FACIES ANALYSIS AND RESERVOIR CHARACTERIZATION OF SEMBAR FORMATION, LOWER INDUS BASIN, PAKISTAN

By

AWAIS RASUL

Department of Earth and Environmental Sciences
Bahria University, Islamabad

2019

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A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of MS in Geophysics

AWAIS RASUL

Department of Earth and Environmental Sciences
Bahria University, Islamabad

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CERTIFICATE OF ORIGINALITY

This is to certify that the intellectual contents of the thesis Facies Analysis and Reservoir Characterization of Sembar Formation, Lower Indus Basin, Pakistan are the product of my own research work except, as cited properly and accurately in the acknowledgements and references, the material taken from such sources as research papers, research journals, books, internet etc. solely to support, elaborate, compare and extend the earlier work. Further, this work has not been submitted by me previously for any degree, nor it shall be submitted by me in future for obtaining any degree from this university, or any other university or institute. The incorrectness of this information, if any, proved at any stage, shall authorize the university to cancel my degree.

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ABSTRACT

Pakistan petroliferous basin have vast area that remain unexplored. Independent international studies indicate that it has much more hydrocarbon potential than these proven reserves. Southern Indus Basin of Pakistan is considered sedimentary basin with immense hydrocarbon potential. The proven source rock in the Southern Indus Basin is the Sembar Formation which is being analyzed in this research study in terms of its hydrocarbon potential and facies analysis. Wireline log data of three wells and seismic lines of Gupchani area has been used for this. Sembar Formation has been divided into two main facies i.e sand and shale . Different lithological and mineralogical crossplots have been used for determining the type of lithology and clay mineral identification. The major part of the Sembar Formation is comprised of shale which is dominant in the lower part of the formation whereas the upper part is having sand facies in all the three (03) wells i.e Duljan-Re-Entry-01, Miran-01 and Shahdadpur-01. However, the top most sand facies decreases in thickness towards Shahdadpur-01 well moving from North to South direction. TOC values computed for the shales ranges between 1.5-2.5 wt% which lies in the fair to good source rock potential. However these shales are majorly composed of Illite and Kaolinite which are brittle clay minerals and are suitable for the frac job which is the most important criteria in evaluating the shlaes as a gas shale resource. Seismic data has been used to generate the subsurface structural trends in the area which shows planar to sub-vertical normal faults forming the horst and graben structures in the area due to extentional tectonics. Time and depth contour maps have been generated at the Sembar level in order to demarcate the depth of the Sembar and dipping trend in the area. The top most part of the Sembar Formation is mainly composed of sand facies so the possible lead marked on the contour map can be exploited for the hydrocarbon potential within the sand facies of the Sambar Formation. the faults do not penetrate up to the Chiltan Limestone and dies out with in the Sembar. This shows that the lower part which is mainly composed of shales might not be as much disturbed as the upper part. Moreover, the brittle clay minerals present within these shales are suitable for frac job but the sealing capacity of the faults has to be evaluated in order to exploit these shales as a gas shale resource for which high resolution seismic data is required.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Mr. Muhammad Raiees Amjad for his guidance, supervision and encouragement. I am also thankful to my teachers Mr. Muyyassar Hussain and Ms. Urooj Shakir for their guidance and cooperation during this research work. I would like to pay tributes to my family members for their prayers and unsurpassed wishes. Without their encouragement and cooperation it would have been impossible for me to finalize this research work. I am deeply indebted to my friends for their continuous support.

I owe special thanks to Prof. Dr. Tahseenullah Khan (Head of Department, Earth and Environmental Sciences) and Prof. Dr. Muhammad Zafar (PGP Coordinator) and all the faculty members of Earth and Environmental Sciences Department, Bahria University for their competent and devoted guidance. Lastly, I am extremely thankful to Land Mark Resources (LMKR), Pakistan for providing Geographix software for this research.

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CHAPTER 1
INTRODUTION

1.1 Introduction

Shale gas, a naturally produced gas from tightly rich shale formations has become an important source of natural gas in world due to its technological advancements and excessive inflation in natural gas prices in order to meet significant supply and demand pressures and keep a balance. The rapid increase in growth of shale gas production in the United States has started a global race to know the potential of shale gas in other regions to attain the success in this matter. Pakistan in Asia-Pacific region is also an area of main focus. Expanding population and economic growth in Pakistan is one of the big challenge to meet ever growing energy demands. So, it is now inevitable to discover the unconventional resources of energy along with the conventional one to fulfil the energy needs of the country (Ehsan et al.,2018).

Pakistan petroliferous basin have vast area that remain unexplored. Independent international studies indicate that it has much more hydrocarbon potential than these proven reserves (MPNR-2013).so. it is essential to know about the hydrocarbon potential of the reservoir formations in Pakistan, as well as, explore and drill new oil and gas fields to cut down the import bill (35-40%) of country and to fulfil the energy need and supply of the country. Keeping the scenario at hand, Southern Indus Basin (SIB) of Pakistan is observed and analysed (Ehsan et al.,2018) which is located in Sind and is considered sedimentary basin with immense hydrocarbon potential. (Quadri, 1986)

This research is focused on reservoir characterization and facies analysis to check out the reservoir and source rock potential evaluation of Sembar Formation of Cretaceous age and its future prospects as the Shale Gas Resource in Lower Indus Basin (LIB). In any hydrocarbon well an E&P company after drilling is interested in detailed subsurface knowledge, to determine hydrocarbon resources and producibility of such resources.

Source rock basically is a low permeability sedimentary rock which has a potential to generate hydrocarbons at proper burial depth and temperature/pressure conditions. The source rock can help in the maturation of the kerogen at a specific temperature and pressure condition in its burial. Source rock is able to store the generated hydrocarbon on maturation while due to its less permeable nature, all the hydrocarbons generated are not expelled out of it. Temperature, pressure, time along with anoxic conditions is a basic requirement for source rock deposition and maturation (Gakkhar et al., 2012). The creation/birth of hydrocarbons from a good source rock is content dependent of the matter organically deposited along with sediments, which in turn is characterized by (TOC) content.

This dissertation research work is based on reservoir characterization and facies analysis to check out the reservoir and source rock potential of the Sembar Formation. Three wells and seven seismic lines have been utilized for the evaluation of reservoir properties of Sembar Formation.

1.2 Introduction to study area

The area in the south of Mithan Kot to the Arabian Sea is known as The Lower Indus Plain, which comprises of most of the area of Province of Sindh. The study area is located near to Nawabshah and Shadadpur area of SIB Pakistan at approximately 200 km north-east of Karachi. Kadanwari surrounds the study area at its north. At southeast lies Mirpur Khas and on south lies Tando Adam and at west lies Shaheed Benazirabad.

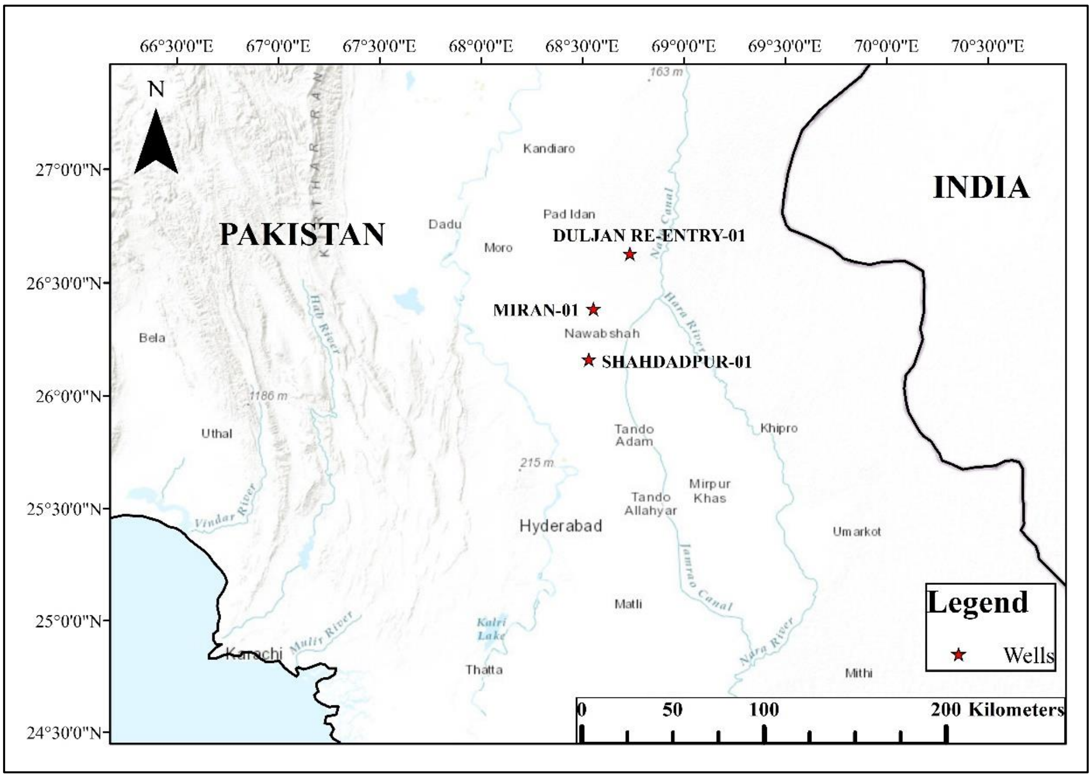

Figure: 1.1. Map showing location of wells used in the research study. (generated in ArcGIS 10.3)

The soil is very fertile and where ever proper supply of water is available for crops production. Climate, in this region is normally dry, upto 53˚C in the summer, especially in Nawabshah area surrounds the study zone. River Indus is about 35 kilometres away from the study area. The city is famous for its sugarcane, Mango, Kappas and Banana production.

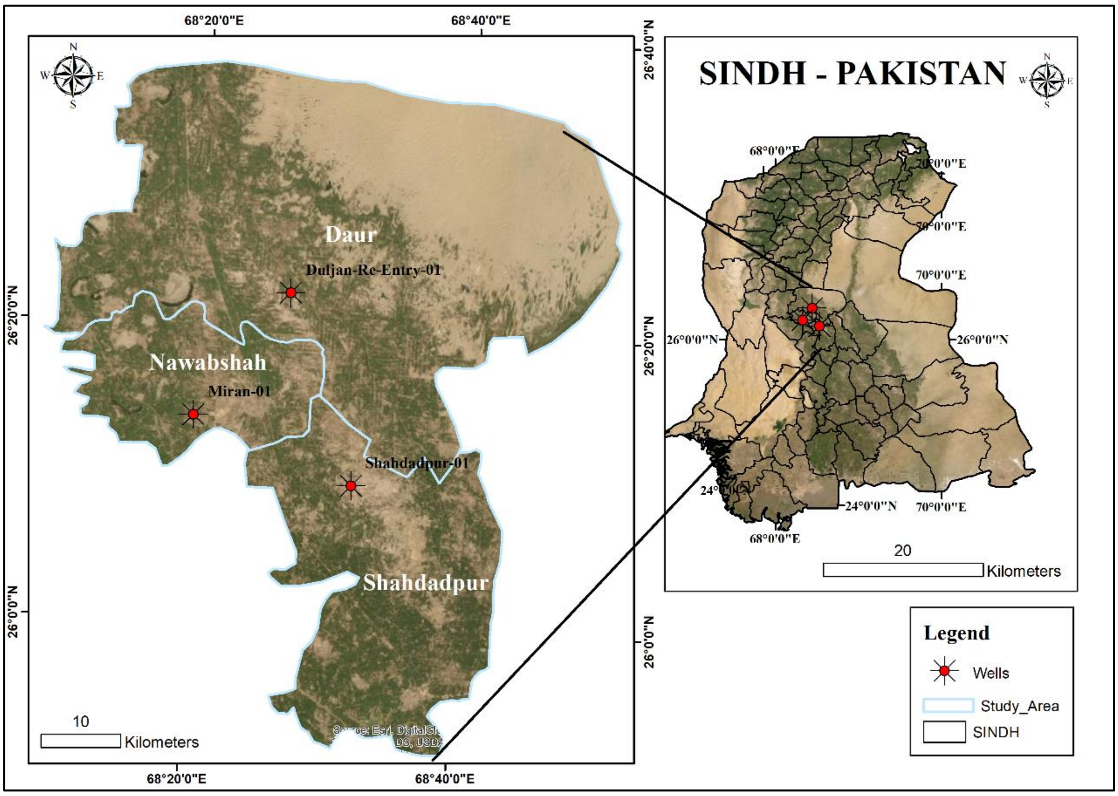

Figure 1.2. District map of Sind provinve showing the location of the study area wells in Shahdadpur, Nawabshah and Daur regions (generated in ArcGIS 10.3).

1.3 Previous work

Published data has been reviewed in order to understand the lithological characteristics of the Sembar Formation. Some researchers have worked on the source potential of the Chichali Formation in different areas of the Indus Basin. These research articles are being discussed here.

Nazir et al. (2012) carried out the hydrous pyrolysis of the five samples of Early Cretaceous sedimentary sequence of Sembar Formation to release hydrocarbons from extracted sediments and fractionated by liquid chromatography. Saturated fractions from both Soluble Organic Matter (SOM) and Pyrolysed Organic Matter (POM) were further analyzed by gas chromatography flame ionization detector. The study suggested that Cretaceous sequence of Sembar Formation has marine algal source with an anoxic depositional environment of organic matter due to which it has fair to good hydrocarbon source potential.

Khan et al. (2013) in their paper estimate the petrophysical parameters based on well data to identify hydrocarbon bearing zones of Sembar Formation. The logging data from the gamma ray, spontaneous potential, resistivity, neutron and density have been applied. The Archie's equation was used to estimate petrophysical parameters and the findings have shown five main prospective zones (ranges from 3250-3480) having good porosity and high movable hydrocarbon saturation.

Nazir et al. (2015) in their paper, performed the biomarker diagnostic test on the samples of source rock and crude oil from Cretaceous succession of LIB. The biomarker geochemistry indicators showed that the terrigenous organic matter is predominantly present in crude oil. Crude oil and source rock sediments geochemical correlation investigation showed that shales of Lower Goru and Sembar Formation could be the potential source rocks for the petroleum generated from Cretaceous strata in LIB, Pakistan.

Qayyum et al. (2016) in modeling one-dimensional maturity of source rocks in LIB concluded the vertical and lateral extents of Sembar formation maturity levels. The data from 22 main exploration wells in the area was used to construct a maturity model with the stratigraphic data to include thickness of formations, formation tops, deposition time and lithology, age and amounts of erosion and ages of non-depositional events. His research concluded that Sembar Formation is considered as conventional petroleum source rock due to its enough maturity or can be exploit as unconventional shale gas/oil source.

Ahmad et al. (2013) investigate shale gas potential of Early Cretaceous Sembar Formation within a large area of Central and Southern Indus basins. Total organic content of Sembar formation ranges from 0.55 wt. % to 9.48 wt. % with present day generation potential of 0.14 – 18.69 mg HC/g rock as shown in geotechnical study results. Total organic content of immature samples is averaged out to be 1.0 wt% with generation potential of 2.88 mg HC/g rock.

1.4 Objectives

Sembar Formation, which is proven as a source rock in the LIB also has potential to be a good reservoir because in some areas Sembar Formation has fair amount of sand facies. So objective of this research is

(a) To analyse the facies of Sembar Formation in terms of shale and sand.

(b) To characterize its reservoir potential in terms of sand facies of Sembar Formation.

(c) To analyse the source potential of the shale facies by computing the TOC using Passey and Density log methods.

(d) To determine the type of clay minerals within the shales for classifying the shales as brittle or ductile.

1.5 Data availability

The data used for this research is demonstrated in the Table 1.1. The data is provided by LMK Resources after getting an approval letter from DGPC (Directorate General of Petroleum Concession).

1.5.1 Seismic and well data

The seismic and wireline log data used for research study for the subsurface geological interpretation in terms of facies analysis and reservoir potential evaluation of the Sembar Formation is given in table 1.1.

Table 1.1. Seismic lines and wells used for the interpretation of subsurface geology.

Seismic Data		Well Data	
Line Number	**Orientation**	**Well Name**	**Logs Used**
O/907-GP-305	S-N	Duljan-re-entry-01	Gamma ray log, Spectral Gamma Ray, Sonic, Resistivity, Neutron, Density, PEF, SP, Caliper, BS
O/907-GP-307	S-N	Shadadpur-01	
O/911-GP-16	W-E	Miran-01	
O/911-GP-62	W-E		
897-GP-310	W-E		
O/741-SH-6	N-S		
O/851-SGR-212	W-E		

1.6 Methodology

The methodology adopted for achieving the objectives on the basis of wireline logs and seismic data is given in figure 1.3.

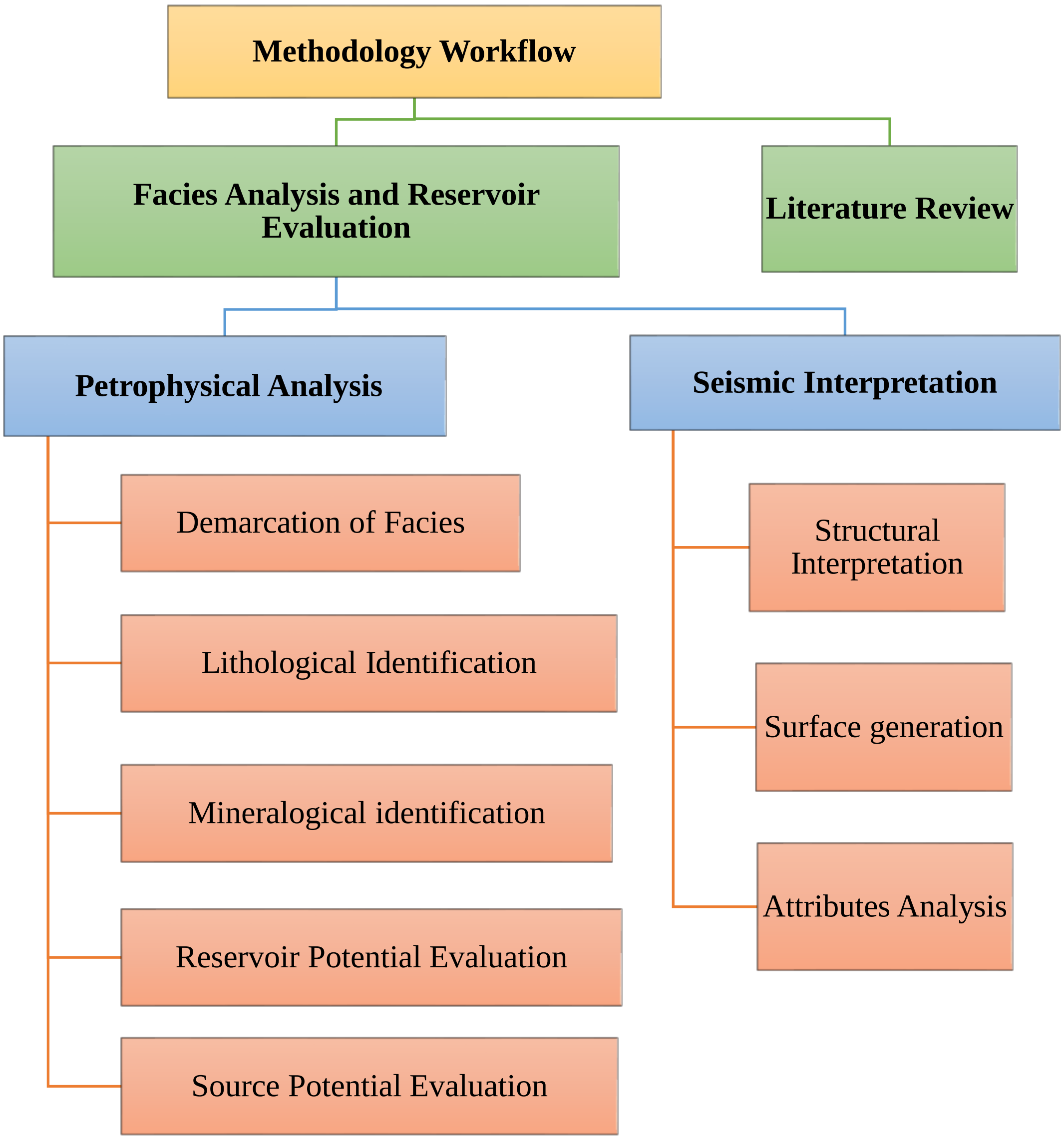

Figure 1.3. Work flow adopted for the research work.

CHAPTER 2
TECTONOSTRATIGRAPHY

2.1 Tectonics of Southern Pakistan

Pakistan is situated on the junction between the Indian, Arabian and Eurasian plates. Murray Ridge, an intra-oceanic transform boundary situated within Pakistan offshore separates Indian and Arabian plates. The Eurasian Plate is comprised of three microplates which amalgamated in Iran-Afghanistan and western Pakistan area in Cretaceous to Paleogene times. (Quad Consulting Limited Report, 1996).

Structural and stratigraphic features in the SIB were caused by the movement of Indian Plate northward with spreading centres in the South. 50 to 55 million years ago Indian Plate get separated from Australian-Antarctic plate and collided with Eurasian plate in North (Kemal, 1992; Zaigham and Mallick, 2000). Indian Plate entered warmer latitudes in the Early Cretaceous, while at the same time, the regional erosion occurred in SIB. This surface has been overlained by the Cretaceous formations.

During the Late Cretaceous time, shelf environment was prevailing which resulted in the deposition of sandstones due to regression (Wandrey et al., 2004). Extentional faults were reactivated due to the shearing of Indian plate in the southward direction (Kemal, 1992) which resulted in the oblique collision and started the formation of Sulaiman- Kirthar fold belts (Jadoon et al., 1994). Lower Cretaceous includes Sembar and Goru formations, while the Late Cretaceous formations are Parh, Mughal Kot, and Pab.

Indus Basin initially formed in the Permian as a result of continental rift during the extensional phase that led to the fragmentation of Pangaea (IEDS, 1995). In the Triassic and Early to Middle Jurassic, Indus Basin was a segment of the passive margin south of the Tethyan Ocean, which stretched W-E from the Mediterranean region to South East Asia. The Indian Sub-continent drifted northwards in late Mesozoic from a paleo-latitude of about 30°S and reached near the equator. Marine shales, turbidities and marls together with shelf carbonates and clastic were also deposited in the LIB (Shuaib, 1982).

The area selected for this study resides in the LIB which composed of five major units of the Indian Shield.

(a) Thar Platform

(b) Karachi Trough

(c) Kirthar Foredeep

(d) Kirthar Fold Belt

(e) Offshore Indus

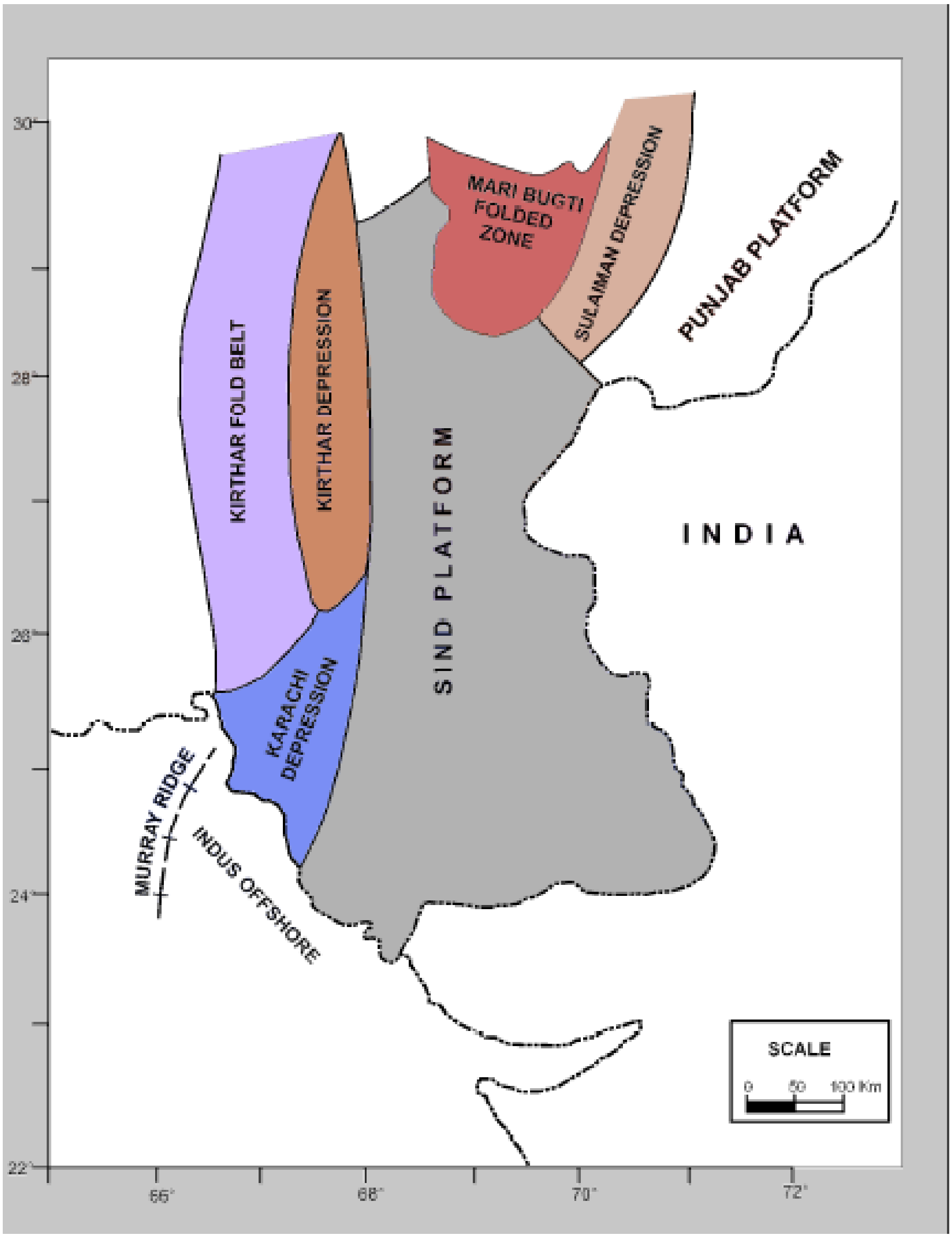

Figure 2.1. Major geologic divisions of the Lower Indus Basin (Raza et al., 1990).

Sargodha High is a structural mark which separates Upper and Lower Indus basins, bounded by marginal transverse zones in west, by Offshore Indus in south and by Indian shield rocks in east (Kadri, 1995). The Khairpur-Jacobabad High is another astonishing and special feature of basement which was seen on the gravity data, and its structures associated with it which grew through Jurassic and Cretaceous / Paleocene ages and subdivide the LIB into two basins namely Southern Indus Basin and Middle Indus Basin (Raza et al., 1989).

