

Evaluation of Gas Potential in Early Cretaceous Shale Lower Indus Basin, Pakistan

Bilal Ahmed¹, Mohibullah Mohibullah², Sadiq Jalal³, Shabeer Ahmed Abbasi⁴, Abdul Salam Khan,^{1*}
Shams-ul-Alam⁴, Hamza Rehman³

¹Centre of Excellence in Mineralogy, ²Department of Geology, University of Balochistan Quetta, Pakistan

³Department of Earth Sciences, Quaid-i-Azam University Islamabad, Pakistan

⁴Oil and Gas Development Company Limited (OGDCL), Islamabad, Pakistan

*Email: asalamk_cem@yahoo.com

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Abstract: The shale gas potential of the early Cretaceous Talhar shale member of the lower Goru Formation in lower Indus basin of Sanghar district, Sindh province, has been evaluated using 2D seismic and well logs data. Graphical and empirical techniques were applied to calculate various geochemical parameters for the evaluation of shale plays. Total Organic Carbon (TOC) is calculated by Passey's (ΔLogR) Overlay technique and its values are about 2.44 wt.%. Vitrinite Reflectance (R_o) is estimated by graphical and empirical relation and the value lies between 0.95-1.0 which implies that the Talhar shale member is in peak oil and initial gas generation phase. Log-derived Maturity Index (LMI) is calculated by NPHI, RHOB or density log and uranium logs. The average value is about 0.55 which reflects that the formation is probably in the initial maturation phase. Kerogen Volume (V_k) is estimated by empirical relation using RHOB log as input and it is about 13 wt. % which reflects that the formation has enough potential of oil/gas expulsion. The results are compared and validated with a study of the adjacent field of the same basin. This study reveals that Talhar member of lower Goru Formation could be the future probable potential unconventional reservoir for exploration in lower Indus basin of Pakistan.

Keywords: Unconventional, total organic content, Passey's, ΔLogR , kerogen volume.

Introduction

Exploration and production of natural resources especially hydrocarbon plays a vital role in the economic growth of a country (EIA, 2009). Since the successful production from shale oil and gas reservoirs in the United States, Russia, Asia, Australia and Canada, the worldwide attention is focused on exploring the unconventional reservoirs of shale oil and gas (Feng, 2013). The shale gas recoverable resources or unconventional resources of the entire globe are about 141259 trillion cubic feet (TCF), which are eight (8) times greater than conventional gas resources (EIA, 2009). Pakistan is gifted with huge amount of natural resources and is listed among the top twenty unconventional shale oil and gas reserves containing countries (Aiyar, 2009). According to US Energy Information Administration (EIA) estimate 2011, Pakistan has about 52 TCF technically recoverable shale gas reserves (US EIA., 2013; APERC, 2015).

The shale can be evaluated either by direct or indirect method. In direct method, the core cuttings obtained during well drilling are analyzed. In the indirect method the shale gas potential is evaluated by studying the behaviour and response of various well logs. It is obvious that direct method is more reliable than indirect. However, indirect method also gives significant results in characterizing shale reservoirs, as it has been tested on various geological basins across the globe. The present study is aimed at evaluating the prospects for early Cretaceous shale play by indirect method. To accomplish this enduring task, various geochemical

properties at the reservoir depth have been determined. The Talhar shale member was geochemically evaluated by calculating its Total Organic Content (TOC), Kerogen Volume, Vitrinite Reflectance (R_o), Level of Maturity (LOM) and Log Derived Maturity Index (LMI). Eventually, the calculated results were calibrated with the published results from core data of the same basin and adjacent field.

Materials and Methods

The data set includes 8 seismic lines and three wells including Chak-66-01, Chak-5 Dim South-01 and Resham-01. The seismic data set includes navigation data and SEG-Y data of five dip lines and three strike lines, which are interpreted and converted into depth section, as the well is drilling in terms of depth. The well log data set comprises of LAS files, formation tops and well headers. Seismic structural interpretation approach was used to identify the structural geometry on the seismic section in the extensional tectonic regime of southern Indus basin. Synthetic seismic or 1D forward model was generated at well location using sonic and density logs to mark the target horizon on seismic section. Depth map of Talhar shale member is generated by using 1D velocity model to identify targeted depth for drilling.

