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Identification of Hydrocarbon Potential of Talhar Shale: Member of Lower Goru Formation Using Well Logs Derived Parameters, Southern Lower Indus Basin, Pakistan

Muhsan Ehsan*[1], Hanming Gu[2], Malik Muhammad Akhtar[3], Saiq Shakeel Abbasi[1], Zaheen Ullah[4]

1. *Institute of Geophysics and Geomatics*, *China University of Geosciences*, *Wuhan* 430074, *China*
2. *Department of Earth and Environmental Sciences*, *Bahria University Islamabad*, *Islamabad* 44000, *Pakistan*
3. *School of Environmental Studies*, *China University of Geosciences*, *Wuhan* 430074, *China*
4. *Faculty of Earth Resources*, *China University of Geosciences*, *Wuhan* 430074, *China*

Muhsan Ehsan: https://orcid.org/0000-0001-9430-5486

ABSTRACT: Using well logs data only, the evaluation of shale gas hydrocarbon potential of Talhar Shale Member of Lower Goru Formation has been a challenge in Southern Lower Indus Basin in Pakistan. Well logs data analysis is helpful to evaluate the gas potential of source shale rocks. We introduced and applied empirical and graphical method to fulfil this task and derived geochemical parameters from well logs data. The method mentioned is cheap and fast. Talhar Shale has kerogen type III and type II which are montmorillonite clay and have potential to produce oil and gas. Talhar Shale has better sorption property. Empirical formulas are used to derive parameters, using well logs of porosity, density and uranium. Porosity and volume of kerogen, calculated from density log, give average values of 11.8% and 11.4%. Average value of level of maturity index (LMI) derived from log is 0.54, which indicates that it is at the early stage of maturity. Vitrinite reflectance is between 0.5%–0.55% as calculated by graphical method and empirical formula. Talhar Shale is at onset of oil generation, with main products of oil and gas. It is a good potential source in the study area.

KEY WORDS: Talhar Shale, kerogen type, sorption property, thermal maturity, vitrinite reflectance (*R*o), Southern Lower Indus Basin.

0 INTRODUCTION

The exploration of hydrocarbons is significant and essential for the economy and growth of a country. At the start of 21st century, depletion of hydrocarbons has put the onus on unconventional hydrocarbon resources. Shale gas exploration is the hottest debate going among the geoscientists nowadays. For the evaluation of unconventional hydrocarbons, geochemical parameters are used, which are expensive in terms of both investment and time. Geoscientists and scholars are trying to develop newer, faster and cheaper methods and techniques for the exploration and production of hydrocarbons than methods and techniques being used before.

In developing countries, geoscientists are facing problems due to lack of funding and unable to study the geochemical parameters like total organic carbon (ζ_{TOC}), hydrogen index (HI), oxygen index (OI), level of maturity index (θ_{LMI}), T_{max}, S_1, S_2, vitrinite reflectance (*R*o), and level of organic maturity (LOM) from Rock-Eval® pyrolysis and well core samples because it is very expensive in terms of cost and time.

Many researchers are working to find out solution to this problem. In previous research, no one was able to find out its complete theoretical solution. Machel et al. (1995) developed a method to check the effect of formation temperature and vitrinite reflectance on oil and gas window. For the evaluation of sorption property, Zhang et al. (2013) introduced another technique. Godec et al. (2013) introduced a formula to derive porosity value from density log. Log derived maturity index (LMI) values calculation is formulated by Labani and Rezaee (2012) by using porosity, density and uranium logs. For TOC value calculation Schmoker (1979) introduced empirical formula and Passey et al. (1990) introduced a Δlog *R* method. Vitrinite reflectance and level of organic maturity (LOM) calculations are introduced by Alyousuf et al. (2011), Lecompte and Hursan (2010) and Hill et al. (2007). In this paper we have arranged and adopted a possible theoretical way to check the hydrocarbon potentials of source rock.

