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Source Rock Potential and Thermal Maturity of Datta Shale Using Well Logs Data of Chanda Deep-01 well, Upper Indus Basin, Pakistan

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Abstract

Several models have been developed in past years to evaluate thermal maturity and calculate total organic content of source rocks using wireline log data. An attempt is made in this current paper to apply one of these models to assess the hydrocarbon and source potential of Jurassic age Datta shales in Chanda Deep-01 through wireline logs and PetroMod-1 software. The extensive Datta shale in Upper Indus Basin serves as potential source and reservoir for unconventional and conventional oil and gas reservoirs. It has good geochemical parameters, which makes it attractive for exploration. Well logs depict various properties of source rock which is treated as Total Organic Carbon (TOC) content. Passey et al. (1990) overlay "ΔlogR" technique has been adopted for TOC calculation in Datta shale. This method resulted in TOC ranging from 1.3-2.0 wt. %, which shows fair good source potential. The comparative similarities between the TOC calculated from logs and through the method of Geochemistry have been observed which validates our finding. Also, Datta shale is mature for hydrocarbons generation and fall in oil window based on VR data obtained by using PetroMod 1 software.

Keywords: Datta Shale, Upper Indus Basin, Well Logs, ΔlogR Technique, TOC and Maturity

1. Introduction

In Indus basin, the Kohat-Potwar fold belt holds 48% of the world's recognized petroleum potentials because it resides at the continental margin where it owns the thick sedimentary deposits that filled the depressions. (Riva, 2019). These mostly comprise of a thick load of fluvial deposits, providing the optimum geothermal condition with burial depth for the hydrocarbons to be cooked and seep here (Khan et al., 1986).

Due to the different geological salient features Kohat sub-basin is considered as one of the most prolific oil and gas prone basins. Hydrocarbons potential of a Formation is estimated by three main parameters, which are: organic matter quantity of rock, quality and maturity grade of organic matter (Alareeq and Albaroot, 2019). Evaluation of a source rock uses the method of geochemistry to determine the nature of organic rich rocks that encompass the forerunners to hydrocarbons so that the types of ousted hydrocarbon can be evaluated (Alareeq and Albaroot, 2019). According to Sanei et al., (2020) geochemical analysis can be done on ditch cuttings and core samples of multiple wells. The geochemical method, regardless of its great advantages, have some problems, such as costly and time consuming, lacks the results in some intervals, missing continuity in core cutting samples etc. (Mann and Muller 1988). In this paper, shales of Datta formation are evaluated as a source rock via open-hole well log data through Passey "ΔlogR" technique. As well logs provide a continuous record, so analysis can be performed throughout the whole interval rather than the small patches.

In order to fulfill the energy requirements of the Pakistan, Khyber Pakhtunkhwa (KPK) province is now providing a momentous number of economic reserves (18.32% oil and 2.14% gas). As this province is less explored yet, therefore, it has immense potential for future hydrocarbon exploration and production (Hanif, 2012). So far vey less work has been carried out and published in this basin to determine source rock potential in terms of total organic carbon content and maturity of the kerogen by using various models and studies. Nazir et al., 2020 worked on evaluation of source potential based on environment of deposition and biodegradation of organic matter. Moreover, Zeb et al., (2020) worked on geochemical study of Chichali Formation in Kohat basin, Pakistan. Gul et al., (2016) published the work on Shale Gas potential Prospect of Datta Formation. Likewise, the source potential and maturity of shales of Datta Formation has been under consideration by many oil companies, therefore the objective of this research is to assess the source potential and thermal maturity of Datta Formation which will prove fruitful to fulfill the future energy needs of Pakistan.

The Chanda oil field is considered as first evident marker of hydrocarbon investigation in the province (KPK) since 1998–1999 having first oil and gas discovery. Since that discovery, according to Pakistan Energy Yearbook (2012), the field has produced 34.57 million U.S. barrels of recoverable oil reserves along with the associated gas. The well is located in District Kohat (Shakardara) at a distance of 70 km southwest of Kohat city (Fig. 1). Chanda oil field includes multiple wells like Chanda-1,2,3, and Chanda Deep-1, having exploration and production from shales of Datta and Kingriali Formations. The principle producing reservoir here is Datta Formation, which is also targeted in several fields of Kohat and Potwar plateau (Khan and Rehman, 2019).

2. Tectonic settings

Kohat and Potwar sub-basins are two major subdivisions of Upper Indus Basin and the main driving boundary between two is Indus River. The Kohat sub-basin carries the northern forelands fold and thrust belt of the Himalayan Range. The unique features of Kohat Plateau is due to this thrust regime which are partially accompanied by Pre-Cambrian evaporite sequence acting as a base decollement (Jaume and Lillie, 1988). The tectonic feature bounded the Kohat Plateau from north and south are Main Boundary Thrust (MBT) and Salt Range Thrust (SRT), whereas western side is bounded by Kurram strike slip fault (KF) and towards east resides the known Indus River. (McDougall et al., 1990).