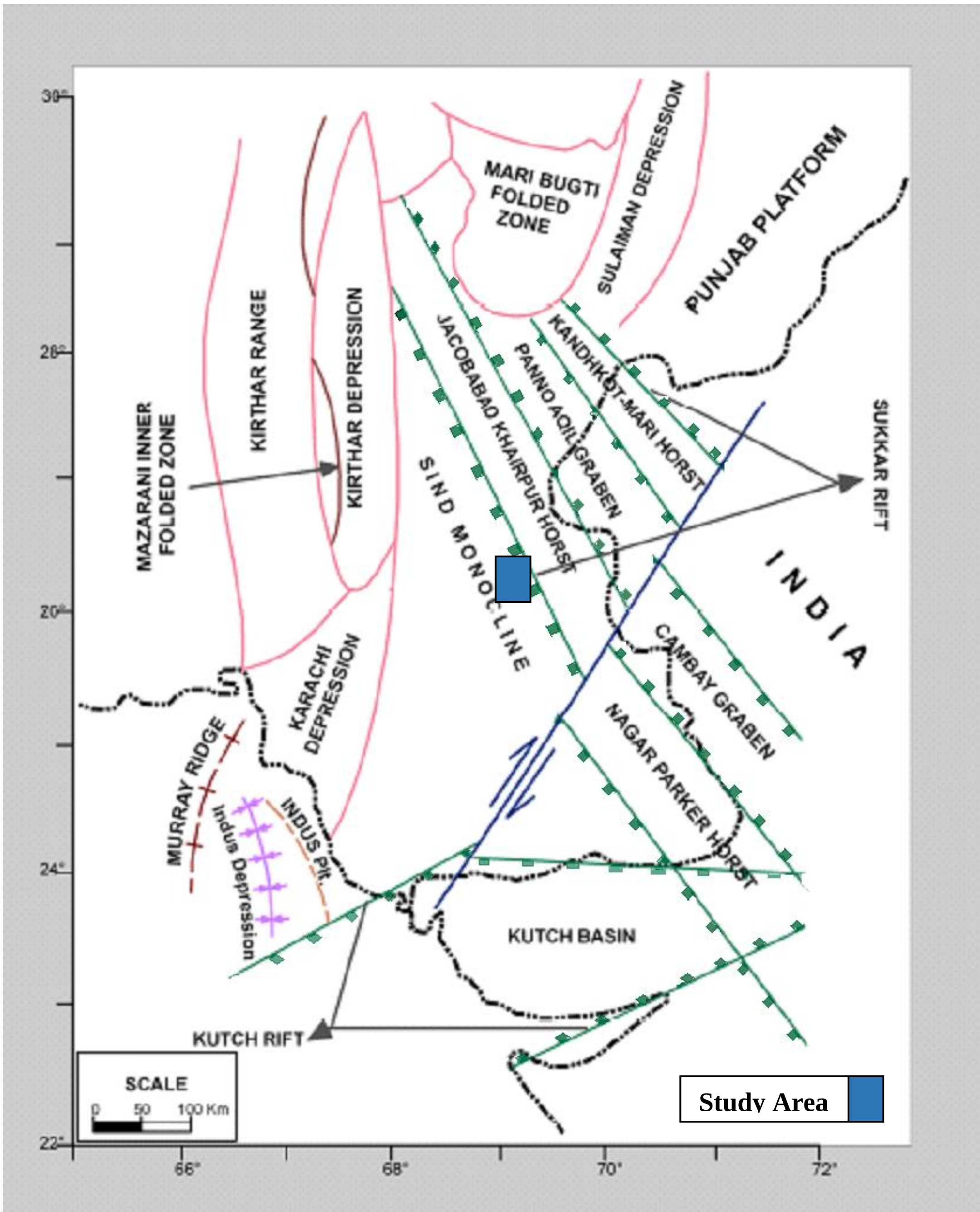

Figure 2.2. Structural settings of the Lower Indus Basin (Raza et al., 1990).

2.1.1 Thar Platform

The platform stable region of Thar is a very low angle slope monocline similar region of stable Punjab Platform administered by hard rock base topography. The wedges of sedimentary origin starts thinning in direction of the Indian Shield whom outcrop surfaces are marked similar to those present in Nagar Parkar High. It shows that the underground base features generated due to spreading tectonics appearing from the recent anticlockwise rotation of Indian Plate. Stable platform region host the development of Cretaceous age sands which are known as most producing reservoir form oil & gas fields in the region Thar platform area lies in the north western part of Sindh monocline structure (Kadri, 1995).

2.1.2 Karachi Depression

This structure is marked distinctly by abundant Early Cretaceous sedimentary load which also tells the final stages of the depositional sequence of marine sedimentation. It possess a huge amount of very narrow anticlines, out of which some are acting as the potential gas fields in the basin (including, Hundi, Sari and Kothar). These Cretaceous age rocks have been well developed in the area (Kadri, 1995).

2.1.3 Kirthar Foredeep

The structure of Kirthar foredeep extends in NS direction and collected huge amount of sediments, combining them to a thickness of about 14,500 m. It creates an eastern boundary with the Thar Platform. The rocks of the Upper Cretaceous age are absent in the area but the rocks of Paleocene age are well developed in the area. This area is characterized with immense potential for the maturation of the potential source rocks (Kadri, 1995).

2.1.4 Kirthar Fold Belt

Kirthar fold belt trends NS tectonically and is similar in features to the Sulaiman fold and thrust belt structurally and stratigraphically (Kemal, 1992). Rocks from ages of Triassic-Recent have been deposited within this area. The organization of the Kirthar fold and thrust belt labels the end of the depositional sequence of Oligocene-Miocene water bodies (Kadri, 1995).

2.1.5 Offshore Indus

This region experiences two distinct historical geologic phases i.e. Cretaceous–Eocene and Oligocene–Recent, and also creates passive continental margin part. Sedimentary deposition in region of Offshore Indus started during the time of Cretaceous age (Kadri, 1995).

2.2 Generalized stratigraphy of the study area

Summary of generalized stratigraphy which has been drilled and exposed in different area of SIB is given in figure 2.3.

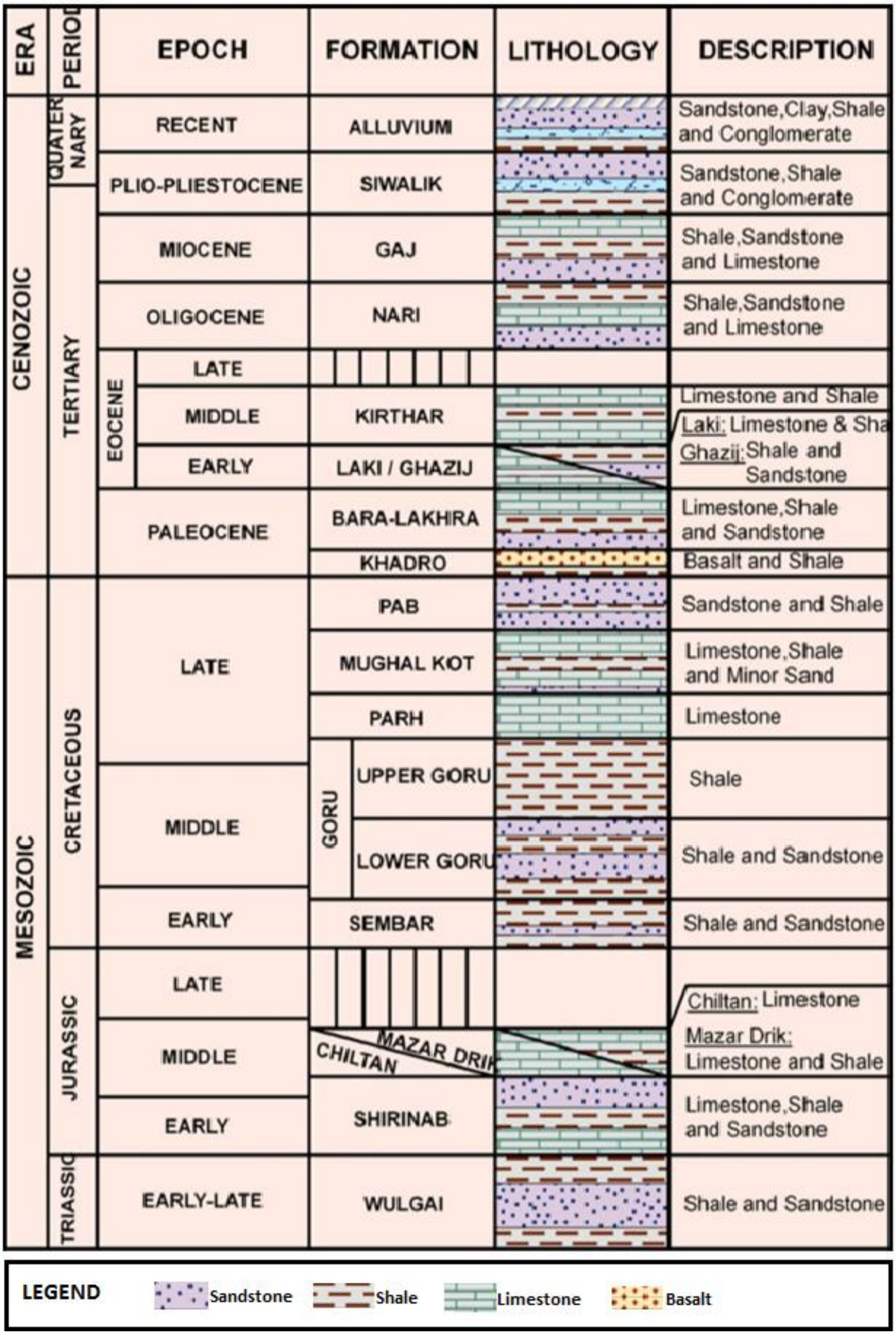

Figure 2.3. Generalized Stratigraphy of Lower Indus Basin. (Raza et al., 1989).

2.3 Borehole stratigraphy of the study area

The formations which have been drilled in Duljan Re-Entry-01, Miran-01 and Shahdadpur-01 wells are shown in the table 2.1.

Table 2.1. Formation tops for all the three (03) wells Duljan-Re-Entry-01, Miran-01 and Shahdadpur-01. (Courtesy by LMKR)

Formations	Formation Tops for Well Duljan-Re-Entry-01	Formation Tops for Well Miran-01	Formation Tops for Well Shahdadpur-01
FF ALLUVIUM	-	0	0
SIWALIK	0.00	-	-
FF KIRTHAR	-	518.00	489
FF LAKI	-	664.00	637
PIRKOH	212.00	-	-
SIRKI	263.00	-	-
HABIB RAHI	302.00	-	-
GHAZIJ	501.00	-	-
SUI MAIN LIMESTONE	1,197.00	-	-
RANIKOT	1,381.00	1,294.00	1079
FF KHADRO	-	1,939.00	1580
FF PAB	-	-	1656
FF MUGHAL KOT	-	-	1700
FF PARH	-	2,065.00	1727
UPPER GORU	2,310.93	2,240.00	1980
LOWER GORU	2,589.03	2,475.00	2950
SEMBAR FORMATION	3,534.29	4,106.00	3702
FF CHILTAN	-	4,204.00	3929

2.4 Sembar Formation

The Belemnite beds of Oldham (1892) has been named as the Sembar Formation which has been deposited in the marine environment with anoxic conditions. The major lithologies include the glauconitic shales and glauconitic sandstone. Presence of glauconite gives the lithologies green color. Sembar Formation expands in Central and Southern Indus basins. Formation thickness varies from few meters in Quetta and Ziarat area and increases up to several hundred meters in Kirthar province. It is widely distributed in the Karachi depression, Badin block, Sind Platform, and in Sulaiman depression of Central Indus Basin (Shah, 2009; Kadri, 1995).

Main source rock of LIB with the TOC value ranges from the 0.5-3.55 is Sembar Formation. Sembar ranges from thermally immature to over mature. The Sembar Formation is more thermally mature in the western, more deeply buried part of the shelf and become shallower and less mature towards the eastern edge of the Indus Basin.

2.5 Petroleum system in the area

In conventional regime, there are different components which collectively formed the petroleum system. these are;

(a) Source rock

(b) Reservoir rock

(c) Seal rock

(a) Source Rock

Source rock is defined as the fine-grained sediment with sufficient amount of organic matter, which can generate and release enough hydrocarbons to form a commercial accumulation of oil or gas. Source rocks are commonly shales and lime mudstones, which contain significant amount of organic matter. Source rocks are classified according to oil generation into three classes, as follows:

(1) Immature Source Rock that have not yet generated hydrocarbons

(2) Mature source rock: that are in generation phase.

Sembar Formation along with the Goru and Mughal Kot formations are the source rocks In LIB (Kadri, 1995).

(b) Reservoir rock

A rock containing porosity, permeability, sufficient hydrocarbon accumulation and a sealing mechanism to form a reservoir from which commercial flows of hydrocarbons can be produced. Porosity and permeability are the reservoir rock most significant physical properties. After the maturation of organic matter the oil and gas are moved to the reservoir rock where it is trapped and accumulated. Sembar Formations' sandy portion has very good reservoir characteristics along with Lower Goru and Pab sandstone in the LIB (Kadri, 1995)

(c) Seal Rock

After the maturation and migration of oil and gas from source rock, it reaches to a reservoir rock by the buoyancy movement for the accumulation of the oil or gas accumulation path has to be stopped by a seal/cap rock. Cap rock is a rock that prevents the flow of a given fluid at a certain temperature and pressure and geochemical conditions. In the absence of cap/seal rock the fluid might not be stored in the reservoir rock and it cannot be explored for the commercial use. The known seal in this petroleum system is composed of shales which are interbedded within the reservoir. While the Ghazij formation is regional seal in the LIB.

CHAPTER 3
CONVENTIONAL PETROPHYSICAL INTERPRETATION

Geographix Discovery suit, a comprehensive tool for Conventional and advance petrophysical analysis, is used in this research study. For the detailed investigation, wireline log data of wells Duljan Re-entry-01, Shadadpur-01 and Miran-01 have been cast-off. The available logs that run in the wells are Gamma Ray log (NGR) Spontaneous Potential (SP), Spectral Gamma Ray (SGR), Resistivity (complete suite including LLD, LLS and MSFL), Density (RHOB), Sonic (DT), Caliper (CALI) and Neutron (NPHI).

Following were the steps followed to carry out the Petrophysical interpretation:

(1) In order to validate the authenticity and reliability of the data a quality check is performed on the available log data at various depth intervals. Caliper log is specially checked since there is always a question mark on the reliability in washout.

(2) Zones of interest are demarcated on the basis of trend of gamma ray log, resistivity logs separation and cross over between density porosity and neutron porosity.

(3) Conventional petrophysical interpretation is performed in order to characterize different reservoir and source parameters.

(4) Different crossplots are generated for lithological mineralogical.

3.1 Raw log curves and QC of log data

The data which is provided by the LMKR on the approval of DGPC is in the raw form. Before proceeding to the interpretation of the data a detailed quality check of the data is required. Different explorer uses the different scale and nomenclature for the well logs data. In the quality check (QC) of the data, all the information in the three (03) well logs i.e Duljan-Re-Entry, Miran-01 and Shahdadpur-01 were placed in a coherency.with each other so it can be corelated with each other in latter stages. The components which were adjusted is;

(a) Scale and units of logs on the basis of available data range

(b) Nomenclature of the data set

The scale is accommodating according to the data available. Gamma ray log scale is confirmed in between 0 to 200, Sp log in between -100 to 50, Resistivity log in between 0.2 to 2000, Neutron log in between -0.15 to 0.45, Density log in between 1.95-2.95 and log scale of sonic is adjusted in between 40 to 140. Raw log curve of the three (03) wells including Duljan Re-Entry-01, Miran-01 and Shahdadpur-01 are shown in the figure 3.2.(a), (b), 3.3 and.3.4 respectively.

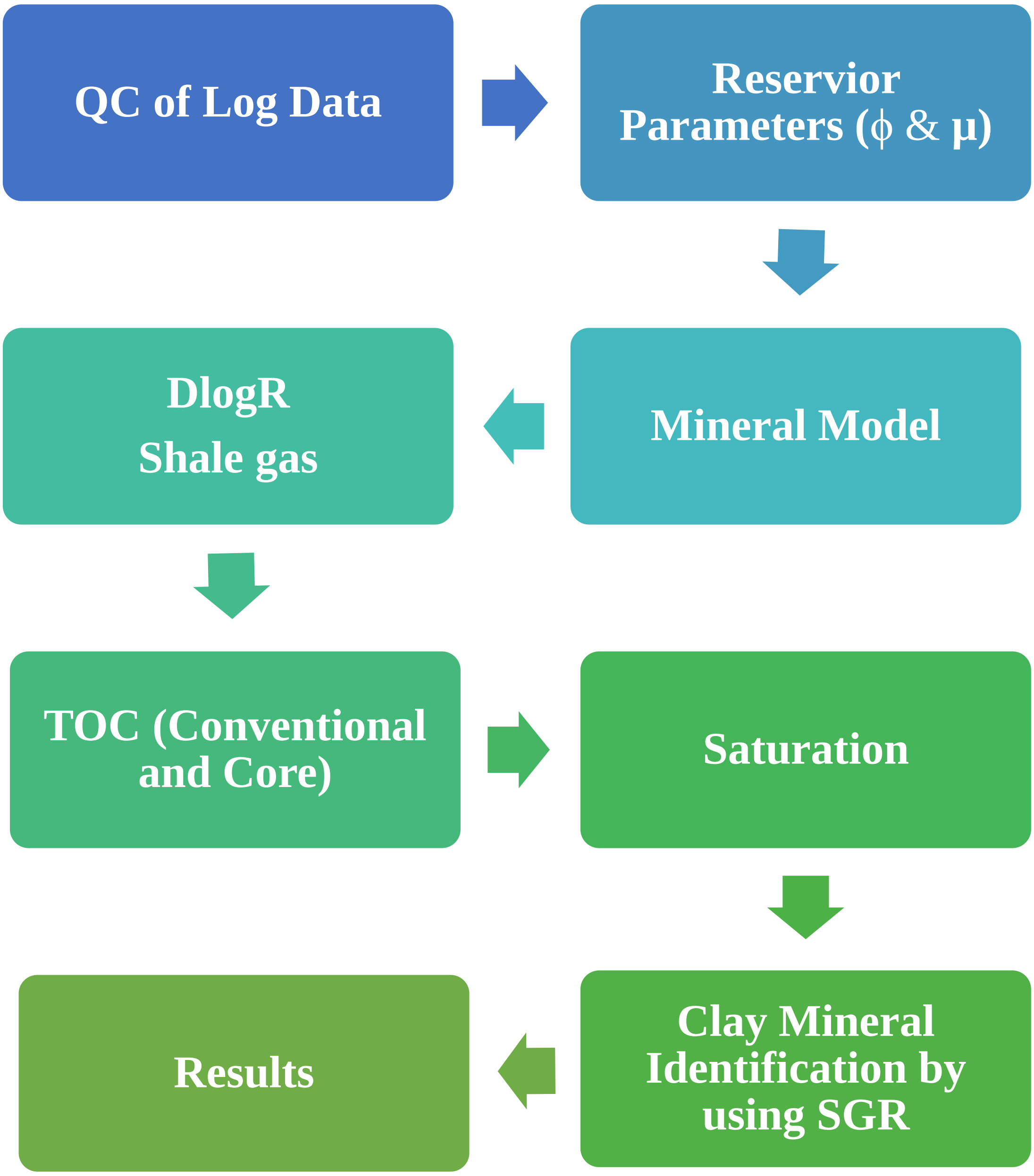

Figure 3.1. Flow chart showing the methodology for the research work.

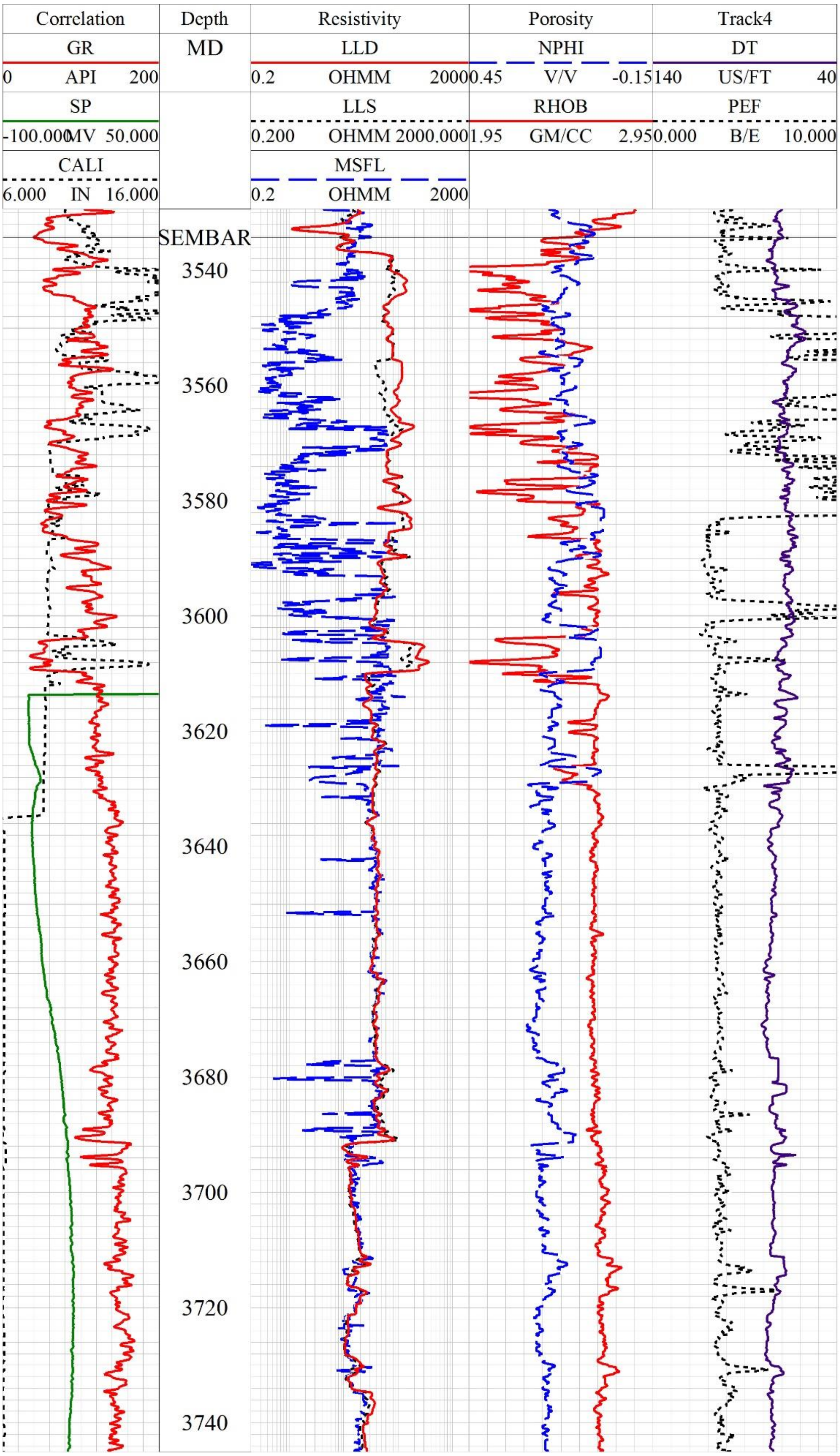

Figure 3.2 (a). Raw log curves and QC of raw log data of Duljan-Re-Entry-01 well. (Part-I)

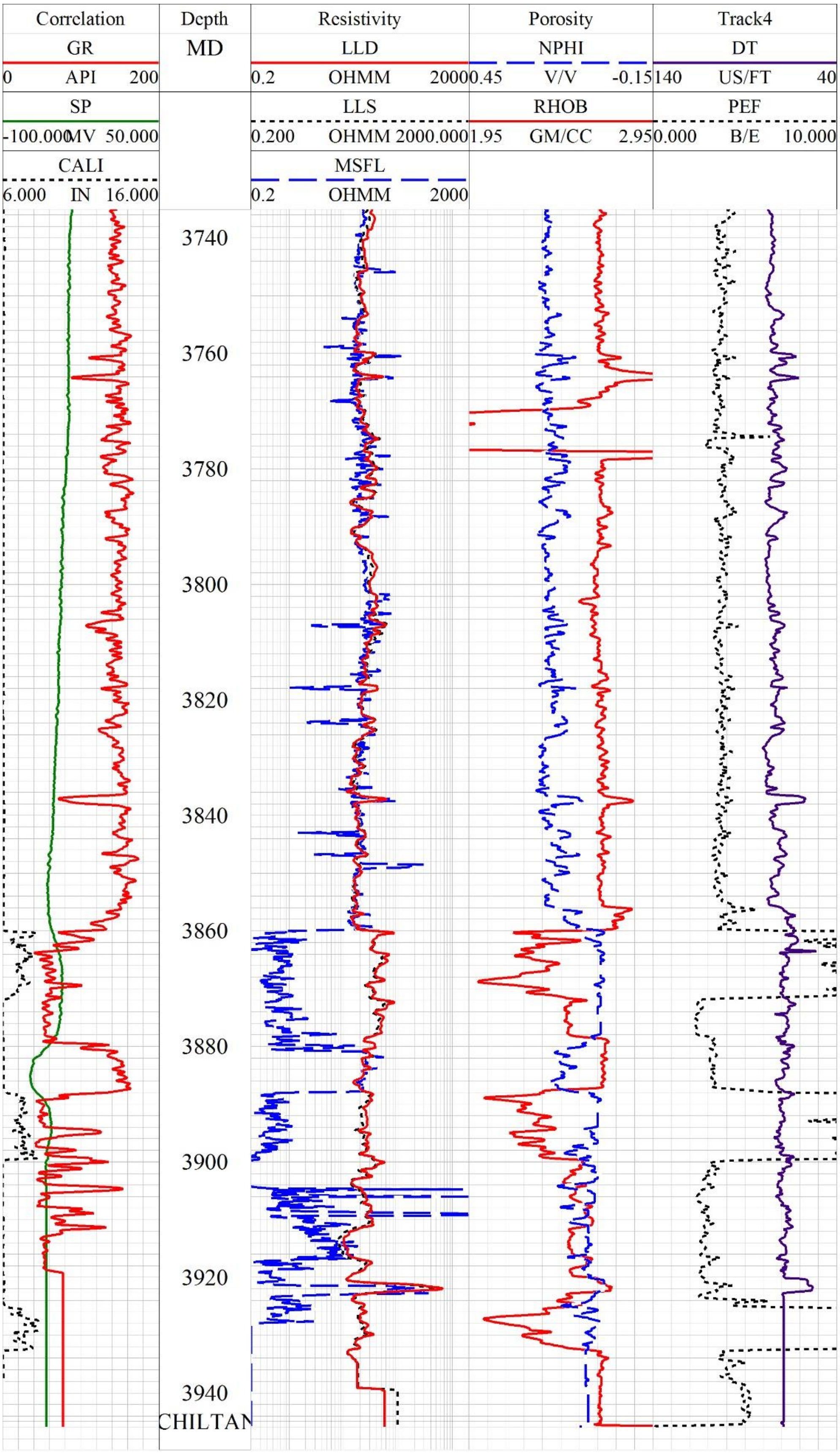

Figure 3.2 (b). Raw log curves and QC of raw log data of Duljan-Re-Entry-01 well. (Part-II)

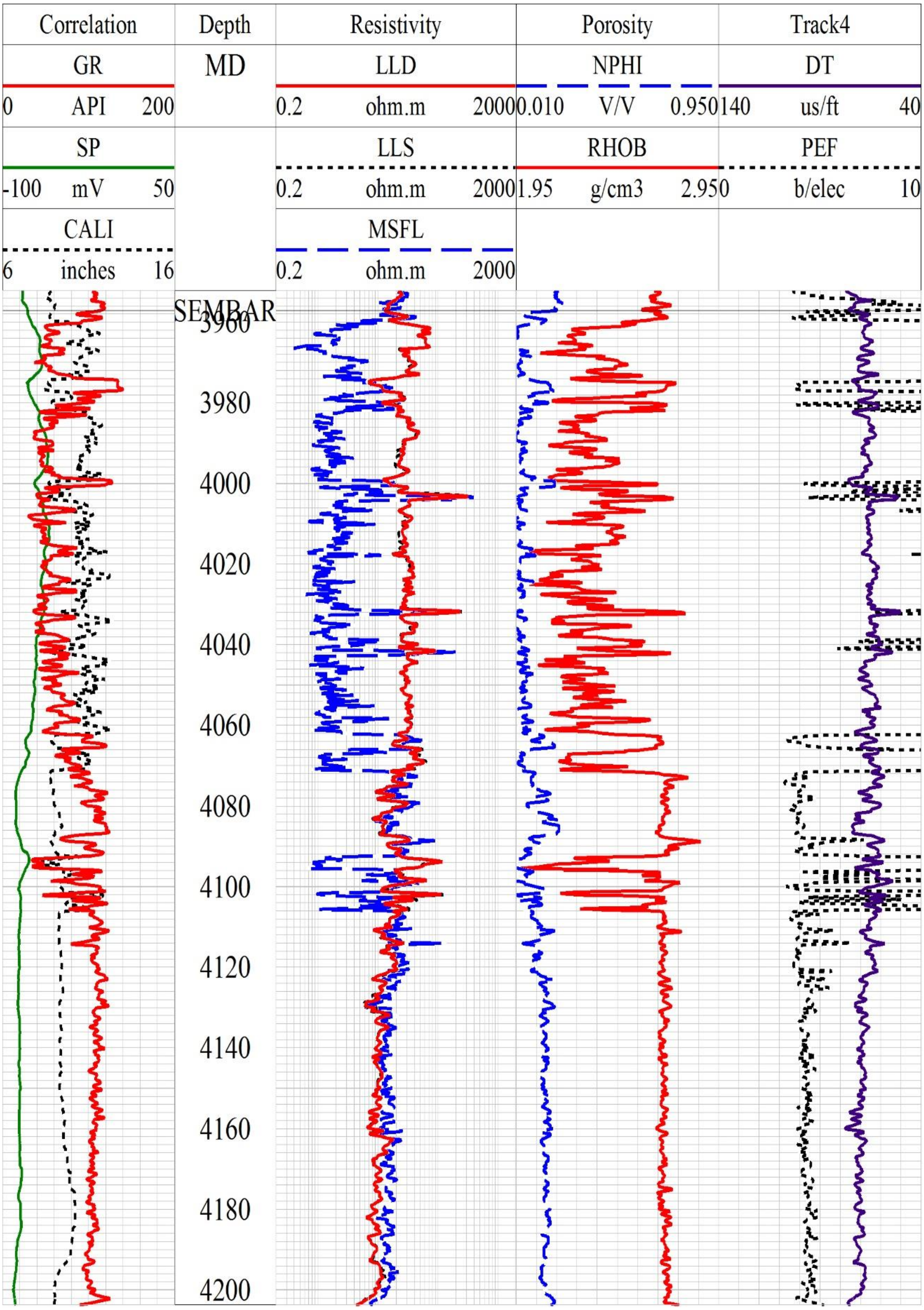

Figure 3.3. Raw log curves and QC of raw log data of Miran-01 well.

