Petrophysical and Geochemical Analysis of Chichali Formation for the Source Rock Evaluation: A Case Study of Chanda-01 Well, Upper Indus Basin, Pakistan

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Abstract:A source rock has the ability of generating hydrocarbons after the maturation of the organic component for a specific period of time. The hydrocarbon generation and release from a potential source rock is dependent on the content of the organic matter, which is determined by Total Organic Carbon (TOC) content. In this research, the Chichali Formation of Cretaceous age is considered to be a source rock in the Chanda gas field, Upper Indus Basin on the basis of petrophysical and geochemical results of well Chanda-01. The study includes computation of TOC, mineralogy and parameters like porosity, permeability and fluid saturation which have been carried out from Well log data. Additionally, geochemical results of the well have been incorporated in order to calibrate and authenticate both results. The formation is encountered at a depth of 4543 m in Chanda-01 well and its thickness is about 34 m. The formation has been divided into two parts on the basis of lithology. The upper part is representing sandy shale, whereas the lower part exhibits massive shale unit. The log data of natural gamma ray, resistivity, density and spectral gamma ray, including uranium, thorium and potassium curves have been interpreted in the lower part of the formation, which confirms that the formation is possibly deposited in anoxic conditions with sufficient organic rich content. Moreover, geochemical analysis of the rock cuttings of the well shows good Vitrinite Reflectance and TOC results which complement the results obtained from the petrophysical analysis. Seven rock samples of Chichali Formation have been analyzed for its TOC & VR value which confirms that shale in this area has fair source potential as the average value of both tests against these samples are greater than 1%. Therefore, having fair source rock potential in Chanda gas field, there is a possibility that Chichali Formation could be a potential source in the other fields of Upper and Middle Indus basins and a prospect for the shale gas resource as well.

Keywords: Chichali Formation, source rock evaluation, total organic carbon, DlogR technique.

Introduction

This research work is based on the source rock evaluation of Chichali Formation using petrophysical analysis of logs from Chanda-01 well, Upper Indus Basin, Pakistan. A source rock has the potential of generating an amount of hydrocarbons after the process of maturation of the organic compound for a specific period of time. The source rock can be shale or a limestone. The conditions for the maturation of kerogen are heat, time, pressure and minerals or there could be some other substances, which might enhance the rate of reaction (Bjorlykke, 2010).

The generation and release of hydrocarbon from a source rock is entirely dependent on the content of organic material, which could be identified through Total Organic Carbon (TOC). It is expressed as weight percent in the potential source rock. Source rock evaluation can be carried out using variety of methods. In this study petrophysical investigation is employed for source rock evaluation along with geochemical analysis of rock cutting samples of Chanda-01 well, which also shows TOC results which complement the results obtained from petrophysical analysis.

Study area

The study area Shakardara is situated in District Kohat of KPK province at a distance of about 70 km from Kohat city (Nawaz, 2015). The Kohat sub-basin is tectonically complex area of the northern Pakistan. The Kohat Plateau structure differs from those of the Potwar Plateau largely on account of the higher salt detachment horizon in the Kohat area against the Precambrian in Potwar. Main Boundary Thrust (MBT) marks its northern limit and in its south Salt Range Thrust (SRT) marks its boundary. Whereas, Kurram fault is in the west and right lateral Kalabagh fault lies in its east.

Regional Stratigraphy of Upper Indus Basin

Upper Indus Basin is divided into two sub basins.