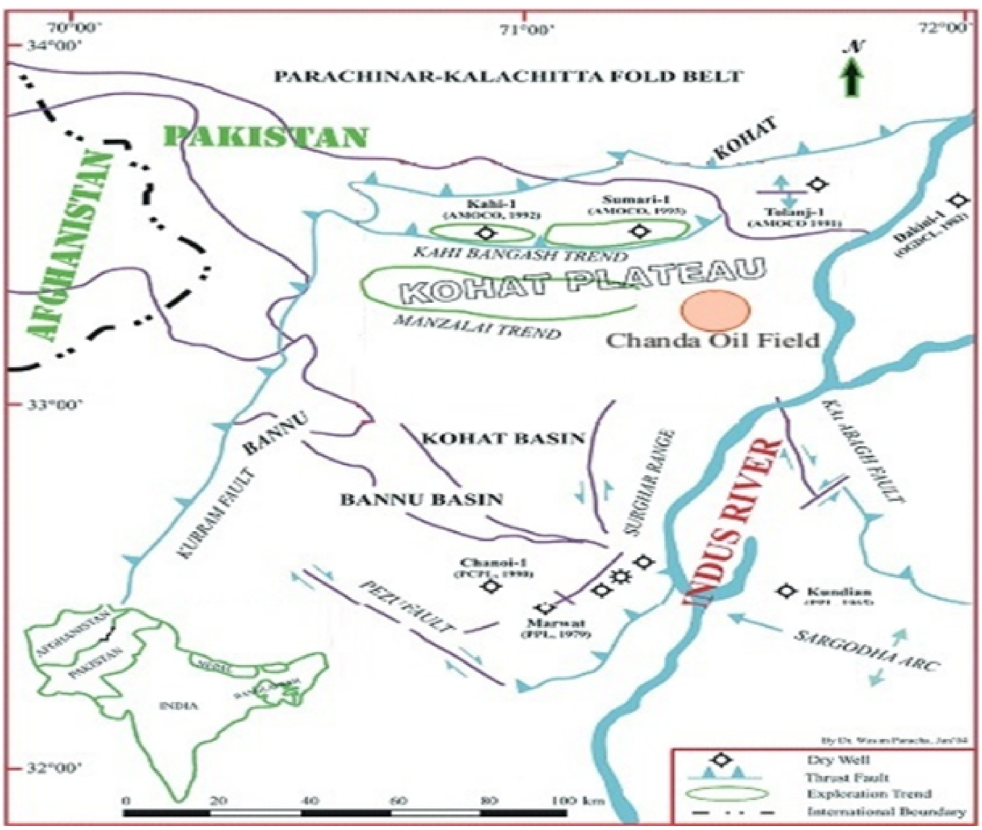

Fig. 1. The location map of Chanda oil field in Kohat Sub-basin. (Khan, 2019).

A number of detachments beneath the Kohat Plateau exist which were detected through different data sets and of surface and subsurface. Numerous analysis of exposed structural features revealed the upper detachment presence at a depth of about 2 Km (Abbasi and Mc Elroy, 1991). This detachment is majorly composed of evaporites (Bahadur Khel salt and Jatta Gypsum) from the base to a complex duplex geometry at the roof which imbricates the Mesozoic and Paleozoic successions. The basal detachment exists at about 6-7 km estimated from outcrop and subsurface data set which is located along the contact between Mesozoic and Paleozoic formations (Abbasi and Mc Elroy, 1991). The structures developed is not due to the thrust phenomenon only, the presence of oblique and high angle reverse faults was also a key factor in the development of complex structural geometry in Kohat sub-basin. (Pivnik et al., 1993). This complex tectonic setting and thrusted overburden sheet is responsible for good thermal maturity and good source rock potential of shales of Datta Formation.

3. Stratigraphy of the study area

In study area, oldest formation is Tredian Formation of Triassic age, overlying by Jurassic to Pliocene sediments with a number of unconformities. In between Cretaceous to Paleocene ages, due to continued thrust, no catchment area was available for sediments, therefore sediments were not deposited in the basin at that interval of time. The second major unconformity is of Eocene age, in which Chorgali Formation was not found throughout the sub-basin. The Cenozoic time marks another depositional gap from some of Eocene sediments to complete Oligocene succession with the absence of molasse deposits. The generalized stratigraphic column of Kohat Basin is given in fig. 2.

In Kohat sub-basin, due to relative sea level fluctuations, multiple shale packages were deposited during different times leading to development of various petroleum systems. These shales packages may act as a source rocks if they bear all the attributes which can generate potential hydrocarbons. Multiple shale packages are present in the Kohat sub-basin as shown in the stratigraphical column below, but in the study area, Datta shales are acting as a source rock for the above lying sands to define the petroleum play.