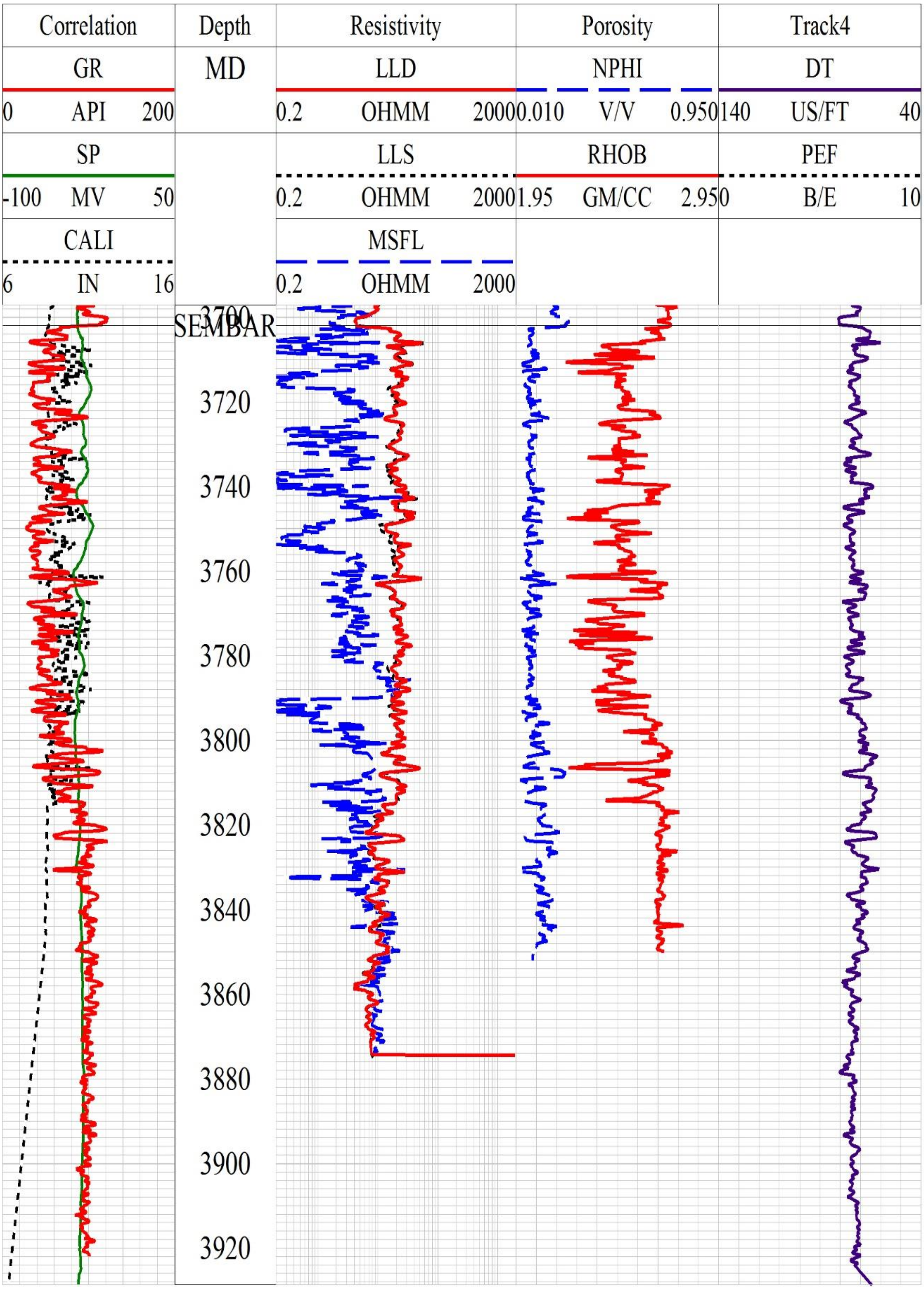

Figure 3.4. Raw log curves and QC of raw log data of Shahdadpur-01 well.

3.2 Petrophysical interpretation

In petrophysical interpretation all the interpretation is carried out on the Sembar Formation drilled in Duljan Re-Entry-01, Miran-01 and Shahdadpur-01. Initially, volume of shale and sand is calculated after which porosities have been calculated including density porosity, neutron porosity, total or average porosity, effective porosity and lastly fluid saturation has been determined. All interpretation is carried out in the Sembar Formation of the LIB.

3.2.1 Determination of volume of shale

Amount of shale present within the reservoir, plays a very vital role in its reservoir potential. Shale volume of can be computed within the reservoirs using GR log. The formula used for calculating volume of shale is given below.

$$\text{Vshl} = \frac{\text{GRlog} - \text{GRmin}}{\text{GRmax} - \text{GRmin}}$$

(Rider, 2002)

Where

Vshl = volume of shale

GRlog = gamma ray reading of formation

GRmin = minimum gamma ray (clean sand)

GRmax = maximum gamma ray (shale)

3.2.1.1 Clavier Correction

Whenever shale is present in the formation, every wireline logging device is affected in one or other way by the presence of the other radioactive minerals. The volume of shale calculated by the formula Vshl (defined above) might. give considerable high values. To counter this problem Clavier.et.al. correction is selected (from four different type of correction) and applied to get the more accurate results and value.

$$Vsh_C = 1.7 - (3.38 - (Vsh + 0.7)^2)^{0.5}$$

(Rider, 2002)

3.2.2 Density porosity

Density porosity is effective where there is no caving and washout and the bore whole conditions are normal and if these conditions do not exist then density porosity cannot be used and results are not accurate and reliable for interpretation. The formula which is used for calculating Density porosity is as follows.

$$\varphi D = \frac{\rho m - \rho b}{\rho m - \rho f}$$

(Rider, 2002)

Where

ρm =2.65 g/cm3

ρf = 1.1 g/cm3

ρb= log response in zone of interest

3.2.3 Average porosity

Average porosity is the average of density and neutron porosity and the formula used is written below.

$$\Phi T = \frac{\Phi D + \Phi N}{2}$$

(Rider, 2002)

Where

ΦT=Total Porosity

ΦD=Density Porosity

ΦN=Neutron Porosity

3.2.4 Effective porosity

Effective porosity is the product of the average porosity and volume of clean (1-Vsh). The formula used for calculating effective porosity is given below.

$$\Phi E = \Phi T \times (1 - Vshl)$$

(Rider, 2002)

Where

ΦE=Effective porosity

ΦT =Total porosity

Vsh=Volume of shale

3.2.5 Water saturation

Sembar Formation is the majorly composed of shales and a proven source rock in the basin. However it also contains some sand facies but these sand faies may contain high amount of shale content. Due to this reason, Indonesian equation has been used for calculating the water saturation instead of Archie's equation as it removes the bound or irreducible water content which is associated with the clays. The formula used for calculating water saturation is:

$$SW_{\mathrm{Indonesia}} = \left\{ \frac{\sqrt{\frac{1}{Rt}}}{\left(\frac{Vsh^{(1-0.5Vsh)}}{\sqrt{Rsh}}\right) + \sqrt{\frac{\phi_e^m}{a.Rw}}} \right\}^{(2/n)}$$

(Rider, 2002)

Where,

Sw = water saturation (Archie)

Rt = the deep resistively

Rw = the resistivity of the formation water

Vsh = volume of shale

Rsh = resistivity of shale

Φe = Porosity

n = the saturation exponent

m = the cementation exponent

The log header information including the surface temperature, Rmf at surface temperature and maximum recorded temperature was not available due to which water resistivity has been calculated with help of Picket plot using LLD and PHIA curve for each well.

3.2.6 Hydrocarbon saturation

Saturation of hydrocarbon is calculated by subtracting the amount of water saturation from the total fluid volume. The formula used for calculating hydrocarbon saturation is given below.

$$S_{hc} = 1-S_w \qquad \text{(Rider, 2002)}$$

Where

S_{hc}=Saturation of hydrocarbon

S_w =Saturation of water

3.3 Source Rock Evaluation

The evaluation of source rock can be carried through three method stated as under.

(1) Qualitative Analysis

(2) Quantitative Analysis

(3) Thermal maturity

Quantitative analysis will be discussed here in detail whereas qualitative analysis and however the thermal maturity has not been conducted in this research.

3.4 Quantitative analysis

The methods that allow quantitative analysis of source is geophysical logging which include the following techniques.

(1) Visual analysis from logs

(2) Passey's "DlogR" method

3.4.1. Visual Analysis from Logs

3.4.1.1 Gamma Ray Log

Gamma Ray Log is very sensitive to the radioactive gamma radiations. Uranium, Potassium and Thorium are the radioactive minerals which are detected by the Spectral gamma ray log. In the source rock, value of the gamma ray is significantly highly. For the same reason indication of uranium in any formation gives an indication about the TOC A source rock displaying a positive uranium anomaly might have been deposited along with the weathered granitic rocks or the deposition might have been occurred under reducing conditions (Rider, 2002).

3.4.1.2 Resistivity Log

The resistivity log responds to the free hydrocarbon fluids, the high resistivity is simply an indication that hydrocarbon fluids are present within the pores and not that a solid organic matter source is present (Rider, 2002).

These logs calculate the resistivity of the formation and it can be used for both qualitatively and quantitatively investigation of the source rock depending on how mature is the organic matter in the source rock. Resistivity value will be low in the zone of less organic content while the values will be high in the zone of high organic content result in differentiating it as immature or mature source rock. In the case of immature source rock pores will be occupied with water while in the case of mature source rock pore spaces are filled with both water and free hydrocarbons.

3.4.1.3 Density Log

Density log measures the bulk density of the formation and it is based on the principle of gamma ray absorption by Compton scattering. It helps in the estimation of organic content as solid organic matter will be less dense then the surrounding rock matrix. The density log method is considered to be more accurate as compared to that of the total gamma ray because the density log has minor effect on its reading when bore is under gauged or over gauged, however the usefulness of the tool is decreased where shales are prone to wash outs (Schmoker, 1979).

In order to derive quantitative organic matter effect on a log over a source interval, the log values are subtracted of the adjoining non source interval. To find out TOC% from density method firstly water filled porosity is calculated and kerogen filled porosity is calculated by using formulas mentioned in equation (i) and (ii).

$$\boldsymbol{\varphi_n} = \frac{\boldsymbol{\rho_{ns} - \rho_{ma}}}{\boldsymbol{\rho_n - \rho_{ma}}} \quad \text{Eq-(i)}$$

$$\boldsymbol{\varphi_{ker}} = \frac{\boldsymbol{\rho_s - \rho_{ns}}}{\boldsymbol{\rho_{ker} - \rho_{ma}}} \quad \text{Eq-(ii)}$$

(Passey, et al., 1990)

In order to calculate the TOC, the formula given in the equation (iii) is used.

$$\boldsymbol{TOC}\% = \frac{\boldsymbol{0.85 \times \rho_{ker} \times \varphi_{ker}}}{\boldsymbol{\rho_{ker}(\varphi_{ker}) + (1 - \varphi_n - \varphi_{ker})}} \quad \text{Eq-(iii)}$$

(Passey, et al., 1990)

Where:

ρ_{ns} = Density non-source interval (average from log)

ρ_s = Density source interval (from log)

ρ_{ma} = 2.70g/cm^3, assumed mudrock density

φ_n = Water filled porosity

φ_{ker} =Kerogen filled porosity

ρ_{ker} =1.1 or 1.2g/cm^3, kerogen density

ρ_n = 1.05g/cm^3, density water

TOC% = 0.85 × wt. % kerogen

3.4.1.4 Sonic Log

Sonic log helps in the calculation of the porosity. With the increase in the organic content there is increase in the travel time as a result of which there is decrease of the velocity in the source rock portion. Increase of organic content causes decrease in density because of which travel time increases. Sonic log greatly reduces the spurious effects of borehole size variation and the errors because of the tilt tool within the borehole (Schlumberger,1972).

3.4.2 Passey's "DlogR" Method

Sonic log gives an indication of porosity but along with it neutron and density logs can also be used. This is done by aligning the resistivity log under the sonic log logarithmic scale in a way 50µs/ft of the sonic scale should be equal to one resistivity cycle. Along the log scale where the Shales having less resistivity values it would be considered as non-source. Considerable crossover between the sonic and resistivity curves is present where we have potential source rock. Absolute values of the sonic and resistivity in the low resistivity shale are termed as base-lines, and these base-lines will vary with geologic age and burial depth (Passey et al., 1990).

TOC estimation can be done from Passey method but, firstly calculation of "DlogR" is required which can be carried out through formula given in equation (iv).

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

(Passey, et al., 1990)

Where:

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

RESDbase = deep resistivity baseline in non-source rock (ohm-m)

DTC= compressional; sonic log reading in any zone (µsec/ft)

DTCbase= sonic baseline in non-source rock (usec/ft)

DlogR= Passey's number from sonic (fractional)

Formula used for the calculation of TOC is given in the equation (v).

$$TOC = (DLOGR)10^{2.297-0.1688LOM} \quad \text{Eq-(v)}$$

LOM = Level of Maturity

For the level of maturity, we should know the vitrinite reflectance. The level of maturity for shales is from 10-13 (Passey et al., 1990).

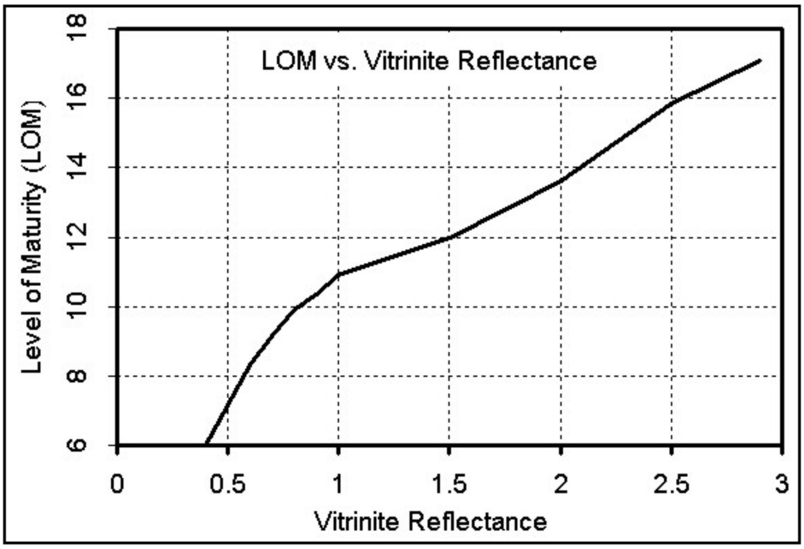

Figure 3.5. Graph for finding level of maturity from Vitrinite Reflectance (Crain's Petrophysical Handbook).

3.5 Discussion on Petrophysics Results

3.5.1 Sembar Formation

Sembar Formation which is comprised of greenish grey to light grey shale, followed by nodular black siltstone and minor limestone bed with the incorporation of fossils commonly beleminites. (Shah, 2009).

3.5.2 DlogR Method

DlogR method is implemented on entire Sembar Formation zone by aligning logarithmic scaled resistivity log under the sonic log so that the resistivity log curves comes under the sonic log curves. In this research resistivity and sonic is scaled where one logarithmic cycle on the resistivity log is equal to 50µsec/feet (Rider, 2002). The difference between resistivity and sonic is termed as DlogR which shows the source interval and where the resistivity and sonic overlay on each other it is termed as baseline interval which is termed as non-source interval. The separation between sonic and resistivity (DlogR) has been noticed at different depths in all of three wells which is showing source interval. DlogR and baseline intervals can be seen in the figure 3.6 (a), (b), 3.7 and 3.8 for Duljan Re-Entry-01, Miran-01 and Shahdadpur-01 wells respectively.

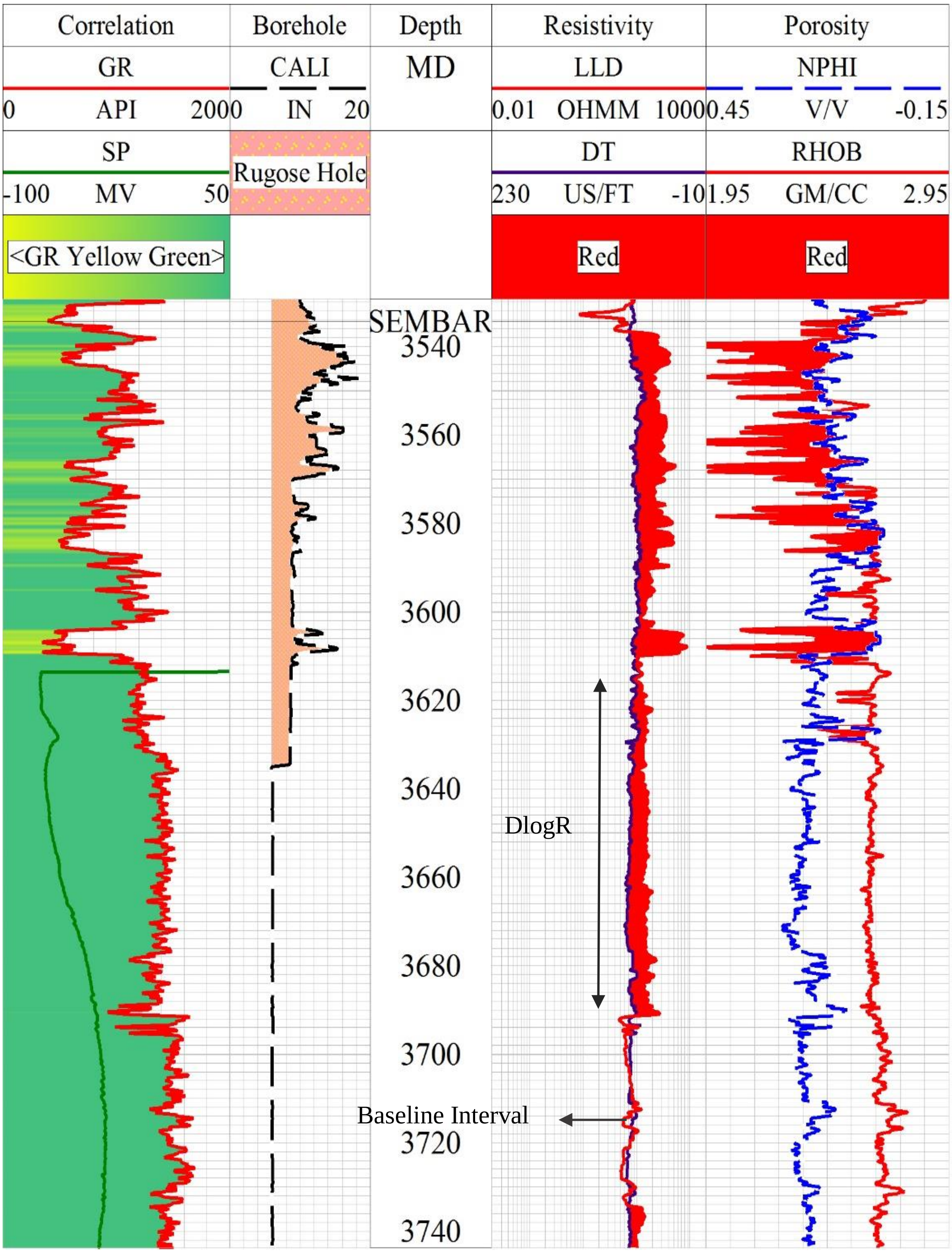

Figure 3.6 (a). Image showing DlogR and baseline interval in well Duljan-Re-Entry-01 (Part I).

In the Duljan Re-Entry-01 well the DlogR interval for the Part-I is from 3616 to 3688 while the baseline interval is from 3720 to 3730. While in the Part-II DlogR interval is from 3770 to 3820 while baseline is from 3830 to 3850. In the Miran-01 well the DlogR value is from 4110-4170 while baseline value is observable at the depth of 4200. In the third well Shahdadpur-01 the DlogR interval is from 3845 to 3870 while the baseline value is from 3880 to 3920.

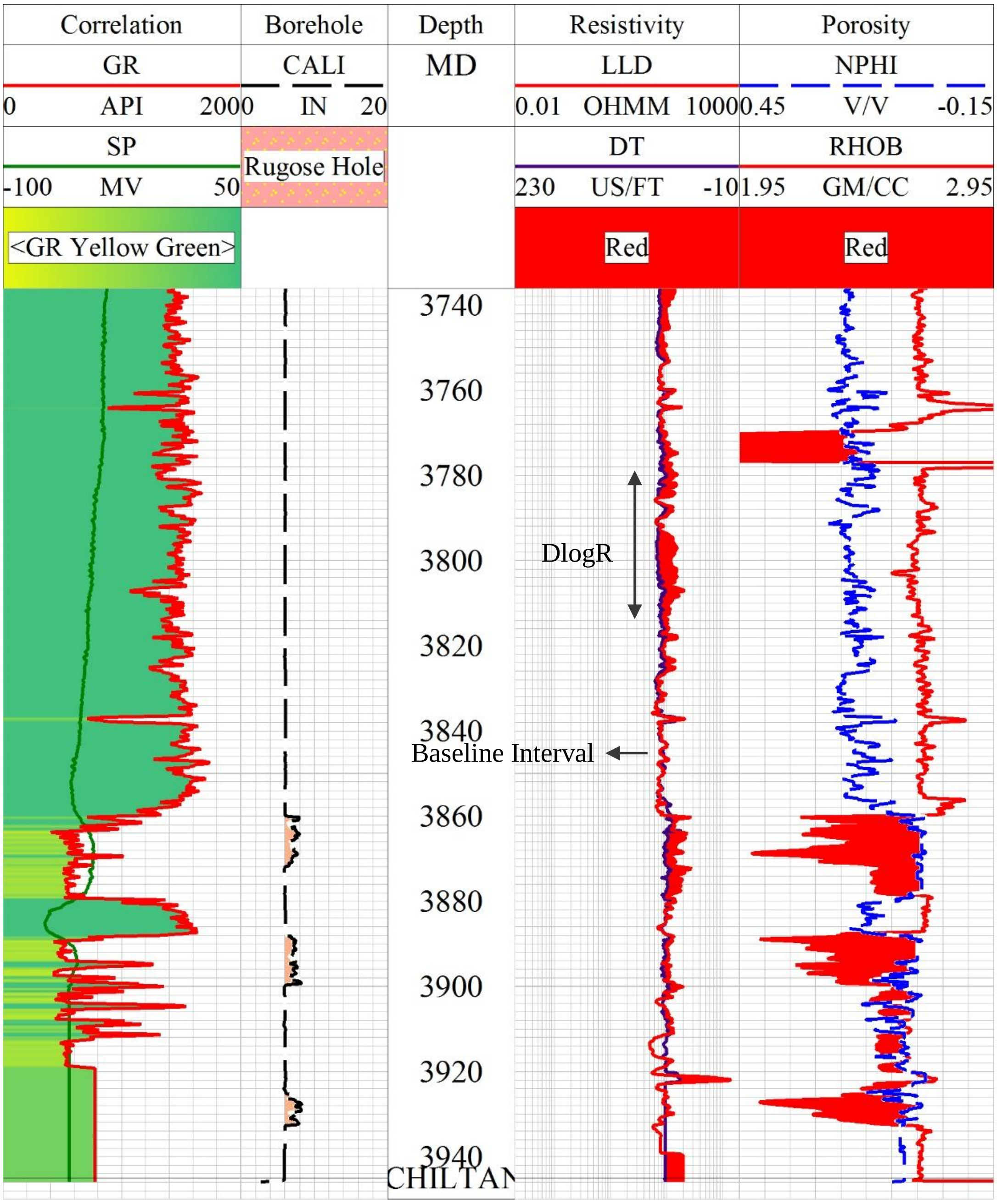

Figure 3.6.(b) Image showing DlogR and baseline interval in well Duljan-Re-Entry-01 (Part II).

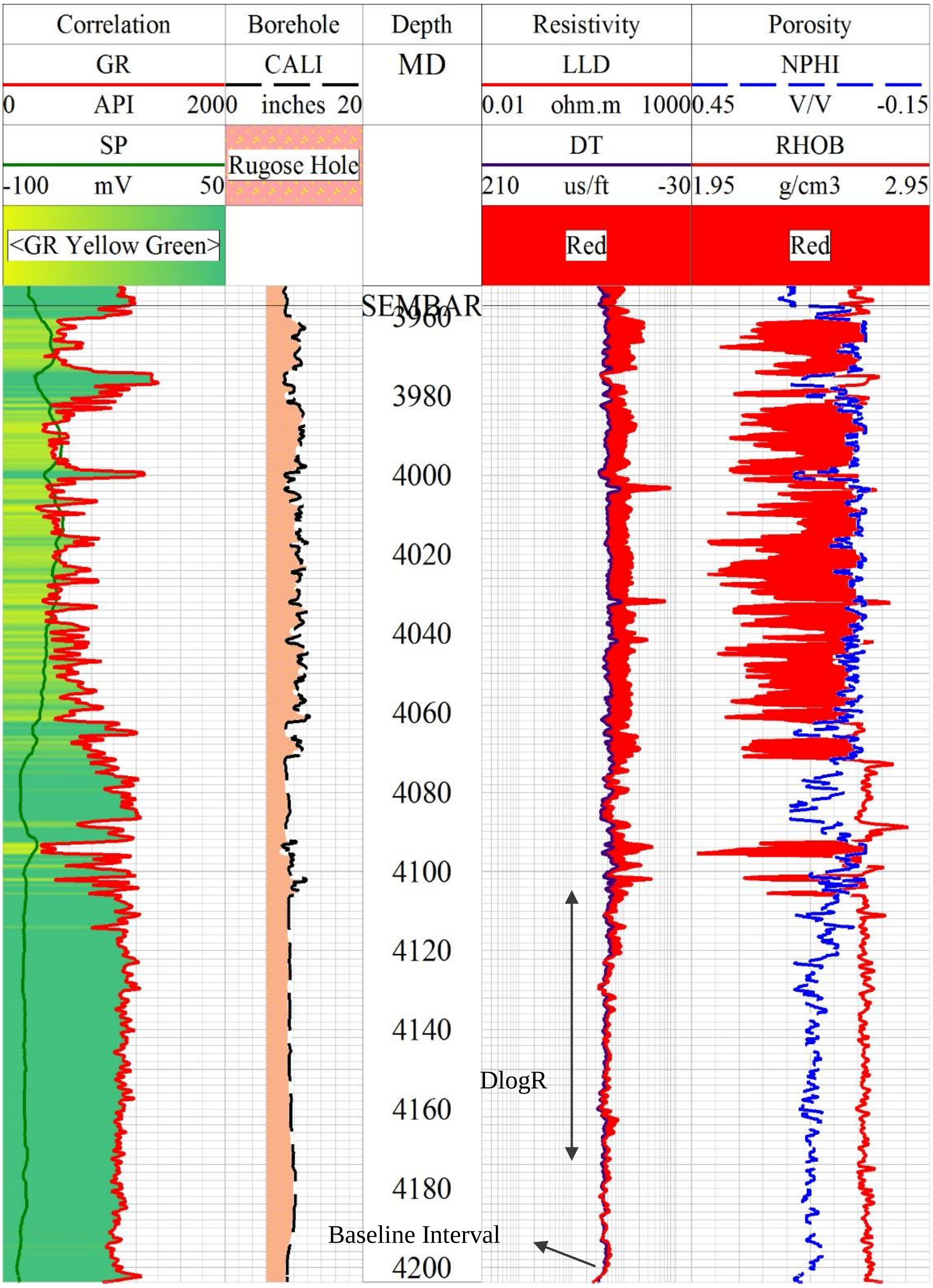

Figure 3.7. Image showing DlogR and baseline interval in well Miran-01.