  (a) Potwar sub-basin
  (b) Kohat sub-basin

Potwar plateau is defined by the rivers Indus to the west and Jhelum to the east, whereas the Kalachitta-

Margalla Hill Ranges to the north and the Salt Range to the south (Kadri, 1995). Siwalik sequence largely covers the Potwar Plateau, though at places upper Eocene shales and limestones are also exposed on the surface. Its northern part, known as the North Potwar Deformed Zone (NPDZ) is extremely deformed. It is characterized by east west trending tight and complex folds, overturned to the south and sheared by steep-angle faults (Kazmi and Abbasi, 2008).
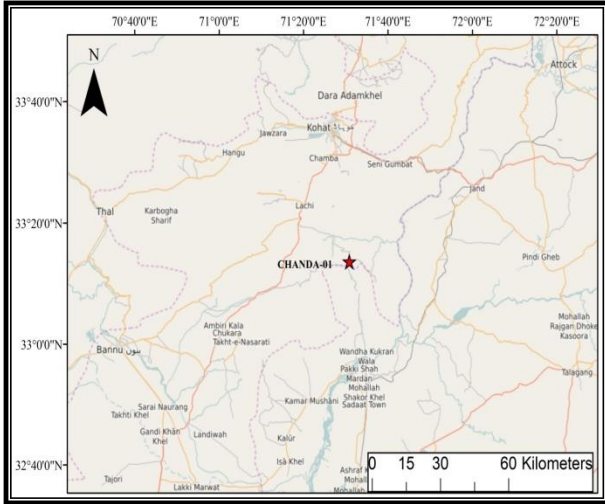

Fig. 1 Map of the study area showing location of Chanda-01 well.

In Kohat sub basin, the oldest rock exposed belongs to Zaluch group of Permian age and youngest rocks are the Dhok Pathan Formation of Pliocene age (Kazmi and Abbasi, 2008). This basin represents numerous significant facies though it is comparatively small in size. The Trans-Indus Ranges in south of Kohat sub-basin exhibit sediments from Cambrian to Pliocene age. Mesozoic sediments are also exposed around the basin rim. In Kohat sub basin, west of the Potwar sub basin, Eocene rocks developed a complex fold and thrust belt through Siwaliks strata in which salt of the Eocene age resides the core of the many anticlines. Pliocene stratigraphy is fully established on Kohat sub basin (Kazmi and Abbasi, 2008).

Methods and materials

The research work is carried out by the computation of reservoir parameters, creation of 3 and 4 Mineral Model, clay minerals identification by using Spectral Gamma Ray Log, computation of TOC from conventional logs and shale gas identification by DlogR technique. Moreover TOC from ditch cuttings from different depth has also been examined. Additionally, cross plots including lithology identification cross plot using neutron and density log data, mineralogical identification cross plot using SGR log data, cross plot between effective porosity and volume of shale for determining the origin of clay mineral and cross plot for the identification of shale play have been generated and discussed.

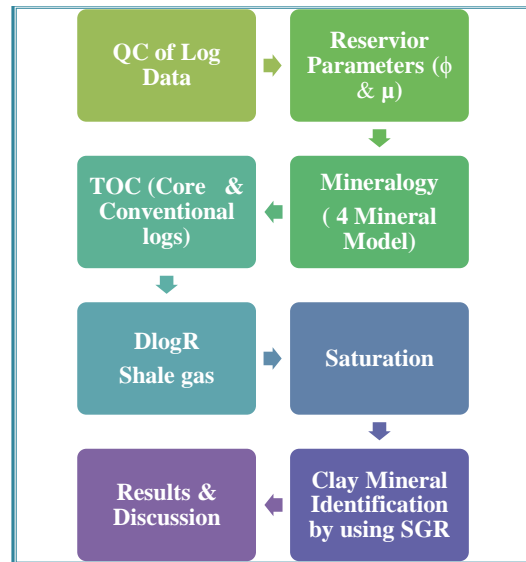Fig. 2 Stratigraphic column of Upper Indus Basin, Pakistan (EIA, 2015).

Fig. 3 Flow chart showing methodology followed.

Results and Discussion

The Chichali Formation comprises mainly of sandstone, which is dark green and greenish grey, glauconitic and highly fossiliferous along with shale facies, which is dark grey, bluish grey, greenish grey, sandy, silty and glauconitic in nature (Shah, 2009). Three different members of the Chichali Fomration have been identified on the basis of the exposed strata in the Western Salt Range, Trans-Indus Ranges and Samana Range (Kohat). The lower part represents sandy glauconitic shale with phosphate nodules, Middle part is dark grey glauconitic, calcareous and fossiliferoussandstone, whereasupper part contains glauconitic sandstone, which is for the most part unfossiliferous. However, locally a few bivalves and ammonites are present (Shah, 2009). The lower shale member has been assessed for the source rock potential in Chanda-01 well.

