RESERVOIR EVALUATION OF EOCENE SEQUENCE IN SELECTED WELLS OF WESTERN POTWAR SUB BASIN, PAKISTAN

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August, 2021

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A thesis submitted in fulfillment of the requirements for the award of the degree of Master of Science (Geology)

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August, 2021

APPROVAL OF EXAMINATION

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DEDICATION

I dedicate my thesis to my family and teachers

AKNOWLEDGEMENTS

I would first like to thank my supervisor Prof. Dr. Tahseenullah Khan, Department of Earth and Environmental Sciences from Bahria University, Islamabad whose expertise was invaluable in the formulation of the research topic and methodology in particular and encouraging statements on selection of the topic. I am thankful to Dr. Muhammad Fahad Mehmood, Assistant Professor and Mr. Mumtaz Ali Khan, Assistant Professor, Department of Earth and Environment Sciences, Bahria University, Islamabad for their technical assistance. Dr. Said Akbar Khan, Head of Department, Dr. Moshan Ehsan, Senior Assistant Professor and PG Coordinator and Mr. Saqib Mehmood, Senior Assistant Professor and Cluster Head Geology, and staff of the department are thanked for their cooperation and facilitation. I am also indebted to Prof. Dr. Mohammad Zafar and Dr. Birkhez Aslam Shami, internal and external evaluators, respectively for their constructive review of the thesis and fruitful suggestions.

I would like to acknowledge Directorate General of Petroleum Concession (DGPC) and Bahria University for access to data. Besides, I would like to thank my parents for their wise counseling and sympathetic ear.

Last but not the least, there are my friends, who were of great support in deliberating over my problems and findings, as well as providing happy distraction to rest my mind during of my research.

ABSTRACT

The Eocene sequence (Chorgali Formation) of western Potwar sub-basin contains Meyal oil field that lies in Attock district ~110 km southwest of Islamabad. It is bounded between 33° 11´ to 33° 22´ N latitudes and 71º 59´ to 72º 81´ E longitudes. Structurally, the Salt Range thrust to the south of the Meyal oil field. The Cambrian to Eocene sequence covers the shally formations mostly in Meyal area. The Jhelum Group lies above the Salt Range Formation. A petrophysical interpretation was carried out on two selected wells (Meyal-01 and Meyal-17) for the identification of hydrocarbon zone and to calculate the shale volume, total porosity (average), totally effective porosity (average), water saturation (average) and average hydrocarbon saturation. Different sequences are found in the two wells which show the deposition of environment encountered in cycle of transgression and regression. On the basis of environment of deposition, Meyal-01 and Meyal-17 well had Highstand and Lowstand system tracts, respectively. Both show Transgressive system tracts indicating that the progradation geometry was decreasing away from the regression base level. A coarsening uphill trend characterized in Highstand system tract. Transgressive system tract marks below High system tract (HST) which follows retro-gradation sedimentation to support fining upward trend. Lowstand system tract formed at regressive base levels and upward coarsening of grains is the feature of Lowstand system tract. The Chorgali Formation in Meyal-01 well is indicating shallow marine environment and in Meyal-17 well shallow marine and estuarine shelf environment.

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LIST OF ABBREVIATIONS

Aphi	Average Porosity
AR	Archie's
DGPC	Directorate general of petroleum concessions
Dphi	Density Porosity
DT	Sonic log
Ephi	Effective Porosity
Etotal	Total SP potential
G.G	Geothermal Gradient
GR	Gamma ray
GRmin	Minimum value of GR
GRmax	Maximum value of GR
LLS	Laterology shallow
LLD	Laterology deep
LMKR	Land mark resource
MSFL	Micro resistivity log
Nphi	Neutron log
RHOB	Density log

Rmf	Resistivity of mud filtrates
Rw	Resistivity of water
Sh	Saturation of hydrocarbon
Sphi	Sonic porosity
Sw	Saturation of water

CHAPTER 1

INTRODUCTION

1.1 General Statement

Geoscientists are continuously trying to find out different exploration method to explore hydrocarbon. Pakistan's oil exploration history is as old as the country's oil sector. In 1866, the first oil well was drilled in Pakistan, in the Kundal region of Mianwali. At Khaur, in 1915 first oil field was discovered in the Indus basin. Pakistan has a significant hydrocarbon potential in many parts of the country, especially in the northern and southern parts. The Potwar sub-basin is one of the oldest and most well-known for its gas and oil occurrences. To date, 142 wells have been drilled in the Kohat-Potwar sub-basins including Pindori, Meyal, Dhurnal, Makhori, Manzalai, Makori and Adhi oil and gas fields. In Potwar sub-basin, structural traps are mostly dominated.

Geophysically, well logging is important tool which is mostly used to analyze the formation properties which are having hydrocarbon potential. With the help of geophysical interpretation it indicates hydrocarbon containing zone.

1.2 Study Area

Meyal oil field was discovered near Islamabad in the Attock district, 110 km south west of Islamabad, with latitudes 33° 11´ to 33° 22´ N and longitudes 71° 59´ to 72° 81´ E. Meyal oil field is located at western side of the Potwar plateau. On the eastern side of the oil field, the Indus River flows, while the Soan River flows on the western side. On the northern side of the Meyal oil field, the Kalachitta-Margalla mountain ranges occur, while the Salt Range occurs on the southern side.

The Potwar sub-basin is formed by post Eocene activities. This area is affected mostly by transpressional forces which lead to pop up structures. The area of Meyal oil field is tectonically complex comprising thrust faults associated pop up and anticline structures (Kazmi, and Jan, 1997).

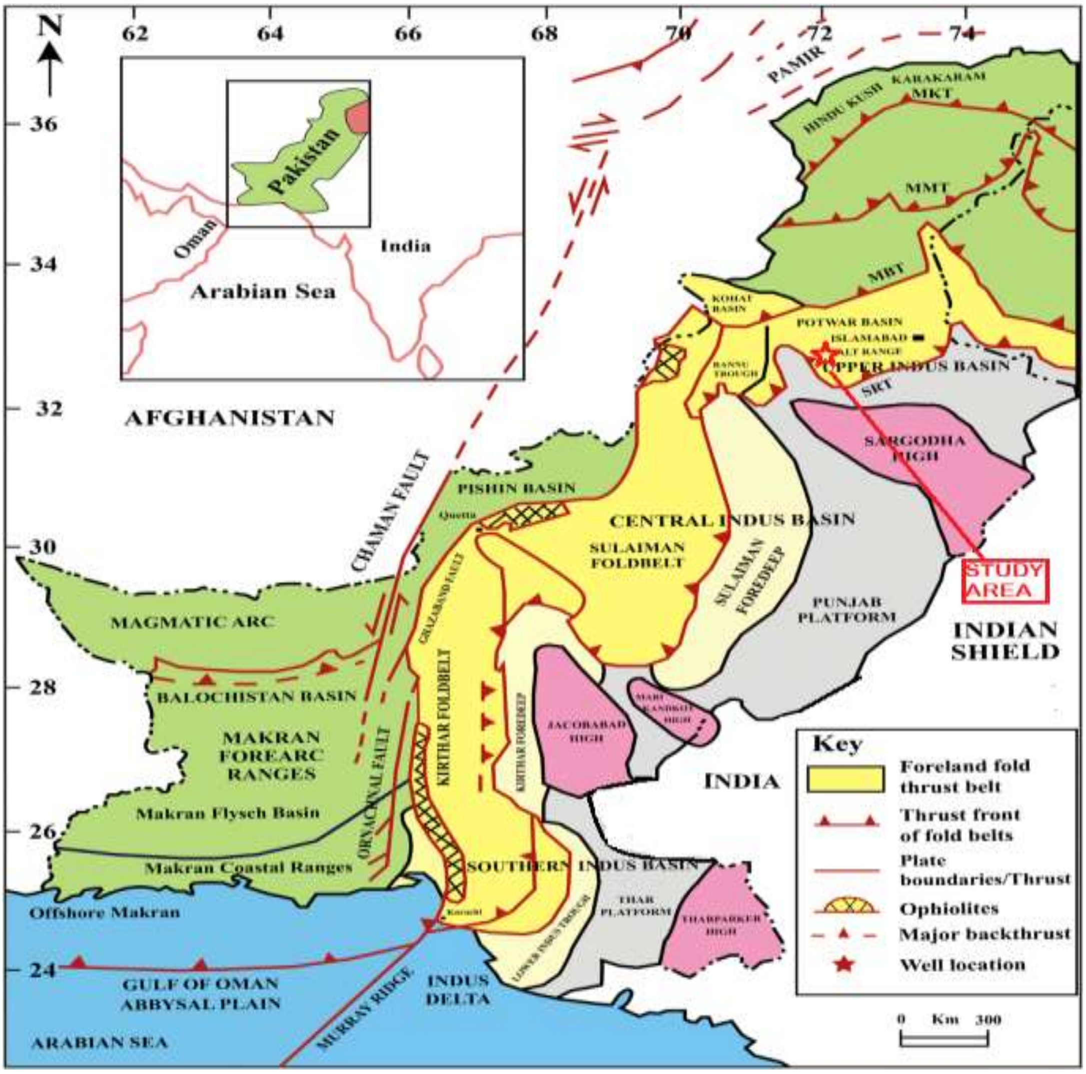


Figure 1.1 Tectonic and Sedimentary basin map of Pakistan (After Aziz and Khan, 2003).

1.3 Objectives of the Research

This proposed study was aimed at assessing the reservoir potential of the rocks that was drilled in Potwar sub-basin. The main objectives of the proposed thesis work are:

1. To determine the petrophysical parameters of the rocks drilled in study wells
2. To establish sequence stratigraphic framework
3. To find out environment of deposition with help of the Wireline logs

1.4 Data Acquired

Complete Wireline log suite such as Digital LAS file- Caliper, Density, Gamma Rays, Sonic, Spontaneous Potential and Resistivity log for two selected wells, namely Meyal-01 and Meyal-17 were acquired from LMKR through the Directorate General of Petroleum Concession approval. The quantitative and qualitative analyses of reservoir intervals are achieved by addressing shale volume, water saturation, hydrocarbon saturation and porosity using Wireline logs.

CHAPTER 2

GEOLOGY AND TECTONICS

2.1 Regional Tectonics of the Study Area

Pakistan is located on northwest boundary of the Indian continental plate. The Indian continental plate is moving in northward direction at about 2.5-6 mm per year and is striking with the Eurasian continental plate (Kazmi and Jan, 1997). The under-thrusting process between Indian and Asian continental plates generated thick skinned tectonics on the northern side of Indian continental plate (Kazmi and Jan, 1997) (Fig. 2.1). Due to continue under-thrusting of Indian continental plate since Cretaceous time, Himalayas and foreland fold and thrust belts formed which thrust over the Indian Craton (Kemal et al., 1997).

