RESERVOIR POTENTIAL OF EOCENE LIMESTONE IN UPPER INDUS BASIN, PAKISTAN.

BY

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CERTIFICATE

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In the name of ALLAH, the most beneficent, the most merciful I bear witness that there is no God but ALLAH and Holy Prophet Hazrat Muhammad (PBUH) is the last messenger. With the grace of ALLAH, I have been able to overcome yet another task which was impossible without ALLAH‟s Blessings. All praises are for Allah, who always gave me the strength and ability to overcome challenges, this dissertation yet another example of blessings of ALLAH. I am highly obliged to Dr. Aamir Ali, HOD, Earth sciences, Quaid-i-azam University Islamabad, for his compassionate behavior, able guidance and scholastic criticism during the entire study. Heartfelt appreciation goes to Dr Aamir Ali, for his supervision, constant support and timely advice to shape this dissertation into its final form. His invaluable comments, his helpful nature and academic support have contributed most in making this task easier and more comfortable. I would like to express cordial gratitude to my whole family, especially my parents. Their support, prayers, encouragement and confidence has always given me strength to be able to achieve my goals. I sincerely wish to express my appreciation to the whole faculty of Department of Earth Sciences. Their support and guidance has been priceless throughout my course and dissertation work. Finally, I offer my cordial thanks to all our friends who helped me and always prayed for my success throughout the span of study for their endless support, care and affection.

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ABSTRACT

Two dimensional seismic interpretation has been carried out in Missa Kaswal area (study area) located near Gujar Khan in the district of Rawalpindi, Pakistan to reveal the subsurface geology. The data used for this study was provided by DGPC. Seismic data given for well Qazian-01X includes navigation of well and segy data whereas well data include well tops and well headers. Geologically, study area is located in Potwar sub-basin, Upper Indus basin bounded by Soan syncline in the north, Salt Ranges in the south, Jhelum fault in east and Kalabagh fault in west. Prospect evaluation (including gridding, time and depth contouring and identification of structures) has been carried out using Kingdom suit of Software. Structural interpretation has identified anticlinal structure bounded by two reverse faults and is marked on seismic sections. These structures have been marked at Chorgali of Eocene and Patala Formation of paleocene. The horizons are identified and named on the basis of well and generalized stratigraphic data. Seismic Attributes analysis shows that the Chorgali Formation is marked on high acoustic impedence and consolidated material exists. Different petrophysical parameters like volume of shale, water saturation, porosity and hydrocarbon saturation are taken into consideration for reservoir characterization. By performing petrophysical analysis on Chorgali Formation, it is found that the value of volume of shale in Chorgali is 40%, effective porosity is 7%, hydrocarbon saturation is 15% and water saturation is 85%. Facies analysis is performed on the Chorgali Formation, which indicates the presence of shale, limestone and shaly limestone in the formation. Coloured inversion shows the inverted seismic section of the control line, confirming the picking of reflectors marked and Chorgali Formation at high acoustic impedence.

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CHAPTER 1

INTRODUCTION TO STUDY AREA

The study area is Missa Kaswal**,** located near Gujar Khan in the district of Rawalpindi. This area has been viewed as an area of great interest for hydrocarbon exploration. The Missa Keswal field was discovered in June 1991 and came on a regular production from December 1992. Geologically, it lies in the Upper Indus (Potwar basin) which is characterized by large numbers of thrust and normal faults producing asymmetrical structures (anticlines/ synclines). Basically Pakistan has two main basins these are Indus basin and Baluchistan basin. Indus basins is further divided into sub-basins, these are Upper Indus Sub-Basin, Central Indus Sub-Basin and Lower Indus Sub-Basin. This research is focused on upper Indus Basin which is sub-part of Indus Basin, as study area is situated here shown in figure 1.1.