The targeted Formation has variable thickness trend in study area, generally thinning towards east (Shah 1977). It has a good outcrop exposure in western Salt Ranges, and Trans Indus Ranges while in western Potwar and Kohat sub-basin, it lies in subsurface (Shah 1977). In the former-said ranges, Datta Formation majorly consist of variegated color sandstone, clay, and carbonaceous shale with shaly part restricted to certain localities. (Qureshi et al. 2005). In later regions, the above said formation has been encountered in many wells due to its existence in the sub surface and is composed of mainly sandstone with multiple reservoir behavior (Kadri 1995). In Kohat, the facies change from interbedded sandstone with siltstone along with and coal stringers and particularly to clastic with carbonate deposition. (Kazmi and Abbasi 2008). The reservoir potential of Datta sandstone is well proven while the carbonaceous black shale has capabilities of serving as a good potential source rock.

3.1. Bore hole stratigraphy of Chanda Deep - 01 well

The bore hole stratigraphy of the studied well ranges Pliocene to Permian (Table 2).

4. Data set and methodology

The open-hole well logs including Porosity, Gamma Ray (GR), and Resistivity logs along with Petro MoD 1 software has been utilized for the assessment of source potential including Toc and thermal maturity of shales of Datta Formation using ΔlogR technique. Rider (2011) used geological well logs and different models to interpret and differentiate source and non-source rock intervals (Passey et al., 1990). Schmoker (1979), Schmoker and Hester (1983; 1989) used both Resistivity and Density log for calculation of TOC (wt. %). Passey et al. (1990) have used the ΔlogR for calculation of TOC%.

In this technique, log separation is usually observed between porosity and resistivity logs in organic rich intervals while this separation does not exist in non-source beds, as illustrated in figure 3 & 4. Maturity stages are classified in relation to vitrinite reflectance and Tmax adopted from Ibrahimbas and Reidiger (2004) (Table 2). Thermal maturity of the Datta shale was computed by using the Early %Ro kinetic model (Smith, 2007). This maturity model was created in PetroMod 1 software of Schlumberger by providing the data of formations top and bottom values, erosion of the strata in a well in meters and each age of the formation when its deposition started and ends in million years. After providing this data to software, stimulation process initiated and as an output software provided maturity model.