To the northern side of Pakistan, Himalayan mountain ranges are divided into four main subdivisions. Hindu Kush and Karakorum mountain ranges occur in north side of the Main Karakoram Thrust (MKT), a suture zone between the Kohistan magmatic arc and the Asian or Karakoram continental plate. Main Mantle Thrust (MMT) marks southern boundary of the Kohistan magmatic arc with the Indian continental plate. The Main Central Thrust (MCT) and Main Boundary Thrust (MBT) separate Higher-Lesser and Sub-Himalayas, respectively. The Salt Range Thrust lies to the south of Sub-Himalayas (Pennock et al., 1989). The shortening of Himalayan mountain ranges is caused by folding and thrusting processes. The Northwest Himalaya fold and thrust belt including Potwar, Kohat and Bannu sub-basins comprised of many mountains and covers the entire area of 250 to 560 km^2

(Kazmi and Jan, 1997). This fold and thrust belt extends up to Kashmir basin. The youngest basins in the western Himalaya exhibit compressional regime (Kazmi and Jan, 1997).

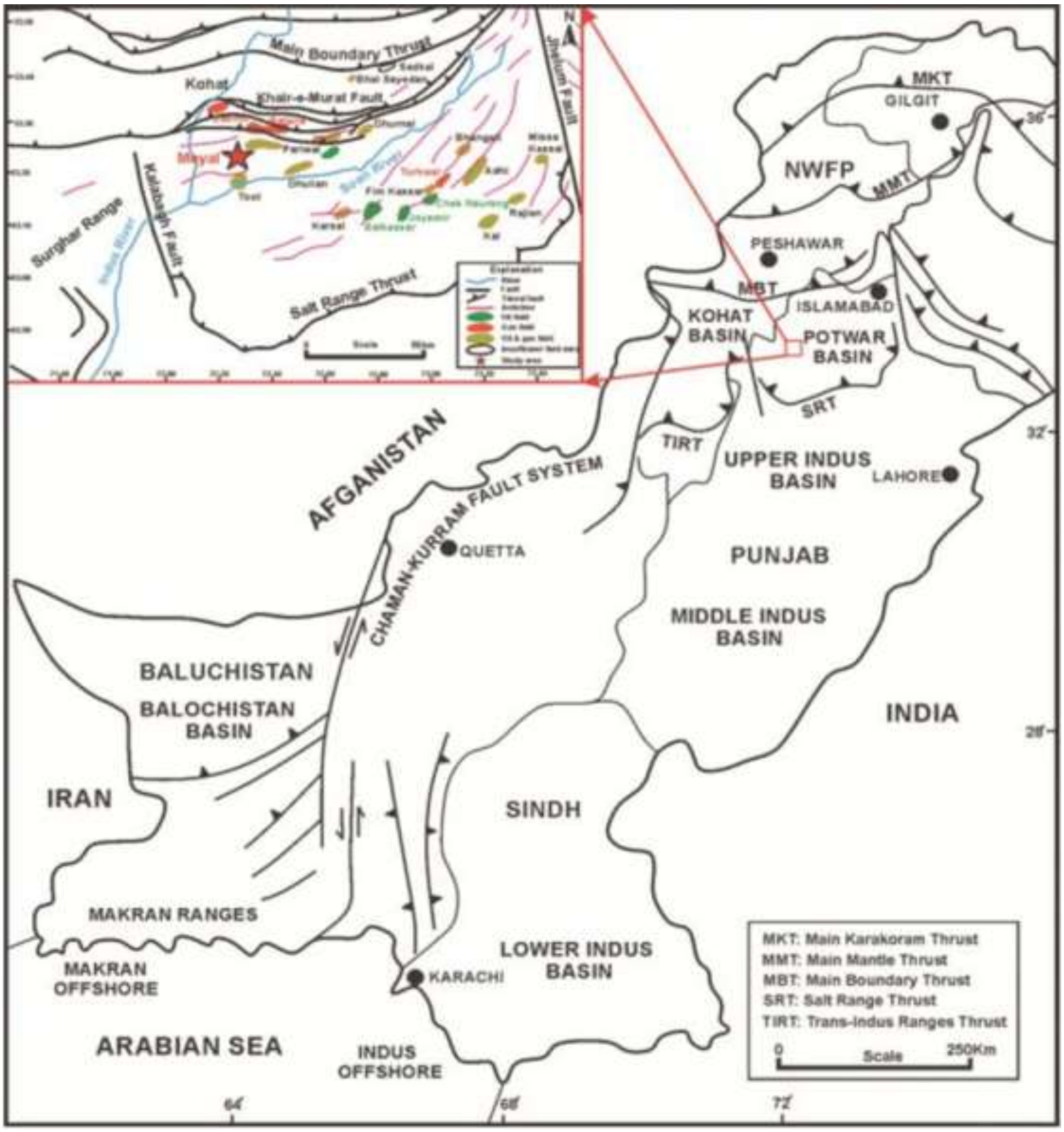


Figure 2.1 Tectonic map of Pakistan. The inset map shows tectonic regime of the Potwar sub-basin and the location of the study area (Shami and Baig, 2002).

2.2 General Geology of Potwar Sub-basin

The Indus basin, which splits into Upper and Lower Indus basins by Sargodha high, is located in north Pakistan (Khan et al., 1986). The Upper Indus basin's northern and eastern boundaries are also delineated by the MBT, which continues westward into the Margalla hills, Kala Chitta, and Kohat mountain ranges (Khan et al., 1986) (Fig. 2.2). The Indus River divided the Upper Indus basin into two main sub-basins, 1) Potwar sub-basin in the east and 2) Kohat sub-basin in the west (Khan et al., 1986). The southern side of Potwar sub-basin is enclosed by less deformed zone having width nearly to 140 km in north-south direction (Khan et al., 1986). In the northern side of Potwar sub-basin, it is bounded by Kala Chitta mountain ranges and at the southern side by Salt Range Thrust.

During Indian and Eurasian continental collision, the rocks of the Potwar sub-basin deformed into numerous folds and faults. The Precambrian rocks are exposed at southern side of Potwar sub-basin in the Salt Range. In Precambrian time interval, strata were frequently not buried deeply enough in terms of hydrocarbon maturity, and the Precambrian to Paleocene sequence remained thermally immature (Khan et al., 1986; Grelaud et al., 2002). However, in a specific area, abnormally high pressure formation caused by compression along with profound burial by overburden rock, marked the beginning and outflow of hydrocarbon from pre- Eocene source rocks, (Law et al., 1998; Grelaud et al., 2002) (Fig. 2.2).

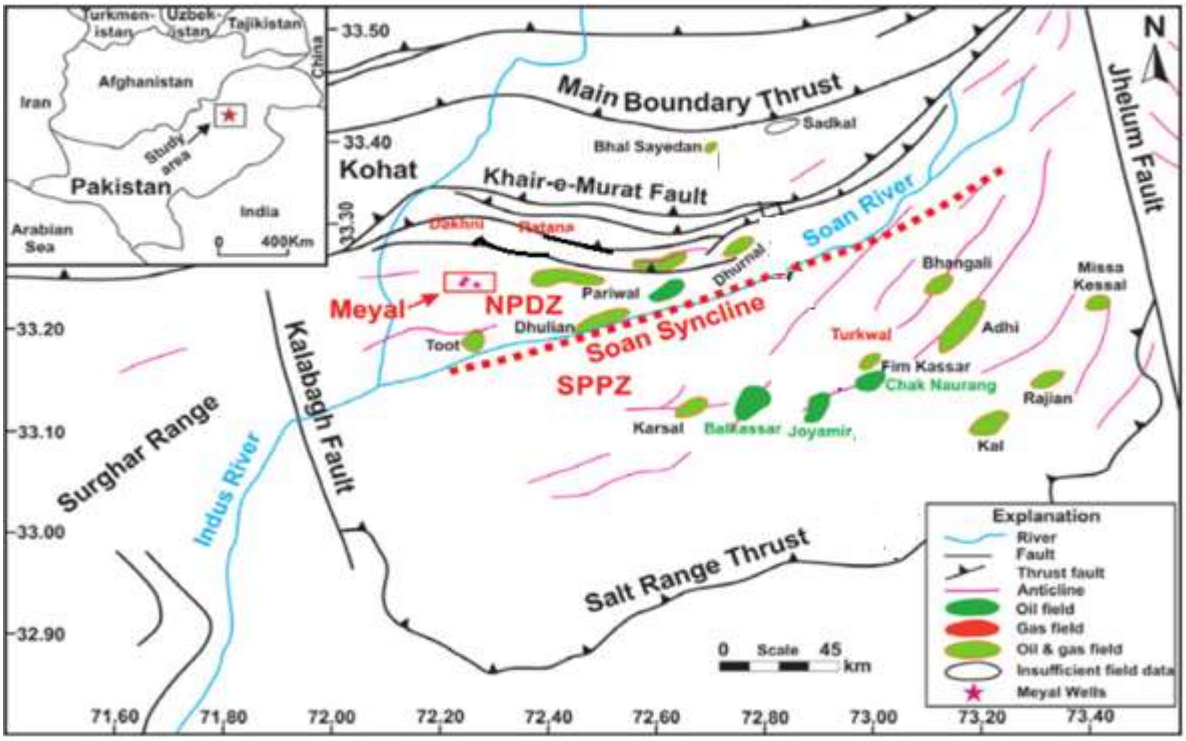


Figure 2.2 Generalized oil and gas fields, and geological and structural map of Potwar sub-basin (after Shami and Baig, 2002). Star represent Meyal oil field.

Upper Indus basin is bounded by Murree fault in north whereas Surghar and Salt Range occur at its south. To the east of Upper Indus basin lies Jhelum fault whereas on the western side Kurram fault (Fig. 2.2). During the collision of Indian continental plate with Eurasian continental plate, the Kohat-Potwar plateau deformed structurally. A large number of rolled over faults are formed. In Kohat-Potwar plateau, shallow marine stage is characterized by Permian Nilawahan, Triassic Musa Khel and Jurassic Samana Suk Formation. Top of the Samana Suk Formation, erosional surfaces are present where sandstone and shale of the Lower Cretaceous Chichali Formation is overlaying. Further, multiple detachment surfaces are developed by the shallow northeast trending anticline. Detachment surfaces are diagnostic by deep Eo-Cambrian salts that also have developed as a result of continuing plate convergence and crustal shortening of up to 12.5 km (Kemal et al., 1992; Jaswal et al., 1997).