Many oil and gas exploration and development companies

*Corresponding author: muhsanehsan98@hotmail.com

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are trying to explore the shale gas potential of Southern Lower Indus Basin of Pakistan and their main target is Talhar Shale Member of Lower Goru Formation. The area is terrain and shallow to deeper depth of the formation makes it lucrative for the study. The reason lies in high rate of success and easy drilling of the wells. The study area lies in petroleum concessions zone III, where it has low cost, low to medium risk with high success rate. Lower Goru reservoir potential is good to excellent and has porosity values range lies between 10%–35% and permeability values 1 000–1 280 mD. Lower Goru Formation has structural as well stratigraphic trap mostly composed of horst and graben structure which is favourable for oil and gas accumulation (GOP, 2012; Khattak et al., 1999; Quadri and Shuaib, 1986).

In this paper, our main focus is to check the hydrocarbon potential of Talhar Shale as a test case, which is member of the Lower Goru Formation belonging to Cretaceous Age with a lithology of alternate bedding of sandstone and shale. It is considered unconventional reservoir, which has similar geochemical properties as Sember Shale, which has been proved as main conventional source rock in the Southern Lower Indus Basin location of the study area, as illustrated in Fig. 1. We checked the sorption property of Talhar Shale and calculated density derived porosity, volume of kerogen, level of thermal maturity index and vitrinite reflectance (*R*o) values by empirical and graphical methods using well logs data.

In this research we are able to overcome the above-mentioned problem for the evaluation of hydrocarbon potential. The results are very close to the results obtained by using geochemical data, the results are calibrated with geochemical parameters to check the validity of this research. According to authors finding it is the best and cheap way to check the hydrocarbon potential of any unconventional reservoir formation by using well logs data in the absence of core and other geochemical data sets, to apply this method to minimize the effect of different shales of different ages some local calibration is necessary.

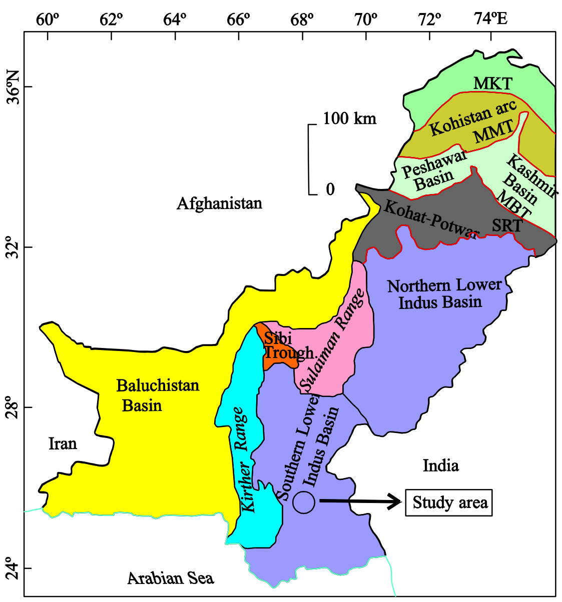

Figure 1. Location of the study area with respect to a basin of Pakistan (modified after Hanif et al., 2014). MBT. Main boundary thrust; SRT. salt range thrust; MKT. main karakoram thrust; MMT. main mantle thrust.

1 DATA SET

The data set used for calculations comprises of formation temperature, formation depth, geothermal gradient, surface temperature, level of organic maturity (LOM) and total organic carbon (TOC) of Hakeem Daho-01 Well. Gamma ray, porosity, density, deep resistivity, sonic and uranium logs are used. While parameters such as hydrogen index (HI), oxygen index (OI), T_{max}, S_1 and S_2 are taken from Oil and Gas Development Company Limited (Pakistan). Some input parameters are taken from stranded published values.

2 METHODOLOGY

Kerogen type is found by using oxygen index (OI) and hydrogen index (HI) cross plot. To check the effect of formation temperature and vitrinite reflectance on oil and gas window applied according to Machel et al. (1995) method. The sorption property of Talhar Shale is checked by Zhang et al. (2013) technique. Porosity values are derived by using density log values, the method introduced by Godec et al. (2013). Kerogen volume is determined by using empirical formula of density log values. Porosity, density and uranium logs are used for the log derived maturity index (LMI) by using Labani and Rezaee (2012) method. To calculate the LOM value, we use TOC value which is calculated by using Schmoker (1979) empirical formula and $\Delta\log R$ value which is calculated by using Passey et al. (1990) method. Vitrinite reflectance value is calculated by the use of level of organic maturity (LOM), as introduced by Alyousuf et al. (2011). Lecompte and Hursan (2010) transformed the LOM values (ξ_{LOM}) into *R*o values and developed an empirical relation from graph which is used to calculate *R*o values. Vitrinite reflectance values are found by using formation temperature as introduced by Hill et al. (2007), using graphical method. The method adopted for all mentioned calculations is by comparing the values with stranded charts. In the current research, cheaper and faster way to find out the hydrocarbon potential before investing and drilling by the use of well logs derived parameters is introduced.

