, 1982).

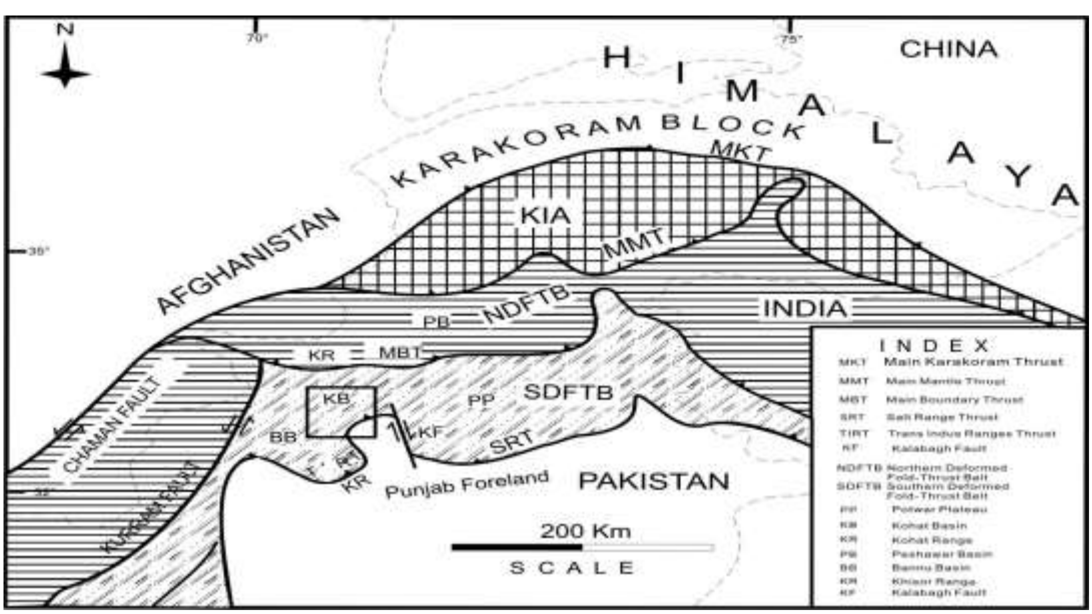

Fig. 2. Tectonic map showing major structural features of northern Pakistan (Kazmi and Rana, 1982).

3. Borehole stratigraphy of Chanda-01 well

The Borehole stratigraphy of Chanda-01 well located in Kohat is depicted in table 1.

Table 1. Borehole stratigraphy of Chanda-01 well.

AGE		FORMATION	LITHOLOGY
Pliocene-Pleistoncene		Soan	
		Dhok Pathan	
		Nagri	
Miocene	Late	Chinji	
	Middle	Kamlial	
	Early	Murree	
Eocene	Middle	Kohat	
		Kuldana	
		Sheikhan/Jatta gypsum	
		Panoba/Bahadar Khel salt	
Paleocene	Late	Patala	
		Lockhart	
	Early	Hangu	
Cretaceous		Kawagarh	
		Lumshiwal	
	Early	Chichali	
Jurrassic	Late	Samana Suk	
	Middle	Shinawri	
	Early	Datta	

4. Materials and methodology

The data used in the present study consists of suit of wireline logs. These logs include gamma ray, neutron, density, deep resistivity and sonic log for the evaluation of Total Organic Carbon (TOC) in the Chichali Formation. In addition to the logs data, six drill cuttings of the formation were also obtained from Pet-core Hydrocarbon Institute of Pakistan (HDIP) and analyzed for TOC and Vitrinite reflectance. The results are given in table 2.

The ΔLogR technique (Passey et al., 1990) was applied to determine total organic carbon (TOC wt %). This technique involves the overlay of properly scaled porosity log with resistivity curves. In organic lean rocks, these two curves overlap each other, whereas in organic-rich rocks, a separation between the curves will occur.