2.3 Stratigraphy of Meyal Area

The Cambrian to Eocene formations are present mostly in the Meyal area of the Potwar sub-basin. The Jhelum Group overlies the Salt Range Formation (Gee, 1989). The Cambrian Khewra and Kussak formations belong to the Jhelum Group. These formations were most probably formed in a shallow marine environment. No sediments have really been deposited in Salt Range- Potwar foreland basin since it was uplifted from the Ordovician to the Carboniferous (Shami and Baig, 2002).

There is dis-conformable contact between Eocene Cherat Group and Miocene Rawalpindi Group. The Nammal, Sakesar, Chorgali, Kuldana and Kohat formations belong to Cherat Group. Murree and Kamlial formations are members of the Rawalpindi Group. There is conformable contact between Cherat Group and Makarwal Group. Hangu, Lockhart and Patala all are members of the Paliocene Markarwal Group (Fatmi et al., 1973).

The early Paleocene oceanic transgression was generated in a massive carbonate shale sequence (Shami and Baig, 2002). Hangu, Lockhart, Patala, Sakesar, Chorgali, and Kuldana formations are mostly part of it. These formations which comprise carbonates are expected to be the main reservoir for oil accumulation. In the Salt Range- Potwar foreland basin, the Himalayan orogeny caused Eocene–Oligocene uplifting and erosion (Shami and Baig, 2002).

Top of the Potwar sub-basin normally consists of non-marine molasses deposits (Fig. 2.3) known as the Rawalpindi Group rocks (Kamlial and Murree formations). The Siwalik Group consist of Nagri, Dhok Pathan, Chinji, and Soan formations. A major percentage of these strata in the northern Salt Range Potwar foreland basin fall with in oil window zone, over reservoir rocks, it serves as a regionally pressurised cap (seal) rock (Shami and Baig, 2002). The lithostrigraphic chart (Fig. 2.3) and the borehole stratigraphy of Meyal 01 and Meya-17 (Table 2.1) are shown.

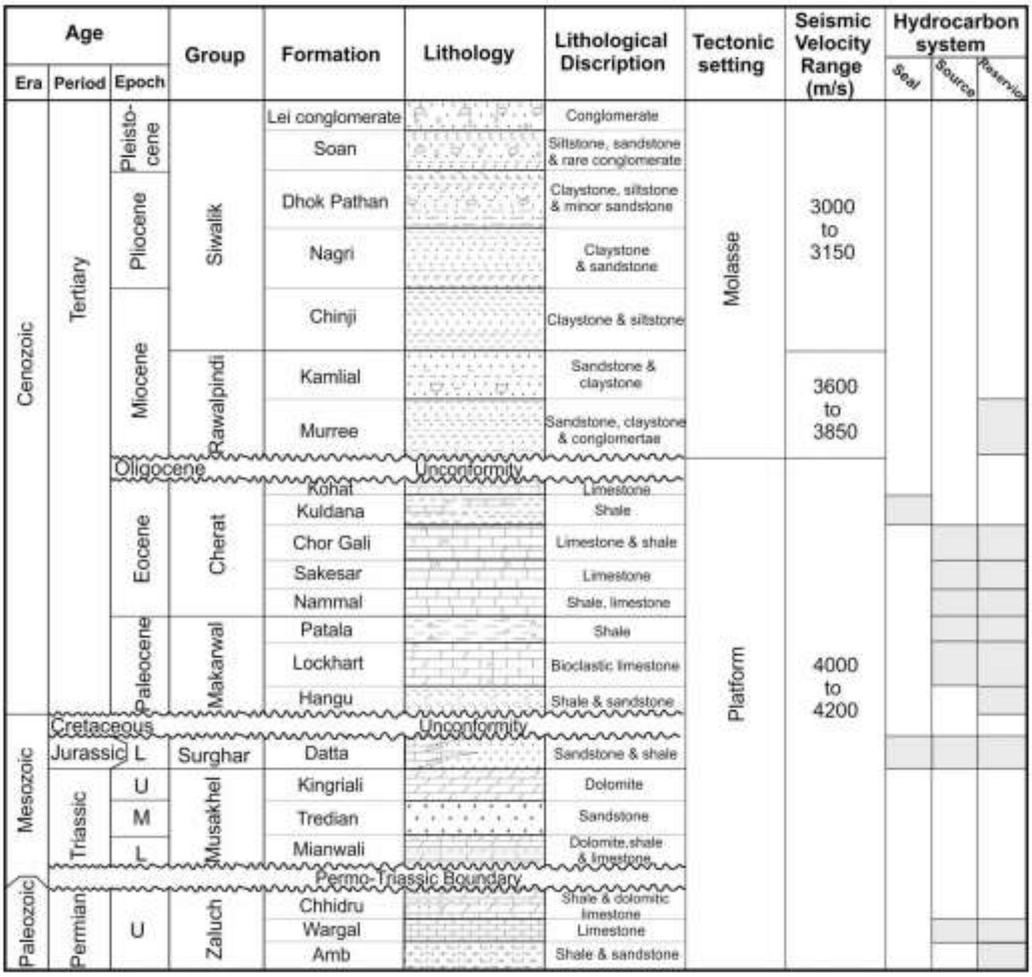


Figure 2.3 Lithostratigraphic chart of Potwar sub-basin, northern Pakistan (after Fatmi 1973; Shah, 1977; Jadoon, 2015).

Table 2.1: Borehole stratigraphy of Meyal-01well

Age	Formation	Formation Top (m)	Thickness (m)
Pliocene	NAGRI	0	598
Miocene	CHINJI	598	1322
Miocene	KAMLIAL	1920	152
Miocene	MURREE	2072	1561
Miocene	FATEHJANG	3633	17
Eocene	KOHAT	3650	38
Eocene	CHORGALI	3732	66
Eocene	SAKESAR	3798	83
Jurassic	KULDANA	3688	

Table 2.2: Borehole stratigraphy of Meyal-17 well

Age	Formation	Formation Top (m)	Thickness (m)
Pliocene	NAGRI	0	510
Miocene	CHINJI	510	1409
Miocene	KAMLIAL	1919	223
Miocene	MURREE	2142	1462
Miocene	FATEHJANG	3604	12
Eocene	KOHAT	3616	65
Eocene	RED CLAY	3681	19
Eocene	CHORGALI	3700	97
Eocene	NAMMEL	3797	119
Paleocene	RANIKOT	3916	155
Paleocene	KHAIRABAD	4071	

CHAPTER 3

PETROLEUM PLAY OF THE AREA

3.1 Introduction

Salt Range-Potwar foreland basin has characteristics similar to the continental warp basin (Shami and Baig, 2002). It possesses a thick sedimentary marine sequence, a continental margin, and possible source cap and reservoir rocks, all of which are ideal for hydrocarbons (Shami and Baig, 2002). Thick mollasse deposits present at burial depth provides maximum geothermal gradient for oil generation. The basin produces oil from 2.75 to 5.2 km depth (Shami and Baig, 2002). Kohat and Potwar sub-basins have specific features which make it suitable place for hydrocarbon generation and accumulation. At area of the continental margins, these sub-basins represent petroleum play system. The overburden of fluvial deposits (3.3 km) in this area allows enough depth and suitable temperature for the oil seep (Khan et al., 1986).

Fault propagation folds which form structural traps in Kohat and Potwar sub-basins occur on the top of main anticline (Khan et al., 1986). Traps in this fault propagation folds are on the top of main anticline. Secondary traps may form within main thrust sheets, specifically at the front edge of the thrust sheets and above fault plane ramps (Khan et al., 1986).

3.2 Hydrocarbon Production History of Potwar Sub-basin

In the Potwar sub-basin, first oil well was drilled in Kundal at 1866. The Attock Oil Company drilled the first commercial oil well in Khaur in 1915. After this discovery, approximately 340 wells were drilled in this area. In this field production recorded from Murree and Sakesar formations. Drilling from 1915 to 1969 produced oil at Joya Mair in 1944, Karsal in 1956 and Meyal in 1969. Adhi is the first commercial gas field in this area. The production recorded in Adhi gas field from a rock of Cambrian to Eocene age. In the Kohat and Potwar sub-basins, primary production received from faulted anticline traps, and from those rocks where age ranges from Cambrian to Miocene and depth ranging from 20 m to 1030 m (Jaswal et al., 1997).

The reservoir from which production is normally obtained are Datta Formation of Jurassic age, Lockhart limestone of middle Paliocene age, Sakesar limestone of early Eocene age, Chorgali Formation of late Eocene age and Murree Formation of Miocene age. In this area, Jurassic and Eocene age formations are the oil producers (Shami and Baig, 2002). It has been verified that production take place from Jurassic and Miocene age formations mainly because of granular porosity (Iqbal and Shah, 1980). Because of fracture porosity the limestone from Eocene to Paleocene are producing. Shale also behaves as a seal and a cap rock (Iqbal and Shah, 1980).

Oil in the Datta Formation is widely regarded to come from Jurassic shales, while oil in the Lockhart, Sakesar, and Chorgali formations is considered indigenous, whereas oil in the Murree Formation was migrated from the beneath Eocene rocks (Fatmi et al., 1973).

3.3 Source Rocks

The gray shale of Triassic Mianwali Formation, Jurassic Datta Formation and Eocene Patala Formation are main potential source rocks in Salt Range-Potwar foreland basin. In the Salt Range Formation, oil shales have 28-40% total organic carbon in the localized areas of shales and utilized as the Salt Range-Potwar foreland basin source rock (Shami and Baig, 2002). In the Potwar sub-basin, the Patala Formation considered to be source of hydrocarbon. Several source rocks can be found in the Kohat Potwar sub-basins. Other Formations include the Salt Range Formation, the Wargal, Sardhai and Chidru formations, the Paleocene Lockhart Formation, and the Patala Formation (Quadri and Quadri, 1996). Salt Range Formation is the oldest source rock in this area, which dominant lithology of clastic rock at lower part, carbonate dominant into middle part and evaporites dominant in upper parts.

The Sardhai and Chidru formations are sandy lithology and seem to have significant TOC values, indicating that they were exploited as source rocks (Quadri and Quadri, 1998).Total TOC with in Patala Formation ranges from 0.6 to 3.6 percent. Except at Joyamair, where sulphur level reaches 2%, the oil has a sulphur content less than 0.5% (Khan et al., 1986).