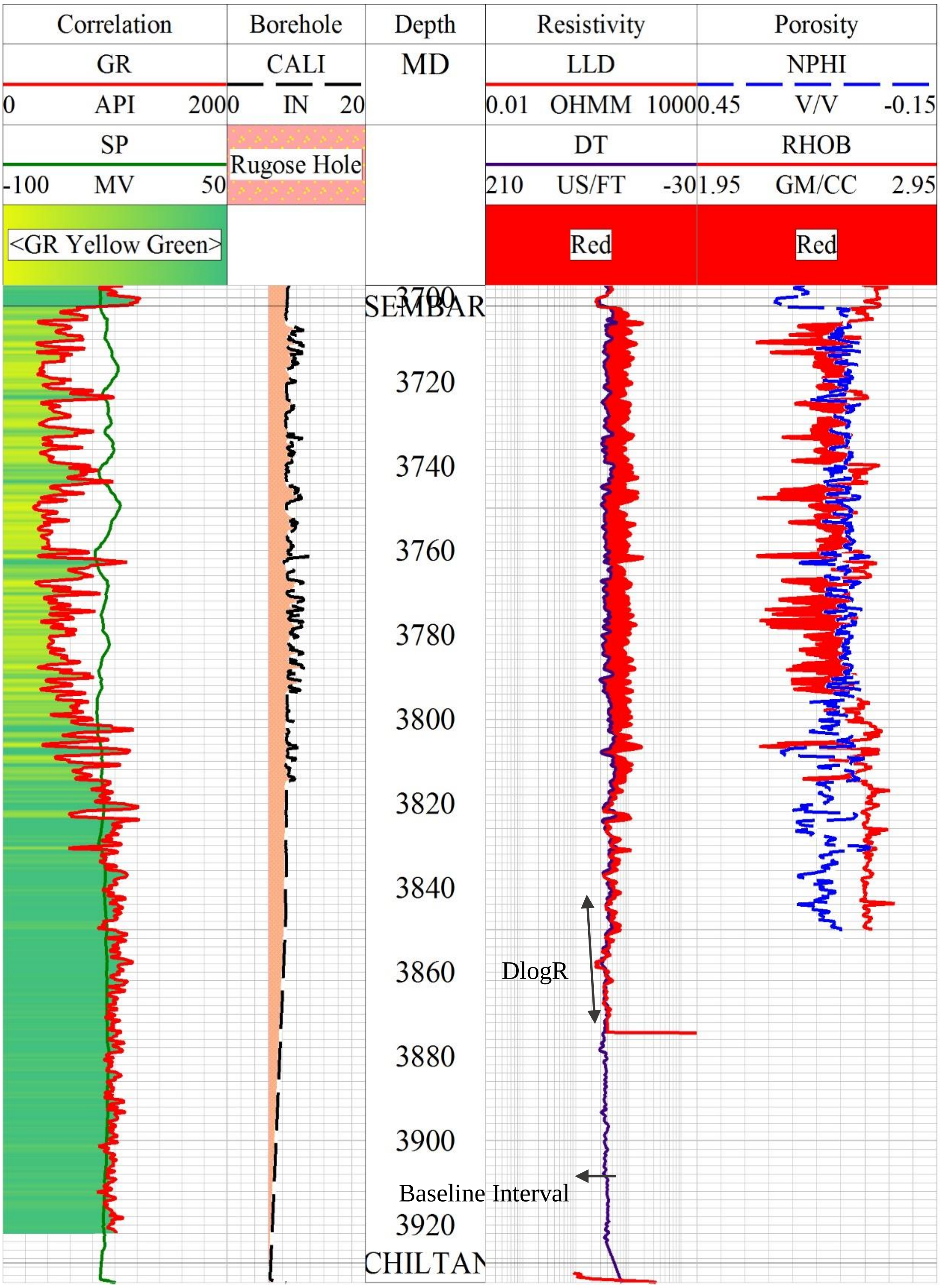

Figure 3.8. Image showing DlogR and baseline interval in well Shahdadpur-01.

3.5.3 Wireline log analysis

The main aim of this research is to perform facies analysis of Sembar Formation for which conventional wireline log data has been used. The Cretaceous Sembar formation is encountered at the depth of 3534m in the Duljan-Re-Entry-01 well and the thickness of formation is 410.71m. On top of formation, from 3534m to 3630m and at the bottom of the formation from 3860 to 3940 is majorly composed of sandstone. Sembar Formation has been divided into two distinct facies i.e sand and shale . The major part of the Sembar Formation is comprised of shale which is dominant within the lower part whereas the upper part is having sand facies in all the three (03) wells i.e Duljan Re-Entry-01, Miran-01 and Shahdadpur-01. However, the top most sand facies decreases in thickness towards Shahdadpur-01 well moving from North to South direction. Based on the available log data, in the northern part of the study area in Duljan Re-Entry well, base of Sembar Formation is also composed of sand below the shale facies.

The second objective of research study was to evaluate the reservoir potential of the sand facies of the Sembar Formation. Conventional reservoir log analysis has been done on the sand facies in which GR log has been used for calculating the volume of shale which depicts more than 65% sand facies. Lithological model has been prepared in order to determine the percentage of shale, sandstone, limestone and dolomite that confirms the presence of shale in the middle part whereas sand in the lower and upper part of the formation. The presence of the calcite can be interpreted as the calcite cement within the sands. These sand shows very good porosities of about 15-20% with separation in the deep and shallow resistivity curves showing presence of hydrocarbon. Picket Plot was used for calculating the Rw i.e 0.05. As the Sembar Formation is mainly composed of shale facies Indonesian water saturation formation has been used for the calculation of fluid saturation in order to remove the amount of bound water. The results of the fluid saturation shows more than 70% hydrocarbon saturation

The main objective of the research was to evaluate the source potential of the shale facies of Sembar Formation. In order to do so, log data has been used for determining the shale minerology and TOC. Mineral model has been computed for the identification of clay mineral including Kaolinite, Illite and Chlorite. The shale facies of the Sembar Formation is mainly composed of Illite and Kaolinite as shown in figure 3.10 (a), (b) and (c). The percentage of chlorite is negligible in the shale facies whereas it increases towards the sand. The calculation of TOC is carried through methods namely Passey DlogR method and Density Log method. Both the methods have shown overall similar results having 1-2.5% TOC within the shale interval which lies in the range of fair to good.

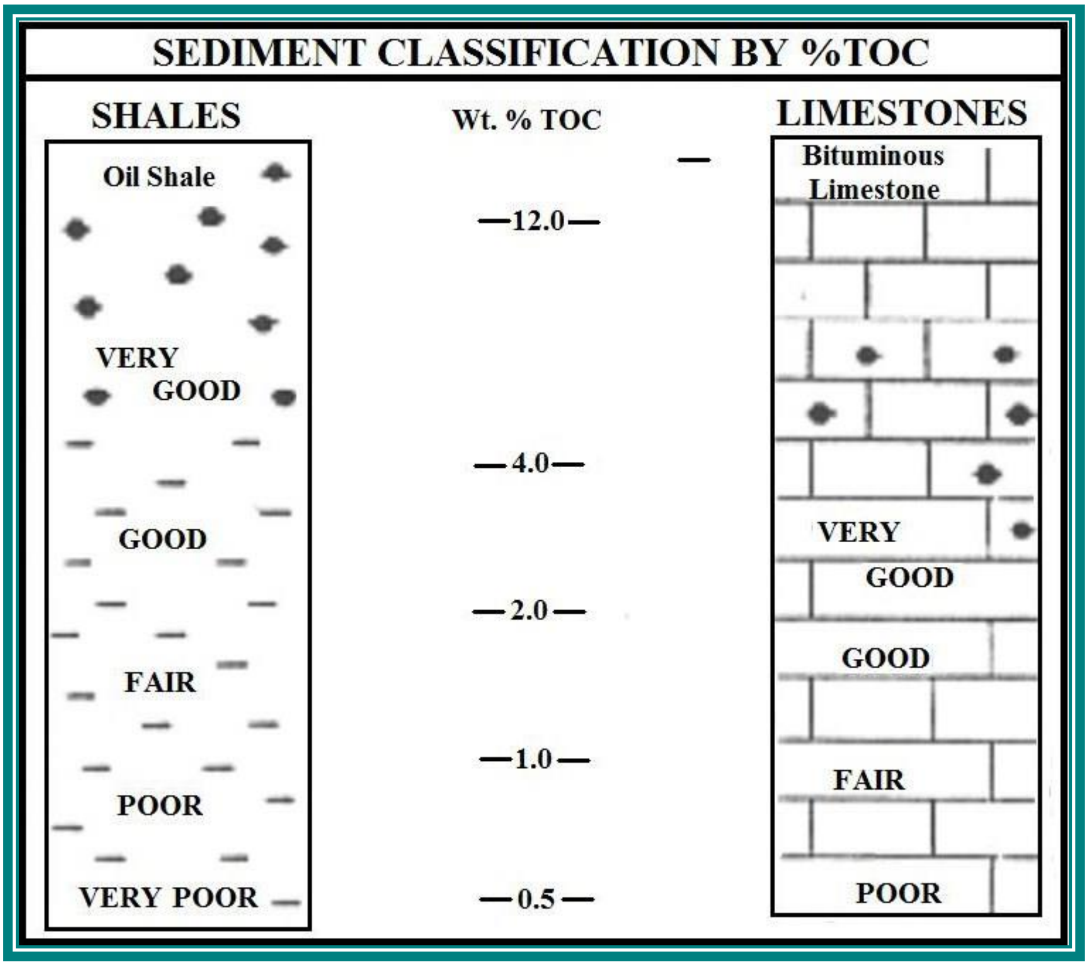

Figure 3.9. Classification of source rock richness as a function of TOC content for shales and carbonates (Mujtaba, 1999).

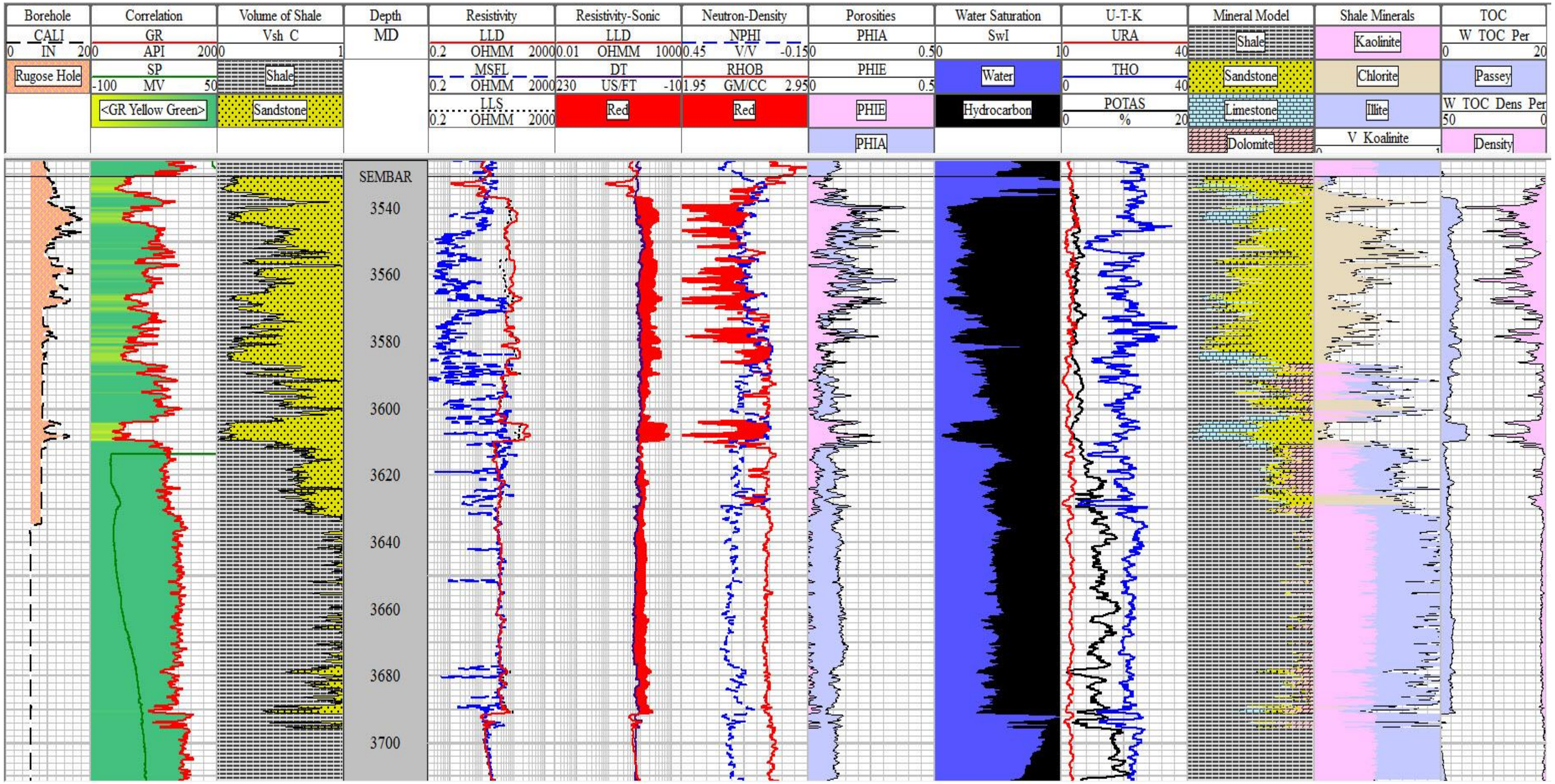

Figure 3.10 (a). Wireline log interpretation of well Duljan-Re-Entry-01 for the conventional reservoir potential in the sand facies and source rock potential of the shale facies and its mineralogical identification (Part-I).

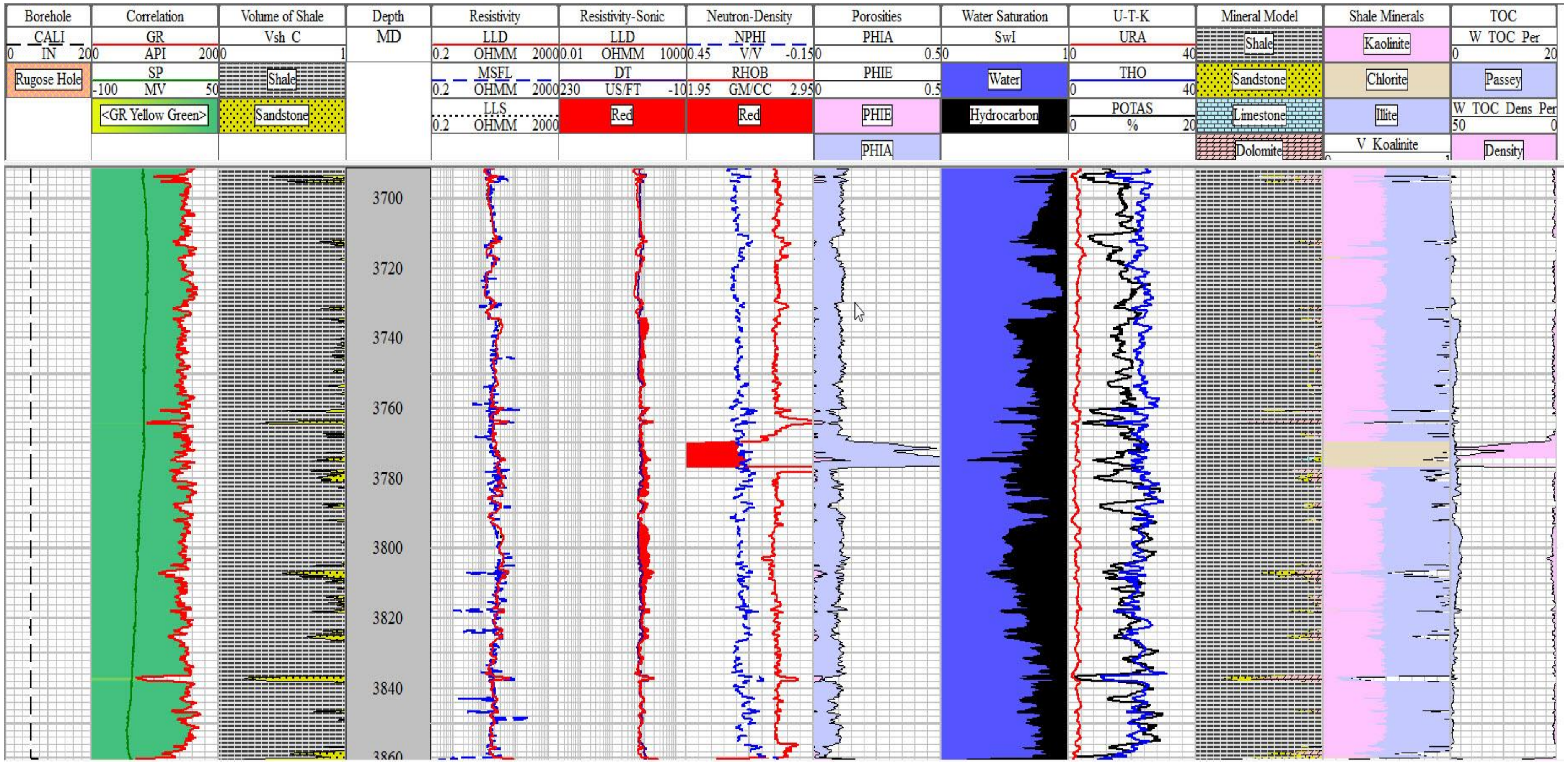

Figure 3.10 (b). Wireline log interpretation of well Duljan-Re-Entry-01 for the conventional reservoir potential in the sand facies and source rock potential of the shale facies and its mineralogical identification (Part-II).

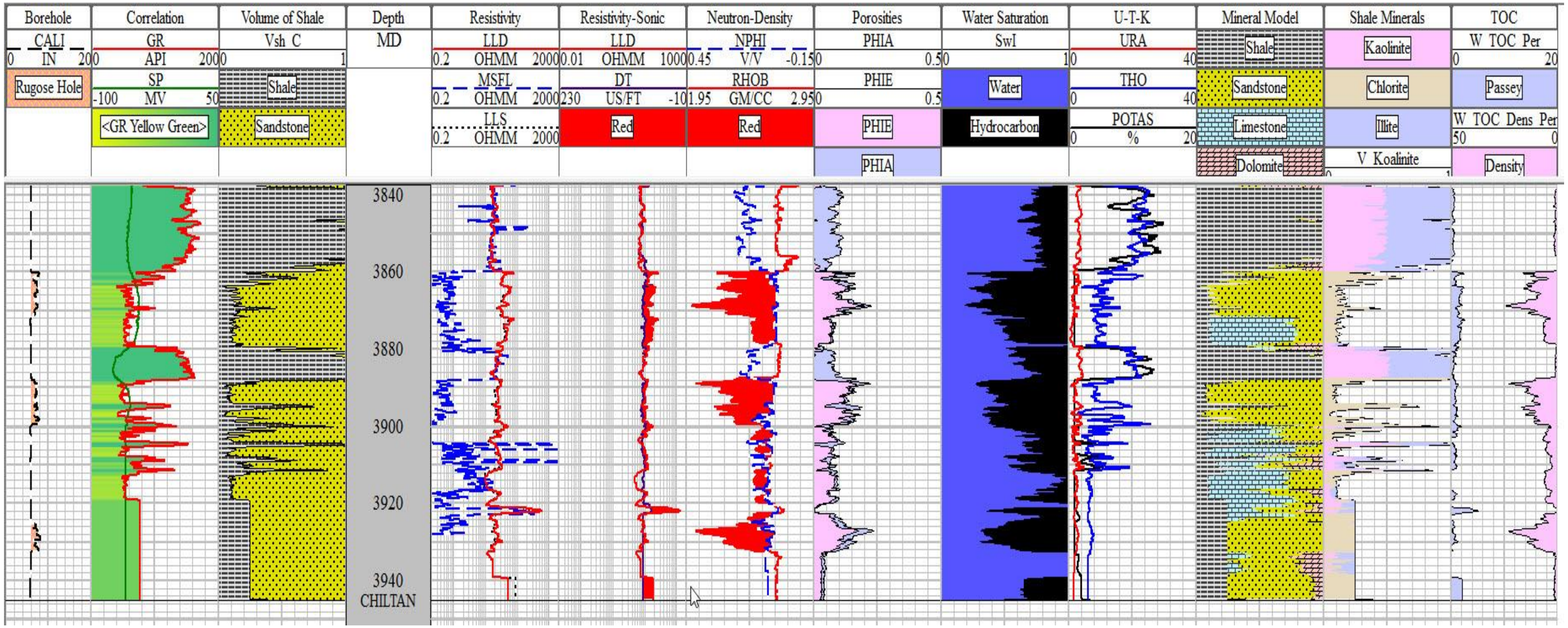

Figure 3.10 (c). Wireline log interpretation of well Duljan-Re-Entry-01 for the conventional reservoir potential in the sand facies and source rock potential of the shale facies and its mineralogical identification (Part-III).

In Miran-01 and Shahdadpur-01 wells, Sembar Formation is divided into two main parts. The top part of the formation is composed of sand facies whereas the bottom part is composed of shale facies. All the petrophysical parameters have been computed in these two wells in order to evaluate the conventional reservoir potential within the sand facies and to evaluate the source rock potential of the shales and further its clay mineralogy has been determined. The sand are relatively more in thickness in the Miran-01 well as compared to Duljan Re-Entry-01 well with more porosities ranging between 20*25% and higher hydrocarbon saturation which is about 80%. The shales of the formation have relatively less thickness in Miran-01 well and also the DlogR interval in this well is very less. These shales are more water saturated and the visual log analysis also confirms that the sonic and resistivity cross-over is present at a very small interval. Mineral model has shown that the sands are dominant in the upper part and shales with having higher concentration of illite is present in this area. The TOC values of these shales are also very less in this well and shows poor to fair source rock potential. the detailed petrophysical interpretation of Miran-01 well is shown in figure 3.11.

In Shahdadpur-01 Sembar Formation is encountered at 3700 m depth about 227 m thick approximately The calculated petrophysical parameters and indicates that the sands become thicker as we move from north east towards southwest. in the study area. The sands are cleaner having very less amount of shale volume and shows the presence of calcite which could be present in the form of cement within these sands as shown by the mineral model in figure 3.12. Apart from the gamma ray log curve, rest of the log data has not been recorded on the complete interval of the Sembar Formation and only half part of the shale facies has been recorded with the wireline log curves. So the complete interpretation of the shales within Shahdadpur-01 well could not be evaluated due to unavailability of data. The part of the shales which has been evaluated shows the presence of illite and the TOC computed by the density method depicts that these shales have poor source potential in this well, whereas the results computed by the Passey method shows negligible values of TOC.

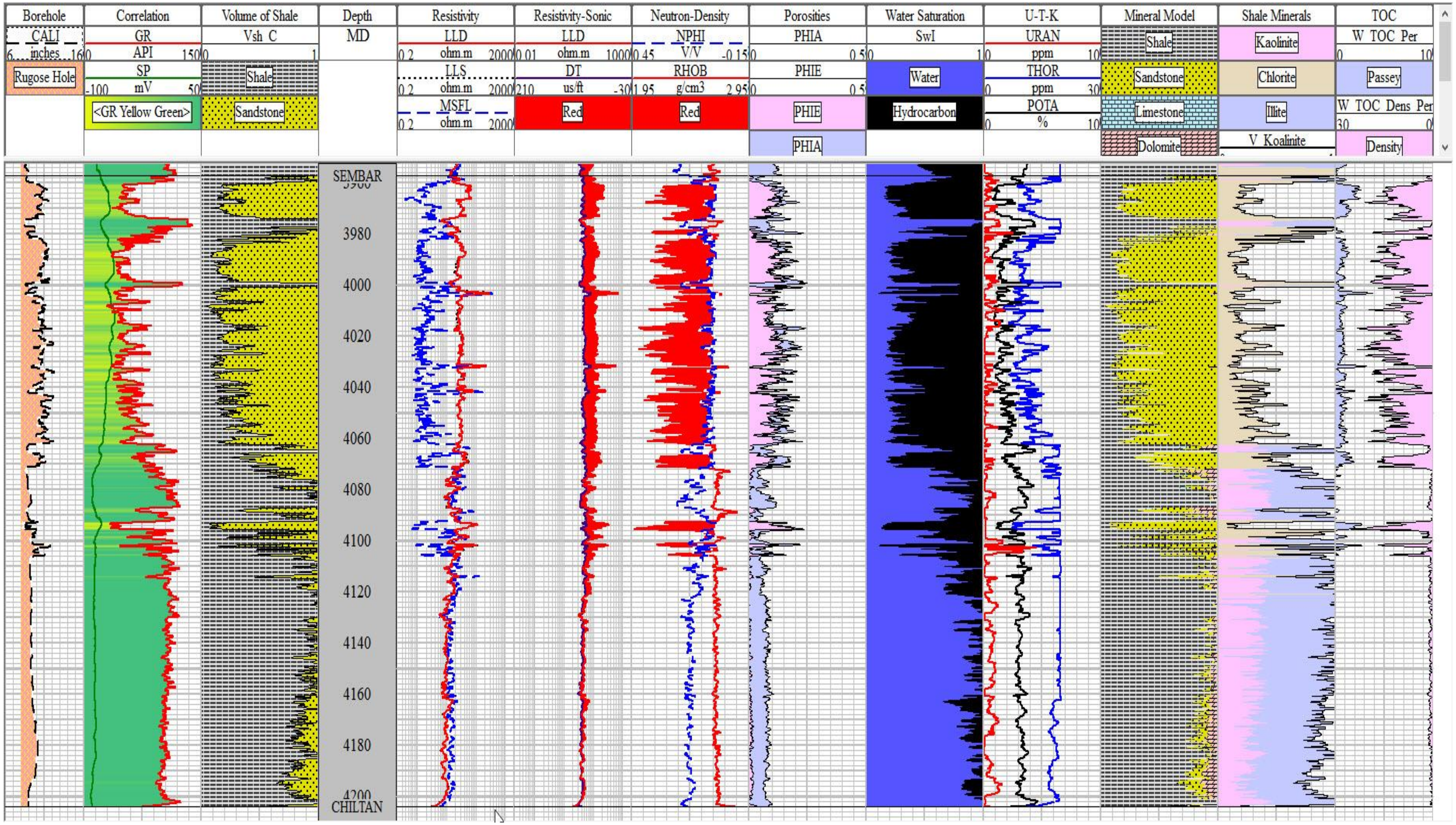

Figure 3.11. Wireline log interpretation of well Miran-01 for the conventional reservoir potential in the sand facies and source rock potential of the shale facies and its mineralogical identification

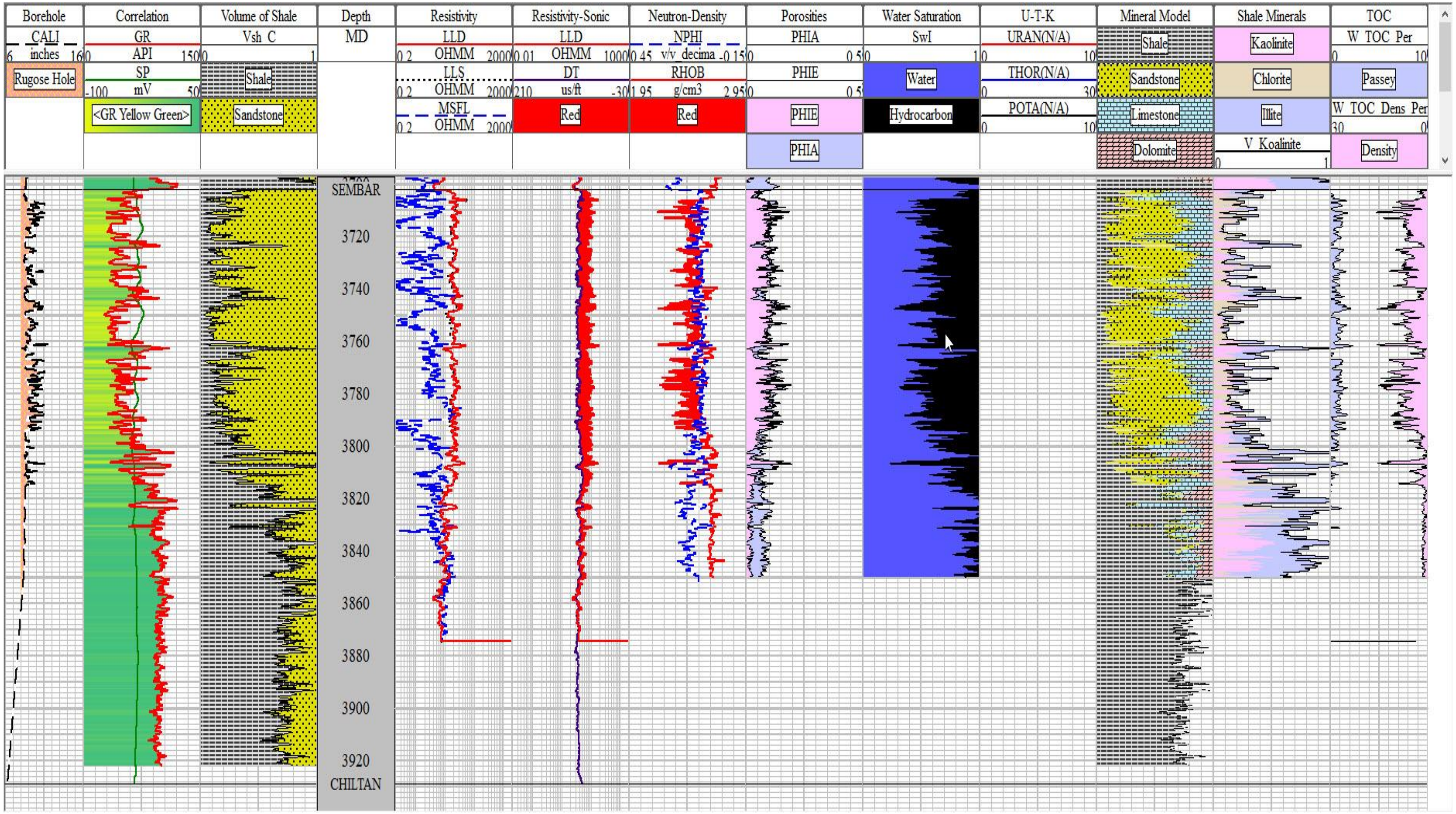

Figure 3.12. Wireline log interpretation of well Shahdadpur-01 for the conventional reservoir potential in the sand facies and source rock potential of the shale facies and its mineralogical identification.