Different logs show different behavior in source rock like average transit time of sonic log for the organic matter is suggested as 180µs/ft. This log response to OM is increasing over 140µs/ft depending upon the distribution of organic matter in a matrix (Flower, 1983). The neutron log basically measures hydrogen concentration of a formation, which is usually found in water and hydrocarbons of a rock. The neutron log values are greater in source rocks than in non-source rocks as these contain more water and hydrocarbon (oil) comparatively. The specific gravities of organic matters are in the range of 0.95 to 1.05 gm /cm3 (Meyer, 1984). In source rocks, the organic matter is the part of matrix, suggesting reduction in bulk density in source (Schlumberger, 1987). Source rocks show high resistivity values measured by deep lateral log because of high organic carbon contents (Autric, 1985). Different organic rich zones in the Chichali Formation were marked by low density, high resistivity and high sonic values.

The porosity sonic log (Δt,) and the Deep resistivity Log (LLD) are scaled such that they override each other in non-source intervals called a baseline. This condition was observed in the above fine grained non-source rocks. Sometimes it may be within same formation or other formation located above or below. The organic-rich intervals of Chichali Formation were established by separation of the two curves (resistivity and sonic). This separation between resistivity and porosity log is Δ log R which was calculated by the following formula:

$$\Delta \log R\ \text{sonic} = \log10(R/R\text{baseline}) + 0.02 \times (\Delta t - \Delta t\ \text{baseline})$$

Where Δ log R is the separation, Rbaseline is the deep resistivity value and Δtbaseline is the sonic values when the curves are baseline in non-source, clay rich strata. ΔT is a sonic and R is a resistivity log reading in source rock. For TOC calculation the given empirical formula was used.

$$TOC = (\Delta \log R) \times 10^{(2.297 - 0.1688 * LOM)}$$

In above equation the level of maturity (LOM) was calculated by plotting vitrinite reflectance value in Crian (1986) plot as shown in figure 3.

5. Results and discussions

The source rock horizons were marked by increase in gamma ray, neutron, sonic and deep resistivity values and by decrease in density log in Chichali Shale. The gamma ray log values is high in depth ranging from 4545 to 4547 m indicating clay zones (Fig.4). And the high resistivity and low sonic value representing as these are organic rich horizons in the formation, because the organic rich horizon will have high resistivity value, high neutron and high sonic value (Crain, 1986). The average vitrinite reflectance value for the Chichali Formation is 0.77% which was measured in laboratory from drill cuttings, while the Level of maturity (LOM) is 9 obtained by putting the value of vitrinite reflectance in the plot of Crain (1986) as shown in figure.3. In the Passey overlay equation the resistivity and sonic baseline was marked in the overlying shaly formation of the Chichali Formation, where the R baseline value is 7 and Δt baseline 85 μs/ft. The TOC resulted through this method for the depth interval 4542 to 4576 m range from 0 - 1.38 for the Chichali Formation which are similar with measured TOC (Tab.2 and Fig. 4). In figure 4 it is clear that the two results of TOC (measured and calculated) has close relation, indicating that Chichali Formation has fair to good potential for hydrocarbons generation according to Bacon et al., 2000 classification of source rock based on TOC.

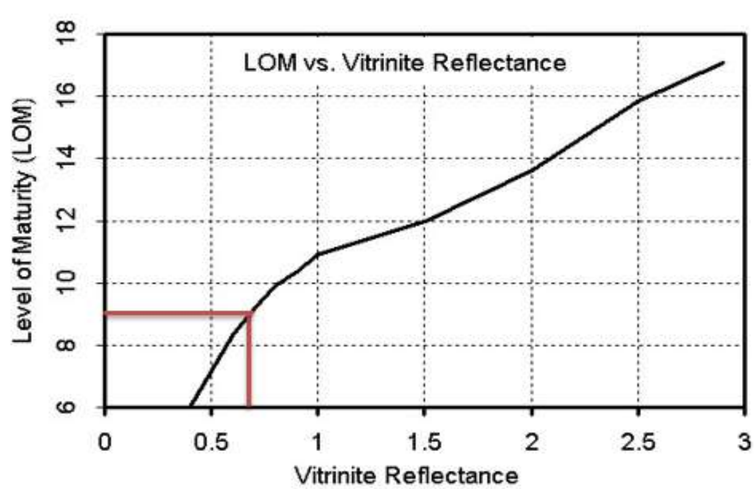

Fig. 3. Relationship between vitrinite reflectance and LOM of Chichali Formation (Crain, 1986).