3 KEROGEN TYPE

Kerogen type decides the potential of oil and gas in a source rock. Kerogen is of four types, which are: type I, type II, type III and type IV. Type I can only produce oil, type II produces both oil and gas, type III can only produce gas, but it also produces a minor amount of oil and type IV produces none of the hydrocarbons (Holditch, 2011). Cross plot of kerogen types in Lower Goru Formation is shown in Fig. 2 as defined by Rock-Eval® hydrogen index (HI) and oxygen index (OI) in which gas-prone type III and type II kerogens are found in Lower Goru Formation.

3.1 Effect of Temperature and Vitrinite Reflectance on Oil/Gas Window

Machel et al. (1995) developed a relationship of temperature and vitrinite reflectance with oil and gas window, shown in Fig. 3. The amount of heat of organic rock is used to define the thermal maturity of rock. Talhar Shale has an average temperature of 93 ºC and vitrinite reflectance 0.5%–0.55%. So, according to Fig. 3, it is at onset of oil generation and has a potential to produce both oil and gas.

4 EFFECT OF CLAY MINERALS ON SORPTION OF GAS

Clay mineral type affects the organic rich shale system in accordance with CH_4 sorption property. Every mineral has its own sorption property. So, clay mineral type is very helpful to understand the sorption of gas. These clay minerals mainly are, according to the sedimentary rocks definition, smectite (montmorillonite), kaolinite, illite and chlorite. Montmorillonite is a member of smectite group. The main components of gas adsorption are organic matter, thermal maturity and clay mineral type. The effect of these components is extensively observed in gas adsorption (Zhang et al., 2012). Methane sorption is controlled by two main factors, which are thermal maturity and clay type. With the increment of thermal maturity, methane sorption also increases because nano-pores are developed and decomposition of organic matter also increases the sorption rate of methane. Methane sorption is also controlled by clay type, the sorption capacity of CH_4 is in following order montmorillonite≫illite with smectite mixed layer>kaolinite>chlorite>illite (Zhang et al., 2013).

Montmorillonite clay type has a greater capacity of CH_4 sorption than other clay types. It has been proved that Talhar Shale is montmorillonite clay type, so it has greater capacity to absorb CH_4 gas. The sorption properties of montmorillonite clay type members of smectite group are shown in Figs. 4a and 4b. It has both capacity of sorption on internal as well as on external surface.

5 DENSITY POROSITY

The porosity is calculated by using formula as given in Eq. (1), the matrix grain density for shale is taken 2.77 g/cm^3 and density of formation water is taken 1.10 g/cm^3 (Godec et al.,

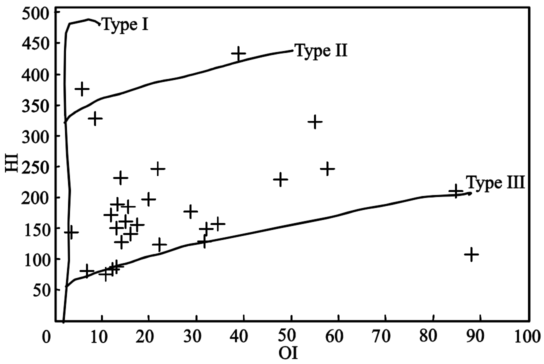

Figure 2. Plot of kerogen type in Lower Goru Formation as defined by Rock-Eval® HI and OI indices; Lower Goru is gas-prone type III and type II kerogen type.

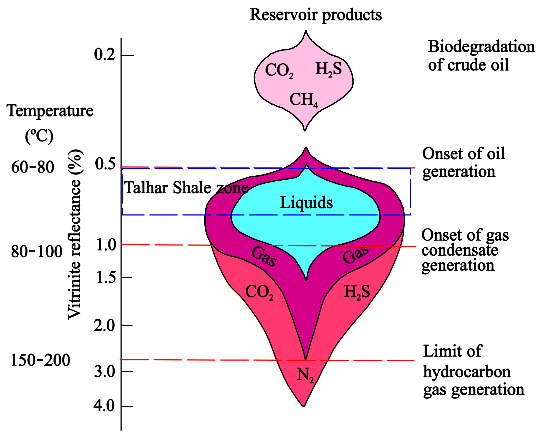

Figure 3. Oil/gas windows relation with temperature and vitrinite reflectance (modified after Machel et al., 1995).