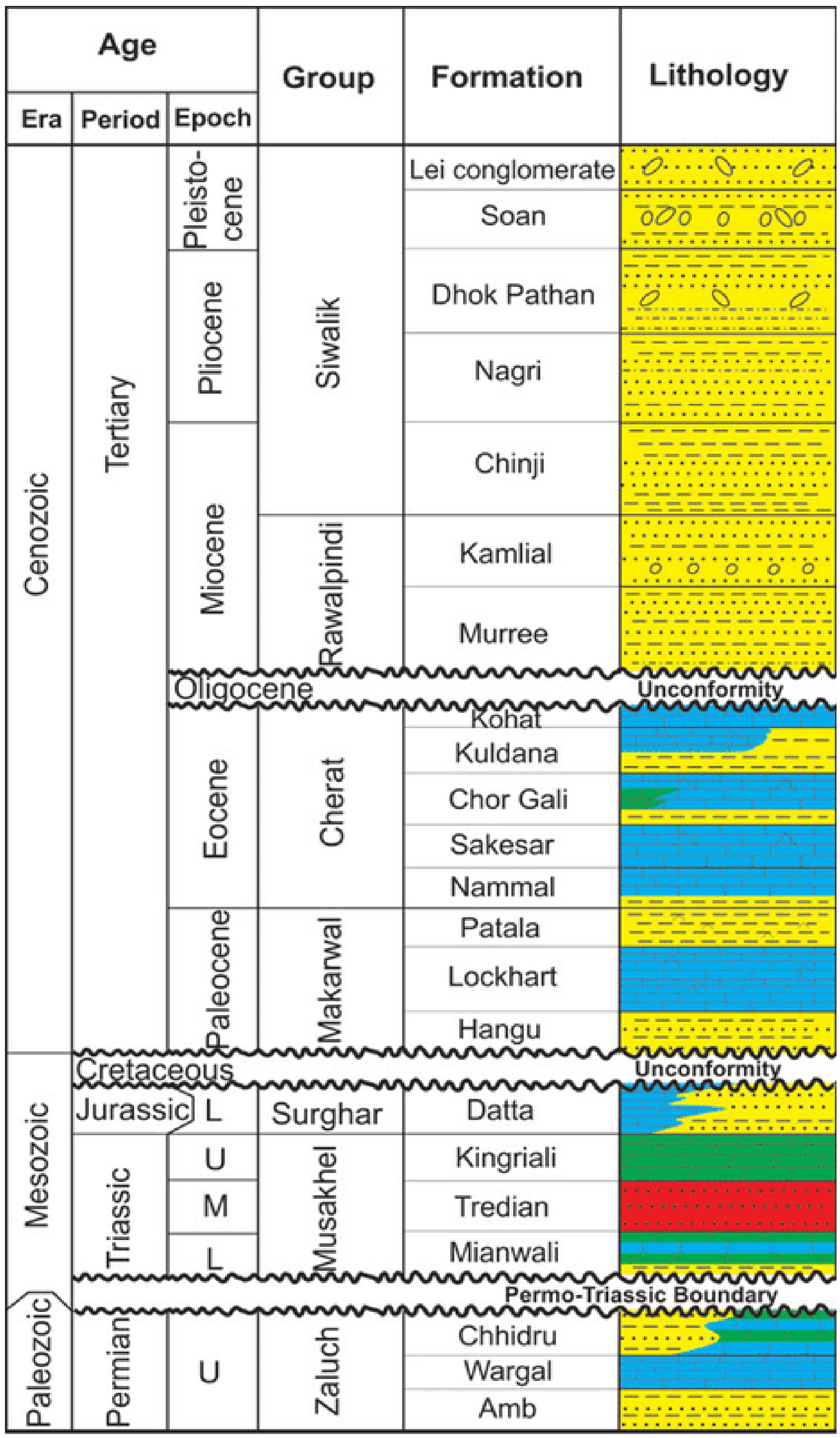

Fig. 2. Generalized stratigraphic column of Potwar Basin (Shah., 1977).

Table 2. Formations encountered in Chanda deep -01 well.

Age	Formation	Depth (m)
Pliocene-Pleistocene	Nagri	0
Miocene	Chinji	503
	Kamlial	2146
	Murree	2864
Eocene	Kohat	4056
	Kuldana	4068
	Jatta gypsum	4102
Paleocene	Patala	4143
	Lochkart	4229
	Hangu	4399
Cretaceous	Lumshiwal	4427
	Chichali	4450
Jurassic	Samana Suk	4499
	Shinawri	4579
	Datta	4650
Triassic	Kingriali	4810
	Tredian	4829
	Mianwali	4899
Permian	Chidru	4963
	Wargal	5044

4.1. Well log behavior/response in source interval

The generalized log motif/behavior in order to identify source intervals are taken as:

1. Gamma Ray log: Generally, gamma ray response tends to increase in the rich organic matter interval, which is due to the association of clay with uranium.

2. Resistivity log: In the matured source intervals, free oil resides in fractures and void spaces, which significantly tends to increase the resistivity by a factor of 10 or more.

3. Density log: Non-source shale intervals generally have matrix density from 2.67 to 2.72 g/cc, which lowers down due to presence of organic matter.

4: Neutron log: As this log calculates the hydrogen index, so log readings tend to increase in presence of matures shale source intervals.

5. Sonic log: this log reflects the two cases at the same lithological and packing conditions. i.e travel time will increase in immature source rock, or will tend to decrease in matured source intervals.

4.2. ΔLog R technique

4.2.1.Formula for resistivity & sonic

According to Passey et al., 1990

$$\Delta Log\ R = \log10\ (R / Rbaseline) + 0.02 \times (\Delta t - \Delta t\ baseline) \qquad (1)$$

Where ΔLog R = Separation between resistivity and sonic in high organic interval,

R = Resistivity value at particular depth
Rbaseline = Resistivity baseline value where DT and LLD overlies each other
Δt = travel transit time at specific depth
Δt baseline = sonic base line value where DT and LLD overlies each other

4.2.2.Formula for resistivity & density

According to Mahmoud et al., 2017

$$\Delta Log\ R = \log10\ (R / R\ baseline) - 2.50 \times (\rho b - \rho b\ baseline) \qquad (2)$$

Where Rbaseline = Resistivity baseline value where Rhob and LLD overlies each other
ρb = Density value at a specific depth interval
ρb baseline = Density base line value where Rhob and LLD overlies each other

4.2.3. Formula for calculating TOC

$$TOC = (\Delta Log\ R) \times 10(2.297 - 0.1688 \times LOM) \quad (3)$$

The LOM was obtained as 10 by plotting vitrinite reflectance value on Passey chart of the level of maturity as shown in figure 5.

4.2.4. Vitrinite reflectance

Vitrinite reflectance (Ro) is considered to be a major indicator in assessing organic maturity level (LOM). The values of Ro lying between 0.60 and 0.78 generally represents presence of oil intervals. Ro values greater than 0.78 indicates gas prone intervals. High values indicate the presence of sweet spots in the wells having shale gas impact.