Wire line Log Analysis

Chanda 01 well is located in Shakardara Block, Kohat sub basin as shown in Figure 1. The well was drilled by OGDC in 1999 and it was an exploratory well and its current status is dry. Its total depth is 4788.70 m.

The foremost objective of this research work is to identify shale gas prospect with the aid of conventional methods. Chichali Formation is considered to be as a source rock on the basis of characteristics shown in the Figure 6.

DlogR Technique

DlogR technique is executed by adjusting sonic log on the top of logarithmic scaled resistivity log in order that the sonic curve lies on the top of the resistivity log. In the current study sonic and resistivity is scaled where 50µsec/feet is equal to one logarithmic cycle on the resistivity log (Rider, 2002). The separation between sonic and resistivity is "DlogR" which depicts the source interval and where the sonic and resistivity overlie each other. It is termed as baseline interval, which is non source interval (Aslam *et al.*, 2015). The separation between sonic and resistivity (DlogR) has been observed at different depths which represents source interval. On the other hand, in the lower part of formation, sonic and resistivity are overly each other, thus indicating base line interval as shown in Figure 4.

Geochemical analysis of seven core samples of Chanda-01 taken at different depths has been carried out by Hydrocarbon Development Institute of Pakistan and average TOC is found to be 1 (Table 1).The TOC and Vitrinite Reflectance results at different depths are shown in the Table 1.

Passey method has been used for the calculation of TOC from the log data. Sonic and resistivity log curves are used for the calculation of TOC.
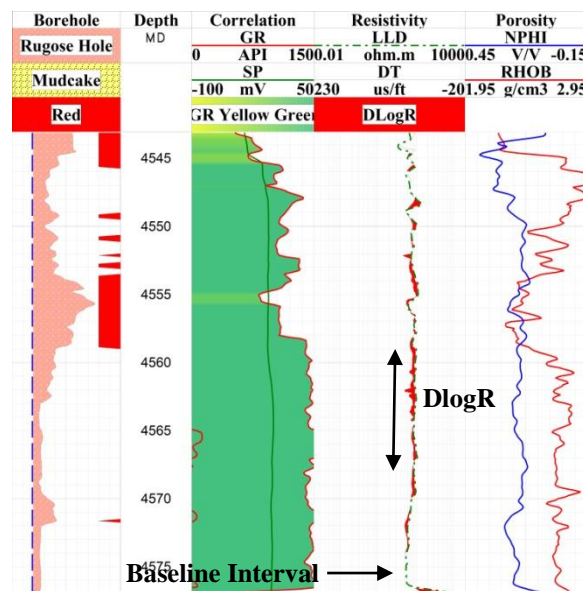

Fig. 4 Image showing DlogR and baseline interval.

Table 1 TOC and VR results of core samples of Chanda-01 well.

Sample No	Depth (m)	TOC (%)	VR
1	4545	1.05	1.1
2	4548	1.15	1.1
3	4556	0.78	1.1
4	4562	0.75	1.18
5	4566	0.88	1.18
6	4572	1.04	0.85
7	4576	0.80	0.85
Average		**0.92**	**1.04**

Passey's "DlogR" Method

In order to calculate TOC using Passey method firstly DlogR is calculated from the following equations (Passey *et al.*, 1990).

$$DlogR = \log\left(\frac{RESD}{RESDbase}\right) + 0.02 \times (DTC - DTCbase) - DTCbase$$

In spite of the fact that the sonic resistivity model is the best recognized form of the Passey method, but density and neutron data can also be used, as given by the equation.

Where:

RESD = value of deep resistivity in any zone (ohm-m).