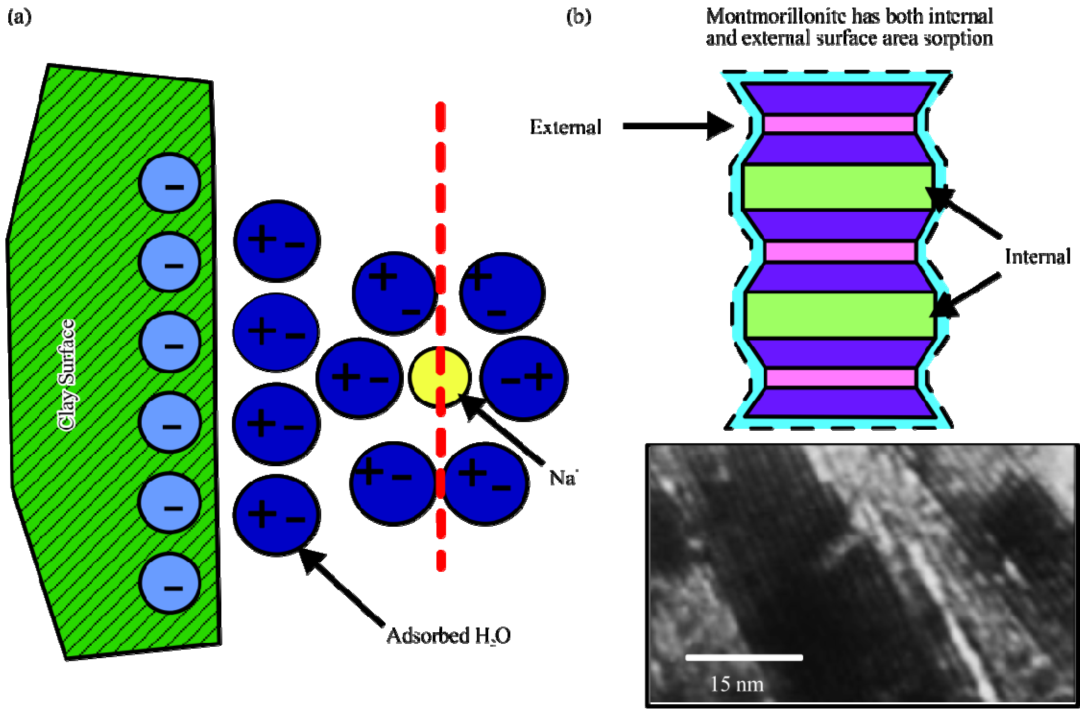

Figure 4. Schematic of sorption (a) clay with water (b) scanning electron microscope (SEM) image of smectite (montmorillonite) which has property of sorption both external and internal surface area (modified after Passey et al., 2010).

2013; Magara, 1978). The bulk density is taken from the density log of Talhar Shale.

$$\Phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad (1)$$

Φ=density drive porosity; ρ_{ma}=matrix grain density; ρ_f=density of formation water; ρ_b=bulk density takes from density log.

The high values of porosity are shown at interval 2 982–2 990 m; from 3 000–3 010 m it has medium range values. It shows low values at interval 3 010–3 061 m, which is shown in Fig. 5a. It is concluded that with depth the values of porosity are showing decreasing trend due to compaction and overburden of rocks.

6 KEROGEN VOLUME

This calculation was done using bulk density of non-organic matter value 2.73 g/cm^3; this value is taken from the shale having low organic contact. The volume of kerogen is calculated by Eq. (2) by Shazly et al. (2013). The values of log density are taken from well log of Talhar Shale density values.

$$V_{kerogen} = \frac{\rho_{no} - \rho_{log}}{1.378} \quad (2)$$

where $V_{kerogen}$=fractional volume of kerogen (organic matter); ρ_{no}=bulk density of non-organic matter; ρ_{log}=density values taken from well logs.