3.4 Reservoir rocks

The Potwar sub-basin contains large number of hydrocarbon reservoirs of Cambrian, Permian, Jurassic, Paleocene, Eocene and Jurassic rock formations (Table 3.1). The fractured non-clastic rocks of the Chorgali and Sakesar formations are major reservoirs in Meyal area. Besides, Datta Formation is also the major oil producing reservoir. The Sakesar Formation is light gray yellowish limestone, partly and massive dolomitized. The Chorgali Formation is partly dolomitic and thick bedded carbonates and sandstone comprises the Datta Formation..

Analysis of core rock samples from different oil/gas fields, e.g., Meyal, Balkassar and Dhulia oil fields shows that primary porosity of Sakesar and Chorgali formation is less than 1%. Because the rock was deformed numerous times during the Himalayan orogeny and the fracture porosity is significantly greater in the wells of northwest Potwar (Shami and Baig, 2002).

Table 3.1: Source, reservoir and seal rocks of Upper Indus Basin

Source (Formation)	Reservoir (Formation)	Seals (Formation)
Patala (Paleocene)	Kohat (Eocene)	Kuldana (Eocene)
Lockhart (Paleocene)	Chorgali (Eocene)	Kuldana (Eocene)
Datta (Jurassic)	Sakesar (Eocene)	Kuldana (Eocene)
Mianwali (Triassic)	Lockhart (Paleocene)	Patala-Nammal (Paleocene-Eocene)

3.5 Seal/cap rock

Mollasse sediments of Rawalpindi Group are considered as cap rock of Potwar oil field. Clays of Murree Formation normally provide an effectively sealing for the Eocene ages reservoir (Shami and Baig, 2002). Shales from either the Nammal Formation or even the Kuldana Formation efficiently seal the Chorgali Formation in the Meyal oil field. Cap rocks, such as shales in Kussak, Dandot, Datta, Patala, Hangu, Kohat, Kuldana, Nammal, and clay in Murree, are found in the Upper Indus basin (Shami and Baig, 2002).

3.6 Maturation

Thermally, maturation of the rocks in Potwar sub-basin range from Ro 0.3-1.7%. For the Tertiary rocks, throughout the productive zone of the Potwar sub-basin, the maturity of vitrnite reflection ranges from 0.65 to 1.0%, according to the basin profile. Fluid inclusion data indicate computed and measured Ro between 0.6 and 1.1% for rocks of Cretaceous age, 0.5-0.9% for Jurassic, and 0.65-0.9% for Permian rocks, using vitrnite reflectance data for calibration (Tobin and Claxton, 2000). Maturities are higher at north side of MBT. Thermal maturities range from 1.0-1.6% for Cretaceous rocks. The dry gas is also generated began near to 1.3 % of thermal maturities.

3.7 Generation and Migration

Hydrocarbon generation is most likely to begin in the Cretaceous period for Cambrian source rocks and the Paleocene period for modern source rocks. Burial history charts (Law et al., 1998) start at 30 Ma, but only suggest a later or subsequent generation that began around 20 to 15 Ma and continues to the current day. Two separate over-pressure zones have been documented in this area. Over pressure zone in Neogene age was attributed to compressional tectonics and Pre-Neogene age where over pressure zone is ascribed to combine hydrocarbon generation in compression tectonic. The maximum burial was roughly 2.5 million years ago, according to the burial history table (Law et al., 1998). However, there had been two unique periods of hydrocarbon generation from two distinct categories of source rocks, and there are insufficient correlation data to clearly link source to reservoir in the petroleum system. Short-distance up dip and vertical migration into surrounding reservoirs, as well as fault and fracture associated with plate collision and thrusting, are the principal routes of migration (Law et al., 1998).

CHAPTER 4

METHODOLOGY

4.1 Petrophysical Analysis

Petrophysical analysis of Meyal-01 and Meyal-17 wells was conducted employing the following available logs.

(i). Caliper log

(ii). Gamma ray log

(iii). Density log

(iv). Neutrons log

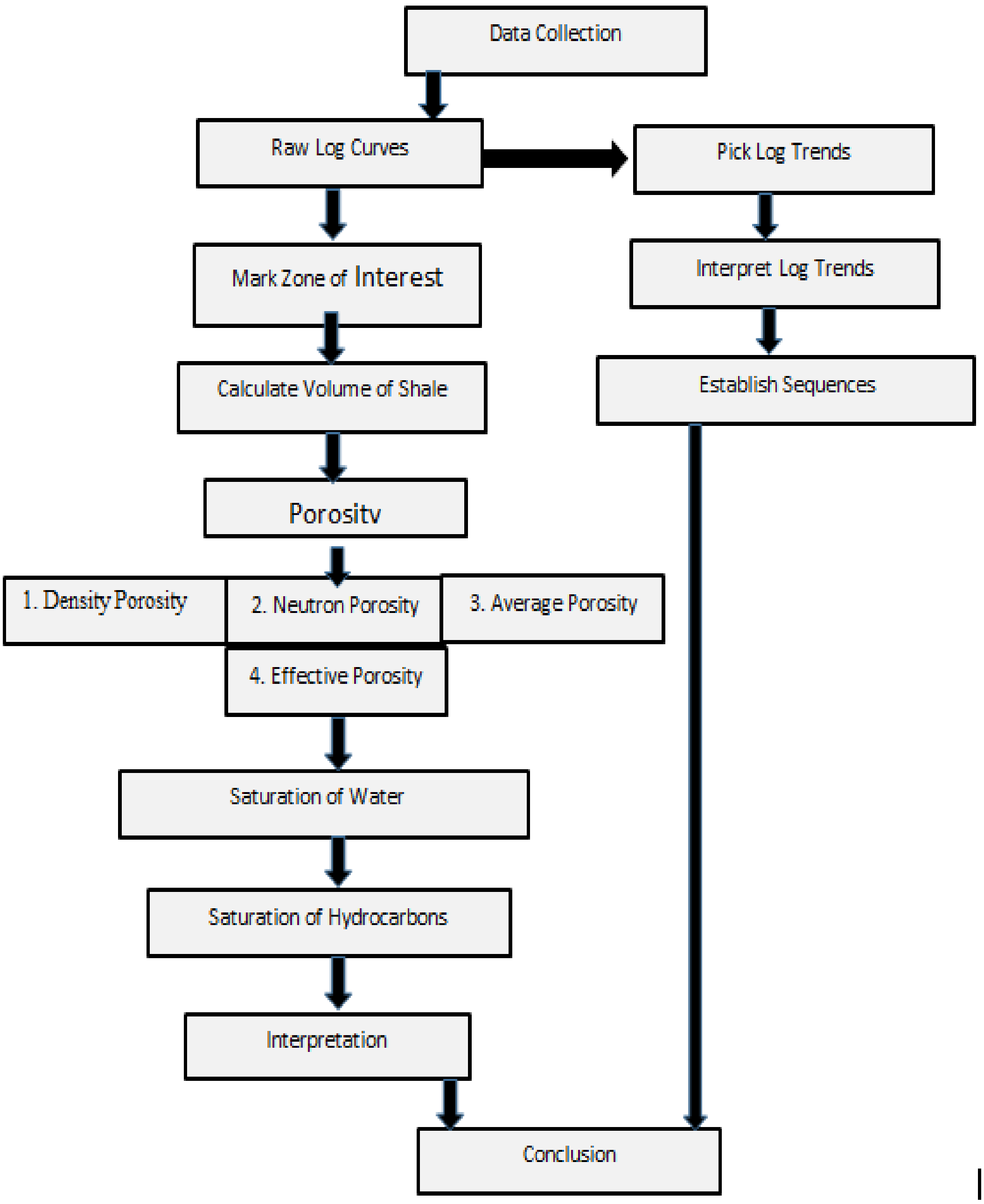
(v). Sonic log

(vi). Spontaneous potential log

(vii). Resistivity log

4.2 Work flow Petrophysical Analysis

Petrophysical analysis has been done by using different type of well logs as shown the flow chart.



4.3 Use of well Log

The following well logs have been used

(i). Hydrocarbon detection

(ii). Borehole condition

(iii). Lithology

(iv). Temperature gradient

(v). Reservoir parameters

4.4 Raw Log Curves

Raw log consist all of logs curves, which provide interpretation and indicate the values of all parameters. At different depth, each log curves give values of specific parameters.

4.5 Marking Zone of Interest

On the base of Density log and Neutron log different zones of interest can be marked where cross-over between them can be found out, which shows the hydrocarbon presence in reservoir.

4.6 Identification of Lithology

With the help of Neutron and Density logs, different lithology's can be found out, but it will be confirmed mostly with help of the Gamma ray log (Lucia 2007). .

4.7 Calculation of Volume of Shale

With the help of Gamma ray log volume of shale can be found out. In comparison to shale rocks, unstable minerals are missing in sandy rocks, according to a quantitative examination of shale lithology. On the base of quantitative analysis of shale lithology, dirty and clean zone can be marked. In dirty zone the value of Gamma ray log is maximum while in clean zone its value is minimum because due to radioactive minerals.

Volume of shale can be calculated by GR log by formula (Rider 1996).

$$Vshl\_GR = (GR-GRcln) / (GRshl-GRcln)$$

Where,

Vshale= Volume of shale

GR= Gamma-ray log

GRclean= Minimum value of Gamma-ray

GRshl= Maximum value of Gamma-ray

4.8 Porosity

Ratio of void spaces in total volume of rock is called porosity. Porosity depends upon following factors such as grain size, compaction, orientation, sorting, roundness, packing, spherical and digenesis. Primary porosity is mostly destroyed by digenetic phenomenon but secondary porosity is developing by digenetic procces.eg, packing, dissolution, pressure solution and tectonic forces. Porosity can be calculated with the help of Density porosity, Neutron porosity and Sonic porosity.

4.9 Density Porosity

The Density log is measured element of density of a formation. It can detect evaporites, gas bearing zone, minerals, hydrocarbon density and also verify shale-sand reservoir. Density porosity is determined with the help of Density log curves, density of fluids and density of matrix. The following formula is used for density log calculation.

PHID = (RhoM - RHOB) / (RhoM - RhoF)

4.10 Neutrons Porosity

Neutrons log measures hydrogen ions concentration in Formation. In Formation where ovoid space are filled with oil or water, neutron log find out liquids filled pore spaces. The Neutrons porosity is directly proportional to Neutron log values.

4.11 Average Porosity

Average porosity is calculated by combination of Neutron and Density porosity.

Average porosity = (Density porosity + Neutron porosity)/2

4.12 Effective Porosity

The sum of all inter-connected void spaces in a rock is called Effective porosity. In most cases, core analysis in petroleum engineering the value of effective porosity equal to the total porosity of the log (Lucia 2007).