RESDbase = value ofdeep resistivity baseline interval in non-source rock zone (ohm-m)

DTC = value of compressional sonic log reading in any zone (usec/ft)

DTCbase = value of sonic baseline interval in non-source rock zone (usec/ft)

The average Vitrinite Reflectance is found to be 1.07 % as shown in Table 1. By plotting the data on the graph in Figure 5, Level of Maturity (LOM) is found to be 11.
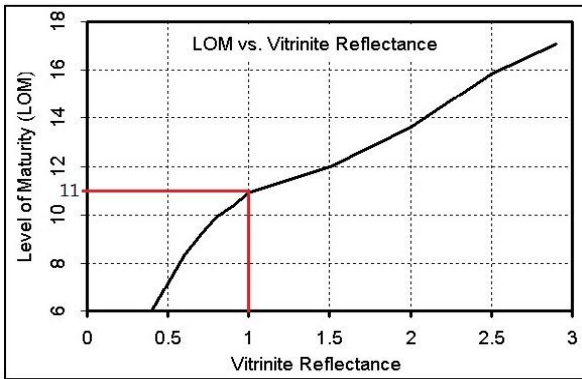

Fig. 5 Graph for finding level of Maturity from Vitrinite Reflectance.

After getting the value of LOM, for the calculation of TOC the formula used is given in the following equation.

$$TOC = (DLOGR)10^{2.297-0.1688LOM}$$

The Chichali Formation of Cretaceous age is encountered at a depth of 4543 m and its thickness is about 34 m in this well. The formation is split up into two main parts on the basis of mineralogy. The upper part is representing sandy shale, whereas the lower part exhibits clean shale as shown in Figure 6. The values of gamma ray, resistivity, density and uranium

due to presence of clay minerals. The presence of clay minerals increases at the bottom of the formation as shown in Figure 6,which resulted in the increase in resistivity and decrease in permeability. The water droplets adhere to the surface of the clay mineral and this water content is choked in the formation thus causing an increase in the water saturation which indicates the presence of clay bound water. Effective and average porosity with very negligible permeability has been observed where sandy shale is present. On the other hand permeability becomes zero in the lower region of the formation as shown in the Figure 6.

The results of TOC obtained from conventional petrophysical analysis complement the results obtained from geochemical analysis of the rock cuttings of Chanda-01, undertaken by HDIP.

RHOB vs NPHI for lithological identification

The cross plot between RHOB and NPHI is generated to depict lithological variations in Chichali Formation. It can be inferred that the lower part of the formation is dominantly shale as demarcated by blue coloured facies, whereas upper part of the formation contains sandy content as well, shown by green color illustrated in Figure 7.

Mineralogical Identification

The clay minerals in the mud rocks or sandstone may have different origins (Bjorlykke, 2010).

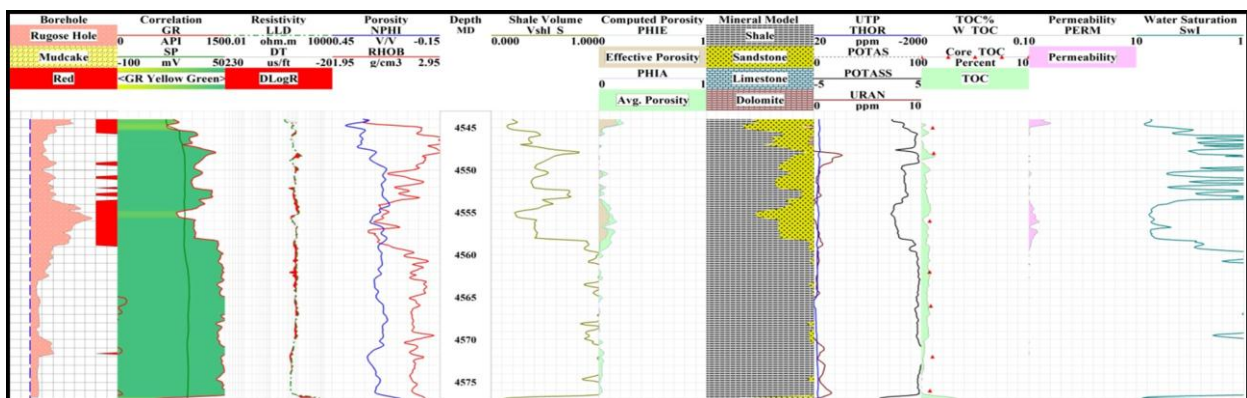(1) Clay minerals developed by the weathering of igneous and metamorphic rocks.