Conventional well logs provided includes Gamma Ray (GR) to identify shale and non-shale reservoirs. Laterolog Deep (LLD), Laterolog Shallow (LLS). Besides, Delay Time (DT) or Sonic log is used for estimation of Total Organic Content (TOC), Vitrinite reflectance (R_o) by Passey et al. (1990) other logs include ΔLogR method (Schmoker and Hestler., 1983) and Cross plot analysis

(Bowman., 2010; Mallick and Raju, 1995) respectively. Oil or gas window is identified using formation temperature with vitrinite reflectance values (Machel et al., 1995). Whereas, density or RHOB log was used to calculate kerogen volume by empirical relation (Shazly et al., 2013). Moreover, density (RHOB) and Neutron Porosity Hydrogen Index (NPHI) logs were used to calculate Log-derived Maturity Index (LMI) proposed by Labani and Rezaee (2012). While, Level of Organic Maturity (LOM) value is derived from graphical method (Alyousuf et al., 2011, Lecompte and Hursan, 2010). The Vitrinite reflectance (Ro) was estimated by graphical method using temperature of the formation under study (Hill et al., 2007). Finally, the calculated results were validated with core sample values of the same basin and adjacent exploration lease (Ehsan et al., 2016).

Geological and Tectonic Setting

The present study area of Sanghar is located in the lower Indus basin south of Jacobabad high. This area lies in the zone-III of Pakistan petroleum concessions, which has low to medium drilling cost and high success rate (Kazmi and Jan, 1997; Wandrey et al., 2004). The stratigraphic sequence drilled in southern Indus basin is from Jurassic to Recent and the sediment source is Indian craton (Kadri, 1995; Ahmad, 2004). The lower Goru Formation of southern Indus basin is deposited in shallow to deep marine environment, composed of alternate shale-sand intervals and the whole formation is divided into seven distinct lithological units attributed by various sand-shale intervals (Baig et al., 2016). Lower Goru Formation is bounded by upper Goru and Sembar formations in the top and bottom respectively. The upper Goru calcareous clay and marl is conformable and transitional with Sembar sequence (Khattak et al., 1999; Quadri and Shuaib, 1986).

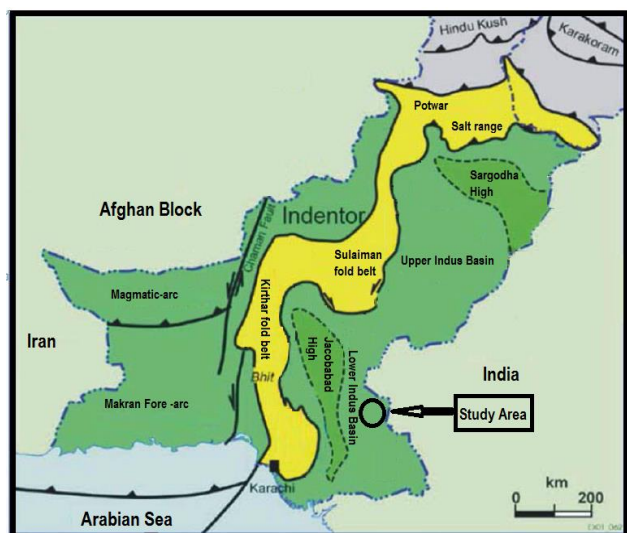


Fig. 1 Regional tectonic map and major basins of Pakistan (after Hanif et al., 2014).

Geologically, Pakistan is located on the verge of convergence zone where three major tectonic plates i.e. Indian, Eurasian and Arabian plates are interacting or colliding (Wandrey et al., 2004). The geological environment in Pakistan and its surrounding region is

greatly associated with the tectonic movement of these three major plates (Wandrey et al., 2004) which divide the region into various geological basins such as Balochistan basin, Pishin basin and the area wise largest Indus basin. The Indus basin is further divided into upper and lower Indus basins. The boundary between upper and lower Indus basin is demarcated by Sargodha high (Bender and Raza, 1995). The lower Indus basin is further subdivided into southern and central Indus basins by Sukkur rift (Bender and Raza, 1995). The dominant structure style in the extensional tectonic regime of the southern Indus basin is normal faulting in NNE and SSW direction or horst and graben geometry mostly accompanied with stratigraphic traps, which is considered most favorable for hydrocarbon accumulation.

Era	Era/Epoch	Formation	Lithology	Reservoir	Seal	Source	Discoveries
Cenozoic	Neogene	Siwaliks/ Alluvium					
		Gaj/Nari					
	Paleogene	Kithar Fm.					
		Laki					
		Ranikot Volcanics					
Mesozoic	Late	Parh					
		Upper Goru					
	Early	Lower Goru					
		Turk Shale	A Sand				Badin
		Badin Shale	B Sand				Badin
		Zhoi Shale	C Sand				Adam X-1, Badin
		Upper Shale	D Sand				Adam X-1
		Middle Sand					
		Lower Shale					
		Basal Sand					
		Talhar Shale					
Jurassic	Late	Massive Sand					
	Middle	Sembar					
		Chiltan					

Fig. 2 Stratigraphic column of lower Indus basin (after Abbasi et al., 2025 and Baig et al., 2016)

The early Cretaceous Talhar shale member of the lower Goru Formation has identical characteristics of shale belonging to Sembar Formation, which is a potential source rock in southern and central Indus basins of Pakistan (Ahmed, 1997). The shale has type-II and III kerogen and on average TOC ranges from 0.5% to 3.5%. Depth of Talhar encountered in well Chak_66-012862 meters with thickness of about 77 meters (Sheikh and Naseem., 1999; Naseer and Asim, 2017; Haider et al., 2012; Solangi et al., 2016).