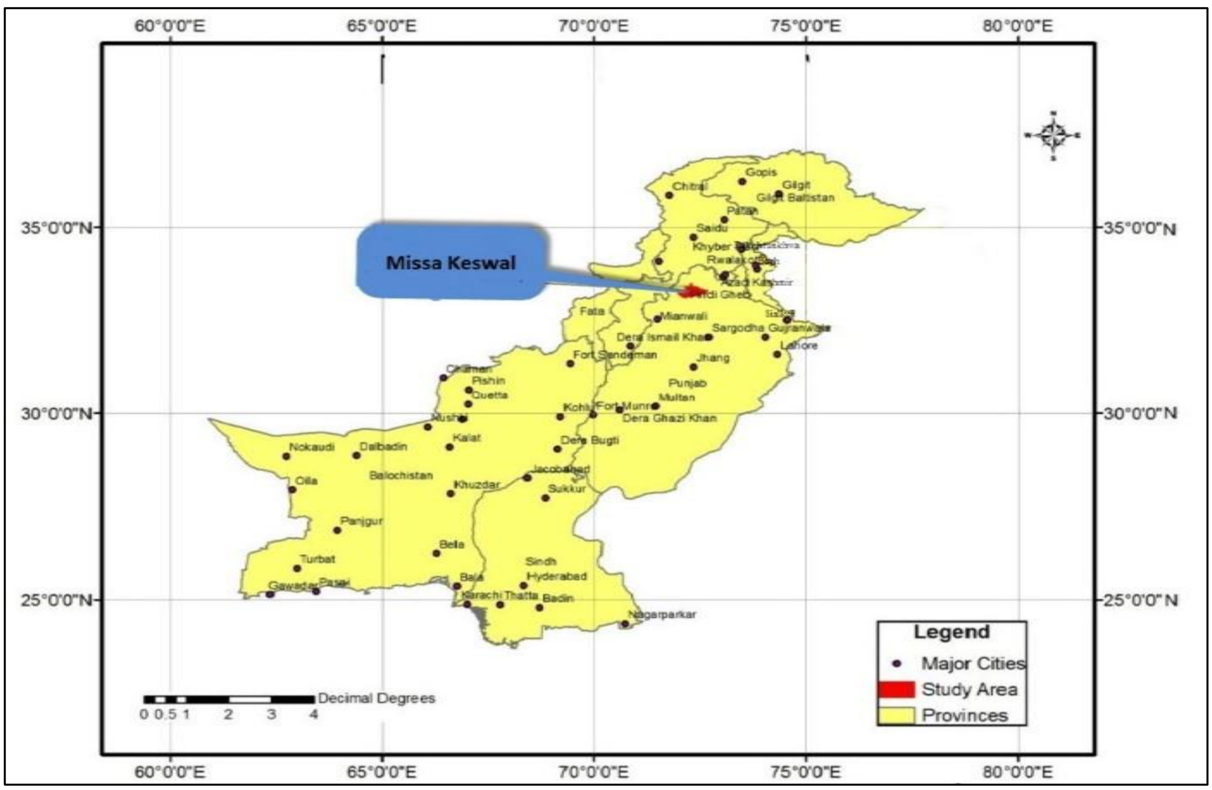

Figure 1.1 Location of study area (Khan et al., 2019).

1.1 Data Used

The data used to complete the research project is provided by DGPC. One well is given for research that is Qazian-01X. This well lies near the line GO-994-GNA-09 in Potwar region. This well is dry well. The UTM coordinate system is used and define the position of this well. In geological perspective this well is present in Upper Indus Basin. The location of QAZIAN-01X is 33° 12´ 09´´ N and 73° 20´ 19´´ E.