Fig. 6 Wireline log image showing extensive caving in the first track. The gamma ray response is on the higher side as shown in the correlation track. DlogR, volume of shale, porosity, mineral model, permeability, TOC from log, TOC from core and saturation of water are also shown in their respective tracks.

increased sufficiently at the bottom of the formation which suggests that the lower contact is possibly deposited in anoxic conditions withorganic rich content.

Neutron and density logs have been used for porosity calculations. Results of water saturation are peculiar

(2) By the erosion of older shales and mudrocks.

(3) From the volcanic ash.

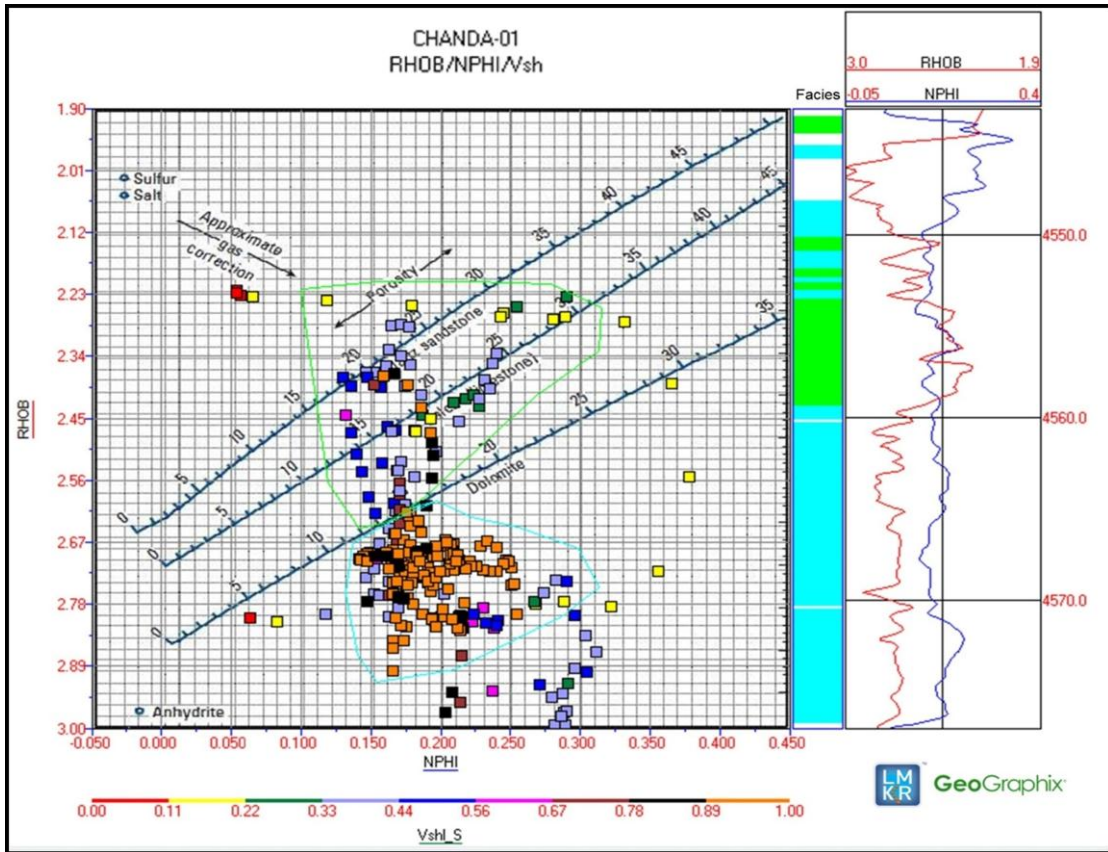(4) By the diagenesis on the seafloor and during burial.