Results and Discussion

In order to correlate well data with post stack seismic data, synthetic seismic was generated at well location. Product of density and sonic log gives acoustic impedance log. Reflection coefficient is calculated by

empirical relation using acoustic impedance log. Convolving reflection coefficient with source wavelet extracted from seismic at well location gives synthetic seismic trace, which is then compared with the observed seismic data (Kearey, 2002). Horizon of interest was interpreted using the generated synthetic seismic at well Chak 66-01 (Fig. 3).

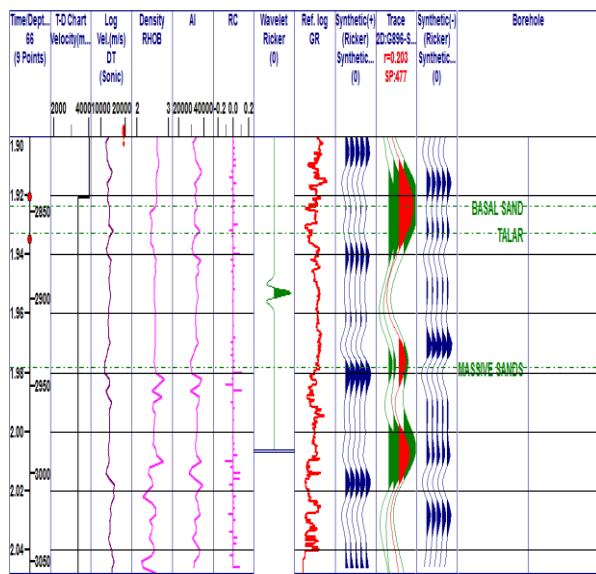


Fig. 3 1-D forward model generated at well location.

Horizon and Fault Marking

In the present study the targeted depth is Talhar shale interval, for this purpose shale horizon is marked on the time section at 1.93 seconds. Sanghar geological succession being in the southern part of the Indus basin has experienced extensional tectonic deformation during early Cretaceous (Kemal et al., 1991). Normal faults are marked on the seismic section, due to extensional tectonic regime (Fig. 4). Normal faulting is considered most favorable and lucrative structure for hydrocarbon trapping mechanism.

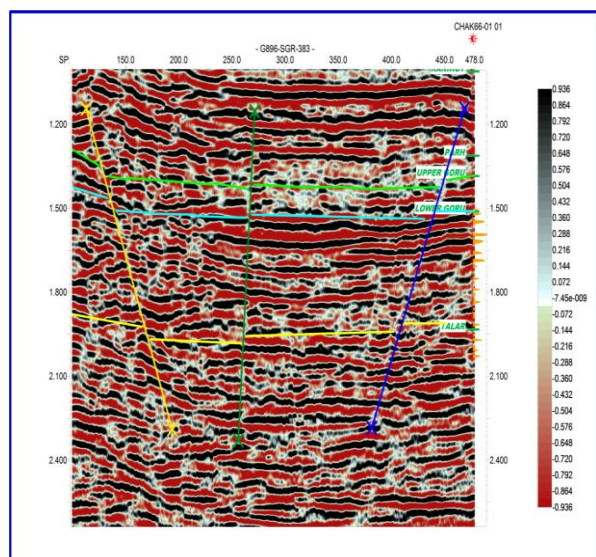


Fig. 4 Interpreted seismic section of line 383.

Time grid generated for Talhar shale and converted into depth map using single 1D velocity function (Fig. 5).

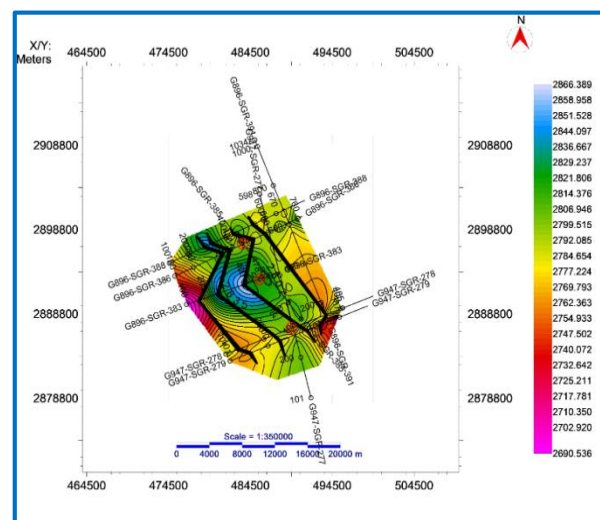


Fig. 5 Depth map of the study area.