The high kerogen volume values are shown at interval 2 982–2 990 m; from 3 000–3 010 m it has medium range values. It shows low values at interval 3 010–3 061 m and it is illustrated in Fig. 5b. It is concluded that the volume of kerogen is decreasing with respect to depth.

7 THERMAL MATURITY OF TALHAR SHALE

To calculate the thermal maturity of Talhar Shale, we use log derived maturity index (LMI) in accordance with log data. In this section, different methods are used to calculate the thermal maturity details of each method. These details are as follows.

7.1 Level of Organic Maturity (LOM)

Level of organic maturity (LOM) defines the source rock thermal metamorphism that has occurred during the process of its burial. It describes the potentials of source rock, i.e., whether it produces oil or gas. LOM plays key role to develop source rock properties like porosity and water saturation at the time of source rock evolution. Due to thermal maturity, the presence of free water as well capillary water is replaced by generated hydrocarbon. With the increase of thermal maturity value of water saturation will be decreased. Normally at higher value of LOM gas is detected in source rock (Labani and Rezaee, 2012; Ariketi, 2011; Hood et al., 1975). LOM value is calculated using TOC and $\Delta\log R$ values. So, LOM values are interlinked with TOC and $\Delta\log R$ values, as shown in Eq. (12), TOC values have been calibrated by previous studies and LOM also calibrated indirectly.

7.2 Labani and Rezaee Log Derived Maturity Index (LMI)

Labani and Rezaee (2012) gave a relationship between thermal maturities and well logs, which is called as log derived maturity index (LMI) and its values range from 0 to 1. The LMI (θ_{LMI}) higher values indicate that this formation is thermally mature and lower values indicate that it is immature. The input logs were used for LMI porosity, density and uranium log. They developed the empirical formulas for the calculation of θ_{LMI}. They adopted following procedures; first they calculated the θ_{LMI} from three logs, then they took average of these logs to overcome the effect of individual log results.

$$\theta_{LMI_\phi} = \frac{\phi_{log} - \phi_{max}}{\phi_{min} - \phi_{max}} \quad (3)$$

$$\theta_{LMI_\rho} = \frac{\rho_{log} - \rho_{max}}{\rho_{min} - \rho_{max}} \quad (4)$$

$$\theta_{LMI_U} = \frac{U_{log} - U_{max}}{U_{min} - U_{max}} \quad (5)$$

$$\theta_{LMI_{av}} = \frac{\theta_{LMI_\phi} + \theta_{LMI_\rho} + \theta_{LMI_U}}{3} \quad (6)$$

$\theta_{LMI\phi}$=level of maturity index derived from porosity log; $\theta_{LMI\rho}$=level of maturity index derived from density log; θ_{LMIU}=level of maturity index derived from uranium log; θ_{LMIav}=average level of maturity index derived from three logs.

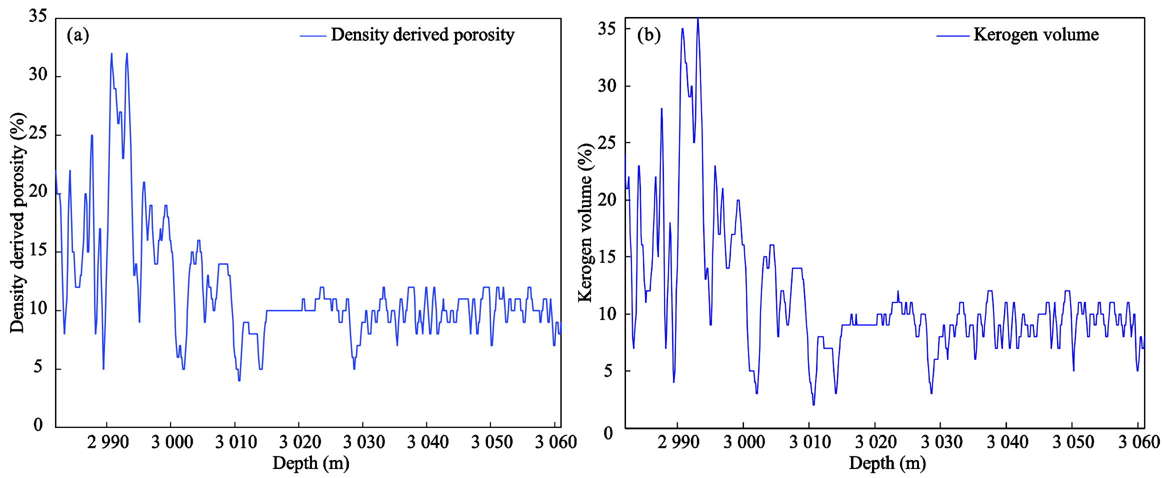

Figure 5. (a) Density derived porosity plot with depth in Talhar Shale and (b) kerogen volume plot with depth in Talhar Shale.