PHIE = PHIA * (1-Vshl)

4.13 Resistivity of Water

Resistivity of water (Rw) is used to find out saturation of water. Rw can also be determined by SP log but in many cases the SP log is not well developed, therefore, Rw method can be used for finding of Rw. Whereas Rw is the resistivity of unknown mixtures of chlorine and water in void spaces. Many methods are used for the calculation of Rw such as standard schulmberger plot or much other standard specific equation..

4.14 Saturation of Water

The fraction of void spaces which contain water is called saturation of water (Sw). In formation where only water is present in void spaces, then Sw of this formation is 100%. The remaining percentage of void spaces in a rock containing gas or oil is known as hydrocarbon saturation, which is equal to 1- Sw. Archie equation is basic equation which is used to find out saturation of water. Archie equation is given below (Rider, 1996).

$$SwA = sqrt (Rw / (RT * PHIA^2))$$

4.15 Saturation of Hydrocarbon

The equation for determining hydrocarbon saturation is as follows (Rider, 1996).

$$Sh = 1-Sw$$

Where

Sh = Saturation of Hydrocarbons

Sw = Saturation of Water

4.16 Reservoir Estimation

The word reservoir actually means different for different peoples. The gas and oil of operator, reservoir or mixture of crude oil, natural gas and other relative product that can be profitable in future for definite sub surface reservoir.

CHAPTER 5

PETROPHYSICS INTERPRETATION

5.1 Petrophysics

The study of rocks physicochemical properties, as well as their relationships with fluids (hydrocarbons, gases, and aqueous solution), is known as petrophysics (Archie, 1950). A Petrophysical property determines lithology, porosity, permeability, resistivity of water and fluid saturation. Pertrophysics not only deal to delineate reservoir quality of rock but also determine composition, facies analysis, depositional environment and source rock potential (Archie, 1950).

Table 5.1: Well selected for petrophysical interpretation

Well	Meyal -01 (Chorgali Formation)	Meyal-17 (Chorgali Formation)
Formation Top (m)	3732 m	3728 m
Formation Bottom (m)	3798 m	3797 m
Total Thickness (m)	66 m	69 m

5.2 Log Curves

Raw logs include all those curves which are given from the specific well. The raw logs include Caliper log, Spontaneous Potential log, Gamma ray log, Resistivity log, Neutron log, Density log and Sonic log. All these logs present in correlation tracks, porosity tracks and resistivity track. In correlation tracks present Caliper, Gamma and SP logs. These logs present in linear scale versus depth. Caliper log tells about diameter of the well in inches. The Gamma ray log measures natural radiation of the well. The Sp log shows the Formation's natural potential in Mv versus depth. MSFL, LLS and LLD logs are present in resistivity tracks which plotted on logarithmic scale against depth. Sonic, Density and Neutron logs are present in porosity tracks. These logs are used to measures the porosity of formation.

5.3 Zone of Interest in Meyal-01

Zone marked in Meyal-01 is from 3735 m to 3751 m having total thickness of 16 m. This zone is marked on the base of Gamma ray and Neutron –Density cross over.

Table 5.2: Interest zone in Meyal-01

Well Name	Meyal-01
Reservoir Name	Chorgali Formation
Start depth (m)	3735 m
End depth (m)	3751 m
Thickness (m)	16 m

5.4 Petrophysical Interpretation of Chorgali Formation in Meyal-01 Well

In Meyal-01 well, potential resource is the Chorgali Formation and by employing above described methods, petrophysical interpretation has been done.

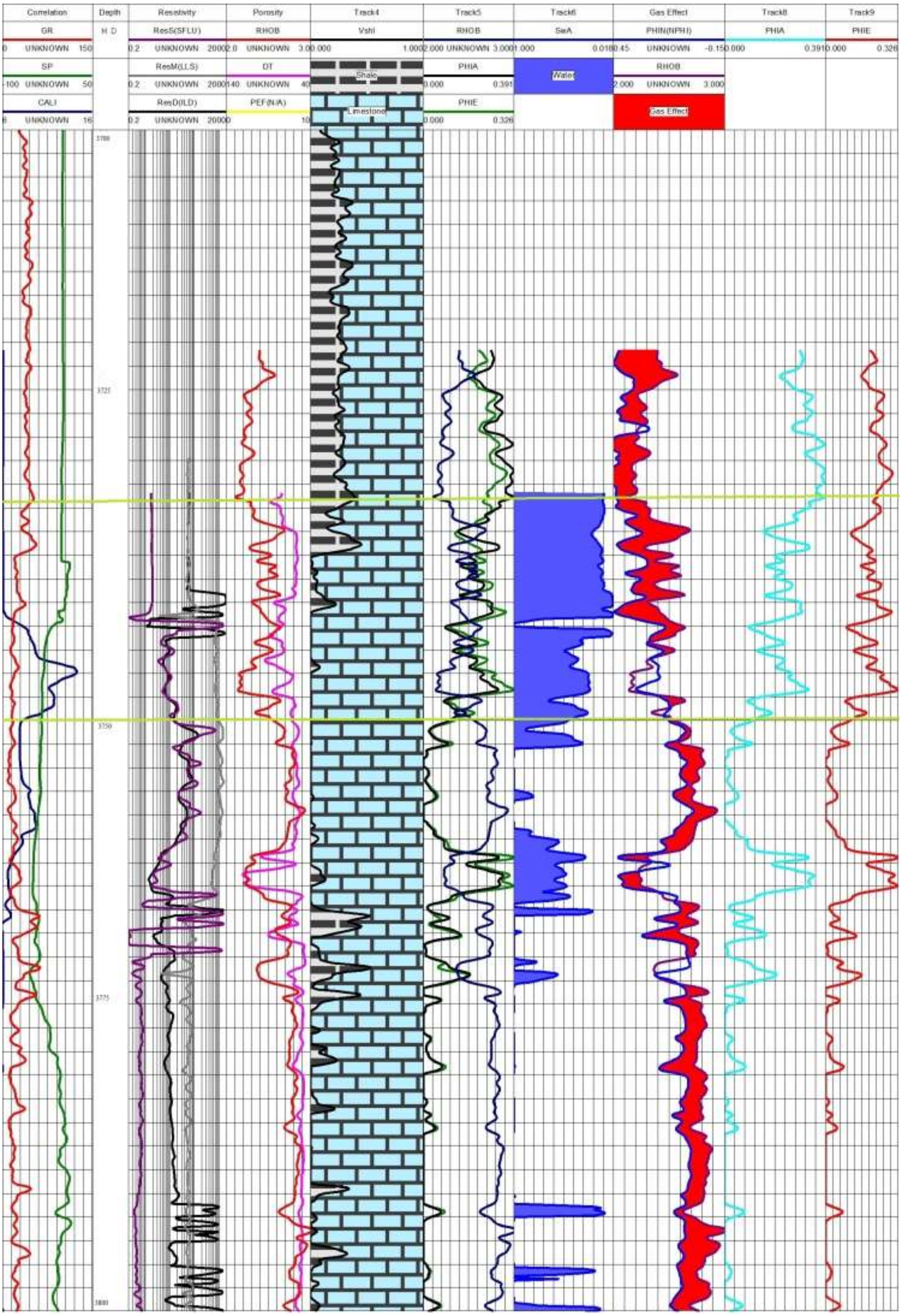


Figure 5.1 Petrophysical analysis (Zone of interest) of the Chorgali Formation in Meyal-01

Table 5.3: Petrophysical results of the Chorgali Formation (measured in %) in Meyal-01 well.

Well	Meyal-01
Formation	Chorgali
Average volume of shale in zone	22.26 to 26.3
Average porosity	3.9 to 4.3
Effective porosity	2.2 to 2.9
Saturation of water	66.14 to 69.78
Saturation of hydrocarbon	34.88 to 37.66

5.5 Zone of Interest in Meyal-17 Well

Zone of interest marked in Meyal-17 well ranges from 3730 m to 3751 m having total thickness of 21 m. This zone is marked on the base of Neutron –Density cross over.

Table 5.4: Interest zone in Meyal-17 well

Well name	Meyal-17
Reservoir name	Chorgali Formation
Start depth (m)	3730 m
End depth (m)	3751 m
Thickness (m)	21 m

5.6 Petrophysical Interpretation of the Chorgali Formation in Meyal-17 Well

In Meyal-17 well, potential resource is the Chorgali Formation and by employing above described methods, petrophysical interpretation has been carried out.

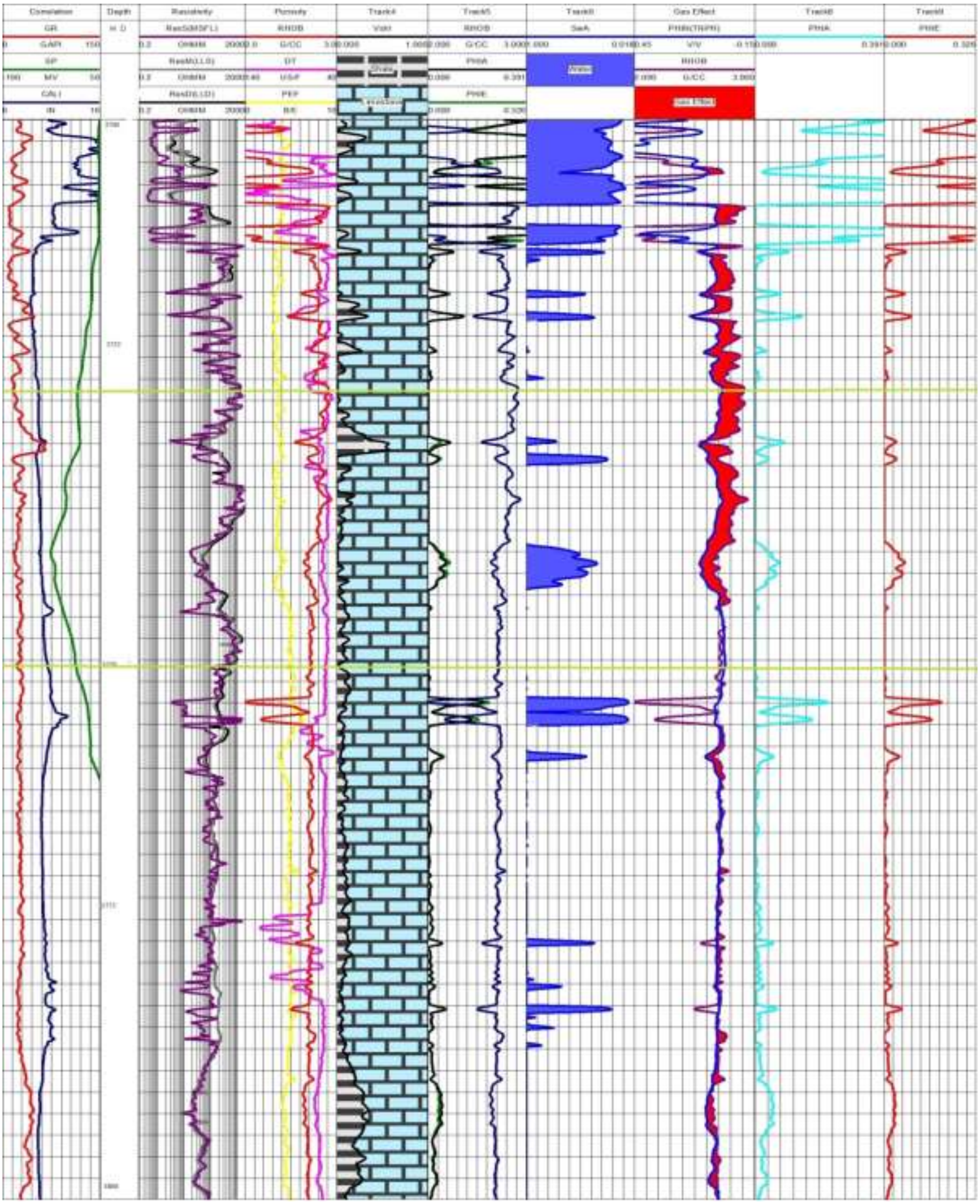


Figure 5.2 Petrophysical analysis (Zone of interest) of the Chorgali Formation in Meyal-17 well