Shale Gas Evaluation Parameters Result

Level of Maturity (LOM)

Hood et al. (1975) introduced the LOM scale based on the thermal diagenesis the rock passed through during its deposition. LOM ranges from 6 to 14. Value from 7.5 to less than 10.5 of LOM shows that the formation is diagenetic methane generating, from 10.5 to 14 is showing oil generation. Using TOC and $\Delta\log R$ values from Schmoker (1979) and Passey et al (1990, 2010), LOM is calculated 10.3 using the empirical relation:

$$LOM = 13.6078 - 5.924 * \log_{10}\left(\frac{TOC}{\Delta\log R}\right) \quad (1)$$

Vitrinite Reflectance

Vitrinite reflection is commonly used in source rock evaluation to identify either the rock will expel oil, gas or condensate. Values greater than 0.8 is considered a mature source rock (Hood et al., 1975). Hood's (1975) equation is transformed into R_o by Lecompte and Hursan (2010).

$$R_o = -0.0039LOM^3 + 0.1494LOM^2 - 1.5688LOM + 5.5173 \quad (3)$$

Value calculated for vitrinite reflectance by this empirical relation using LOM value is 0.95.

Log Derived Maturity Index (LMI)

The general concept is that higher thermal maturity of formation will have higher potential for oil or gas generation (Boyer et al., 2006). Thermal maturity of a formation is estimated by using conventional logs of density, neutron and sonic. LMI scale ranges from 0 to 1. Higher the value, greater they will be thermally maturity of the formation. The correlation coefficient increases when LMI is estimated from all the three logs (Labani and Rezaee, 2012, Ariketi, 2011).

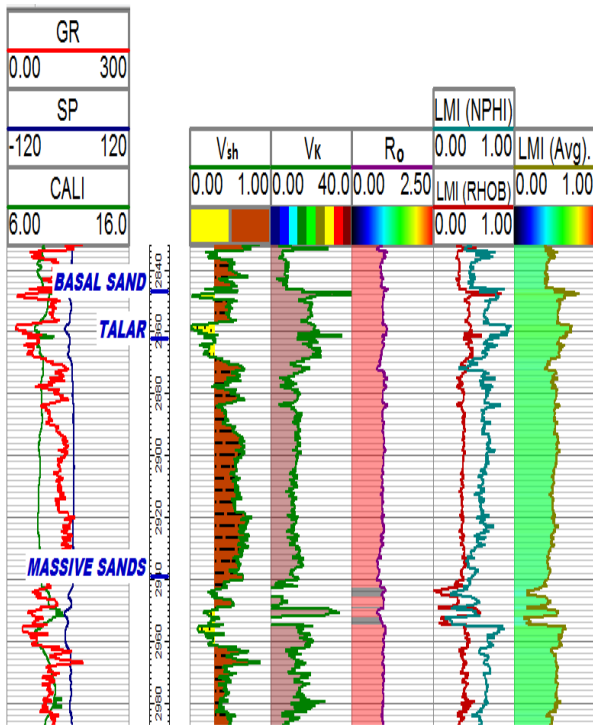


Fig. 6 Geochemical parameters for Talhar shale member including Volume of shale, Kerogen volume, vitrinite reflectance and LMI.

$$LMI_{avg} = \frac{LMI\phi + LMI\rho + LMIu}{3} \quad (2)$$

LMI estimated from above given relation is 0.55 which shows the initial maturation stage of Talhar shale.

Kerogen Volume

Kerogen volume is calculated using density log values at shale interval by the mentioned empirical relation given by Shazly et al., (2013)

$$V_{kerogene} = \frac{\rho_b - \rho}{1.378} \quad (4)$$

Where, ρ_b is the bulk density of non-organic shale sequence whereas ρ is the density values at a depth of shale sequence. Kerogen value estimated by this method is 13%.

TOC Estimation from Passey's ΔLogR method

The Passey's ΔLogR method is successfully applied and tested on many basins worldwide since its beginning in 1979 by Exxon and published by Passey et al. (1990). The method equally works in clastic and carbonates basins. The ΔLogR is separation between the two overlying log curves estimated using sonic, density and neutron or porosity logs along with resistivity log curve. Empirical relation for sonic and resistivity overlay is given as:

$$\Delta\text{LogR}_{\Delta T} = \log_{10} \left(\frac{R}{R_{baseline}} \right) + 0.02 * (\Delta T - \Delta T_{baseline}) \quad (5)$$

ΔLogR is the separation of two curves in logarithmic scale, R is resistivity in $\Omega\text{-m}$ and ΔT is travel time in $\mu\text{s/ft}$. LOM value is also given as input in Passey's equation?