3.5.4 Lithological Identification of Sembar Formation

Lithological identification cross plots, including neutron-density lithological crossplot, M-N crossplot and UMA-DGA crossplot, have been used. These cross plots have been generated for all the three wells for determining lithological variations in Sembar Formation. Density and Neutron log of Duljan-Re-Entry-01 has been used for plotting the data as shown in figure 3.13 Volume of shale was plotted on the z-axis to show distribution of data points as per the colour variations. Red and yellow colour data point having low volume of shale have been plotted on and above the sandstone curve whereas blue colour data point showing maximum volume of shale have been plotted below the dolomite curve depicting high density values. The blue colour area polygon has been marked in order to generate the facies column, which shows the central part of the Sembar Formation i.e shale facies. The top most data points on the cross plot has been marked with the red polygon showing the gas effect and the green colour polygon has been used for sand facies.

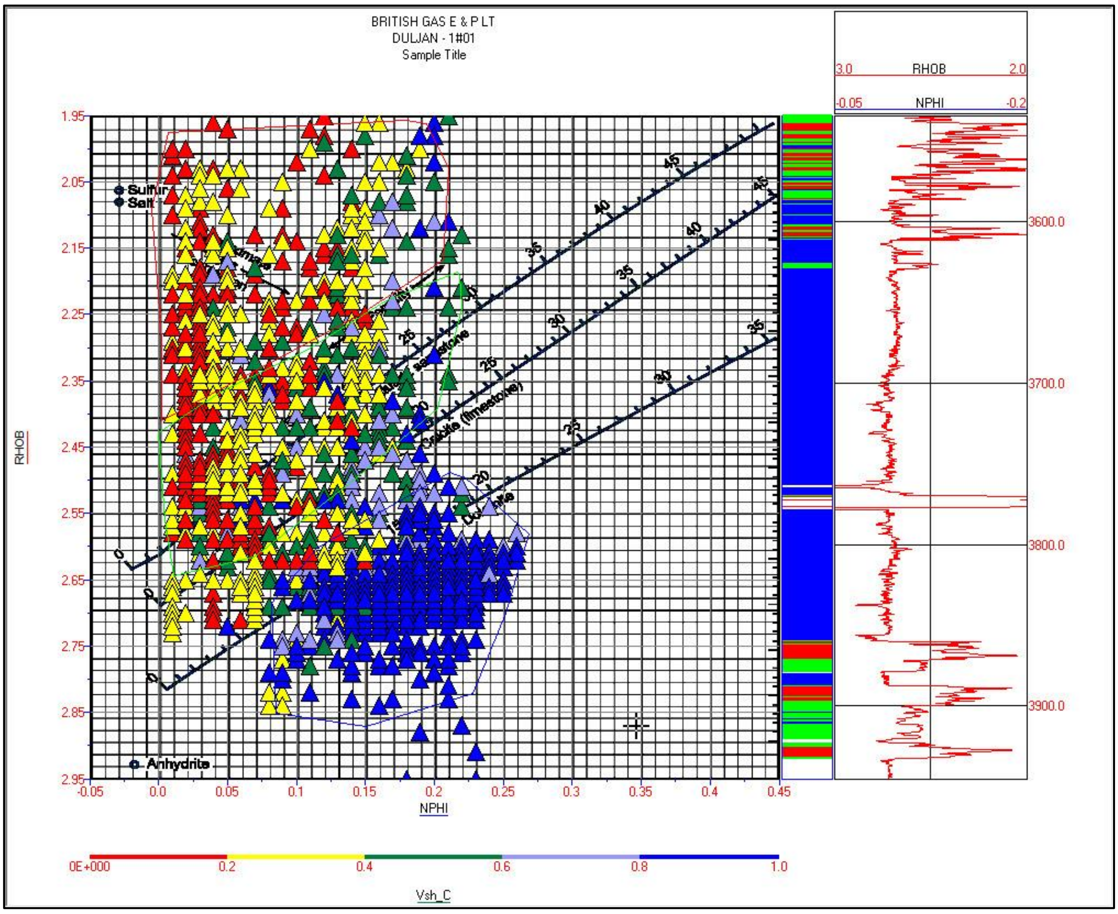

Figure 3.13. RHOB vs NPHI crossplot of well Duljan-Re-Entry-01.

The second crossplot used for the lithological identification is M-N crossplot which is showing the same result as the previous one. Data points falling on the shale region have been marked by the blue area polygon which confirms the middle shaly part of the Sembar Formation as shown in the facies column by blue colour. The sand facies have been highlighted by the green polygon representing the top and bottom part of the formation which also shows the gas effect marked by the red colour polygon.

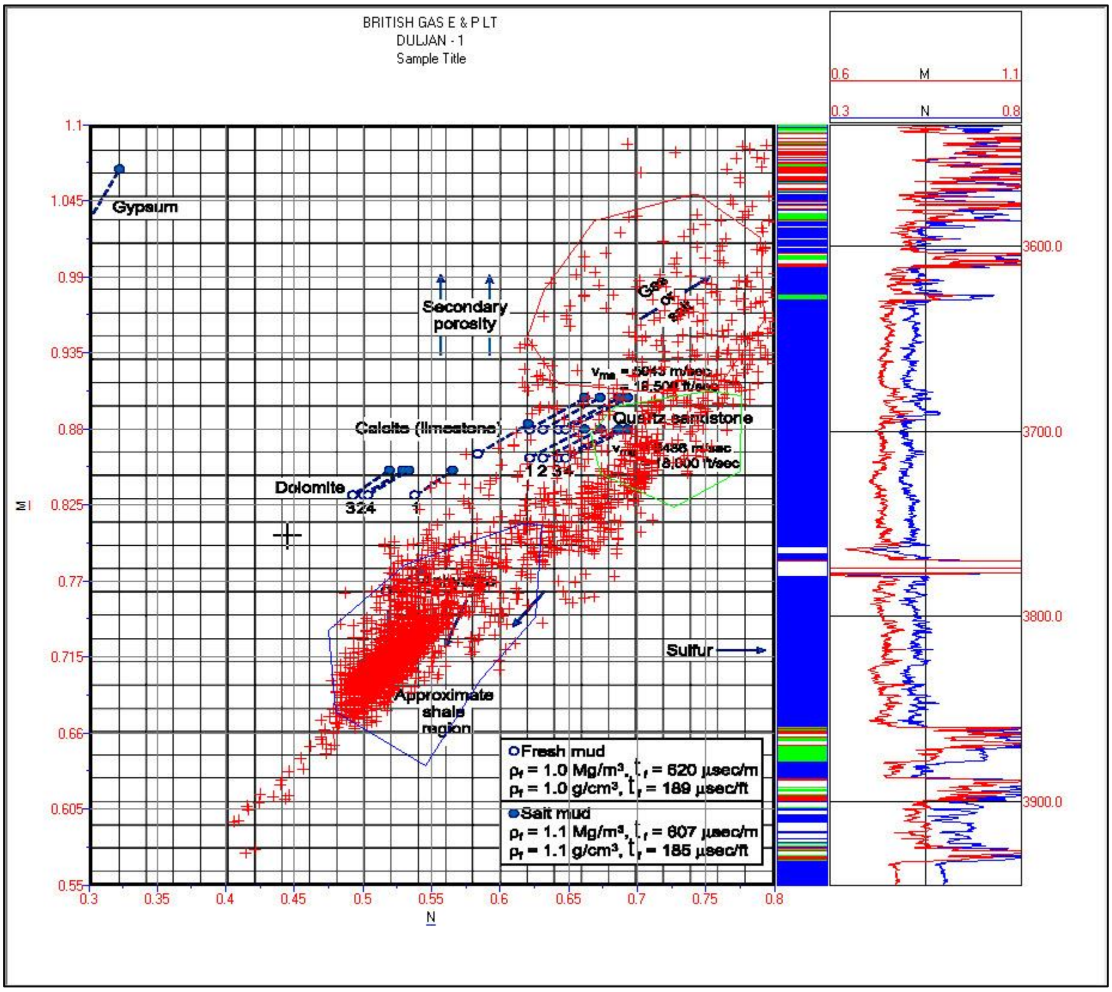

Figure 3.14. M-N crossplot of well Duljan-Re-Entry-01.

The third crossplot used for the lithological identification is the UMA-DGA crossplot. Results of this crossplot also confirms the presence of shale majorly having illite composition and minor kaolinite in the middle part of the formation which confirms the results of the log data analysis. The data points of the top and the bottom part of the formation falls on the quartz region showing the presence of sand depicted by green colour in the facies column. These sands also show the gas effect marked by the red polygon confirming the results of the neutron-density and M-N crossplots.

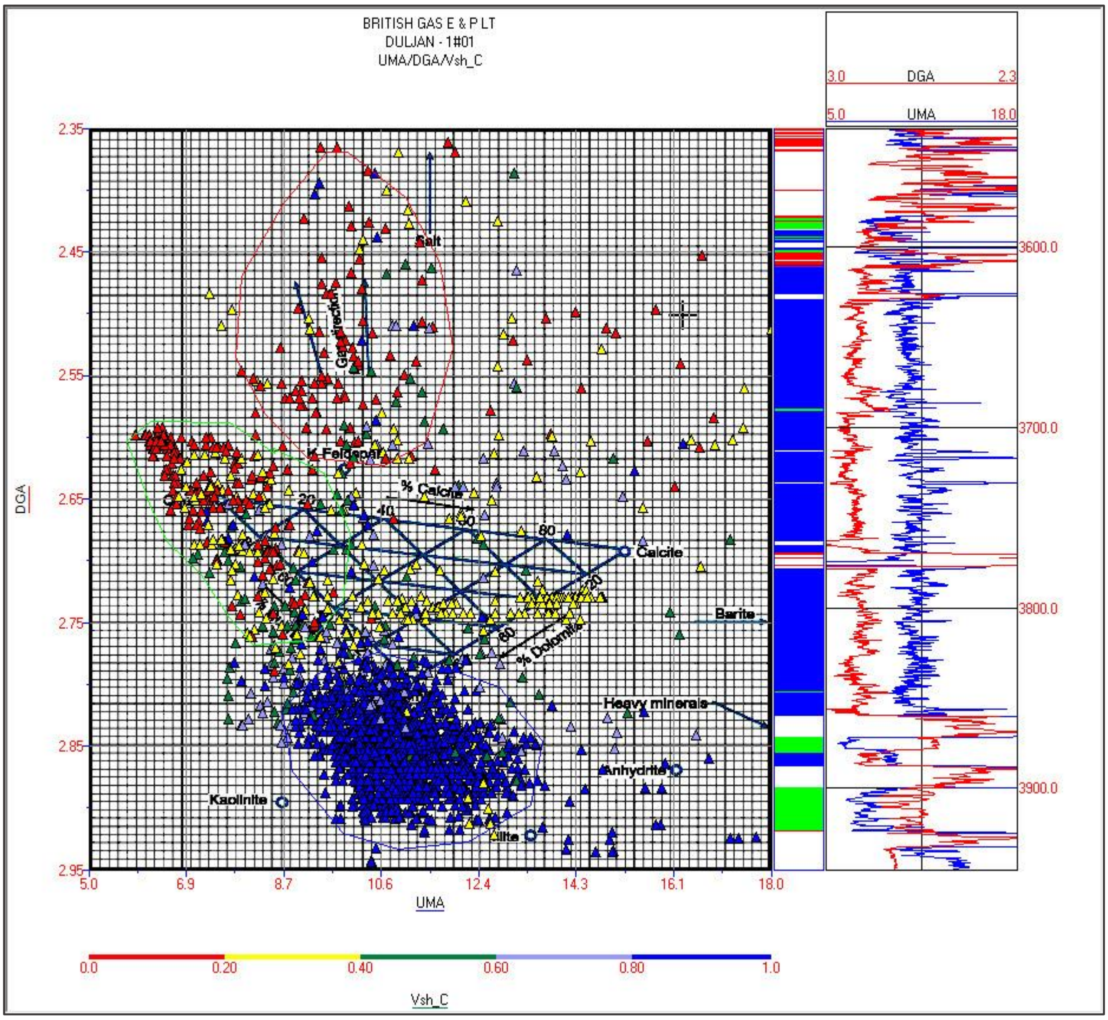

Figure 3.15. UMA-DGA crossplot of well Duljan-Re-Entry-01.

The same three lithological crossplots have been used for the rest of the two wells i.e. Miran-01 and Shahdadpur-01 well. Sembar Formatin has been divided into two parts in both of these wells where the top part showing the sands facies and the lower part presenting the shale facies. Results of all these three crossplots confirms the presence of shale in the lower part of the formation marked by the blue colour polygon and sand has been highlighted by the green colour polygon in the upper part while the red colour polygon showing the gas effect. Apart from the gamma ray log curve, log data in the Shahdadpur-01 well is available only upto the depth of 3850m due to which the complete lower part of the formation has not been evaluated.

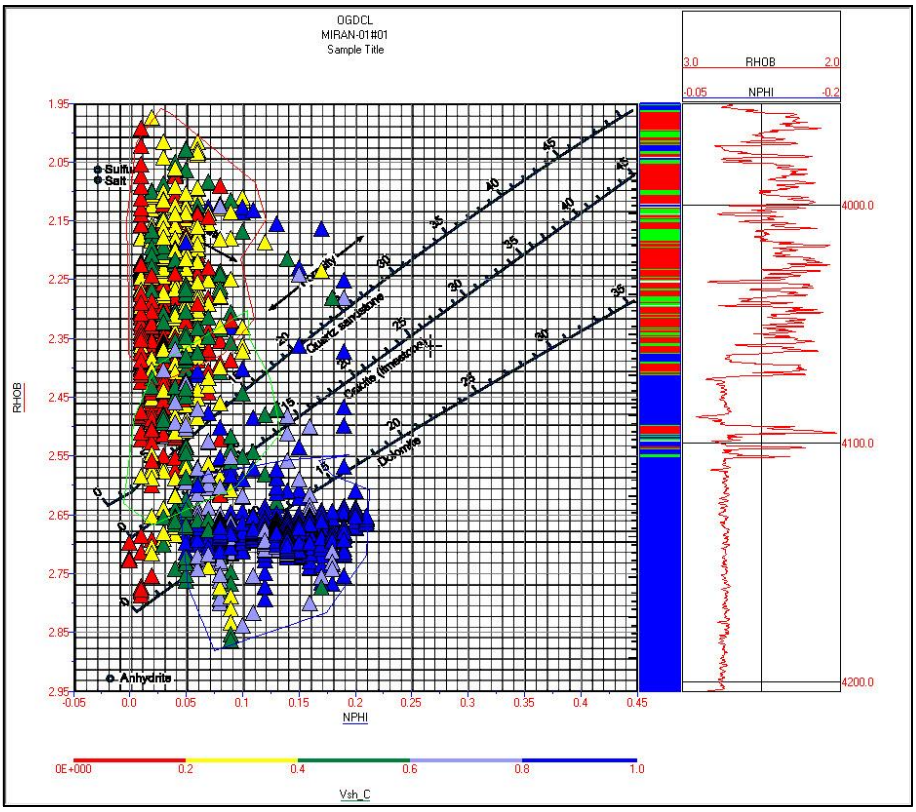

Figure 3.16.. RHOB vs NPHI crossplot of well Miran-01.

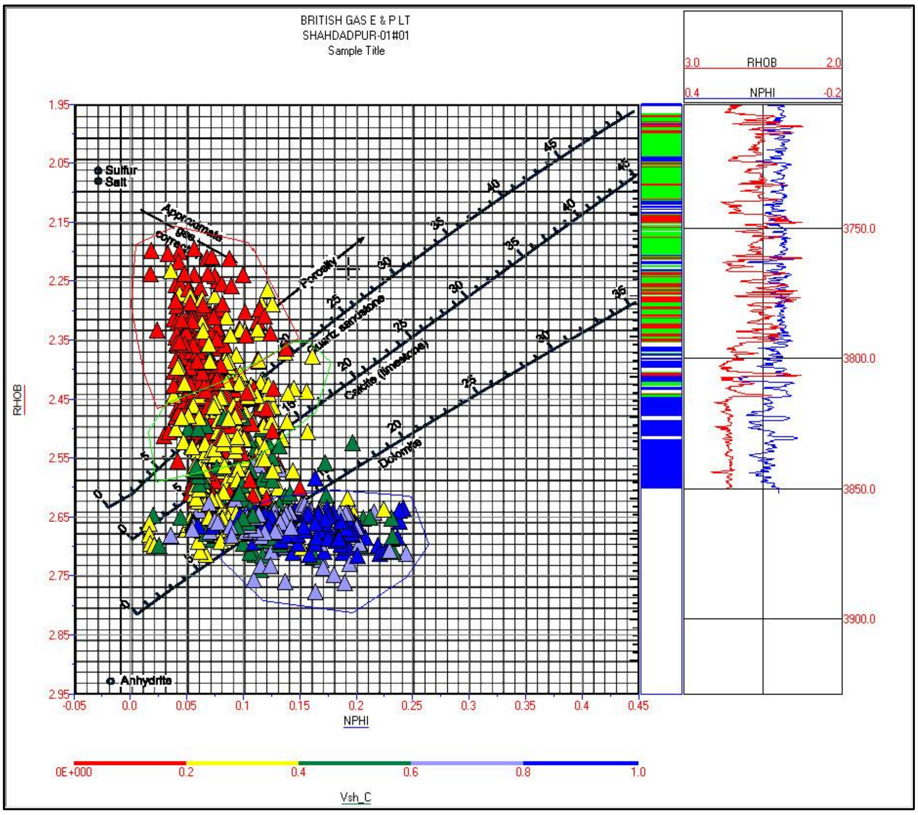

Figure 3.17. RHOB vs NPHI crossplot of well Shahdadpur-01.

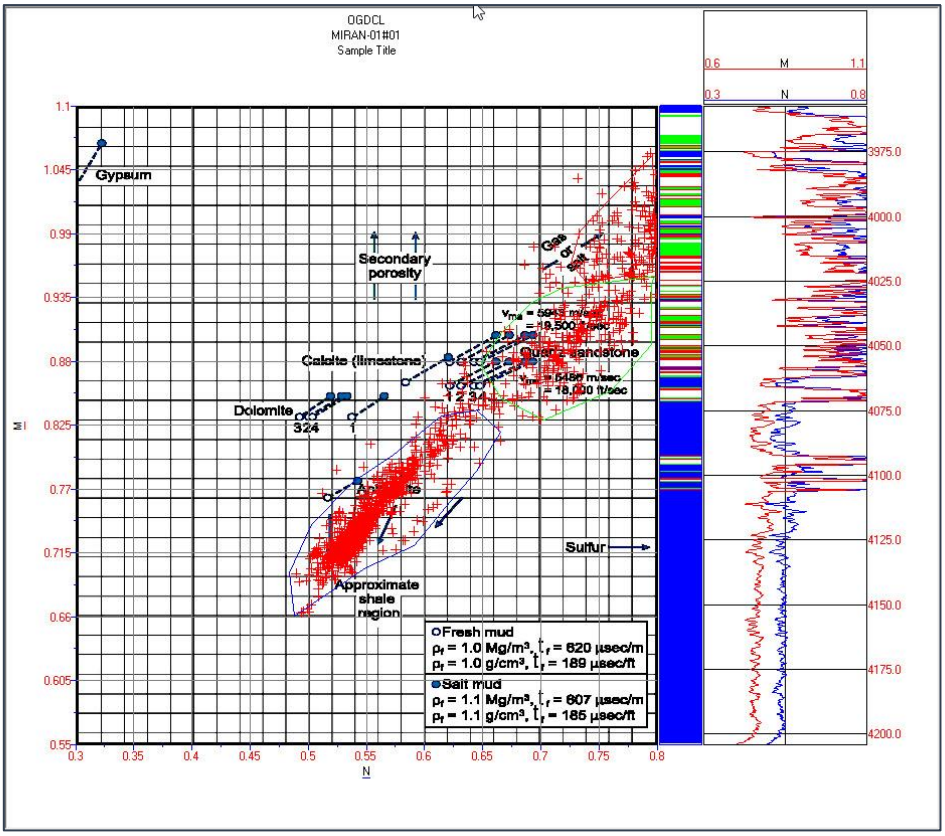

Figure 3.18. M-N crossplot of well Miran-01.

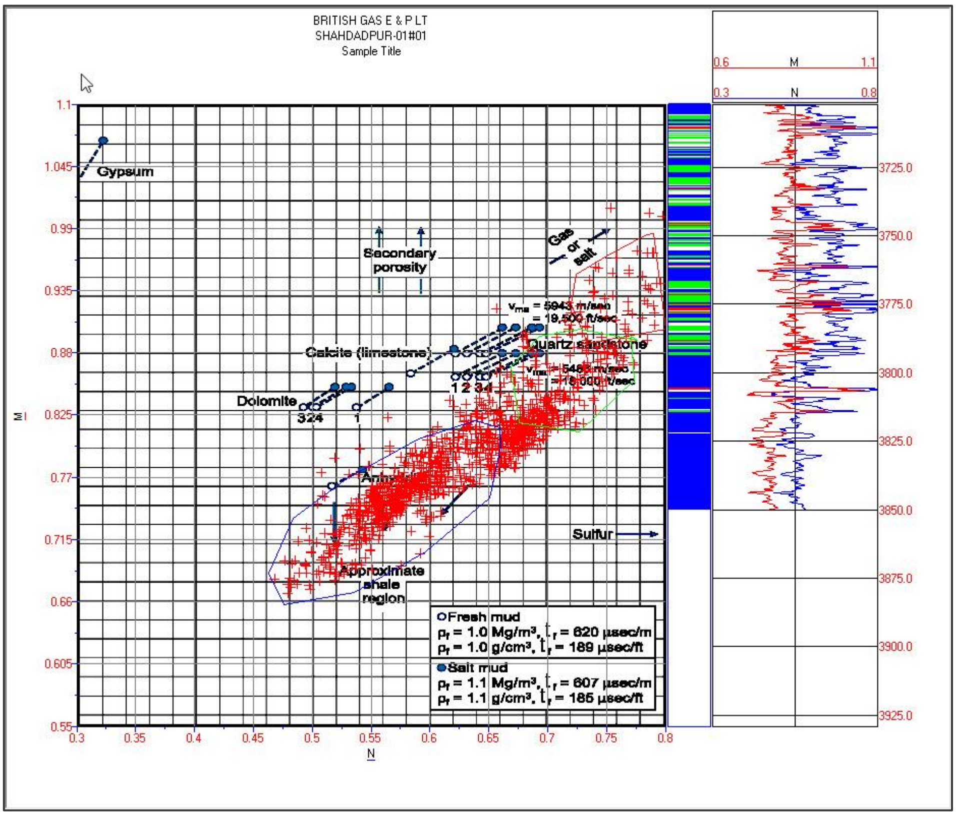

Figure 3.19. M-N crossplot of well Shahdadpur-01.