In this study, Datta shales have been tested for measurement of vitrinite reflectance by using petroMod software. The maturity model graph shown in figure 5 represents the vitrinite reflectance measured in shales of Datta Formation which turned out to be is 0.876.

Table 2. Maturity stages as related to Vitrinite Reflectance and Tmax. (Ibrahimbas and Reidiger, 2004).

Thermal Maturity stages	Vitrinite Reflectance Ro (%)	Rock-Eval-Tmax. (Centigrade)
Immature	0.2-0.6	< 435
Mature	0.6-1.35	435-470
Early	0.6-0.65	435 - 445
Peak	0.65-0.9	445 - 450
Late	0.9-1.35	450 - 470
Post mature	>1.35	> 470

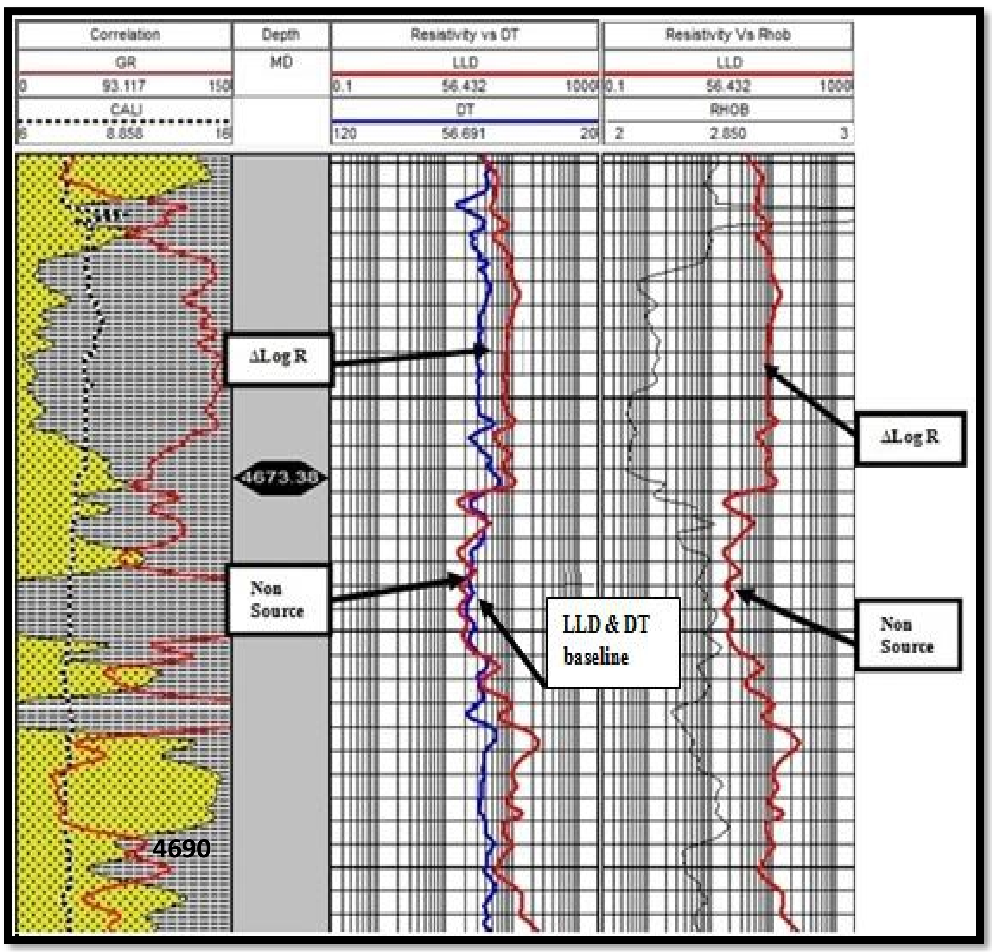

Fig. 3. Source rock horizons in Datta shale of Chanda Deep-01 well marked by porosity and resistivity logs. The yellow color is showing sand facies while black color is indicating shale lithology.