The resistivity and sonic log curves are so adjusted that $100\mu\text{s/ft}$ is taken equal to two resistivity cycles.

Empirical relation for TOC estimation based on ΔLogR technique in shale rock gives 2.44 wt.% of TOC (Fig. 7).

$$TOC(\text{wt} \%) = \Delta\text{LogR} * 10^{(2.297 - 0.1688 * LOM)} \quad (6)$$

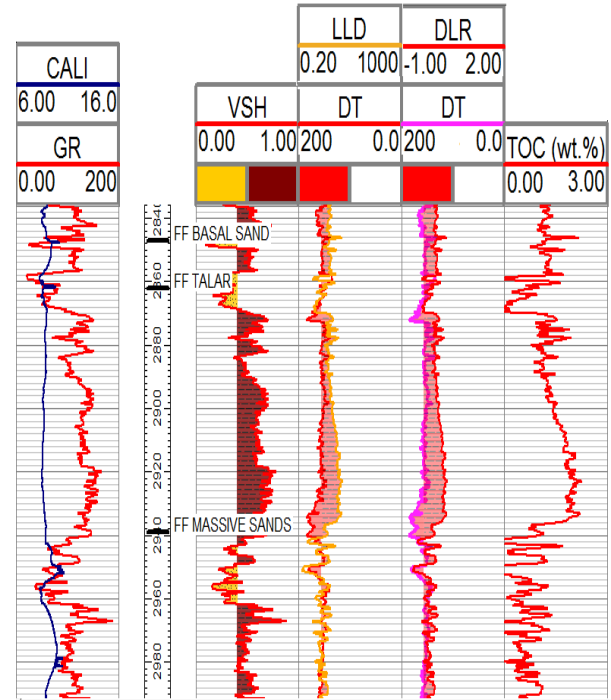


Fig. 7 TOC estimation from Passey's ΔLogR method.

Modified Passey's ΔLogR Method

Cross plot between logarithmic of resistivity (LogR) and sonic (DT) log is the modified form of previously proposed Passey's 1990 ΔLogR method. The method gives a first insight to identify potential tight shale plays identification. The scientific grounds of this method are based on the separation in sonic and pseudo sonic log computed from shale line using slope (m) and intercept (b).

$$DtR = b - m * \text{LogR} \quad (7)$$

This modified Passey's method is applied on well logs of Chak_66-01 and the resultant Bowman, (2010) cross plot analysis (Fig. 8).

Graphical Estimation of Vitrinite Reflectance and LOM

Graphical estimation of Vitrinite reflectance is proposed by Hill et al. (2007). Formation temperature is calculated using well header information including surface temperature and bottom hole temperature. Using Alyousaf et al. (2011) proposed method, this vitrinite reflectance was transformed into LOM value. The value of vitrinite reflectance by this method is 0.9 and LOM value is 10.2 which is almost same as that calculated by empirical relations.

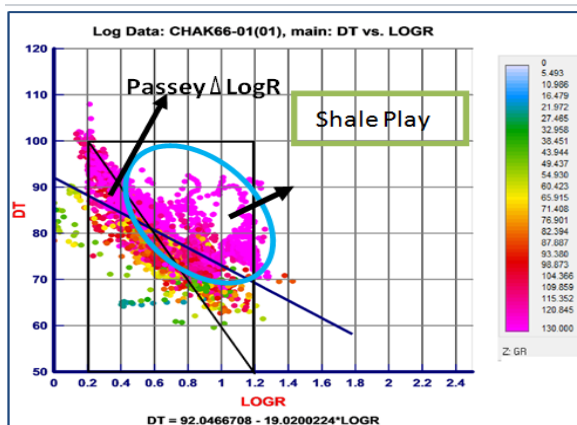
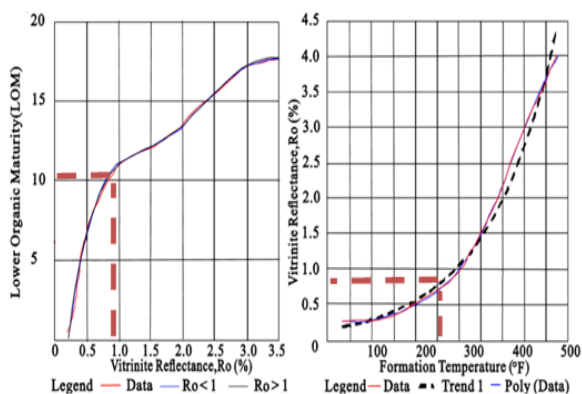
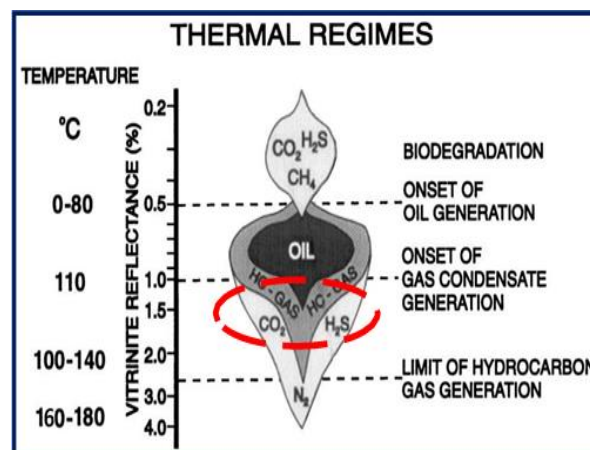
Fig. 8 Modified Passey's ΔLogR method.