Fig. 7 RHOB vs NPHI cross plot for the identification of lithology of Chichali Formation.
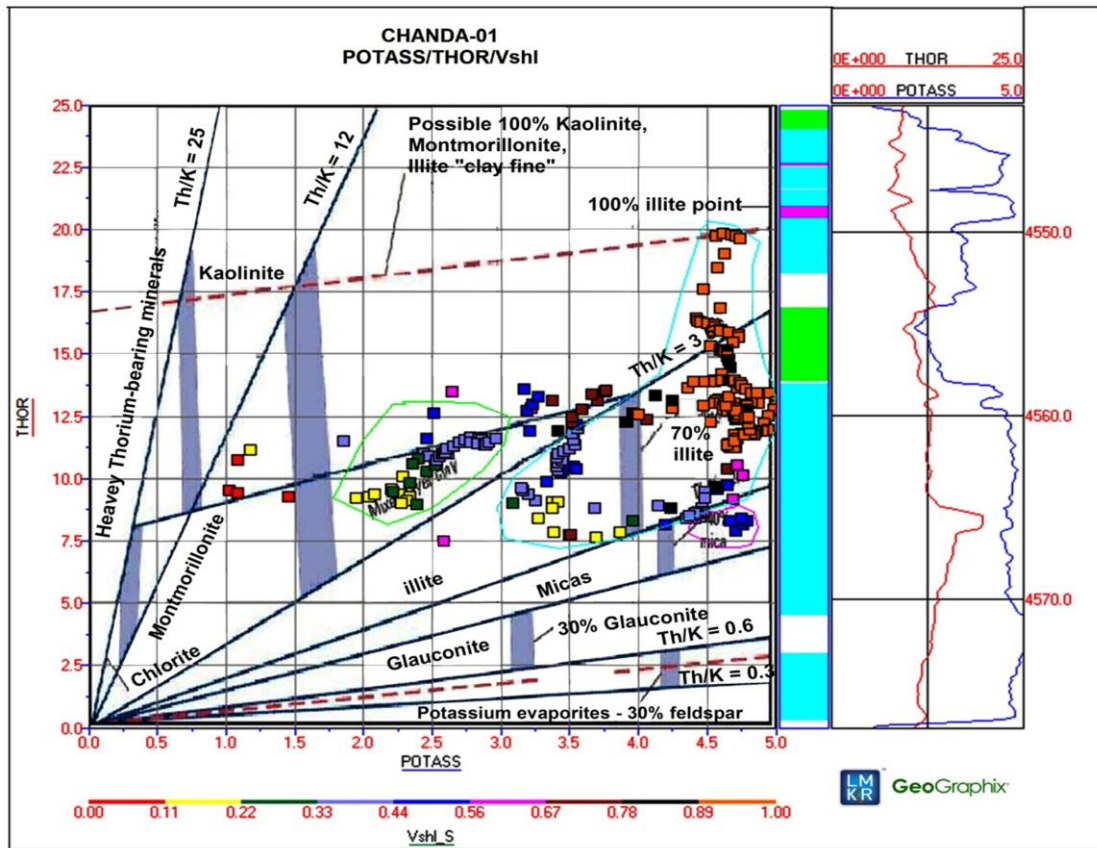