At depth 2 982–2 990 m it shows good maturity index values, but on average its values are medium ranged which are shown in Fig. 6. The porosity and uranium logs show the θ_{LMI} values greater than 0.6 while only density log shows low θ_{LMI} values.

8 VITRINITE REFLECTANCE (*R*o) CALCULATION

To calculate the value of vitrinite reflectance (*R*o) two methods are used, empirical and graphical. In the present study, both methods are applied to calculate the vitrinite reflectance (*R*o) values of the Talhar Shale. It is measured in percentage (%) units normally.

8.1 Empirical Formula of Vitrinite Reflectance by Lecompte and Hursan (2010)

To calculate the vitrinite reflectance using Empirical formula, we first calculated the TOC (ζ_{TOC}) and LOM (ξ_{LOM}) values using well logs. ζ_{TOC} is calculated using density log and Schmoker (1979) method as empirical formula. ξ_{LOM} is calculated using Passey et al. (1990) method, $\Delta\log R$ method. Schmoker (1979) introduced an empirical formula, given in Eq. (7) for the calculation of TOC from density log.

$$\zeta_{TOC}(\text{wt.\%}) = \left(\frac{154.497}{\rho_b}\right) - 57.261 \quad (7)$$

ρ_b=formation density values taken from well log. The values obtained of ζ_{TOC} are 2.84% from this method. The method is used for the calculation of LOM values.

$$\Delta\log R_{\Delta t} = \log_{10}\left(\frac{R}{R_{\text{baseline}}}\right) + 0.02\times(\Delta T - \Delta T_{\text{baseline}}) \quad (8)$$

$\Delta\log R_{\Delta t}$=separation value of resistivity/sonic crossover, R_{baseline}= resistivity baseline values, $\Delta T_{\text{baseline}}$=sonic base line values

$$\Delta\log R_{\rho} = \log_{10}\left(\frac{R}{R_{\text{baseline}}}\right) - 2.5\times(\rho - \rho_{\text{baseline}}) \quad (9)$$

$\Delta\log R_{\rho}$=separation value of resistivity/density crossover, ρ_{baseline}= baseline values of density.

$$\Delta\log R_{\Phi} = \log_{10}\left(\frac{R}{R_{\text{baseline}}}\right) + 4.0\times(\Phi - \Phi_{\text{baseline}}) \quad (10)$$

$\Delta\log R_{\Phi}$=separation of resistivity and porosity, Φ_{baseline}=baseline porosity value baseline interval.

$$\Delta\log R = \frac{\Delta\log R_{\Delta t} + \Delta\log R_{\rho} + \Delta\log R_{\Phi}}{3} \quad (11)$$

ξ_{LOM} is calculated using the TOC values obtained from density log and $\Delta\log R$ values. Which are obtained from crossover method and it has an average value of 0.186 1, used in Eq. (12).

$$\xi_{LOM} = 13.607\,8 - 5.924\times\log_{10}\left(\frac{\zeta_{TOC}}{\Delta\log R}\right) \quad (12)$$

ζ_{TOC}=values taken from the density log calculation, $\Delta\log R$= values taken from each crossover average value by using Eq. (12), we calculated ξ_{LOM}, which is 6.6.

Lecompte and Hursan (2010) transformed the LOM values into *R*o values and developed an empirical relation from the graph.