Fig. 9 Graphical estimation of vitrinite reflectance and LOM (Hill et al., 2007; Alyousaf et al., 2011).

Relation of Formation-Temperature and Vitrinite-Reflectance with Hydrocarbon Generation

Redox reactions are common in diagenetic environment between sulphate and hydrocarbons. Sulphate reduction can either be bacterial sulphate reduction (BSR) or thermo chemical sulphate reduction (TSR). Empirical results show that both BSR and TSR occur in low temperature and high temperature environment, respectively. Vitrinite reflectance is also correlated with absolute formation temperature. Both for the temperature and vitrinite reflectance of the formation distinguish the product obtained from BSR and TSR. The formation temperature of 121°C and Vitrinite reflectance value for Talhar Formation suggest that it lies in peak oil and initial gas generation window (Machel et al., 1995).

Evaluating tight shale reservoirs through various geochemical parameters derived from well logs data is most endeavoring task in exploration geophysical arena. Well logs act as a control point in indirect method of source rock evaluation and has vital contribution in estimating the potential of low permeability shale reservoirs (Zhang et al., 2015). In study, well logs derived parameters estimation was carried out for Talhar shale member.

Fig. 10 Relation of vitrinite reflectance (R_o) and temperature with oil and gas contents (Machel et al., 1995).

Previous studies suggest that Talhar shale has type-II and III kerogen and has the potential of oil and gas expulsion (Robison et al., 1999). Well data suggest that the shale member has average thickness of about 75-80 meters and the formation top is encountered at a depth of 2862 meters in Chak 66-01 well. Almost the same depth was obtained interpreting the observed seismic data through depth contour map.

The well logs of Chak_66-01 were used for the Total Organic Carbon (TOC) estimation by Passey's (ΔLogR) crossover technique. Both resistivity and sonic logs were run in the same track on the scale of 100 $\mu\text{s}/\text{ft}$ equivalent to 2 $\Omega\text{-m}$. The TOC values calculated are 2.44 wt.% ranging in good to very good range (Peters, 1986). Value of 2.35 wt. % is also calculated from the core sample data by Ehsan et al. (2016) for Talhar shale interval which shows an excellent correlation with the calculated results and validates the empirically calculated values. This confirms that the shale reservoir formation has sufficient amount of organic content to produce oil and gas. Modified Passey's ΔLogR method is also applied to identify shale play from non-shale reservoirs, using Bowmen cross plot analysis. The cross plot plotted between LogR and DT and the shale play ranges in medium to high delay time and resistivity values due to the presence of kerogen. Vitrinite reflectance value is calculated empirically and graphically with value ranges between 0.95 to 1.0. These values reflect that the shale member is in peak oil and initial gas generation window (Dembicki, 2016). The formation temperature calculated by using well header information and vitrinite reflectance is used to identify the presence of peak oil and initial gas generation window (Machel et al., 1995).

Log-derived Maturity Index (LMI) was estimated by neutron and density logs of well Chak_66-01. The average LMI value is 0.5-0.55, which depicts the initial maturation stage of source rock. The LMI value estimated from neutron log is considered more reliable than density log because of its sensitivity to borehole conditions. Kerogen volume is calculated using the empirical relation given by

Shazly et al. (2013). The value, estimated using density log and the calculated value is 13%. This amount of kerogen shows presence of enough organic rich material for oil and gas expulsion. TOC estimated by Passey's overlay method using resistivity and sonic log gives value of 2.44 wt. %.