Fig. 8 Thorium vs Potassium cross plot for mineralogical identification of Chichali Formation.
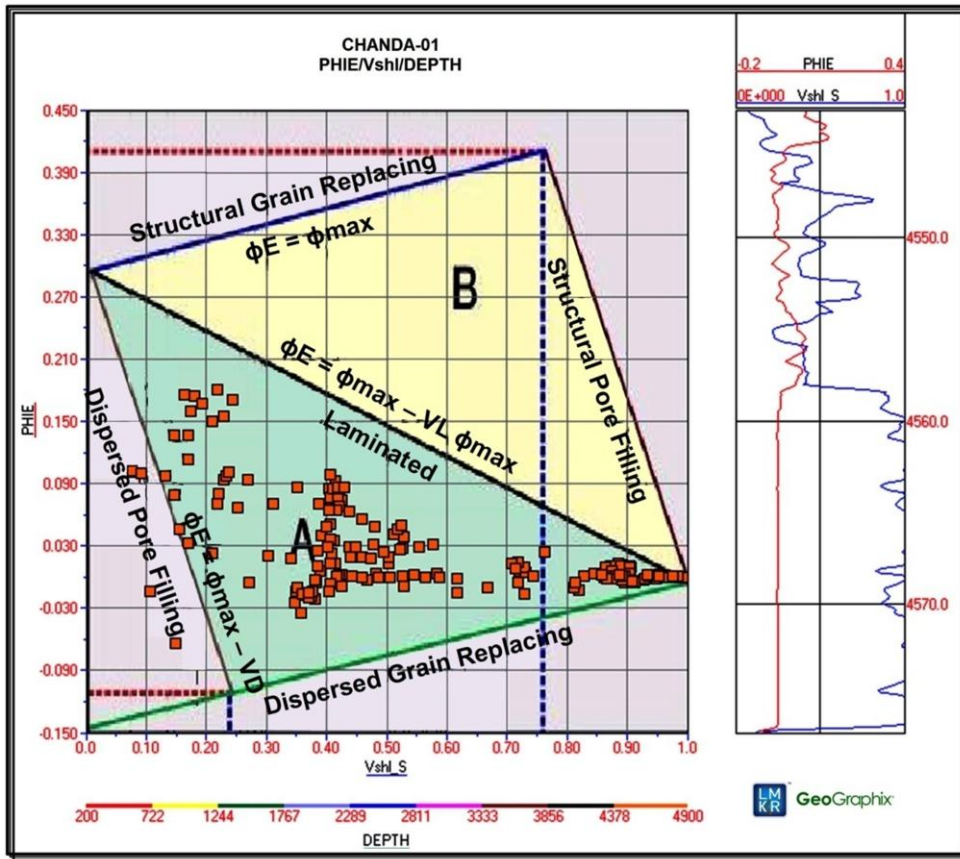
Fig. 9 Cross plot between effective porosity and volume of shale depicting origin of clay mineral.
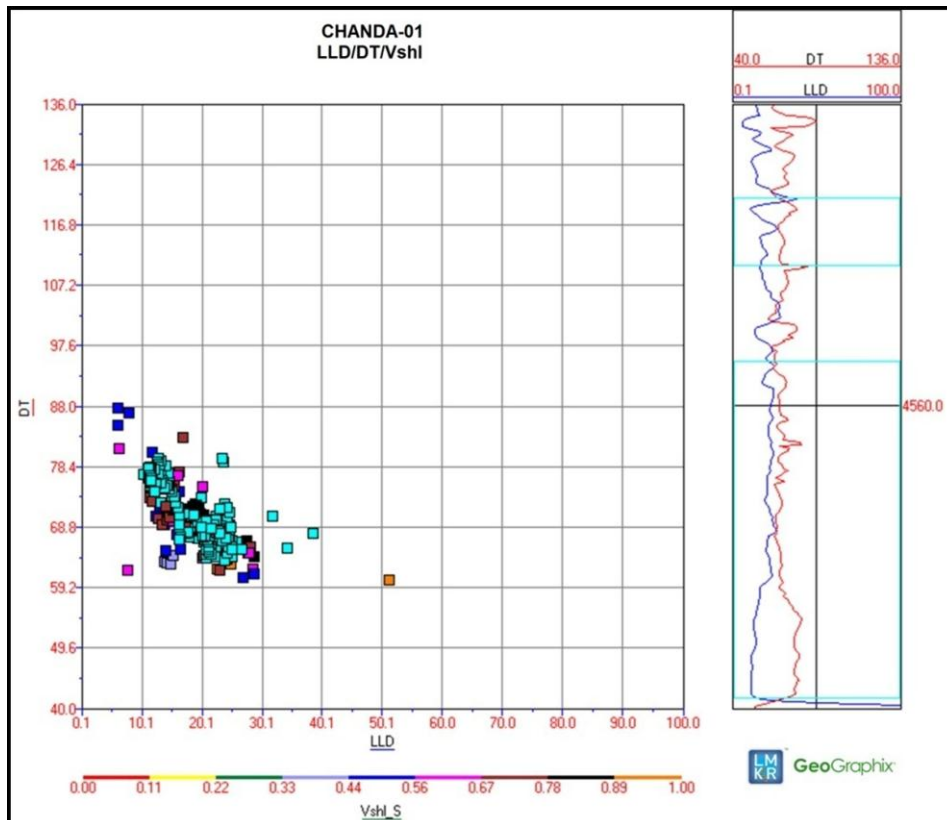