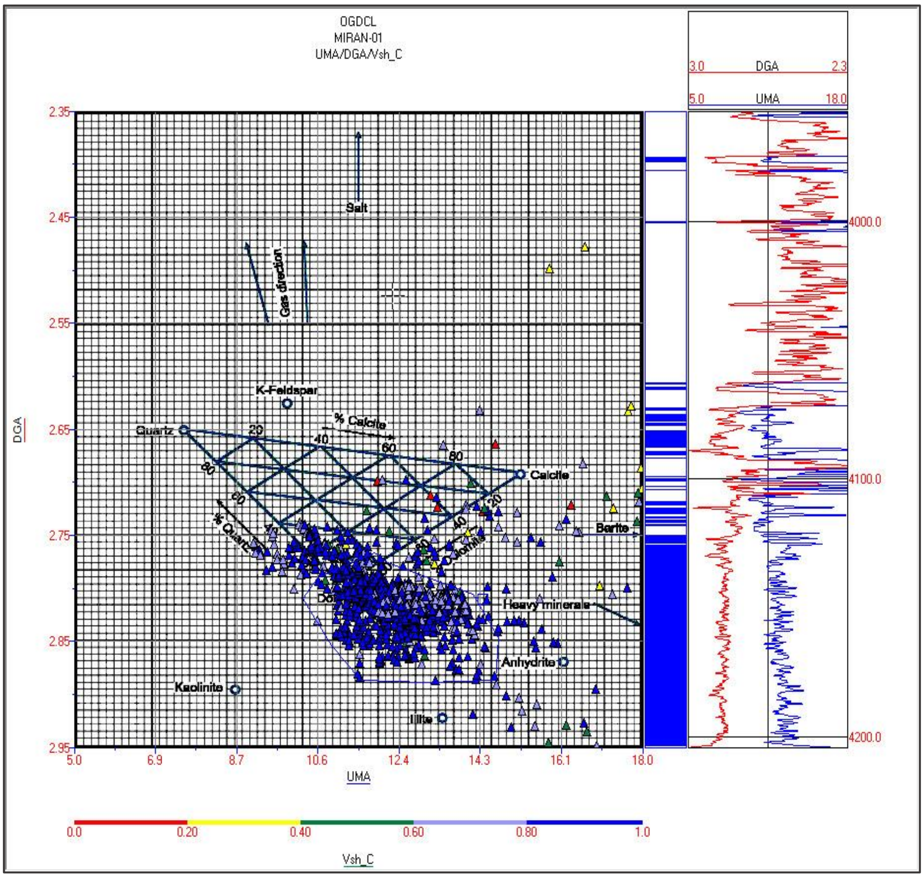

Figure 3.20. UMA-DGA crossplot of well Miran-01

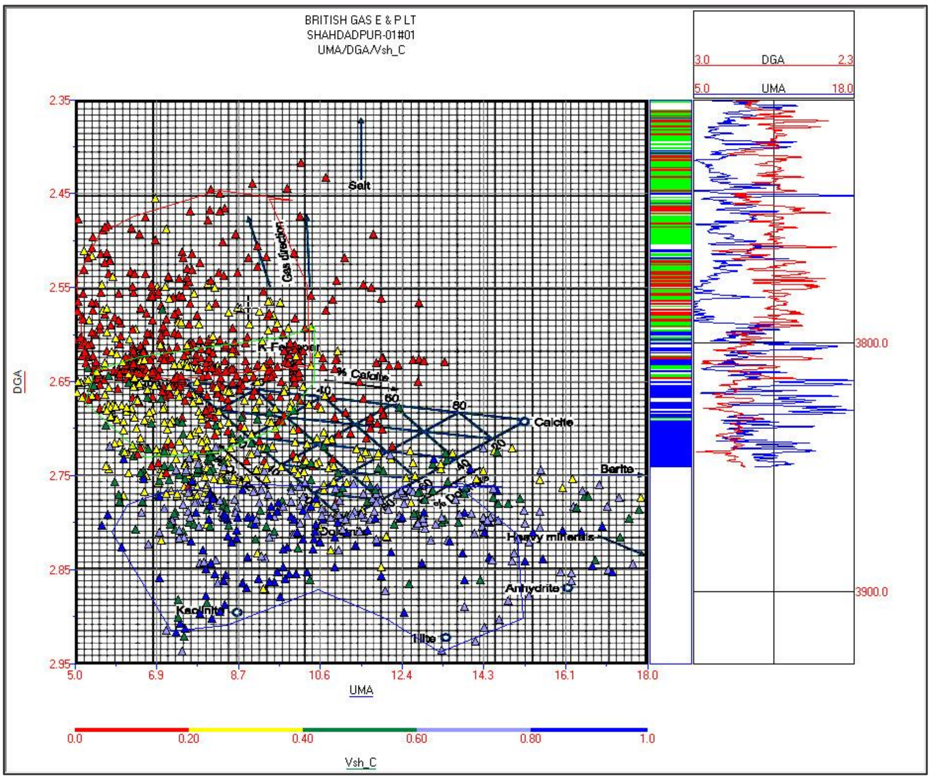

Figure 3.21. UMA-GDA crossplot of well Shahdadpur-01.

3.5.5 Mineralogical Identification

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

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

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

(3) From the volcanic ash.

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

Spectral Gamma Ray log spectral has an undeniable role in the identifying clay minerals. Clay minerals dominating type within the shale facies of the Sembar Formation has been determined using the mineralogical crossplot based on the Spectral Gamma Ray Log (SGR) and Litho-Density Log (PEF). Potassium and Thorium log curves of this SGR log has been used for the interpretation of clay minerals using the Th-K mineralogical crossplot as shown in figure 3.24. The data point showing the maximum shale volume according the Z-axsis have been plotted above the 100% Kaolinite-Illite line (red dash line shown in crossplot). This also indicate that the shale is majorly composed of illite as depicted by the log analysis and UMA-DGA crossplot.

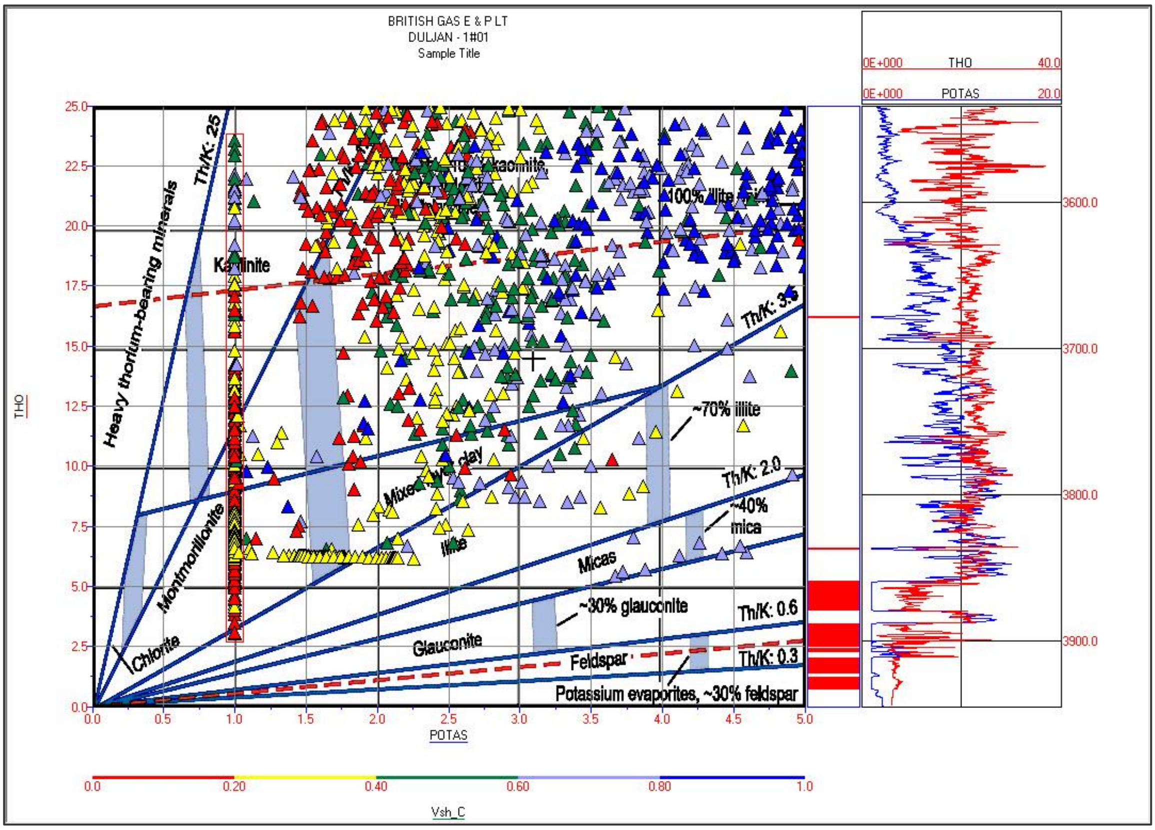

Figure 3.22. Tho vs Pota crossplot for mineralogical identification of Duljan-Re-Entry-01 well.

The other two crossplots use for the mineralogical identification have been computed using the combination of PEF and SGR. The crossplot show in figure 3.25. is generated using the Potassium log curve on the x-axsis and PEF on the y-axsis. The blue colour data point of maximum shale volume have plotted in the illite region. The zone has been highlighted using the blue polygon which shows the middle part of the Sembar Formation in facies column. The rest of the cluster falling in the mixed clay region have been contributed by the top and bottom part of the formation. Same results have also been interpreted from cross plot generated by the combination of Th/k ratio and PEF log as shown in figure 3.26.

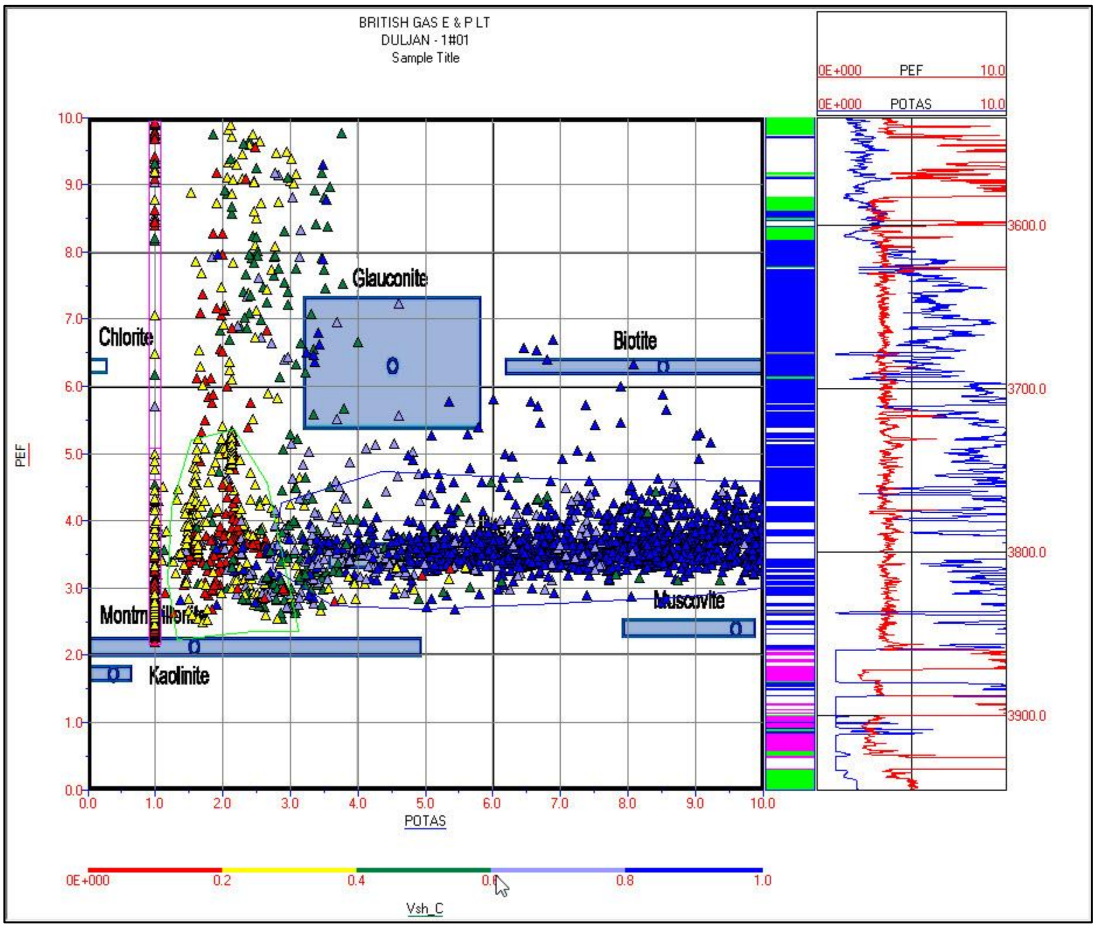

Figure 3.23. Pota vs PEF crossplot for mineralogical identification of well Duljan-Re-Entry-01.

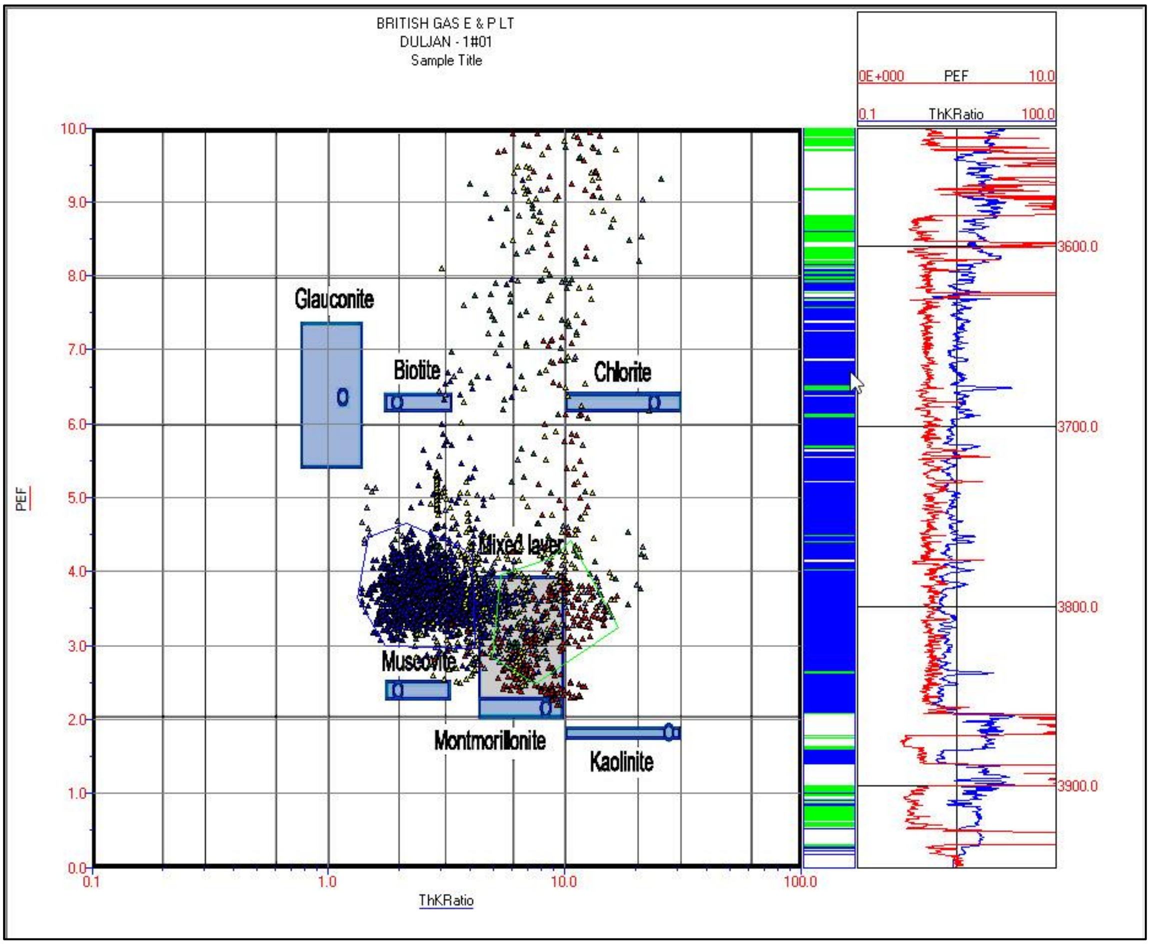

Figure 3.24. Th/K ratio vs-PEF crossplot for mineralogical identification of well Duljan-Re-Entry-01.

The same three mineralogical crossplots have been generated for the Miran-01 well. The bottom part of the formation is having illite mineral as interpreted by the mineralogical crossplots as shown in figure 3.27, 3.28 and 3.29. whereas, the upper part shows the mix clays. However, due to the unavailability of the SGR log these mineralogical crossplot could not be generated for the Shahdadpur-01 well.

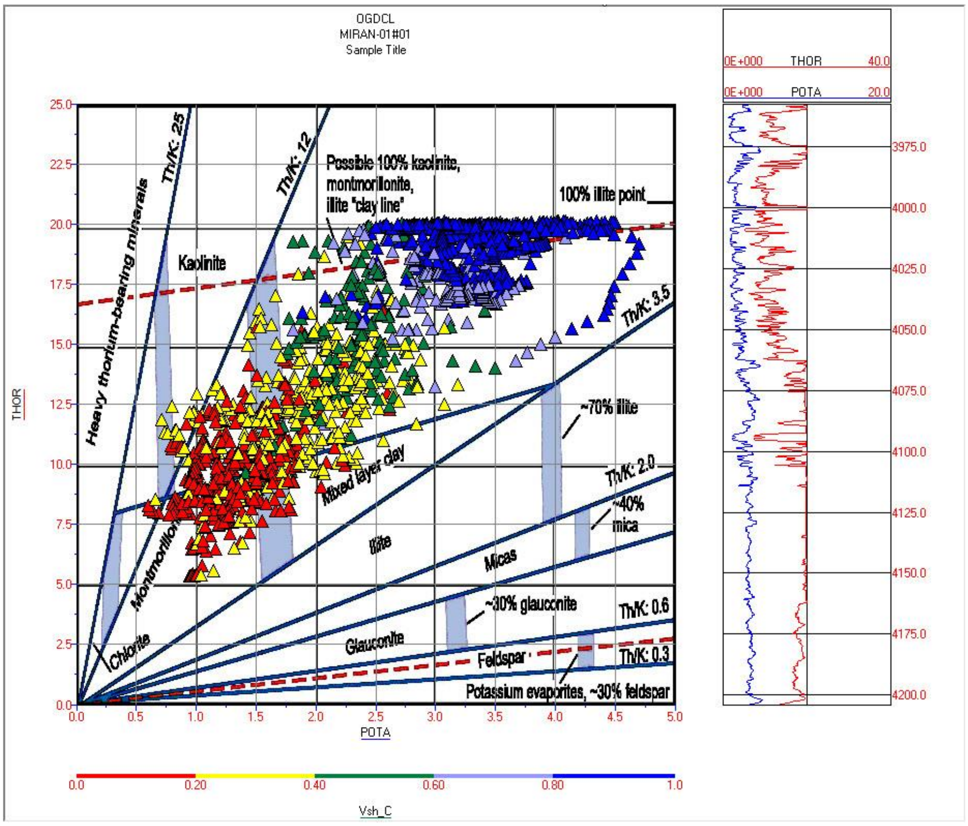

Figure 3.25. Tho vs Pota crossplot for mineralogical identification of well Miran-01.

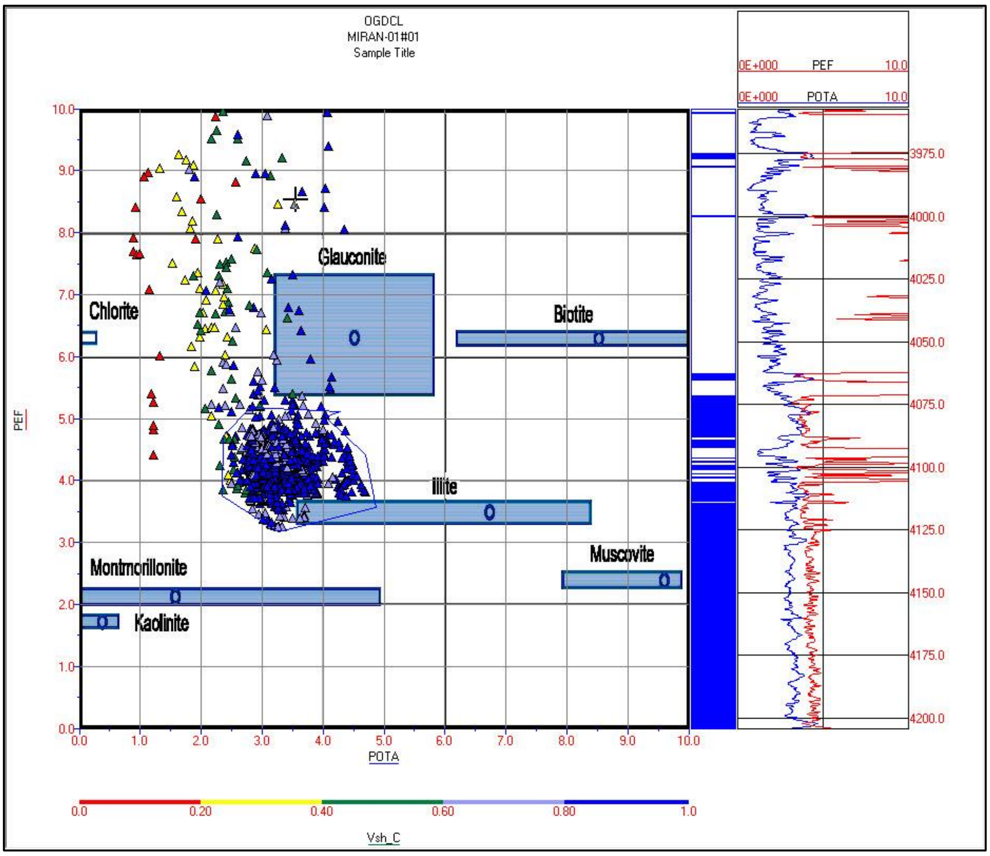

Figure 3.26. Pota vs PEF crossplot for mineralogical identification of well Miran-01.

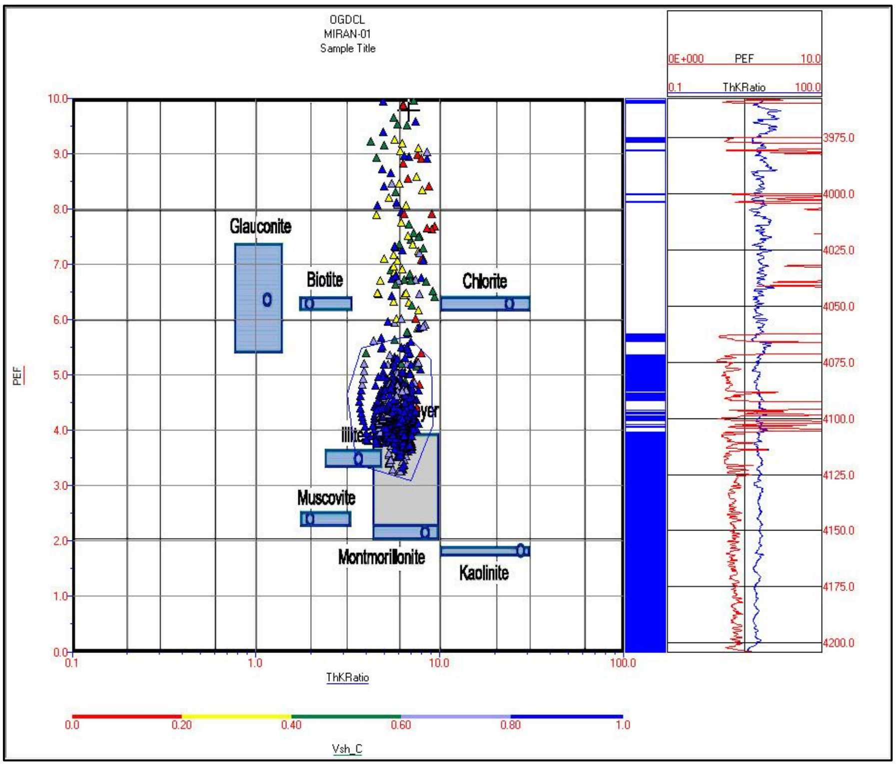

Figure 3.27. Th/K ratio vs-PEF crossplot for mineralogical identification of well Miran-01.

CHAPTER 4
SEISMIC INTERPRETATION

4.1 Seismic interpretation

Seismic interpretation is basically the conversion from seismic data into stratigraphic and structural images by going through different analysis steps. Thus, sewing the present seismic, geophysical and geologic information altogether and then amalgamating them all in a single imagery will give us a close realistic picture of the subsurface. The key objective of this interpretation is to find the source rock potential of Sembar Formation on the basis of detailed attribute analysis. Structural Interpretation is carried out in order to find the structure in the study area and different stratigraphic units are marked on the basis of the contrast in the acoustic impedance of the subsurface strata. The two main methods used for seismic data interpretation includes (Al-Sadi, 1980; Badley, 1985).

(1) Structural Interpretation

(2) Stratigraphic Interpretation

4.1.1 Structural interpretation

Structural analysis can be termed as the study of reflector geometry which help in the demarcation of the subsurface structures where hydrocarbon get concealed after its migration. The main objective of structural analysis is to search out structural traps which contains hydrocarbons. In structural interpreting of the seismic line sections the identification of reflective horizons and picking of seismic travel times for each trace on each horizon were adopted. From this analysis and working of the data we generate contour maps of each reflecting horizon. Synthetic seismogram are often used to calibrate and solve the difficulty of picking horizon times. These subsurface structures includes faults, folds, anticlines, popup structures etc.

4.1.2 Stratigraphic interpretation

In the stratigraphic interpretation, areas which are favourable for accumulation of hydrocarbon which are not formed by the deformation, but in this case these traps are formed by the changes and episodes of deposition. Different stratigraphic features are interpreted which includes pinch outs, reefs, erosional truncations, sand lenses etc. (Robinson and Coruh, 1988; Kearey et al., 2002). Stratigraphic interpretation necessitates elementary subdivision of seismic line sections into succession of reflections which are analysed as seismicity declaration of hereditarily related sedimentary sequences. Deposition gaps/hiatus i.e. unconformity can be drawn from reflection divergence patterns. The existence of unconformity on a seismic line gives erosional and depositional history information of the region and also the information on the environments that were existing at the time of plate movement. The accomplishment of seismic reflection method strongly depends on the type of trap.

According to Badley (1985), in order to investigate the geological and prospect analysis of the area, these type of reflections from the unconformities have to be mapped. When the data resolution is poor and the horizon of interest is too weak to trace over the seismic section it is preferable to pick some dominant horizons on the top and bottom of the horizon of interest.

4.2 Methodology

Following work flow adopted for the 2D seismic interpretation of Gupchani Block is as follows:

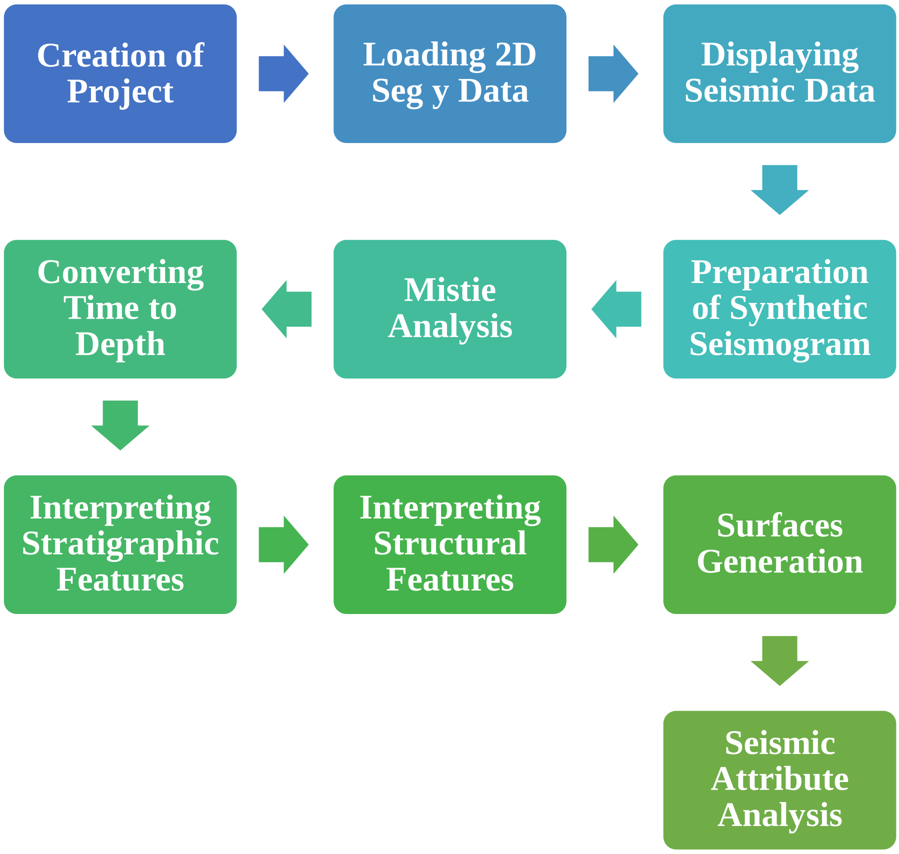

Figure. 4.1. Work flow for Seismic interpretation.

4.2.1 Seismic data loading

Seismic data has been loaded into Greographix software in the SEG Y format of corresponding seismic lines as well as navigation files in order to display the orientation of these lines on the basemap. LAS files of all the three wells Re-entry Duljan-01, Shahdadpur-01 and Mrean-01 along with formation tops and their respective TD charts were also loaded and used for generating synthetic seismogram and hence for horizon picking on seismic sections.