Conclusion

Evaluation of Talhar shale member by estimation of geochemical parameters from well log data of well Chak 66-01 shows that Talhar shale could be a future prospective zone for unconventional reservoirs exploration. The study shows that the depth of formation is about 2862.0 meters and thickness is approximately 70 meters, which is excellent thickness for shale reservoirs. LOM is calculated empirically and graphically, which gives value of 10.3. This value depicts that formation is in gas window. Empirically and graphically estimated results are validated with the core data of the same basin and adjacent field.

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References

- Abbasi, S.A., Solangi, S.H., Nazeer, Ahmed, Asim, S., Habib, W., Solangi, I.A. (2015). An overview of structural style and hydrocarbon potential of Jabo field, southern Sindh Monocline, southern Indus Basin, Pakistan. *Sindh Univ. Res. Jour., (Science Series)*, **47** (2), 347-354.
- Ahmad, A. (1997). Source rock potential of lower Goru in well Bobi-4 lower Indus basin, Pakistan. *Pakistan Journal of Hydrocarbon Research*, **9**, 83-89
- Ahmad, N., Fink, P., Sturrock, S, Mahmood, T., Ibrahim, M. October (2004). Sequence Stratigraphy as Predictive tool in lower Goru fairway, Lower and Middle Indus Platform, Pakistan. PAPG/SPE, Annual Technical Conference, Islamabad, Pakistan.
- Alyousof, T., Algharbi, W., Algeer, R. (2011). Source Rock Characterization of the Hanifa and Tuwaiq Mountain Formations in the Arabian Basin Based on Rock-Eval Pyrolysis and the Modified Delta Log R Method. SPE/DGS Saudi Arabia Section Technical Symposium and Exhibition
- Ariketi, R. (2011). Estimation of level of organic maturity (LOM) and Total Organic Carbon (TOC) in absence of Geochemical Data by using Resistivity and Density Logs – Example from Cambay Shale, Tarapur area, Cambay Basin, India. *Jour. Indian Association of Sedimentologists*, **30** (1), 55-63.
- Asia Pacific Energy Research Centre (APEREC). (2015). Pathways to Shale Gas Development in Asia-Pacific.
- Aiyar, S. A. (2009), Shale gas, could it be a new energy source? *Times of India*.
- Baig, M.O., Harris, N. B., Ahmed, H., Baig M.O.A. (2016) Control on diagenesis in the lower Goru Sandstone formation, Lower Indus Basin Pakistan. *Journal of Petroleum Geology*, **39**, 29-47.10.1111/1/jpg. 12626.
- Bender, F. K., Raza, H. A. (1995). Geology of Pakistan. Borntraeger, Berlin, Stuttgart.
- Bowman, T. (2010). Direct method for determining organic shale potential from porosity and resistivity logs to identify possible resource plays. In AAPG Annual Convention and Exhibition New Orleans, April, *Search and Discovery Article #110128*, p.34
- Boyer, C., Keischnick, J., Suarez-Rivera, R., Lewis, R., Waters, G. (2006). Producing gas from its source. *Oilfields review* 18. Autumn 36-49.
- Dembicki, H.J. (2016). Practical Petroleum Geochemistry for Exploration and Production. *Elsevier Science & Technology Books*, Amsterdam, 331 p.
- Ehsan, M., Gu, H., Akhtar, M.M., Abbasi, S., Ullah, Z. (2016). The identification of hydrocarbon potential of Talhar shale member of lower Goru Formation by using well logs derived parameters, southern lower Indus Basin, Pakistan. *J. Earth Sci.* 1–8.
- EIA (2009). Top 100 oil and gas fields Archived 15 May 2014 at the Way back Machine.
- Feng, Z. (2013). The impact of the changing global energy map on geopolitics of the world, China-united states exchange foundation.
- Haider, B.A., Aizad, T., Ayaz, S.A. (2012). A Comprehensive shale gas exploitation sequence for Pakistan and other emerging shale plays. In SPE/PAPG Annual Technical Conference.
- Hanif, M., Hart, M. B., Grimes, S. T. (2014). Integrated Stratigraphy and Paleo-environment of the P/E Boundary Interval, Rakhi Nala Section, Indus Basin (Pakistan). *Arabian Journal of Geosciences*, **7** (1), 323-339