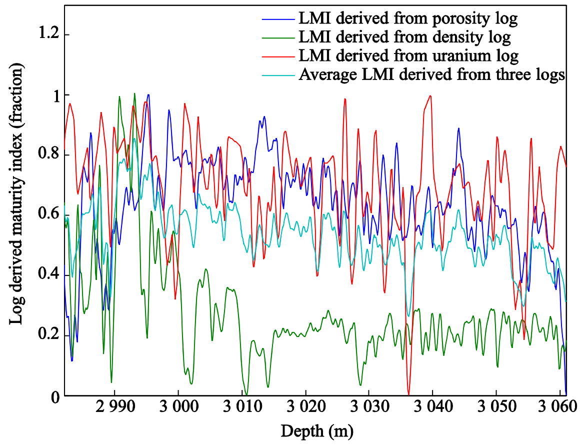

Figure 6. Plotting of Level of Maturity Index (LMI) with depth in Talhar Shale.

Where the correlation of values is 100%, according to this formula, as explained in Eq. (13), Talhar Shale has 0.55% *R*o value.

$$Ro(\%) = -0.003\,9\xi_{LOM}^{3} + 0.149\,4\xi_{LOM}^{2} - 1.568\,8\xi_{LOM} + 5.517\,3 \quad (13)$$

8.2 Level of Organic Maturity (LOM) and Vitrinite Reflectance (*R*o) by Graphical Method

This method is introduced by Alyousuf et al. (2011) to calculate the vitrinite reflectance values using LOM. It is also a graphical method in which vitrinite reflectance (%) is plotted on the *x*-axis and LOM is plotted on *y*-axis. The plot is shown in Fig. 7a. Talhar Shale ξ_{LOM} is 6.6. So, their vitrinite reflectance (*R*o) value is 0.5% according to the Graph.

8.3 Formation Temperature and Vitrinite Reflectance (*R*o)

To calculate the formation temperature, we require mean surface temperature and geothermal gradient of the target formation. The mean surface temperature of the study area is taken from energy year book 2012, published by Hydrocarbon Development Institute of Pakistan, and well header of Hakeem Daho-01 Well. The geothermal gradient values are taken from published geothermal gradient contour map of the study area. The procedure adopted for this calculation is described below.

Input parameters T_1=26.60 ºC (HDIP, 2012), geothermal gradient (δ)=22 ºC/km (Kadri, 1995).

$$T_F = T_1 + \delta\times D$$

T_F=formation temperature, T_1=mean surface temperature, δD=depth of formation in km, average temperature of formation in Celsius scale=93 ºC; average temperature of formation in Fahrenheit scale=200 ºF (~93 ºC).

Hill et al. (2007) introduced the method to calculate vitrinite reflectance (*R*o) values in organic rocks with a condition to have the formation temperature at hand. It is a graphical method in which formation temperature (ºF) is plotted on *x*-axis and vitrinite reflectance (*R*o) in percentage (%) is plotted on *y*-axis. The plot is shown in Fig. 7b. Talhar Shale temperature is 200 ºF (~93 ºC) so their vitrinite reflectance (*R*o) value is 0.5% from the graph.

9 DISCUSSION

Developing a method or technique to evaluate the shale gas

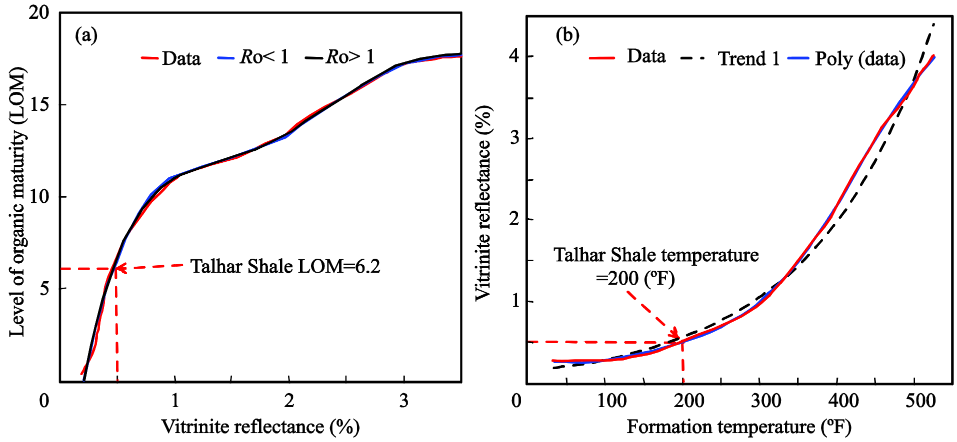

Figure 7. (a) Vitrinite reflectance and level of organic maturity (model modified after Alyousuf et al., 2011); (b) vitrinite reflectance and formation temperature model (modified after Hill et al., 2007).

by using well log derived parameters is not an easy task; it is big challenge for researchers. Well log play a key role for the exploration and production of hydrocarbons. In this research paper, well log derived parameters are being observed very beneficial and helpful to check the hydrocarbon potential of Talhar Shale.