4.2.2 Seismic base map generation

The base map displays the information about orientation and location of seismic lines, their extension, position of wells, concession boundaries and other geophysical information about data. Base map is made by loading the navigation and SEGY's files along with well information in software. Base map provides the plot for contouring. The base map, shown in figure 4.2 represents the orientation of the seismic lines of used for seismic interpretation of research work. Seismic base map includes four dip lines, three strike lines and three wells shown in the base map.

4.2.3 Data QC

Data Quality control procedures are important for:

(a) Detecting missing mandatory information.

(b) Detecting errors made during the transfer or reformatting.

(c) Detecting duplicates.

Seismic data QC is done in order to endure the certainty of the data set before starting the interpretation process. The orientation and the nature of the seismic lines is determined by preparing the basemap of the area using the navigation files. Labelling of the shot points, line names, well names receiver points and ither relevant information is checked. These steps are followed by the calculation of misties within the seismic lines. Here in Gupchani block, no missties were observed on any of the seismic lines. Recording length of the seismic lines is also checked.

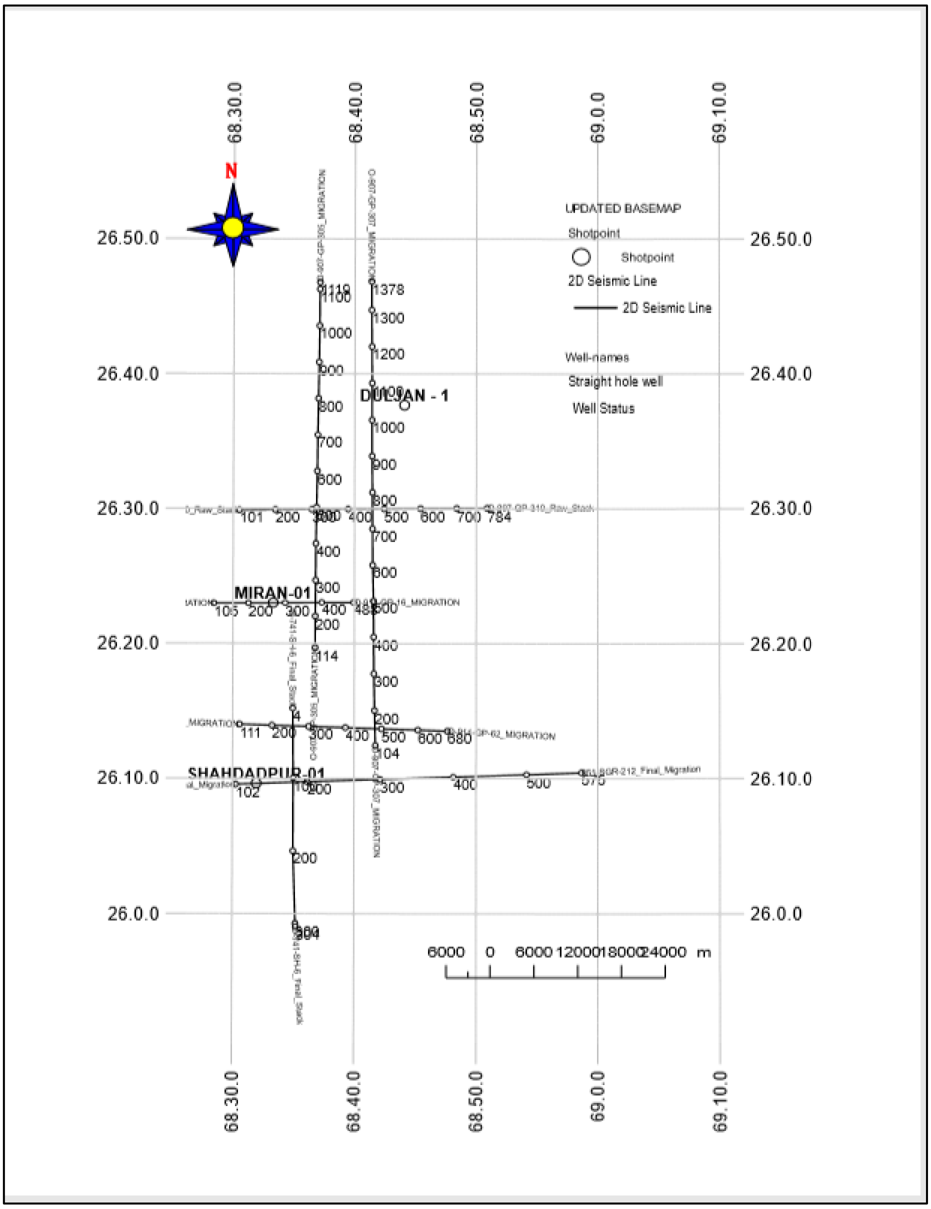

Figure 4.2. Base map showing the orientation of Seismic lines and location of wells.

4.2.4 Correlation of well and seismic datum

Correlation of seismic and well datum was performed by bringing well and seismic on same reference datum. Formation depths were calculated from KB and seismic data was acquired from surface reference datum (SRD). On seismic sections, formation tops were picked by taking SRD and KB on same datum.

Formula used for this purpose is

$$TVD\ seismic = Formation\ top + SRD - KB$$

For Gupchani field, MSL = SRD (MSL = 0 m). By using the above formula, well tops of all the wells measured from KB, were converted into depths with reference to SRD. Further synthetic seismogram was also generated, for well to seismic tie, in order to mark the horizons on each seismic section, accurately.

4.2.5 Generation of Synthetic Seismogram

Synthetic seismogram has been generated for the wells Miran-01 and Shahdadpur-01 because these two wells were located on seismic lines 0/911-GP-16 at SP 250 and 0/851 SGR-212 at SP 110 respectively. For the generation of synthetic seismogram two-way time for each well top is required which was calculated by using depth, sonic log data and replacement velocity of the area. Then Seismically extracted wavelet was used to convolve with reflection coefficient. Time depth chart was prepared by using two way time against each well top. Then that TD was utilized further for synthetic seismogram generation using two wells located on the lines as shown in figure 4.3 and 4.4.

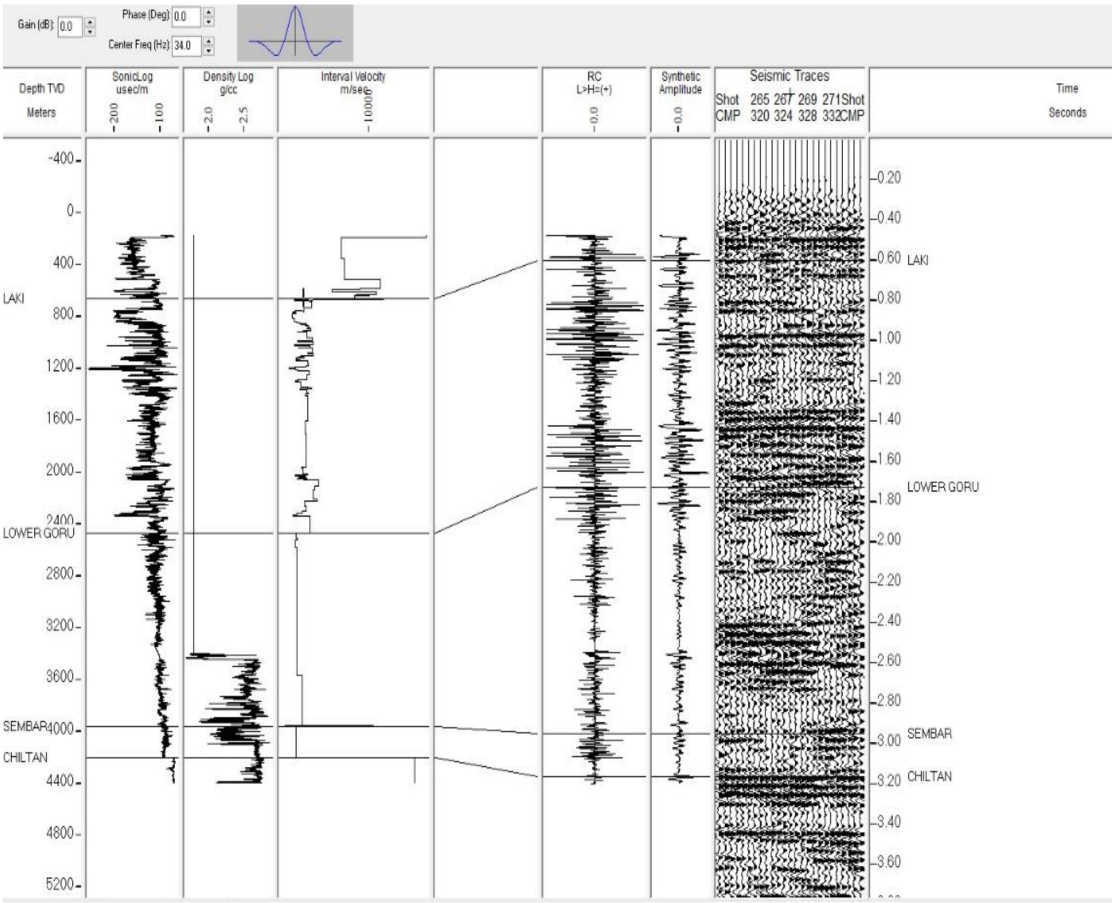

Figure 4.3..Synthetic seismogram generated using well Miran-01 at SP No. 191 of line 0/911-GP-16.

Then these synthetic seismograms were tied and overlaid with their respective seismic lines and corresponding shot points. Actually seismic data is provided in time scale and well tops are given in depth scale as horizons could not be marked in time domain so, the purpose of generation of synthetic is to find two way travel time against each depth for marking of horizons. Using synthetic seismogram four horizons named as Laki Formation, Lower Goru, Sembar Formation and Chiltan Limestone have been marked on the seismic lines. Then these marked seismic lines were tied with remaining lines via loop tie to mark the above said formations.

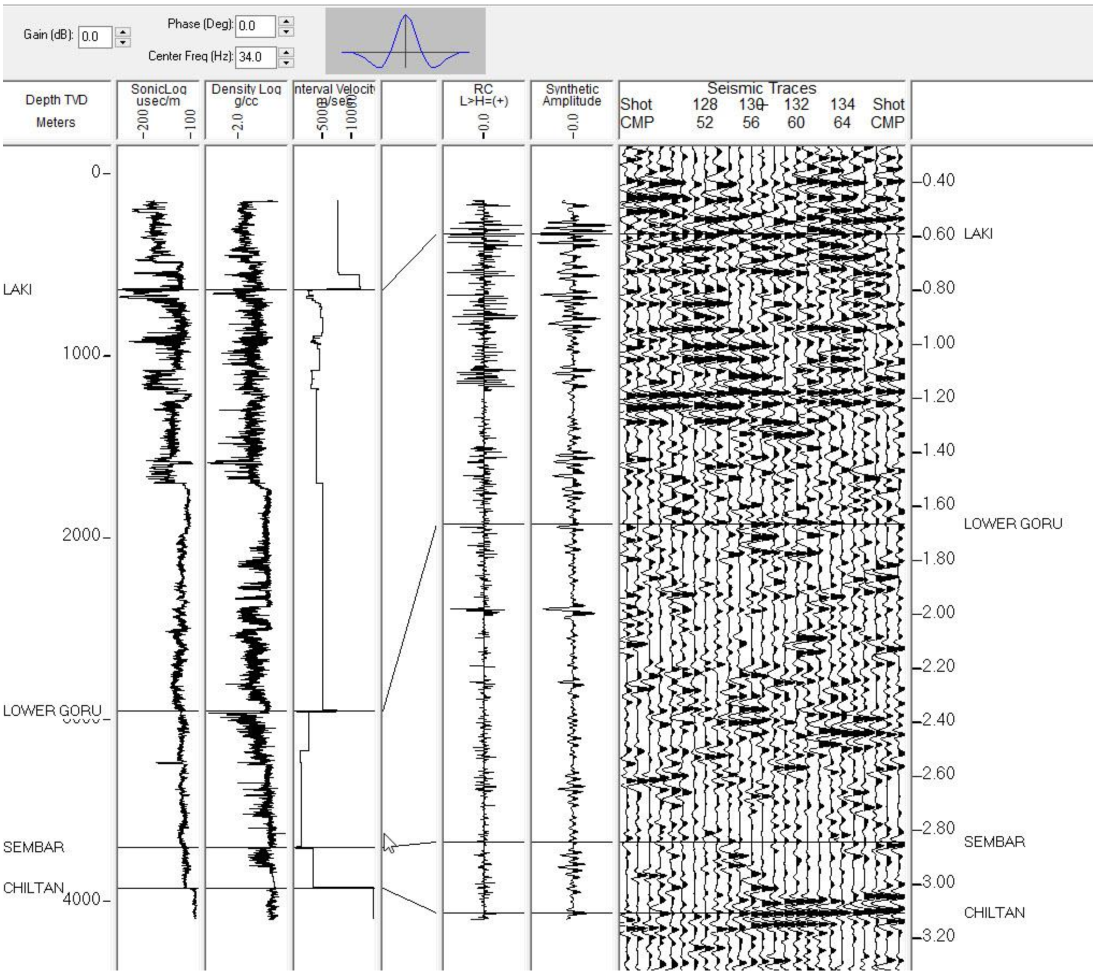

Figure 4.4. Synthetic seismogram generated using well Shahdadpur-01 at SP No. 110 of line 0/851SGR-212.

4.2.6 Horizon Picking and Fault identification

Miran-01 well lies on the seismic line 0/911 GP-16 while Shahdadpur-01 well is located on the seismic line 0/851-SGR-212. Seismic lines with overlaid synthetic are shown below along with the interpreted seismic sections in the figures 5.9 and

5.10. Four horizons, as discussed in section 4.2.5, have been marked after correlation and tying with the other seismic lines by pink, yellow, blue and green colour respectively. The data quality of all the seismic lines is poor to fair so by keeping in mind the geological position of the study area, normal faults have been marked on all the seismic lines. Out of seven lines, four dip lines are extending in EW direction, while three strike lines are running in NS direction. By the first look on all the seismic lines, it is clear that the area is structurally disturbed and lies in the extensional regime.

4.2.7 Seismic attributes

A number of attributes like amplitude, frequency, phase, energy and RMS have been applied to those seismic lines on which the well is located and where the data quality is quite fair along with seismic interpretation between the time window of Laki and Chiltan formations to get the idea about reflector continuity and fault identification (Figures 4.5,4.6,4.7 and 4.8). As seismic data set is of 2D so the attributes cannot be applied with the confidence. Also hydrocarbon presence in the form of sweet and bight spots along with the structure cannot be validated with the help of seismic data set alone. Further outputs after attribute application have not come up to the desired level.

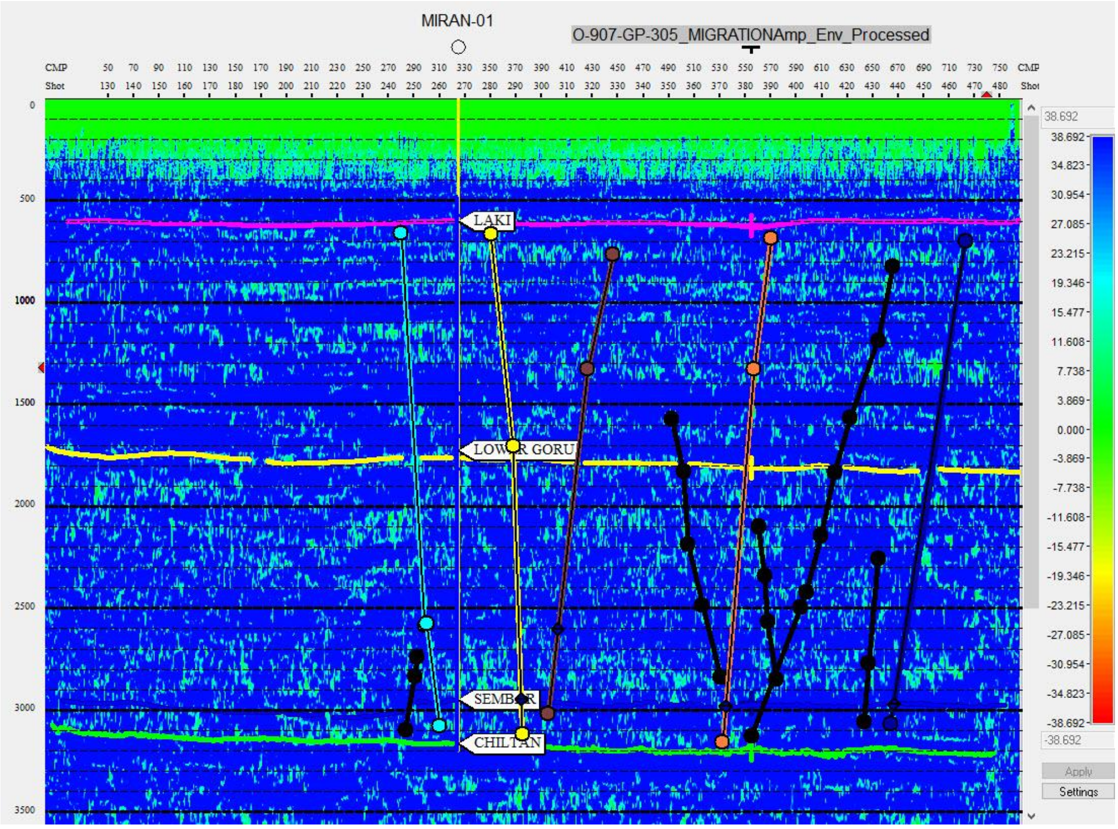

Figure 4.5. Showing the amplitude envelope attribute on seismic line O/911-GP-16

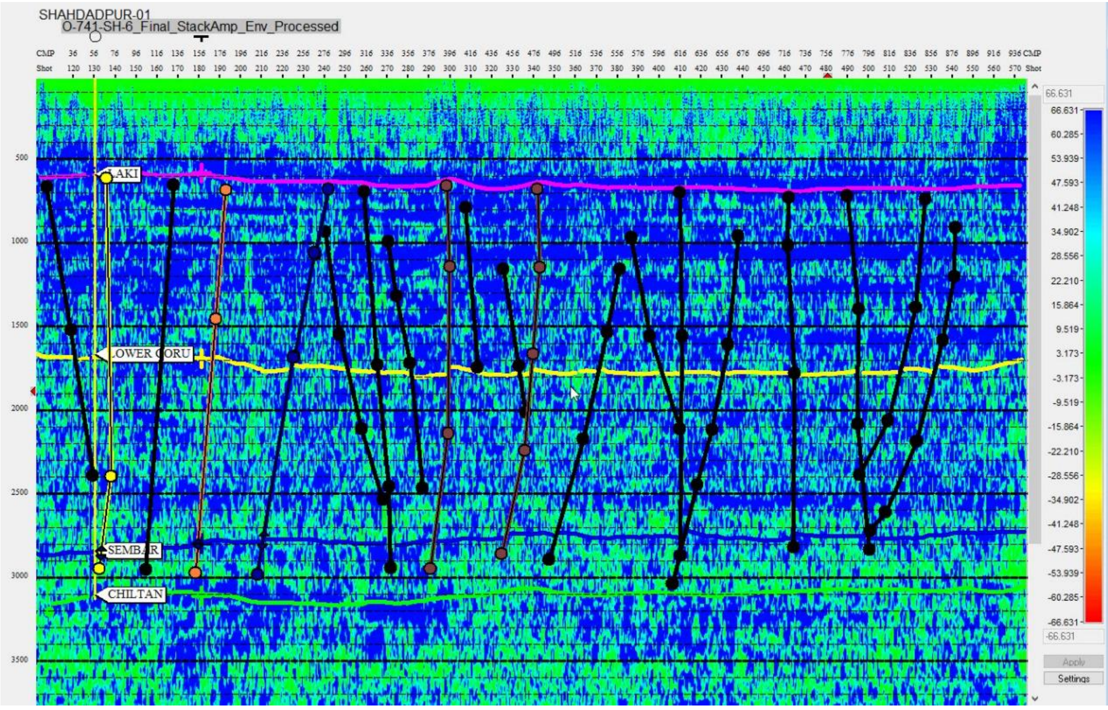

Figure 4.6. Showing the amplitude envelope attribute on seismic line O/851-SGR-212.

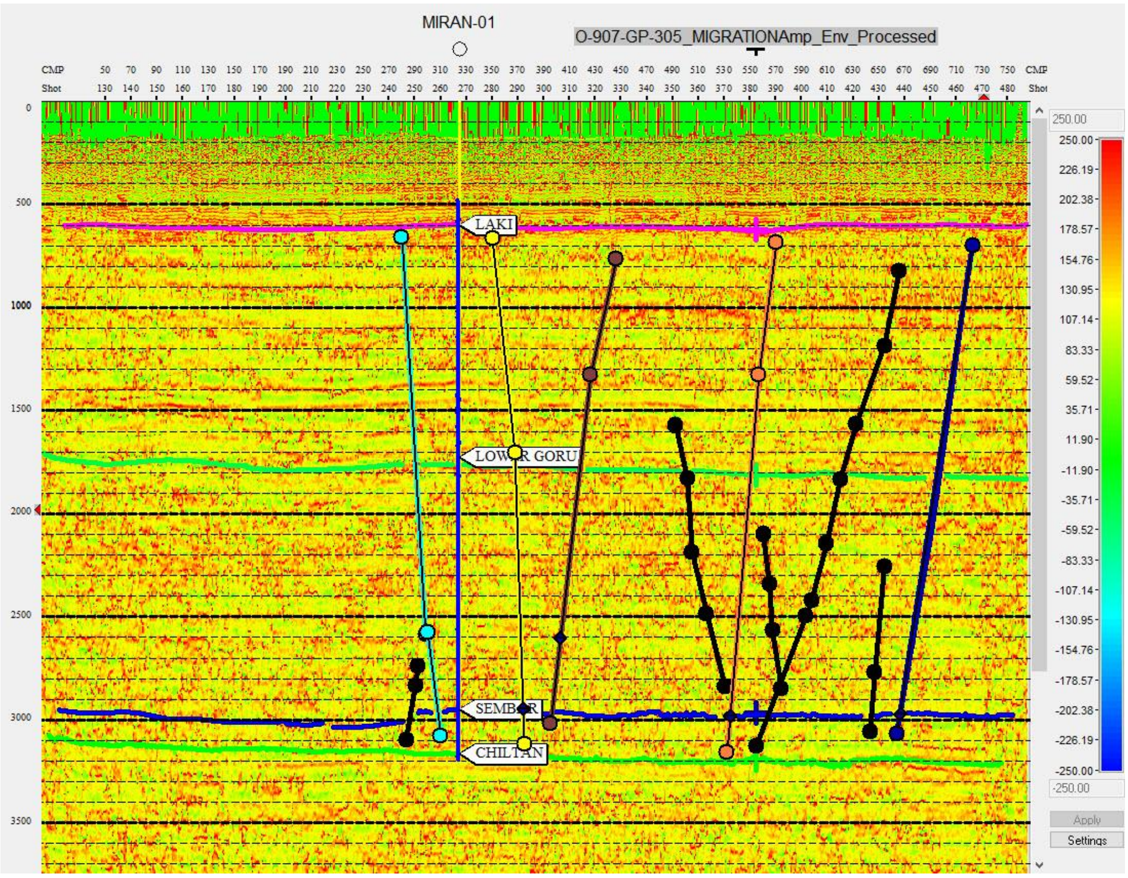

Figure 4.7. Showing the frequency attribute for the line O/911-GP-16.

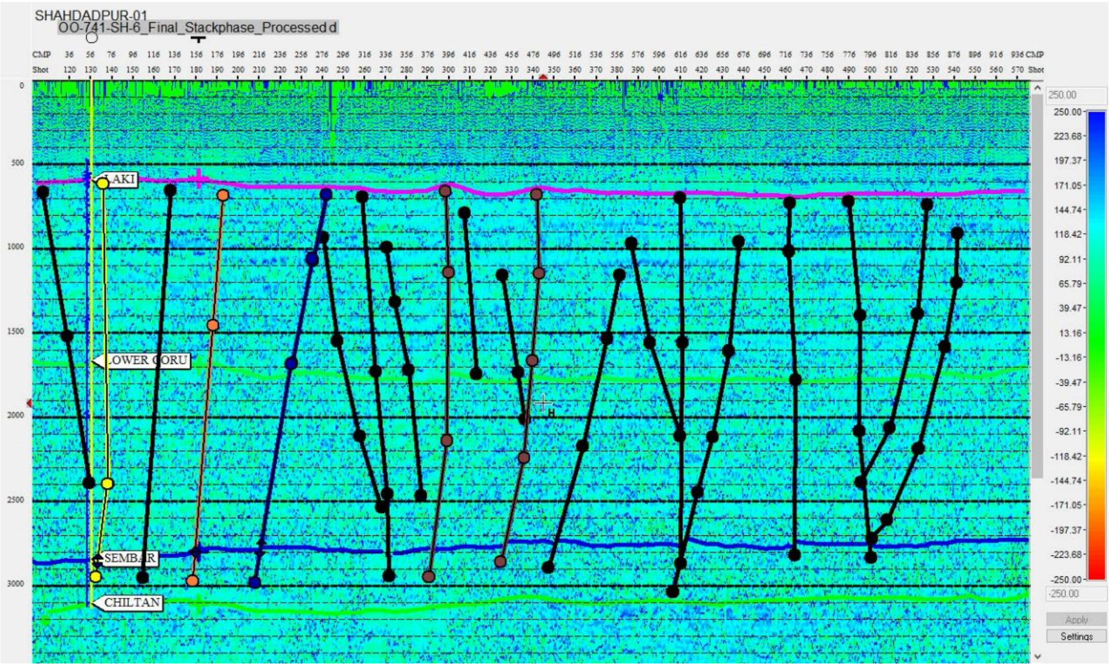

Figure 4.8. Showing the frequency attribute for the line O/851-SGR-212

4.3 Seismic interpretation discussion

Geologically the Gupchani Block lies in extensional regime, so the interpretation of seismic lines was started by observing the discontinuity in the amplitudes and sense of displacement of the horizon/reflector. All the seismic lines show the structural variations. The deepest horizon marked is Chiltan Limestone of Jurassic age and all the faults are originating above this level several faults have been identified, marked and assigned different names. Only three faults have been correlated on all the seismic sections named as F1, F2 and F3 represented by blue, orange and yellow colours. By structural analysis, it has been observed that the lines show extensional tectonics with normal faulting.

The faults are normal, and their nature is planner to sub-vertical. The throw of major faults at Sembar level is negligible which marks/shows the extensional activity from early to late cretaceous. Displacement along the fault at Lower Goru level is maximum which increases progressively upwards in the recent ages. Over all, horst and graben structures within the study area are bounded by steep linked faults which also show the sense of obliqueness along them suggesting the involvement of strike slip component. Line length of dip lines are relatively less as compared to strike lines. No prominent structure was observed on the strike lines while horst and graben can clearly be observed on the dip lines with minimal throw. The interpretation of seismic data has been done on the G-verse utility of Geographix software. The interpreted seismic cross sections along with the marked horizons and interpreted faults have been shown in figures 4.9, 4.10, 4.11, 4.12, 4.13 and 4.14.