- Hill, R. J., Zhang, E., Katz, B. J. (2007). Modeling of gas generation from the Barnett shale, Fort Worth Basin, Texas. *AAPG bulletin*, **91** (4), 501-521.
- Hood, A., Gutzjahr, C., Heacock, R. (1975). Organic Metamorphism and the Generation of Petroleum. *AAPG Bulletin*, **59**, 986-996.
- Kadri, I. B. (1995). Petroleum Geology of Pakistan. Pakistan Petroleum Limited Karachi.
- Kazmi A.H., Jan, M.Q. (1997). Geology and Tectonics of Pakistan, Graphic Publishers, Karachi, Pakistan, 540-560.
- Kearey, P.V. (2002). Introduction to Geophysical Exploration. Blackwell Scientific Publications, Oxford, 1-110.
- Kemal, A. (1991). Geology and New Trends for Petroleum Exploration in Pakistan. *PAPG Bulletin*, 16-57.
- Khattak, F. G., Shafeeq, M., Ali, S. M. (1999). Regional Trends in Porosity and Permeability of Reservoir Horizons of Lower Goru Formation, Lower Indus Basin, Pakistan. *Pakistan Journal of Hydrocarbon Research*, **11**, 37-50.
- Labani, M. M., Rezaee, R. (2012). Thermal Maturity Estimation of Gas Shale Layers from Conventional Well Log Data: A Case Study from Kockatea Shale and Carynginia Formation of Perth Basin Australia. SPE Asia Pacific Oil and Gas Conference and Exhibition.
- Lecompte, B., Hursan, G. (2010). Quantifying Source Rock Maturity from Logs, How to Get More Than TOC from Delta Log R. In Society of Petroleum Engineers.
- Machel, H. G., Krouse, H. R., Sassen, R. (1995). Products and Distinguishing Criteria of Bacterial and Thermochemical Sulfate Reduction. *Applied Geochemistry*, **10** (4), 373-389
- Mallick, R.K., Raju, S.V. (1995). Thermal maturity evaluation by sonic log and seismic velocity analysis in parts of Upper Assam Basin, India. *Organic Geochemistry*, **23** (10), 871-879.
- Naseer, M.T., Asim, S. (2017). Detection of Cretaceous incised-valley shale for resource play, Miano gas field, SW Pakistan: spectral decomposition using continuous wavelet transform. *J. Asian Earth Sci.* <https://doi.org/10.1016/j.jseas.2017.07.031>.
- Passey, Q. R., Bohacs, K., Esch, W. L. (2010). From Oilprone Source Rock to Gas-Producing Shale Reservoir—Geologic and Petrophysical Characterization of Unconventional Shale-Gas Reservoirs. Beijing, China, June, 8.
- Passey, Q., Creaney, S., Kulla, J. (1990). A Practical Model for Organic Richness from Porosity and Resistivity Logs. *AAPG Bulletin*, **74** (12), 1777-1794.
- Quadri, V. N., Shuaib, SM. (1986). Hydrocarbon Prospects of Southern Indus Basin, Pakistan. *AAPG Bulletin*, **70**, 730747.
- Robinson, E.S., Coruh, C. (1988). Basic Exploration Geophysics, Mansoura University, Faculty of Science Geophysics Department.
- Schmoker, J. W. (1979). Determination of Organic Content of Appalachian Devonian Shales from Formation-Density Logs: GEOLOGIC NOTES. *AAPG Bulletin*, **63** (9), 15041509
- Schmoker, J. W., Hester, T. C. (1983). Organic carbon in Bakken formation, United States portion of Williston basin. *AAPG Bulletin*, **67**, 2165-2174.
- Shazly, T., Ramadan, M., El-Sawy, M. (2013). Application of Well Logs Analysis to Identify the Source Rock Capabilities of Rudeis and Kareem Formations in Rudeis Field, Gulf of Suez, Egypt. *Journal of Applied Sciences Research*, 9.
- Sheikh, S.A., Naseem, S. (1999). Sedimentary environment and hydrocarbon potential of cretaceous rocks of Indus Basin, Pakistan. *J. Hydrocarbon Res., Islam*. **11**, 1–14.
- Solangi, S.H., Nazeer, A., Abbasi, S.A., Napar, L.D., Usmani, P.A., Sahilo, A.G. June (2016). Sedimentology and petrographic study of B-sand of upper sands of lower Goru Formation, based well cuttings and wireline logs from wells of southern Sindh monocline, lower Indus Basin, Pakistan. *Bahria Univ. Res. J. Earth Sci.*, **1**(1), 7-16.
- Wandrey, C.J., Law, B.E., & H.A Shah. (2004). Sember Goru/Ghazij Composite total Petroleum System, Indus and Sulaiman-Kirthar Geological Provinces, Pakistan and India, US geological Bulletin 2208-C, US Department of Interior.
- Zhang, Y., Jin, S., Jiang, H., Wang, Y., and Jia, P. (2015). Review of Well Logs and Petrophysical Approaches for Shale Gas in Sichuan Basin, China. *The Open Petroleum Engineering Journal*, **8**, 316-324.