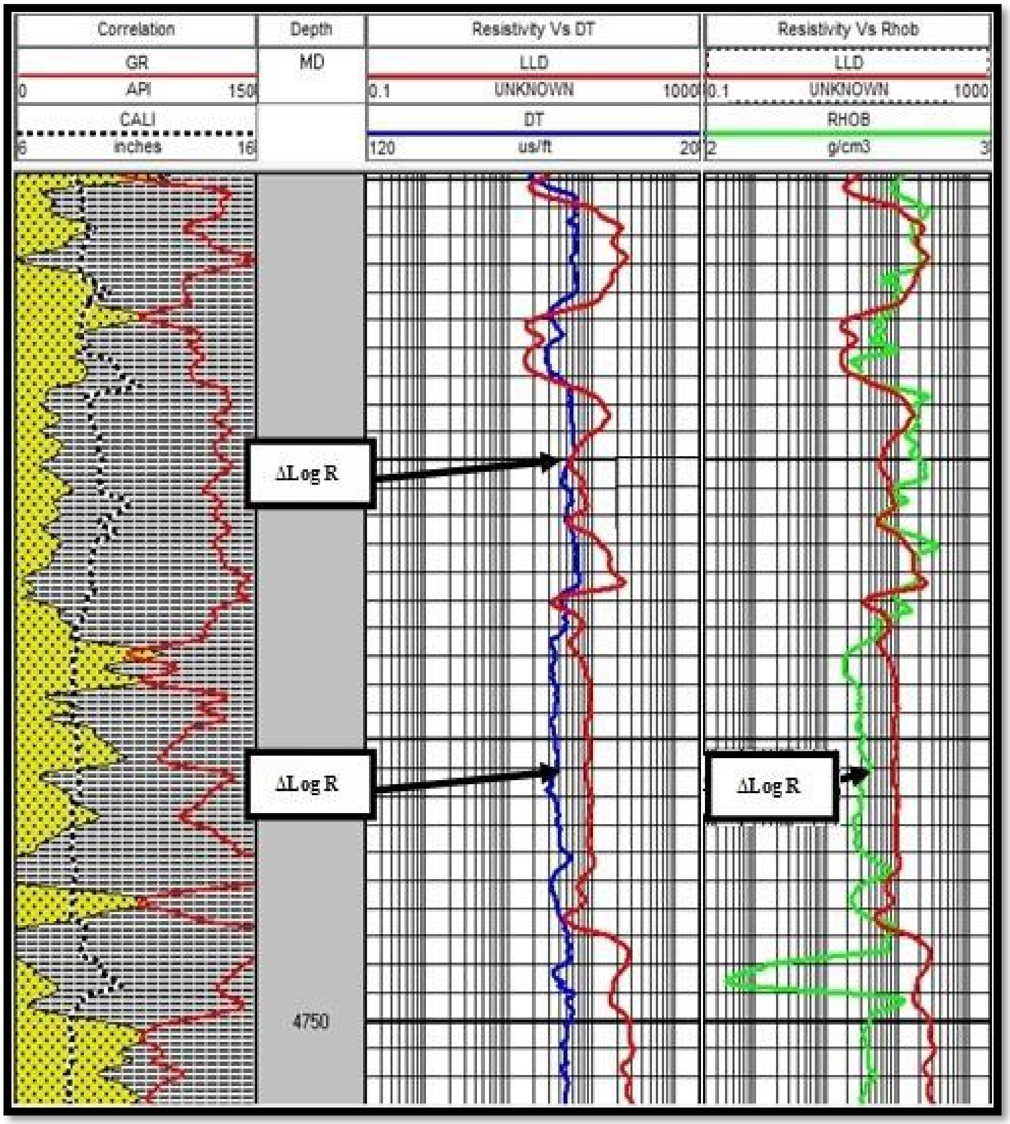

Fig. 4. Source rock horizons in Datta shale of Chanda Deep-01 well marked by porosity and resistivity logs.

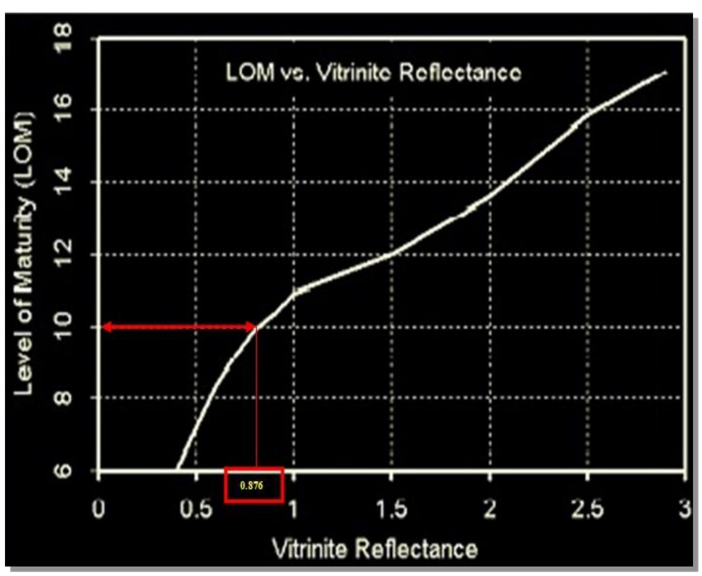

Fig. 5. The relationship between vitrinite reflectance and level of maturity of Datta shale (Crian, 1986).