Table 2. TOC and Vitrinite reflectance data of Chichali Formation.

S.No.	**Depth** (m)	**Samples Interval**	**Formation** (Cretaceous)	**TOC** (wt %)	**TOC (Logs)**	**Ro** (%)
1	4542	4541-42	Chichali	1.63	0.00	0.72
2	4547	4545-47	Chichali	2.76	0.19	0.76
3	4554	4548-54	Chichali	0.96	1.38	
4	4568	4568-70	Chichali	1.04	0.65	
5	4572	4572-74	Chichali	1.13	0.94	
6	4576	4576-78	Chichali	0.47	0.24	0.84

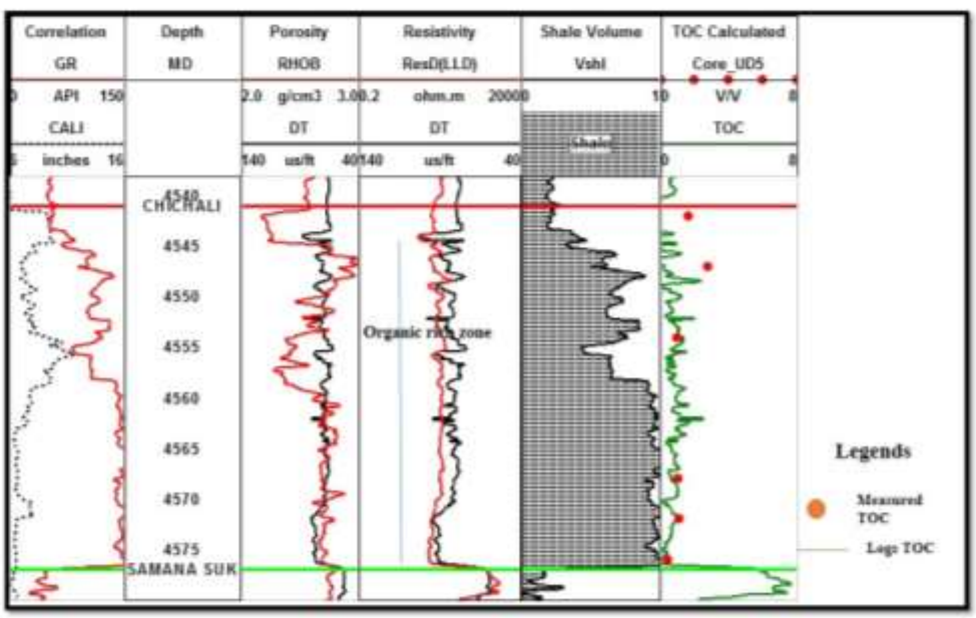

Fig. 4. Comparison of Total Organic Carbon determined through well logs and Laboratory method.

6. Conclusions

The source rock horizons have been identified in Chichali Formation through increasing gamma ray values travel transit times, neutron values, deep and resistivity and decreasing bulk formation density. However this is not necessary to be true in all cases. The Passey overlay technique clearly shows that conventional well logs can only help to identify organic rich formations. The average TOC values 0 to 1.38%, obtained from Δt/Resistivity technique, reflects that the Chichali Formation is a fair to good source rock in the study area. The TOC results from this technique are in good agreement with those measured by geochemical analysis, thereby indicating its importance in delineating the organic rich horizons.

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Authors' Contribution

Syed Mamoon Siyar, performed Lab. work, Software analysis, interpretation and manuscript writing. Muhammad Zafar, did interpretation and manuscript writing. Syed Anjum Shah, did software and interpretation. Tahseenullah Khan, did interpretation and manuscript review. Urooj Shakir, did interpretation and manuscript review. Waqar Ahmad did preparation of figures, tables and review.

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