Table 5.5: Results of the petrophysical analysis (measured in percentage) of Meyal-17 well.

Well	Meyal-17
Formation	Chorgali
Average volume of shale in zone	26.0 to 29.0
Average porosity	2.1 to 2.3
Effective porosity	1.2 to 1.9
Saturation of water	31 to 36
Saturation of hydrocarbon	64 to 69

CHAPTER 6

SEQUENCE STRATIGRAPHIC INTERPRETATION

6.1 Introduction

Sequence stratigraphic analysis of well logging is an essential element for evaluating a subsurface data set. Log records lithology and environment of deposition to be positioned on the seismic section, thus involving facies, properties of rock, and sedimentological facies (Wagoner et al., 1991).

Sequence stratigraphic assessment of Wireline log data is not clear. Some system tract limits may have a clever representation on logs and even difficult to identify in core. Correlation between individual wells is often ambiguous. Where wells are closely spaced and core control is good, for example in a data set of production wells from oil or gas field, the data coverage may be sufficient to resolve the sequence stratigraphy. However, a sparser well data set may not allow a single stratigraphic model to be derived.

The conclusion of depositional influences on sedimentary successions is the subject of sequence research. As a result, a log suite sequence analysis would focus on logging tools that calculate depositional parameters (Kendall 2003). There are different types of log suits such as Gamma ray log, Caliper log, Spontaneous Potential log, Resistivity logs, Neutron log, Density log and Sonic log. These different types of logs are used to mark the log trend on the wireline data. There are five type of log trend that are particularly defined based on Gamma ray log (Fig. 6.1). These log trends help to define the lithology and environment of deposition. Moreover, these log trends are helpful for identification of system tract, sequence boundary and stratigraphical surface (Kendall, 2003).

Since the form of a log is closely related to the grain size of rock successions, Selley (1978) found well log curves to be a fundamental method for interpreting depositional facies. Cant (1992) identified five different log curve shapes for interpreting the depositional environments, as well as the importance of studying core in relation to logs for facies analysis in the subsurface. Log trend are defined based on both carbonate and clastic sequences. Log motif is defined based on lithology log or Gamma ray log. These log trends are also used for assessment of Environment of deposition (Selley, 1978; Cant, 1992; Rider, 1996; Nazeer et al., 2016). .

Log motif does not give direct information of the facies. In log trend we try to access the environment of deposition and then from environment of deposition we move towards lithology. Then lithology is related with log curve along with environment of deposition and then applied in sequences. When well log data or log trend are away from the basin then variations and irregularities are encountered in it. When the well data is close to the basin the log trend behavior is regular and easily matches with log trends. There are five log trends that are named as:

1. Cylindrical/ Box Shape.
2. Bow trend/Symmetrical Shape
3. Irregular trend/ Serrated
4. Funnel shape/ Cleaning-Upward Trend
5. Bell Shaped/ Dirtying-Upward Trend

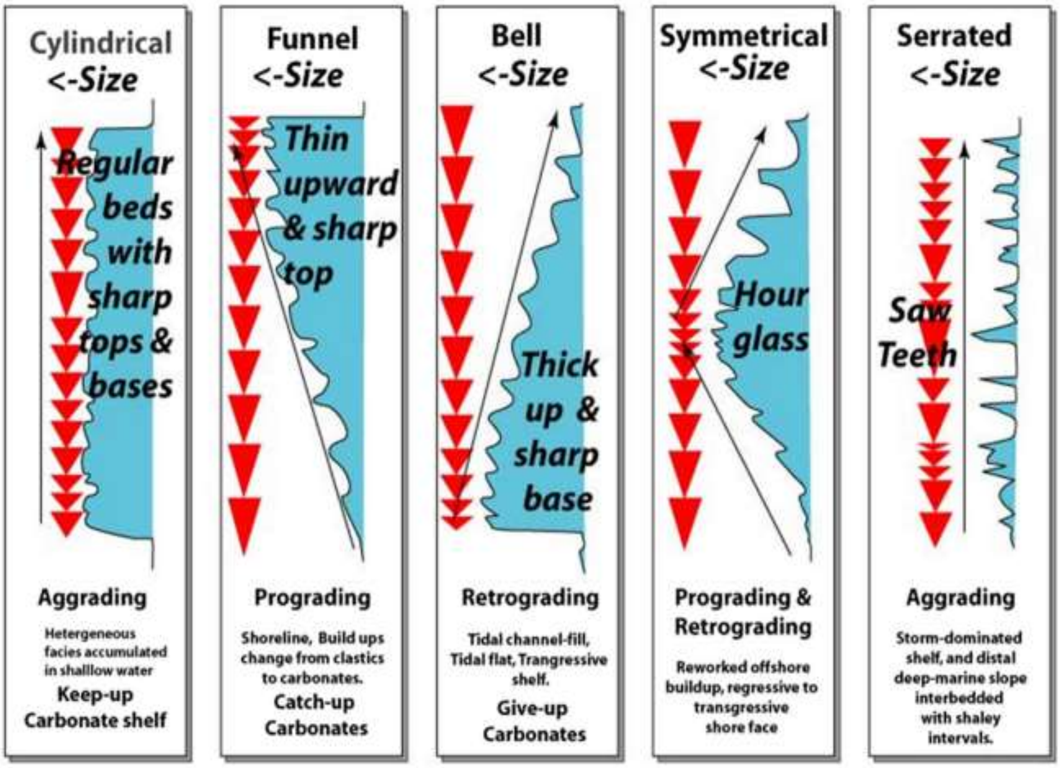


Figure 6.1 Different types of log trends based on Gamma ray log values.

1. Cylindrical Shape/Box Car Trend

Cylindrical shape is also known as Box car trend. It shows a sharp boundary and rapid change. The middle portion of the trend shows thick values and these values are moving towards low Gamma ray. It is a vertical slice with no gradual change, on bottom there is an abrupt increase in Gamma ray, and then the values are decreased and move along lower GR side with no gradual change then again hasty increase in GR values. This change is not high, but its trend varies from middle to base line. The Gamma ray log trend shows a constant decrease in values (Kendall, 2003). This change shows the sudden oxidizing environment. It may cause an immediate change. The lithology shows the presence of carbonates than rapid change to shale or thick deposits of sand.

2. Bow Trend/Symmetrical Trends

Bow trend is also known as symmetrical trend. It is a merger of two trends, from bottom cleaning upward trend followed by dirtying upward trend. There are two environments of deposition formed in this trend. In marine environment this trend is associated with clinoform (Shallow depth). Bottom of clinoform shows the dirty upward trend and shallow basin is also associated with clinoform change. The typical shape of the Gamma ray indicates a reduction in shale levels followed by a rebound. This character also indicates a rapid change in the layer (Kendall, 2003).

3. Irregular Trend/Serrated

Irregular shaped GR log trend is comprised of variation in Gamma ray readings with high and low values over very small time of vertical well profile (Kendall, 2003). Such trends show change in lithology in composite beds, beds of shale and carbonate. This trend may signify the gradient accumulations and sometimes called as turbidities. Such deposits may also have interpreted as flow of debris along slope. In generalized form it is associated with aggradation when no high-level fluctuation is encountered. It shows a typical environment of deposition and occasionally, delta or shallow marine facies sediments also deposit in this trend (Kendall, 2003).

4. Funnel Shape/ Cleaning-Upward Trend

Funnel shape trend is also known as cleaning-upward trend or coarsening upward trend. It shows the dominance that varies for example from shale to carbonate (stretching upwards) (Kendall, 2003). The phase of sea water that occurs in the form of regression. In funnel shape there is a change of environment from reducing to oxidizing environment.

5. Bell Shaped/ Dirtying-Upward Trend

Bell shaped trend is also known as dirtying-upward trend or finning upward trend. In this motif, bottom has low Gamma ray values and moving towards top high Gamma ray values. In dirtying upward trend, the movement is from shale free to shale massive lithology or from carbonate to shale. In finning upward trend, the movement from coarser grain particles to finer grain particles and sand base line to shale base line. Moving toward oxidizing to reducing environment, it shows a retrogradational geometry (Kendall, 2003).

6.2 Log Motif Associated with Meyal Wells

The two wells, Meyal-01 and Meyal-17, based on log trends observed in Gamma ray log (GR) have been interpreted. Firstly, the Chorgali reservoir is marked with the help of well tops file. Later, the log trends are identified based on the behavior of Gamma ray log than the system tracks are defined. Lastly, the environment of deposition is marked by observing the overall behavior of the Gamma ray log.