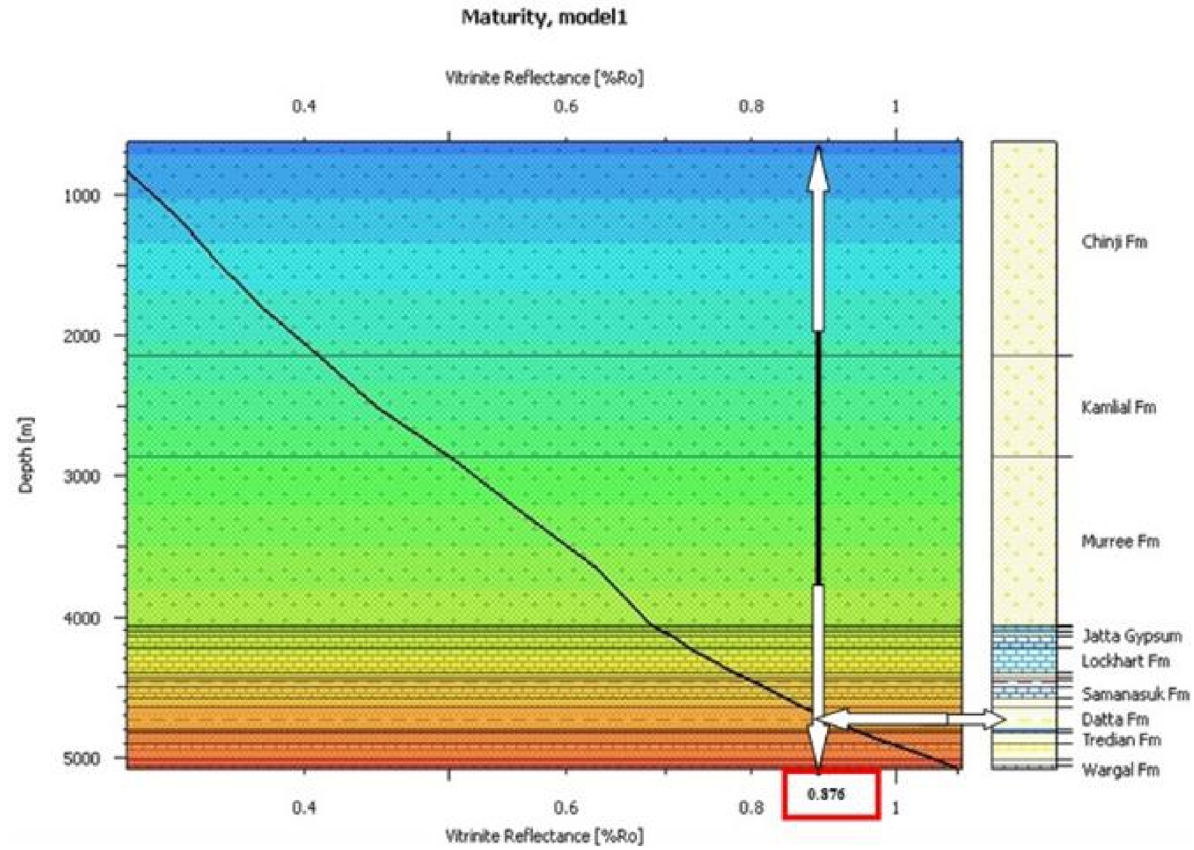

Fig. 6. Graph showing the vitrinite reflectance measurement of Datta shale with lithological overburden.

5. Results and discussion

Source rock evaluation through geochemistry and core samples to find out the level of maturity and calculation of total organic carbon (TOC) in wt%. has been in common use and applied by many researchers. But very less attempt has been made to do the same analysis using well log data. So in the current study, source rock analysis has been performed on Datta shales of Chanda deep-1 well using log data. Geochemical analysis of core samples of shaly intervals within Datta Formation was done in G & R Labs of Oil and Gas Development Company Limited (OGDCL), show fair to very good TOC (0.7 – 2.4 wt. %) with fair to good genetic potential (1.17 – 8.86 mg HC/g rock).

To conduct the analysis, Passey ΔLogR method has been adopted on well logs and calculated total organic carbon (TOC) content ranging from 1.3-2.0 wt.%. The calculations done at shales of Datta Formation falls out in fair to good category having TOC ranging from 1.3-2.0%. Shale is generally mature containing type III kerogen but type II Kerogen is also present as described by Zaidi et al., (2013). The calculations made to find out TOC are given in Table 3. The TOC calculated from logs (1.3-2.0wt.%) and measured TOC through geochemistry/core samples showed fair to good matching, which validated our findings. It also provided confidence that this is a reliable technique and can be frequently applied to well log data for estimation of TOC in circumstances where core samples are not available. Vitrinite reflectance (Ro, %) is widely used thermal maturity indicator. It is the primary microscopic component of coal. Its reflectance increases with time and temperature. The Ro values below 0.6% represent immature source rock, up to 1.35 % represent oil window and above this usually, indicates gas prone. Vitrinite reflectance (Ro) for Datta shale is found out 0.87% (Figure 6) with the help of PetroMod 1 software of Schlumberger. According to Ibrahimbas and Reidiger (2004) classification of source rock based on Ro, Datta shale is quite mature for hydrocarbons generation. Gul e al., (2016) published research work on evaluation of Shale Gas Prospect in Datta Formation Upper Indus Basin, Pakistan, They estimated TOC range of (0.5 – 2 %), kerogen type III was

Table 3. Calculated TOC through well logs in Datta Formation of Chanda deep-01 well.