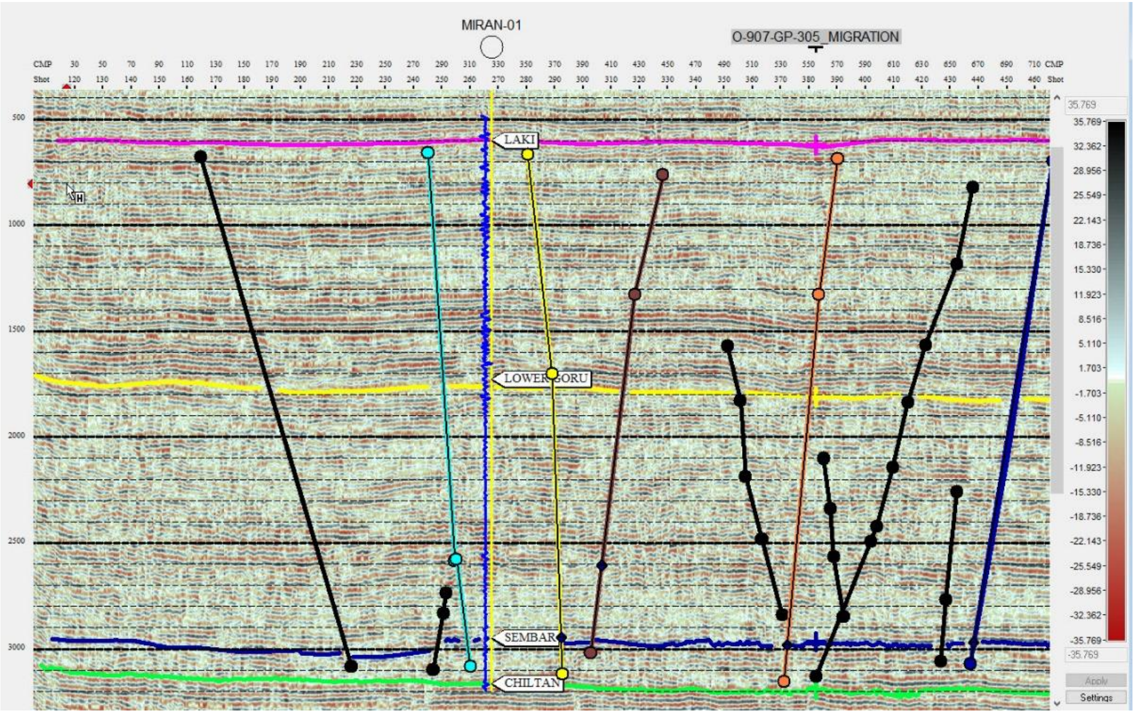

Figure 4.9. Shows Sembar Formation and fault identification on line O/911-GP-16.

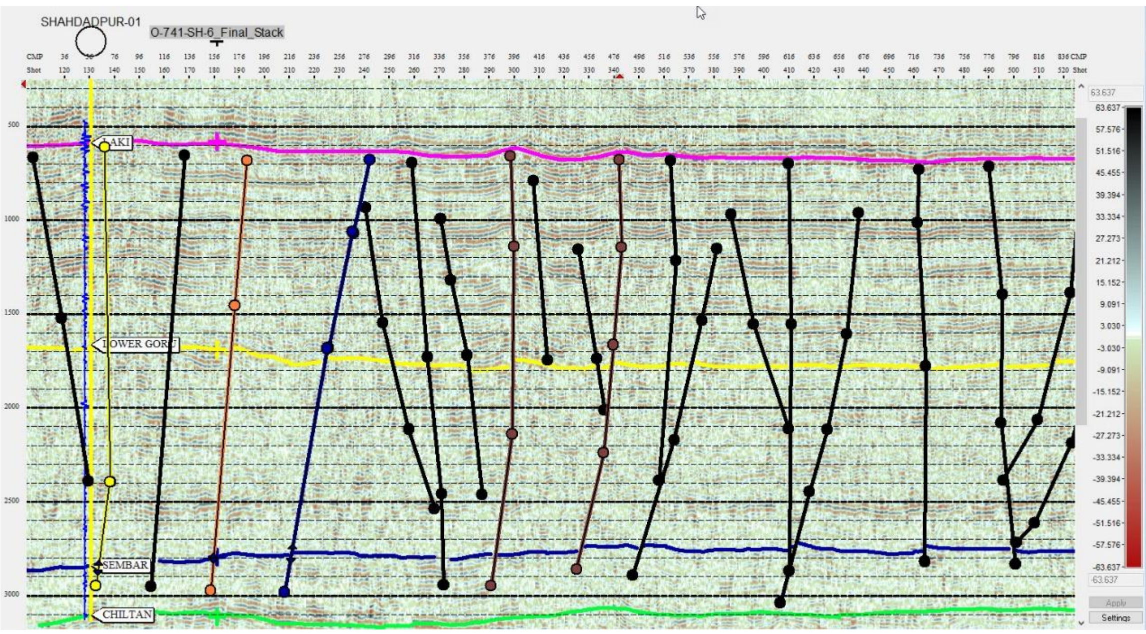

Figure 4.10. Shows Sembar Formation in blue marker and fault identification on line O/911-GP-62.

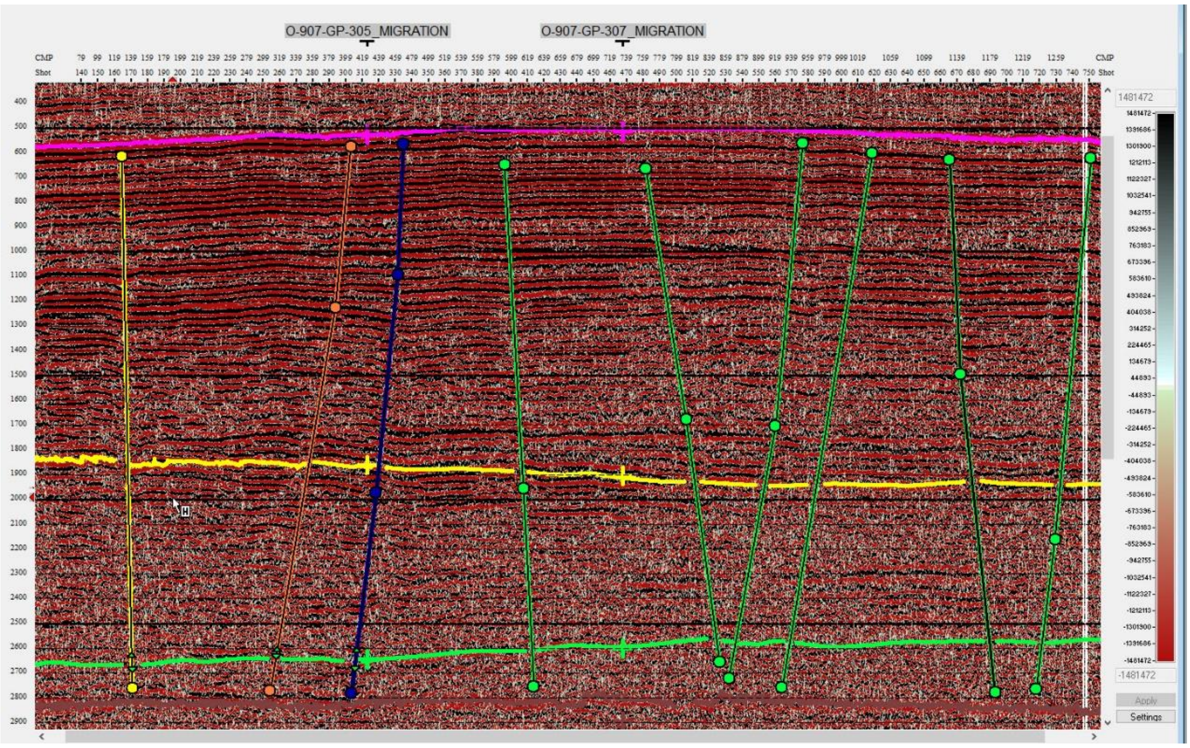

Figure 4.11. Shows Sembar Formation in blue marker and fault identification on line O/911-GP-213.

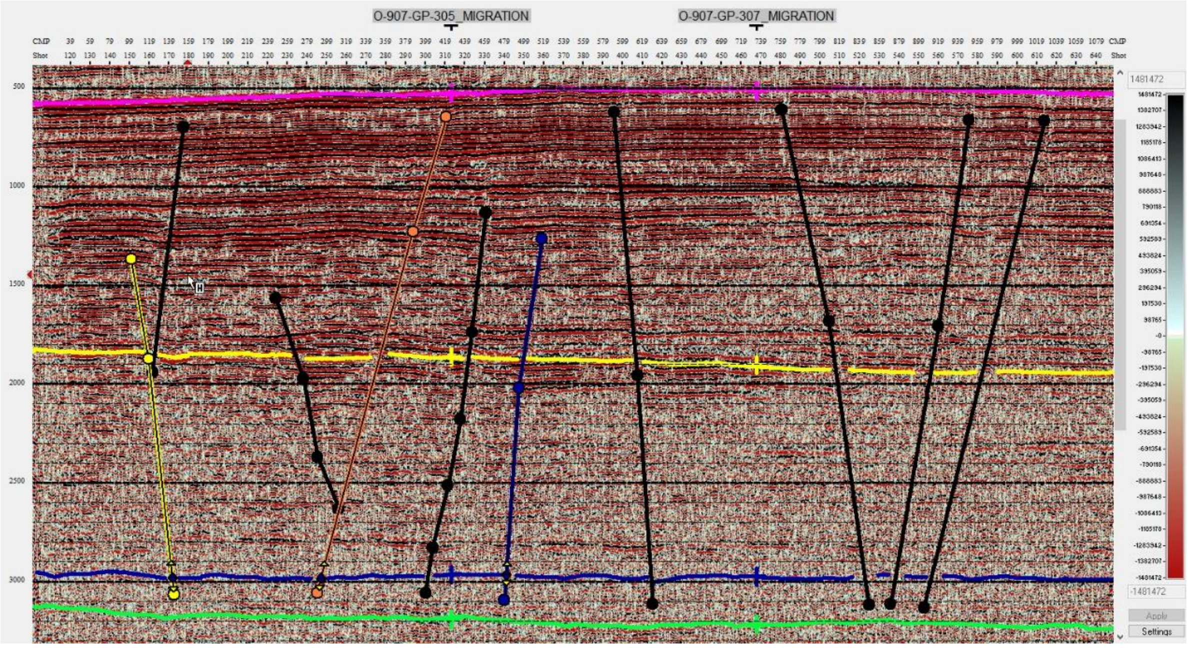

Figure 4.12. Shows Sembar Formation in blue marker and fault identification on line O/911-GP-310.

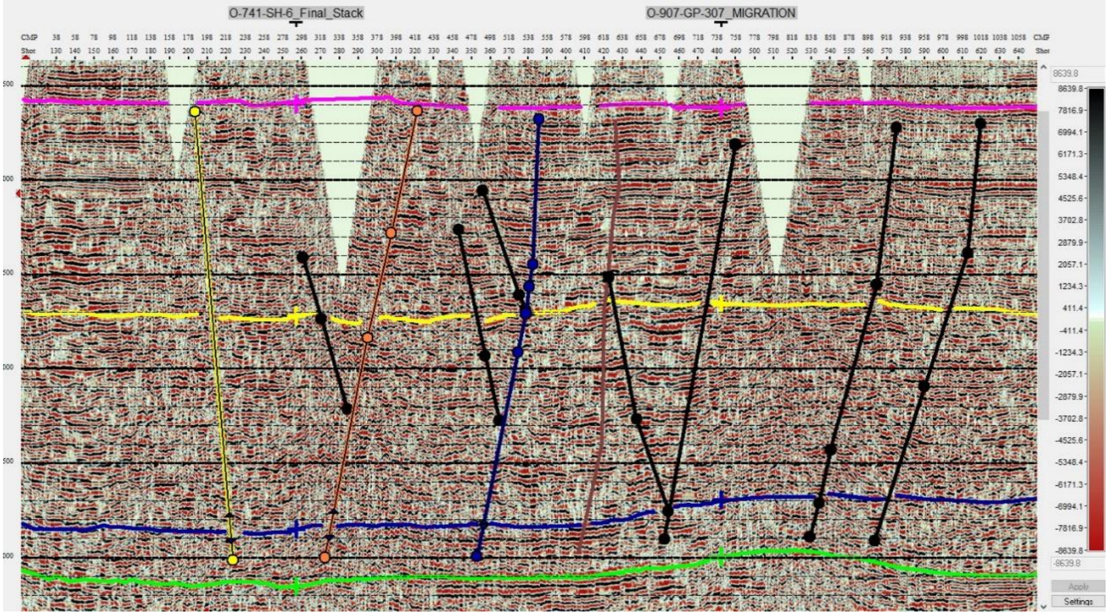

Figure 4.13. Shows Sembar Formation in blue marker and fault identification on line O/851-SGR-212.

4.4 Contour mapping

Final interpreted results of seismic data are shown by contour maps. Contour maps presents a three dimensional feature on a two dimensional flat surface (Coffeen, 1986). These contour maps show the orientation, dip, structural relief, faulting and folding of formations in subsurface. These time and depth surface maps have been generated in Geographix software. Time contour map is converted into depth map by applying following equation $S = V*T/2$.

As main focus of the research is on Sembar Formation, so the surfaces were generated only for Sembar level to check the presence of possible lead. As shaly part is suitable for unconventional reservoir but the target was to map the top sand part for conventional hydrocarbon resource. As top part of Sembar Formation is having fair amount of sand so the conventional exploration technique can be applied to that part. After seismic interpretation, grid maps for time and depth of the marked horizons were generated separately on base map. Only the correlatable major three faults which are labelled as fault F1, fault F2 and fault F3, have been marked on the time and depth surfaces. Contour interval for time map is 20 ms while for depth map is 10 m.

Contour maps of Sembar Formation shows the presence of major three faults N-S oriented and dipping in west direction. Time increases to NW-SE direction in the area while reddish orange colour in time and green colour in depth map shows NE-

SW trending positive structure. The contour values surrounding the well fairly matches with the values obtained from the synthetic seismogram which justifies the structural interpretation.

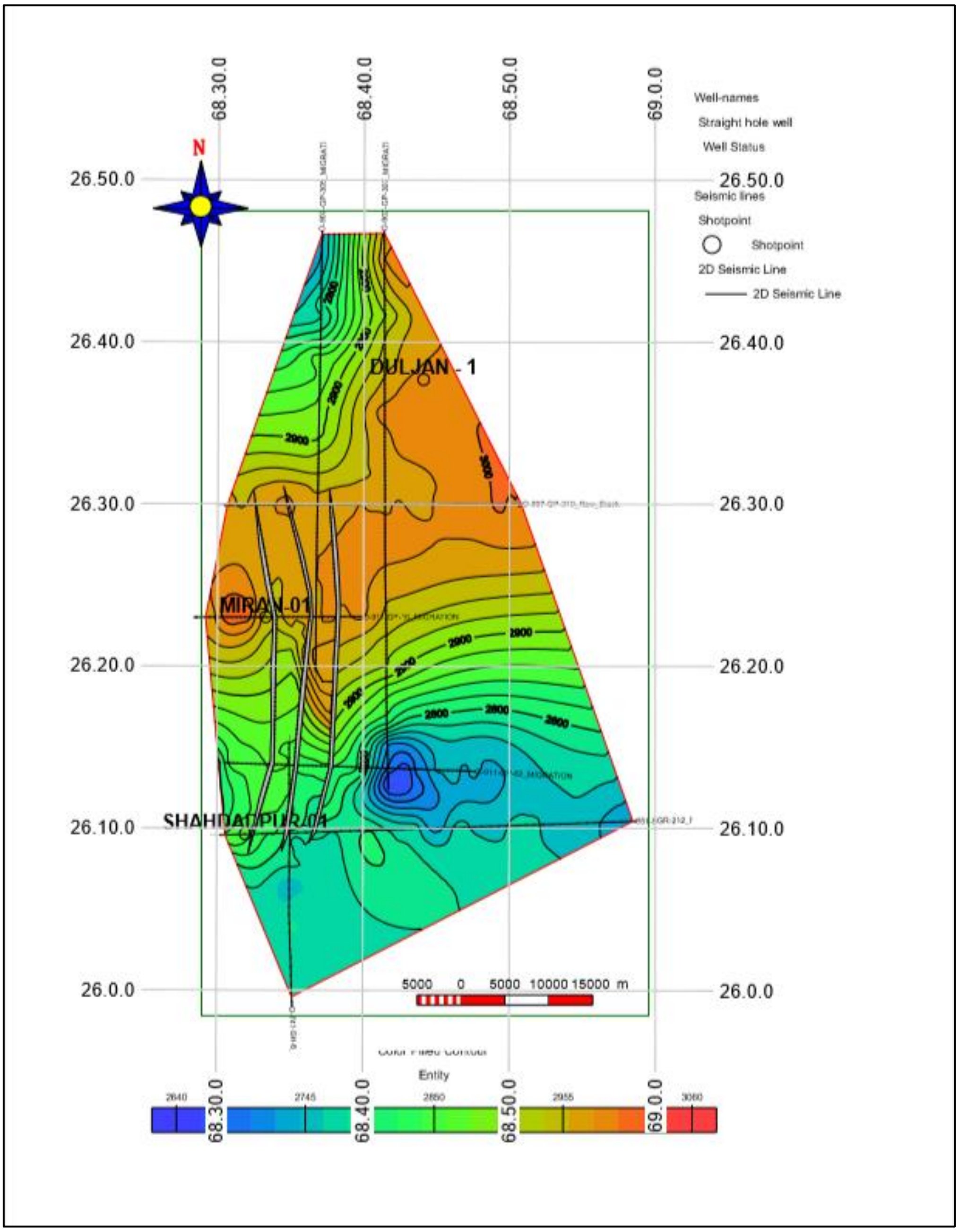

Figure 4.14. Showing the Two way Travel time map of Sembar Formation.

As the top most part of the Sembar Formation is mainly composed of sand facies so the possible lead marked on the contour map can be exploited for the hydrocarbon potential with in the sand facies of the Sembar Formation. The wireline log analysis also confirms that the top most unit contains good percentage of sand having 20-25% porosities with indication of presence of hydrocarbons on the basis neutron density crossover.

However, it has been observed from the seismic interpretation that the faults do not penetrate up to the Chiltan Limestone and dies out with in the Sembar Formation. This shows that the lower part which is mainly composed of shales might not be as much disturbed as the upper part. Moreover, the brittle clay minerals present within these shales are suitable for frac job, but the sealing capacity of the faults have to be evaluated in order to exploit these shales as a gas shale resource for which high resolution seismic data is required.

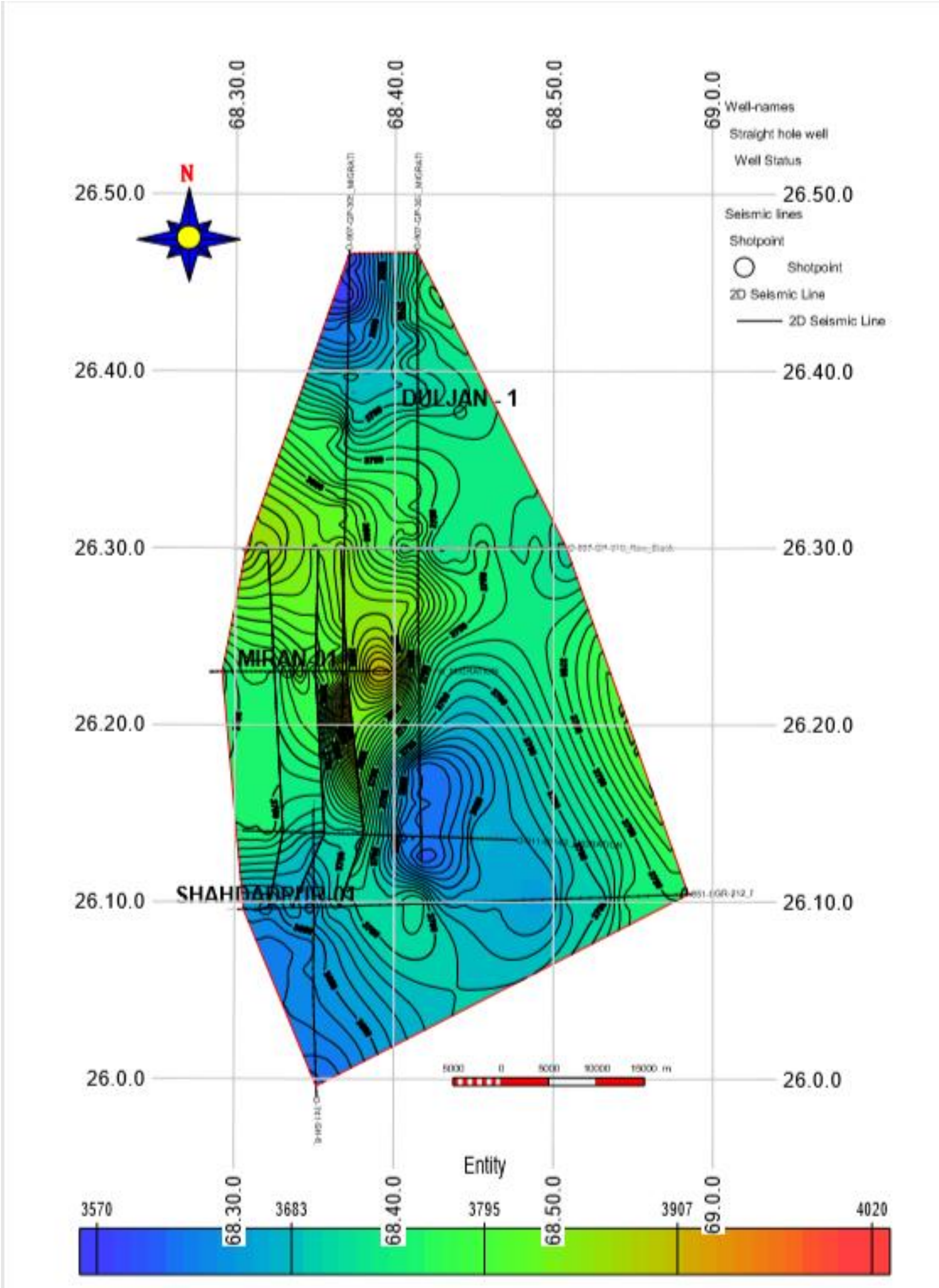

Figure 4.15. Showing the depth contour map of Sembar Formation.

CONCLUSIONS

(1) Sembar Formation is divided into two distinct facies i.e sand and shale. The major part of the Sembar Formation is comprised of shale which is dominant within the lower part whereas the upper part of the formation is having sand facies.

(2) Possible lead identified on the depth contour map can be exploited for the hydrocarbon potential within the sand facies of the Sambar Formation.

(3) TOC values computed for the shales ranges between 1.5-2.5 wt% which lies in the fair to good source rock potential.

(4) These shales are majorly composed of Illite and Kaolinite which are brittle clay minerals and are suitable for the frac job which is the most important criteria in evaluating the shlaes as a gas shale resource.

(5) The brittle clay minerals present within these shales are suitable for frac job but the sealing capacity of the faults has to be evaluated in order to exploit these shales as a gas shale resource for which high resolution seismic data is required.

REFERENCES

Ahmad, N., Mateen, J., Chaudry, K. S., Mehmood, N., and Arif, F., 2013. Shale gas Potential of lower Cretaceous Sembar formation in middle and lower Indus basin, Pakistan. Pakistan Journal of Hydrocarbon Research, 23, 51-62.

Al-Sadi, H.N., 1980. Seismic exploration. Birkhauser Verlag, Basel. Anstey, NA (1965) Wiggles. J. Can. Soc. Exploration Geophysicists, 1, 13-43.

Badley, M. E., 1985. Practical seismic interpretation. Prentice Hall publishers, 266p.

Bjorlykke, K., 2010. Petroleum geoscience: From sedimentary environments to rock physics. Springer Science & Business Media.

Ehsan, M., Gu, H., Akhtar, M. M., Abbasi, S. S. and Ehsan, U., 2018. A geological study of reservoir formations and exploratory well depths statistical analysis in Sindh Province, Southern Lower Indus Basin, Pakistan. Kuwait Journal of Science, 45(2).

Gakkhar, R.A., Bechtel, A. and Gratzer, R., 2012. Source-rock Potential and Origin of Hydrocarbons in the Cretaceous and Jurassic Sediments of the Punjab Platform (Indus Basin) Pakistan.

IEDS, 1995. A sequence stratigraphic study of the Lower Goru – Sembar Formations of Lower and Middle Indus Basins of Pakistan and Rajasthan. Multiclient study.

Jadoon, I. A., Lawrence, R. D. and Lillie, R. J., 1994. Seismic data, geometry, evolution, and shortening in the active Sulaiman fold-and-thrust belt of Pakistan, southwest of the Himalayas. AAPG bulletin, 78(5), 758-774.

Kadri, I.B., 1995. Petroluem geology of Pakistan. Pakistan Petroleum Limited Karachi, Pakistan. Ferozsons (Pvt.) Ltd. 297p.

Kearey, P., Brooks, M., & Hill, I. (2002). An Introduction to Geophysical Exploration, Wiley publishers, 272p.

Kemal, A., 1992, Geology and new trends for hydrocarbon exploration in Pakistan, in Ahmed, G., Kemal, A., Zaman, A.S.H., and Humayon, M., eds., New directions and strategies for accelerating petroleum exploration and production in Pakistan:

Proceedings, international petroleum seminar, Ministry of Petroleum and Natural Resources, Islamabad, Pakistan, November, 22–24, 1991, p. 16–57.

Khan, N., Zhu, P.M. and Konaté, A.A., 2013. Petrophysical Parameters Estimation Using Geophysical Well Log Data of Indus Sub-Basin Area, Pakistan. Journal of Geography and Geology, 5(4), 71.

Mujtaba, M., 1999. Source rock distribution and evaluation in Middle Indus Basin, Pakistan. Hydrocarbon Development Institute of Pakistan, 125p.

Nazir, A., Fazeelat, T. and Asif, M., 2012. The geochemical characterization of sediments from Early Cretaceous Sembar Formation. Petroleum Science and Technology, Vol. 30, p. 2460-2470.

Nazir, A., Fazeelat, T. and Asif, M., 2015. Petroleum Geochemistry of Lower Indus Basin, Pakistan: II. Oil-oil and Oil-source Rock Correlation. Petroleum Science and Technology, Vol. 33, p. 1295-1304.

Oldham, R.D., 1892. Report on the Geology of Thal Chotiáli and Part of the Mari Country. Ibid., Rec., Vol. 25, p. 18-29.

Passey, Q.R., Creaney, S., Kulla, J.B., Moretti, F.J. and Stroud, J.D., 1990. A practical model for organic richness from porosity and resistivity logs. AAPG bulletin, 74(12), 1777-1794.

Qayyum, F., Hanif, M., Mujtaba, M., Wahid, S. and Ali, F., 2016. Evaluation of source rocks using one dimensional maturity modeling in Lower Indus Basin, Pakistan. Arabian Journal of Geosciences, Vol. 9, p.1-22.

Quad Consulting Limited, 1996. Geological and Geophysical Evaluation of Block-35 and Adjacent Areas, Northern Pakistan for Pakistan Petroleum Limited, p.1-47.

Raza H.A., Ali. S.M. and Ahmed, R., 1990. Petroleum geology of Kirthar sub-basin and part of Kutch Basin. Pakistan Journal of Hydrocarbon Research, v.2, no.1, 29-73.

Raza H.A., Ali. S.M., Ahmed, R. and Ahmed, J., 1989. Petroleum prospects: Sulaiman sub-basin, Pakistan. Pakistan Journal of Hydrocarbon Research, v.1, no.2, 21-56.

Rider, M., 2002. The Geological Interpretation of Well Logs. Ryder-French Consult Ltd, 1, 32.

Robinson, E.S. and Coruh, C., 1988. Basic Exploration Geophysics John Wiley & Sons. New York, 562p.

Schlumberger,1972. Log Interpretation, vol. I-Principles. Schlumberger Limited, New York, NY, 10017.

Schmoker, J.W., 1979. Determination of organic content of Appalachian Devonian shales from formation-density logs: Geologic notes. AAPG Bulletin, 63(9), 1504-1509.

Shah, M.I., 2009. Stratigraphy of Pakistan. GSP memoirs, Ministry of Petroleum and Natural Resources, Government of Pakistan. 381p.

Shuaib, S.M.. 1982. Geology and Hydrocarbon Potential of Offshore Indus Basin, Pakistan: Geologic Notes. AAPG bulletin, 66(7), 940-946.

Viqar-Un-Nisa Quadri, S. M., 1986. Hydrocarbon prospects of southern Indus basin, Pakistan. AAPG Bulletin, 70(6), 730-747.

Wandrey, C.J., Law, B.E. and Shah, H.A., 2004. Sembar Goru/Ghazij Composite Total Petroleum System, Indus and SulaimanKirthar Geologic Provinces, Pakistan and India: USGS Bulletin 2208, US Department of Interior, 23 p

Zaigham N.A., and Mallick, K.A., 2000, Prospect of hydrocarbon associated with fossil-rift structures of the southern Indus basin, Pakistan: American Association of Petroleum Geologists Bulletin, v. 84, no. 11, p. 1833–1848.