6.3 Identification of System Tracts on Logs

The system tracts can be traced on the well logs. System tract links simultaneous depositional units, which are identified by the kinds of surfaces that bind them. (Brown and Fisher, 1977). Lowstand, Highstand and Transgressive system tracts are the three types that are usually separated into a sequence. A sequence boundary on the baseline and a transgressive surface on top determine the Lowstand system tract. The basin floor fan deposited with the rapid fall in sea level distinguishes the Lowstand system tract. Lowstand prograding wedge accumulated during later sea level drop or initial rising sea levels and associated by progradational to aggradational parasequence patterns (Vail, 1987; Posamentier and Vail, 1988; Vail et al., 1991). The transgressive surface is at the bottom of the

Transgressive system tract, while the maximal flooding surface should be at the top. Yet another or even more retrogradational parasequence sets identify the transgressive system, which would be deposited during quick rising sea levels. The maximal flooding surface and a sequence boundary from the bottom and top, accordingly, limit the high stand system tract. During early comparative sea rise, sea level still remains, and early relative sea level drop, high system tract is deposited. Yet another or even more aggradational parasequence patterns, preceded with one or more progradational parasequence sets, identify high stand system tract. Highstand, Transgressive and Lowstand system tract, were detected in Meyal-01 and Meyal-17 wells.

6.4 System Tract of Meyal-01

From 3732 to 3850 m, a Highstand system tract (HST) may be detected, indicating that progradation geometry is decreasing away from the regression base level (Fig. 6.2). A coarsening uphill trend characterizes the tract in this system.

The Transgressive system tract can be found between 3850 and 4000m. The Transgression system tract indicates retrogradation sedimentation toward the transgressive level. Between depths of 3975 and 4075m, a Lowstand tract was identified, forming a regression in the base level toward progradation pattern geometry. There is a significant drop in sea level in this system tract. The coarsening downward trend is typical of this system tract.

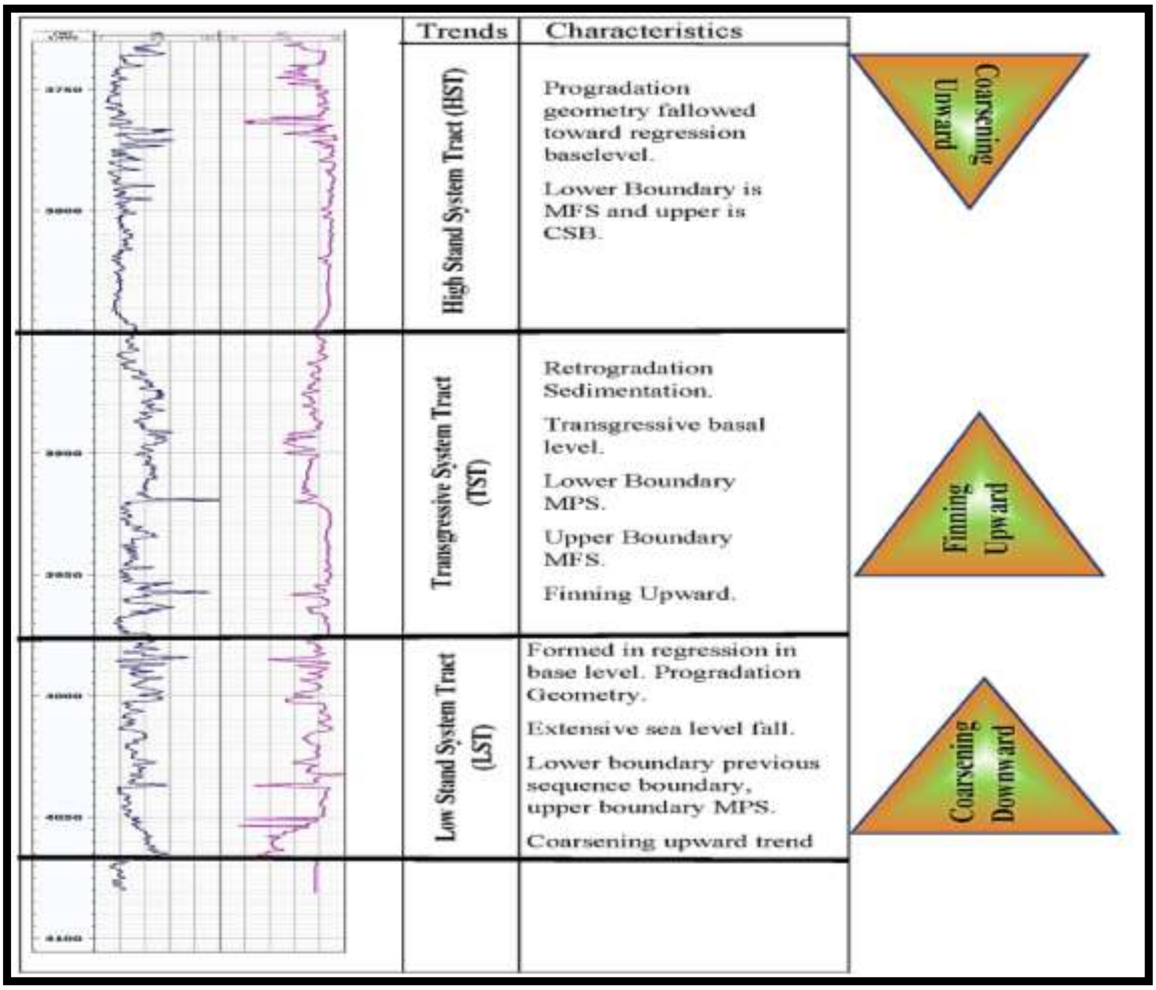
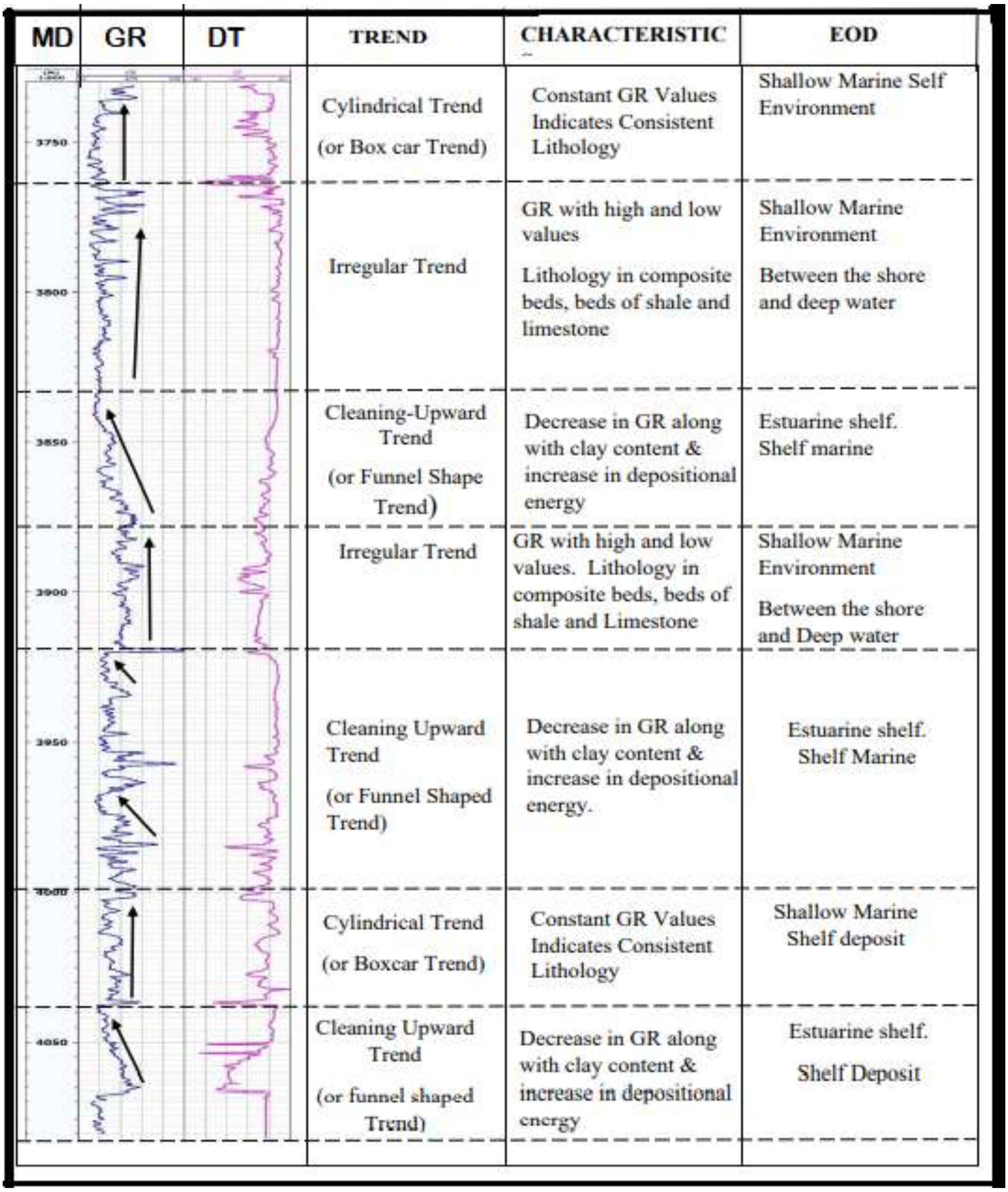


Figure 6.2 Sequence stratigraphic interpretation of the Chorgali Formation in Myal-01 well

6.5 Depositional Environment of the Chorgali Formation in Meyal-01 Well

The Chorgali Formation depositional environment was determined using the GR log. A cylindrical trend may be seen in figure 6.3 from 3730 to 3760 m, indicating shallow marine deposits (Fig. 6.3). There is an uneven pattern from 3760 to 3830 m showing those deposited between coast and deep water, and a funnel-shaped trend from 3830 to 3870 m indicating shelf marine environment. From 3870 to 3930 m, the pattern is irregular again, and from

3930 to 4000 m, the trend is boxcar. Because the GR log value decreases below 4000 m and the trend returns to a funnel shape.



TREND	CHARACTERISTIC	EOD
Cylindrical Trend (or Box car Trend)	Constant GR Values Indicates Consistent Lithology	Shallow Marine Self Environment
Irregular Trend	GR with high and low values Lithology in composite beds, beds of shale and limestone	Shallow Marine Environment Between the shore and deep water
Cleaning-Upward Trend (or Funnel Shape Trend)	Decrease in GR along with clay content & increase in depositional energy	Estuarine shelf. Shelf marine
Irregular Trend	GR with high and low values. Lithology in composite beds, beds of shale and Limestone	Shallow Marine Environment Between the shore and Deep water
Cleaning Upward Trend (or Funnel Shaped Trend)	Decrease in GR along with clay content & increase in depositional energy.	Estuarine shelf. Shelf Marine
Cylindrical Trend (or Boxcar Trend)	Constant GR Values Indicates Consistent Lithology	Shallow Marine Shelf deposit
Cleaning Upward Trend (or funnel shaped Trend)	Decrease in GR along with clay content & increase in depositional energy	Estuarine shelf. Shelf Deposit

Figure 6.3 The environment of deposition of the Chorgali Formation in Meyal-01 well

6.6 System Tract of Meyal-17 Well

Highstand system can be observed between 3600 and 3635 m, indicating progradation geometric features. The maximum flood surface is noted at the low boundary, whereas the candidate sequence boundary is marked at the higher boundary. The grain size pattern has become much coarser. Transgressive system tract can be indicated from 3635 to 3720 m. The retrogradation sedimentation is represented by the Transgression system tract. The grain size pattern is characterized by upward finning.