The thickness of Talhar Shale is variable and generally lies in between 80–100 m range (>200–350 feet (~61–106 m)) in the study area (Haider et al., 2012). The thickness calculated by authors is 79 m by using well logs data which shows good match with the previous value. Talhar Shale (member of Lower Goru Formation) has kerogen type II and type III which is found out by cross plot of HI and OI shown in Fig. 2. In previous studies which were done by Robison et al. (1999), Ahmad (1997) and Smith et al. (1992), reported that Lower Goru Formation has kerogen type II and type III which calibrates the present research. The effect of temperature and vitrinite reflectance on oil and gas window which is developed by Machel et al. (1995) is shown in Fig. 3 indicates that Talhar Shale has capacity to produce oil and gas. It has already been described that it is kerogen type II and type III, so it produces both oil and gas. The Lower Goru Formation was deposited in most oxidizing shallow water condition (Smith et al., 1992).

Talhar Shale is montmorillonite clay type as shown in Figs. 4a and 4b which has high capacity to absorb CH_4 gas as described by Smith et al. (1992) it has high potential to produce gas which is verified by present research. Its average porosity values is 11.8% shown in Fig. 5a which is good for reservoir in general if any formation has porosity value greater than 6%, it is considered to be a reservoir.

The cutting core samples from Sann-1 and Bobi-4 wells, which are located in the study area, were used for the calculation of TOC values. To find out, key parameters TOC and Rock-Eval® pyrolysis are used for the determination of organic richness and hydrocarbon potential. The method is used for reflectance analysis and vitrinite reflectance values measured by using *R*-reflex computer program developed by Leitz-BGR. The TOC value is 2.35%, it is taken from 27 samples of Lower Goru Formation (Robison et al., 1999; Ahmad, 1997). The TOC values indicate that this formation has a hydrocarbon source potential from good to excellent. The value of TOC calculated in this paper is 2.84% which is in correlation with the core samples results of almost 83% which indicates the validity of this research.

Maturity of organic rich source rock is mostly determined by core samples and well drills cutting samples to evaluate properly and precisely the maturity index. In literature some indirect techniques to find LMI are also documented by using well logs data. So, we use sonic, porosity, density, uranium and resistivity logs to evaluate it (Prasad, 2001; Vernik and Liu, 1997; Passey et al., 1990; Schmoker and Hester, 1983). In this paper, LMI values are found out by using well log data. The values found out by using porosity as well uranium logs show good maturity index, most values are greater than 0.6 as shown in Fig. 6, which indicates good maturity of Talhar Shale while density logs do not give us much better results as compared to other logs.

Vitrinite reflectance values are calculated by using graphical and as well as empirical formulas. In present paper, vitrinite reflectance value ranges between 0.50%–0.55%. The values calculated by geochemical data ranging of 0.61%–0.66% (Ahmad, 1997) which indicates that this formation is in early mature form for hydrocarbon generation. The correlation of vitrinite reflectance values between present research and values calculated by geochemical data is 83% which verifies our work.

10 CONCLUSION

Talhar Shale is a member of Lower Goru Formation. It has kerogen type III and type II which have potential of producing oil and gas. Talhar Shale has montmorillonite clay type which means that it has good sorption property. This sorption property is present at both, internal and external surface. The results of the study show that the average value of density derived porosity is at 11.8%, the volume of kerogen is calculated from density log and its average value is 11.4%. Level of maturity index (LMI) is derived from three well logs density, porosity and uranium. Its average value is 0.54 which indicates that Talhar Shale is at early stage of maturity. Vitrinite reflectance is calculated by graphical as well as empirical formula and it ranges from 0.5%–0.55%. So, Talhar Shale is at onset of oil generation and can be used for the production of mainly oil and gas. Current research findings of well logs data derived parameters and their correlation with geochemical parameters is about 83% which is good to excellent. This correlation validates the authenticity of our study.

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