DEPTH	LLD (Ohm-m)	DT (microsec /m)	RHOB	LLD Base	DT Base	RHOB Base	ΔlogR Dt	ΔlogR RHOB	TOC Dt (%)	TOC RHOB (%)
4664.88	53.65	61.86	2.83	14.5	67.05	2.56	0.53	0.56	2.2	2.3
4667	46.33	63.40	2.80	14.5	67.05	2.56	0.48	0.50	2	2
4668.38	43.60	64.70	2.77	14.5	67.05	2.56	0.46	0.47	2	1.9
4669.38	42.94	64.17	2.79	14.5	67.05	2.56	0.45	0.4	2	2
4670.38	42.67	64.41	2.89	14.5	67.05	2.56	0.45	0.46	2	2
4671.38	36.05	63.34	2.86	14.5	67.05	2.56	0.37	0.39	1.5	1.6
4671.63	27.87	66.81	2.87	14.5	67.05	2.56	0.28	0.28	1.1	1.1
4671.75	29.53	67.91	2.88	14.5	67.05	2.56	0.31	0.30	1.3	1.1
4672.75	40.97	60.14	2.89	14.5	67.05	2.56	0.40	0.44	2	1.8
4673.75	51.51	56.88	2.75	14.5	67.05	2.56	0.48	0.54	2	2.2
4735.38	27.68	59.14	2.72	14.5	67.05	2.56	0.23	0.27	1	1.1
4736.38	30.20	63.70	2.59	14.5	67.05	2.56	0.29	0.31	1.2	1.3
4737.38	42.28	64.02	2.48	14.5	67.05	2.56	0.44	0.46	2	2
4738.38	48.66	62.90	2.54	14.5	67.05	2.56	0.5	0.52	2	2.1
4739.38	44.66	64.22	2.53	14.5	67.05	2.56	0.47	0.48	2	2
4740.38	49.78	62.71	2.55	14.5	67.05	2.56	0.50	0.53	2.1	2.2
4741.38	45.44	63.90	2.55	14.5	67.05	2.56	0.47	0.49	2	2
4742.38	52.50	62.63	2.55	14.5	67.05	2.56	0.53	0.55	2.1	2.3
4743.75	48.07	61.59	2.53	14.5	67.05	2.56	0.48	0.52	2	2.1
4743.88	49.39	60.93	2.53	14.5	67.05	2.56	0.49	0.53	2	2.2
4746	36.47	61.63	2.53	14.5	67.05	2.56	0.36	0.4	1.5	1.6
4746.88	59.13	59.14	2.65	14.5	67.05	2.56	0.56	0.60	2.3	2.5
									Avg	Avg
									2	2

estimated with low hydrogen index, which shows that the formation has good potential to produce hydrocarbons. Also the Tmax and Ro estimated by these authors, placed the formation in well mature zone. All these results can be correlated with the results estimated by authors in this research work, which is clearly showing the authenticity of work carried out by authors.

6. Conclusion

Source rock evaluation done on shale units of Datta Formation of Jurrasic age showed fair to good source rock potential. As Datta Formation contains major sandstone with some portion of shale and also its environment of deposition is deltaic so it is having good porosity and sand part is having good permeability as well. For interpretation, D R Log technique of Passey has been adopted which proved shales in the matured kerogen type III having good TOC value 2.0 wt %. The comparison and calibrations of log findings with the geochemical analysis (core/ditch cuttings) enhanced the confidence with validated results. The vitrinite reflectance (Ro) for Datta shale is 0.87%. It is mature for hydrocarbon generation as interpreted by vitrinite reflectance data and falls in oil window. These results show that Datta Formation has good source rock potential.

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Author's contribution

Urooj shakir is the principal supervisor of the thesis also give the final proof reading of the manuscript. Muyyassar Hussain assisted in providing the software's utilized in the research work. Nouman Malghani proposed the main concept and defined the methodology of the work. Syed Mamoon Siyar did the well log analysis. Hafiz Shehzad Anjum assisted in the technical work. Fahad Mehmood did the technical review of the paper before submission of manuscript. Masood Anwar collected the write up material. Tausif Ahmed compiled the material and did initial drafting.

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