Lowstand system tract can be encountered between 3720 and 3830 m, indicating a regressive base level. In this system, the rising trend is coarsened. The proposed sequence limit is marked between 3830 and 3850 m. This boundary is marked by a sharp increase in GR value.

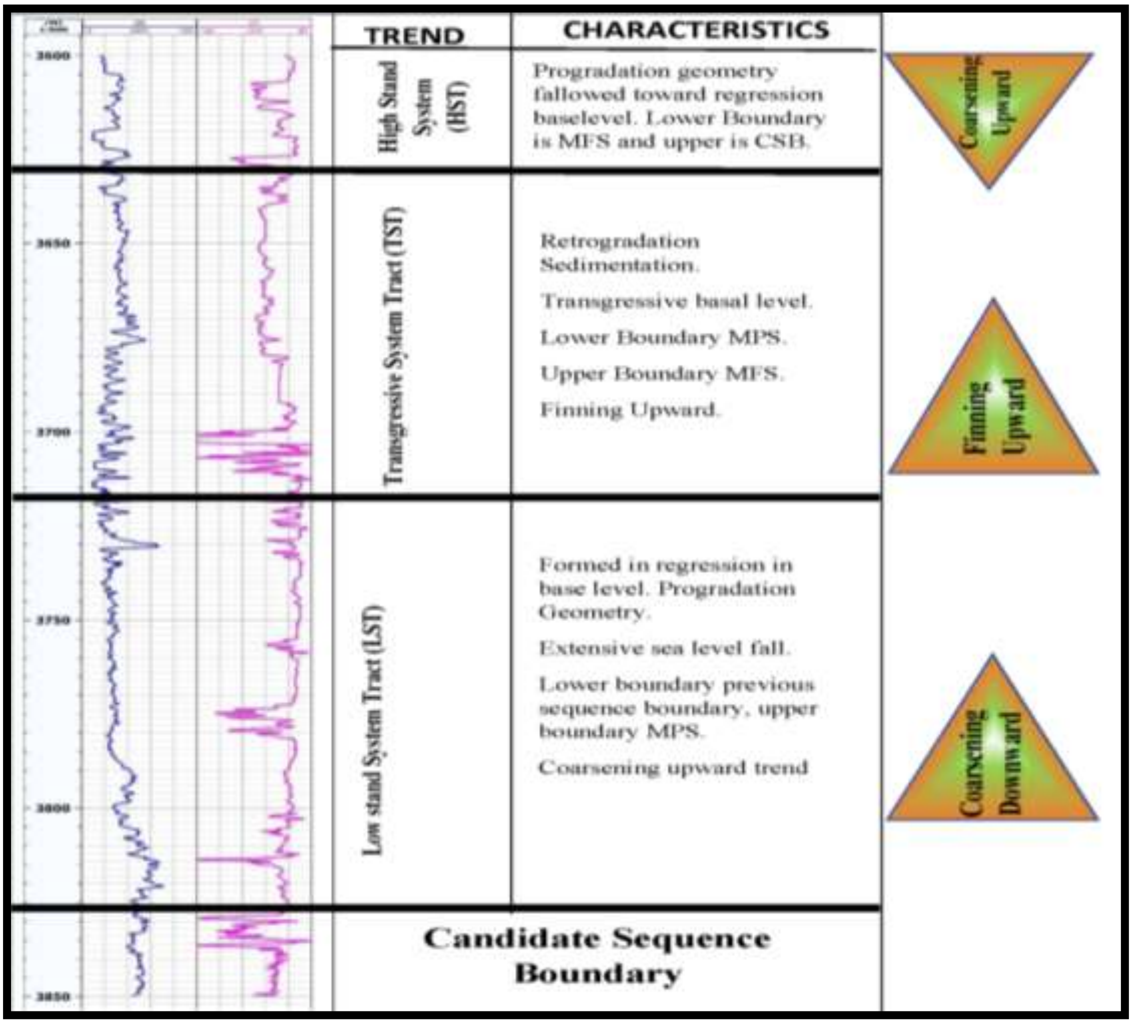


Figure 6.4 Sequence stratigraphic interpretation of the Chorgali Formation in Meyal-17 well

6.7 Depositional Environment of the Chorgali Formation in Meyal-17 Well

Figure 6.5 shows an uneven pattern from 3600 to 3670 m, indicating shallow marine shelf deposits. Those deposited in a transgressive marine environment are shown from 3670 to 3700 m with a cleaning upward trend from 3700 to 3730 m, indicating a shallow marine shelf habitat. The pattern is irregular again between 3730 and 3790 m, and below 3790 m, the trend is unclean.

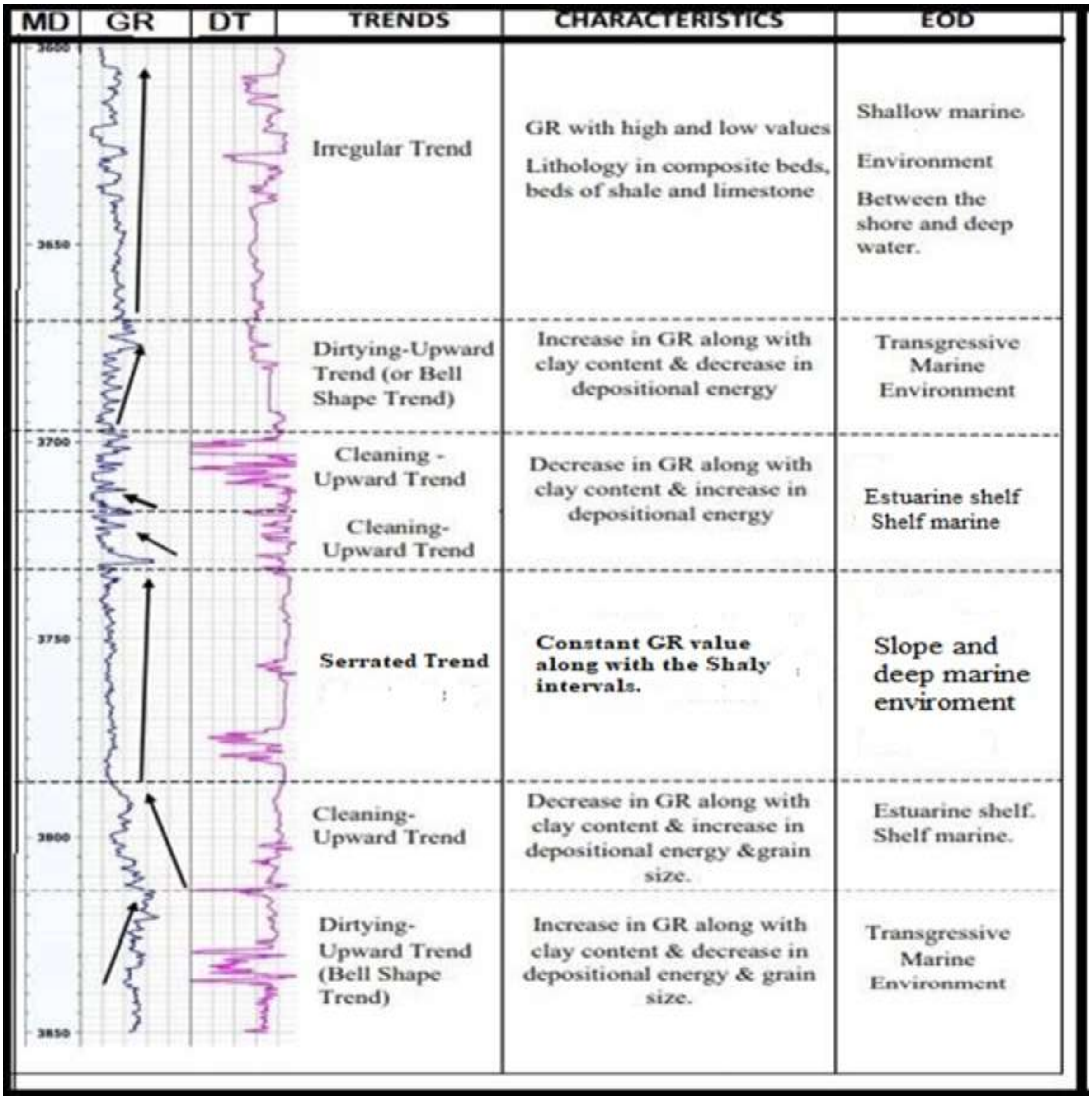


Figure 6.5 The environment of deposition of the Chorgali Formation in Meyal-17 well.

Conclusions

On the basis of petrophysical analysis and sequence stratigraphy in Meyal-01 and Meyal-17 wells, the following conclusions are drawn.

1. Volume of shale computed for the zone of interest in the Chorgali Formation ranges from 22.26 to 26.03% for Meyal-01 and 26.00 to 29.00% for Meyal-17 wells.
2. Total average porosity ranges from 3.09 to 4.03% for Meyal-01 well and 2.01 to 2.03% for Meyal-17 well. Average total effective porosity ranges from 2.03 to 2.09% in Meyal-01 well and 1.2 to 1.9% for Meyal-17 well. The data indicate suitable reservoir qualities of the Chorgali Formation in Meyal-01 well.
3. Average saturation of water ranges from 66.14 to 69.78% for Meyal-01 and 31.00 to 36.00% for Meyal-17 wells of the Chorgali Formation. Average saturation of hydrocarbon ranges from 34.88 to 37.66% for Meyal-01 and 64.14 to 69.69% for Meyal-17 of the Chorgali Formation. The data indicate that the Meyal-17 well is the potential reservoir of hydrocarbon.
4. Meyal-01 and Meyal-17 wells had Highstand and Lowstand system tracts, respectively. The Transgressive system tract marks below High system tract (HST) which follows retrogradation sedimentation. This trend indicates that fine grains sizes are upward. After Lowstand system tract (LST) formed regressive base levels and the features of Lowstand system tract (LST) are that coarsening upward.
5. The Chorgali Formation in Meyal-01 well is indicating shallow marine environment and in Meyal-17 well shallow marine and estuarine shelf environment.

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