Fig. 10 Cross plot for the identification of shale play.

Spectral Gamma Ray log has an integral role in the identification of clay minerals. The type of dominating clay minerals can be determined based on the cross plot of thorium and potassium. It can be inferred from the cross plot that the lower part of the formation ranging from depth 4557m to 4576m is principally illite indicated by blue colored facies. Montmorillonite has also been found between depths 4544m to 4554 with some concentrations of mixed clays which is indicated by green coloured facies as show in Figure 8.

The lower part of the Chichali Formation exhibits illite mineralization, which might be the due to the diagenesis on the seafloor and during burial. Illite is normally associated with migration of fines along with reduction in permeability. High porosity values and irreducible bound water saturation is often related with illite clays that is the reason water saturation responses are on the higher side in the lower part of the formation.

Origin of Clay Minerals

Juhasz (1986) proposed a system for the assessment of shale distribution and determination of average volume of shale, porosity and hydrocarbon saturation in the shaly sands. This system is partially derived from the relationship described by Thomas and Stieber (1975) between porosity and volume of shale.

Equation of effective porosity is used in order to assume that shale's bound water does not contribute to the effective porosity. Only the combination of laminated and dispersed shale occurs in the Triangle A of the clay distribution plots, whereas in the Triangle B, only the combination of laminated and structural shale occurs (Juhasz, 1986).

Well data is plotted between effective porosity and volume of shale in order to assess the type of clay mineral. All the data clusters are spread in triangle A as shown in Figure 9. It can be inferred that type of the clay is dispersed clays. Dispersed clays come in the class of authigenic clays. These clays either form a coating around the sand grains or fill the pore spaces between the sand grains. Therefore dispersed clays occur as pore filling component of the rock and thus can produce adverse effects on the fluid flow and fluid saturation properties. While in the lower part of the formation glauconitic sands are converted to shales due to increase in overburden stress and temperature, which resulted in the alteration of the clay minerals.

Shale Play identification

DlogR is separation between resistivity and porosity logs like sonic, density and neutron. Deep resistivity and sonic is considered to be the best combination for the calculation of DlogR (Aadil *et al.*, 2014). The areas, where DT, LLD, and GR logs have sufficient high values are said to have considerable amount of organic matter. The above cross plot is generated

between DT, LLD and GR logs which could be the indication of rich organic shale content.

Cross plot is constructed by keeping volume of shale values on the z-axis in order to confirm the existence of shale content in the zone, where there is considerable amount of organic matter. In the cross plot shown above along the blue color facies, gives indication of the shale plays especially from the depth range of 4556m to 4574m of the Chichali Formation. As in this vicinity, there are high values of DT, LLD and GR.

Conclusion

(1) TOC determined by the DlogR technique is verified by the results of TOC from the rock cuttings of Chanda-01 well.
(2) The dominant clay mineral is illite with some concentration of montmorillonite and mixed clays.
(3) The major lithology shale is authigenic in nature there might be glauconitic sands, which have been converted into shale due to alteration of the clay minerals as a result of diagenesis.
(4) Chichali Formation may act as a potential source rock in Chanda gas field on the basis of the results obtained.

Acknowledgements

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