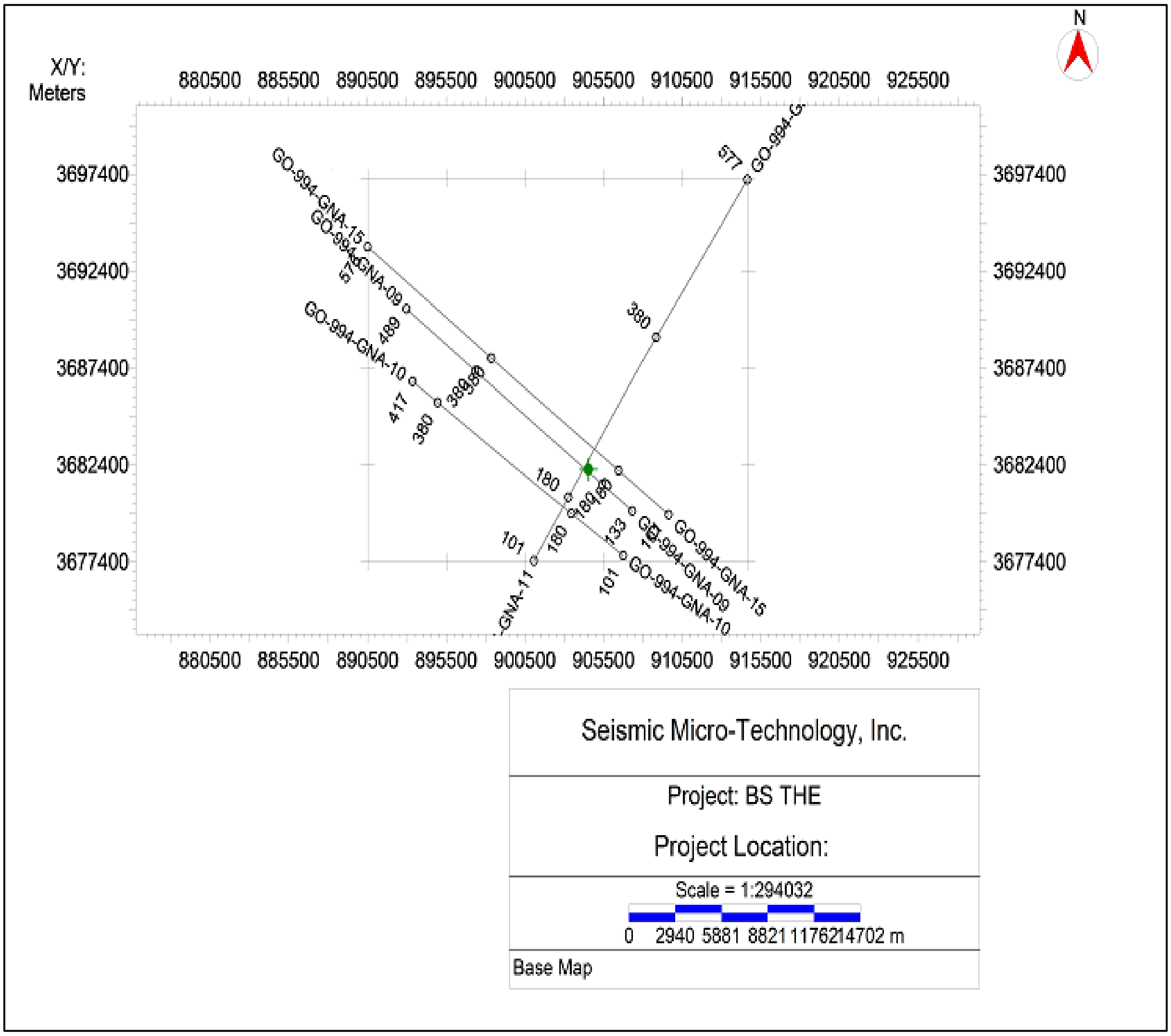

Figure 1.1 Basemap of seismic lines and well Qazian-01X.

The Missa Keswal is found almost 70 km southeast of Islamabad in the Gujjar Khan, District Rawalpindi, Potwar region of Punjab, Pakistan.

Table 1.1 shows seismic lines used for construction of base map of study area. The bolded lines are lines of interest.

Table 1.1 Seismic lines with their type.

S.NO	**LINE Name**	**TYPE**
1	GO-994-GNA-09	dip
2	GO-994-GNA-10	dip
3	GO-994-GNA-11	strike
4	GO-994-GNA-15	dip

The logs provided in well data are Caliper log (CALI), Gamma ray log (GR), Spontaneous potential (SP), Neutron porosity log (NPHI), Sonic log (DT), Density log (RHOB), Latero log shallow (LLS), Latero log deep (LLD), Micro spherically focused log (MSFL) and Micro Latero Log (MLL).

1.2 Objective Of Research

The objective of this research is to determine the hydrocarbon potential of Qazian-01X with the help of petrophysical analysis using wireline well logs. The main proposed objective of this studies are:

- Structural interpretation of the study area in order to delineate structures favorable for hydrocarbon accumulation .
- Seismic attribute analysis to aid the interpretation of seismic data.
- Petrophysical analysis in order to delineate the reservoir characteristics of the study area.
- Facies analysis to indicate the lithology details of the reservoir formation.
- To investigate the variation in relative acoustic impedence at reservoir level.

1.3 Methodology

Kingdom software is used for the complition of this research. In this software, followings steps were taken into account:

- Load SEG-Y data of 2D seismic lines with line navigation and well data which includes navigation of well, formation tops and well logs.
- Generate synthetic seismogram and correlate well and seismic data.
- Mark horizons, Chorgali and Patala. Mark various geological features like faults etc.
- Then prepare grid contour maps for various formations in time and depth domains.
- Seismic attribute analysis to aid interpretation of seismic data.
- Now perform Petrophysical analysis to calculate volume of shale, porosity, hydrocarbon saturation on the basis of given well logs.
- Facies analysis to indicate the lithology details of the reservoir formation.
- Coloured inversion to investigate the variation in relative acoustic impedence at reservoir level.
- Results and conclusion.

CHAPTER 2

GEOLOGY AND TECTONICS OF THE AREA

2.1 Regional Geology Of Pakistan

In late Paleozoic Pangaea split into two parts. The northward drift of Indian plate started in late Mesozoic time (Cretaceous) and continued till late Eocene. When the plate collided with Kohistan Island arc the Island arc formed as a result of calcium alkaline activity in the subducting oceanic crust during Cretaceous time. This northward drift finally resulted in formation of Himalayas Mountains.

Pakistan acquired its structural and stratigraphic features from tectonic events associated with plate movements, which occurred from late Paleozoic time to present. From Permian through middle Jurassic time, the area known today as Indus Basin was located in the southern hemisphere.

Pakistan comprises of the main geological subdivisions referred as Laurasian, Tethyan and Gondwanaland domain. On this scenario Pakistan is unique in as much as it lies at the junction of two convergent Indian and Eurasian plate. The southern part belongs to Gondwanian domain and is sustained by Indo-pak crustal plate. The northern and western regions of Pakistan fall in Tethyans domain and present a complicated geology and complex crustal structure (Kazmi & Jan, 1997).

Pakistan has two main basins these are Indus basin and Baluchistan basin. These basins are evolved through different geological episodes after which they welded together during Cretacious and Paleocene age along chaman strike slip faults. Indus basins is further divided into sub-basins, these are Upper Indus Sub-Basin, Central Indus Sub-Basin and Lower Indus Sub-Basin. Upper Indus Basin is further divided into Kohat Sub Basin and Potwar Sub Basin. The study area lies in Potwar region shown in figure 2.1.

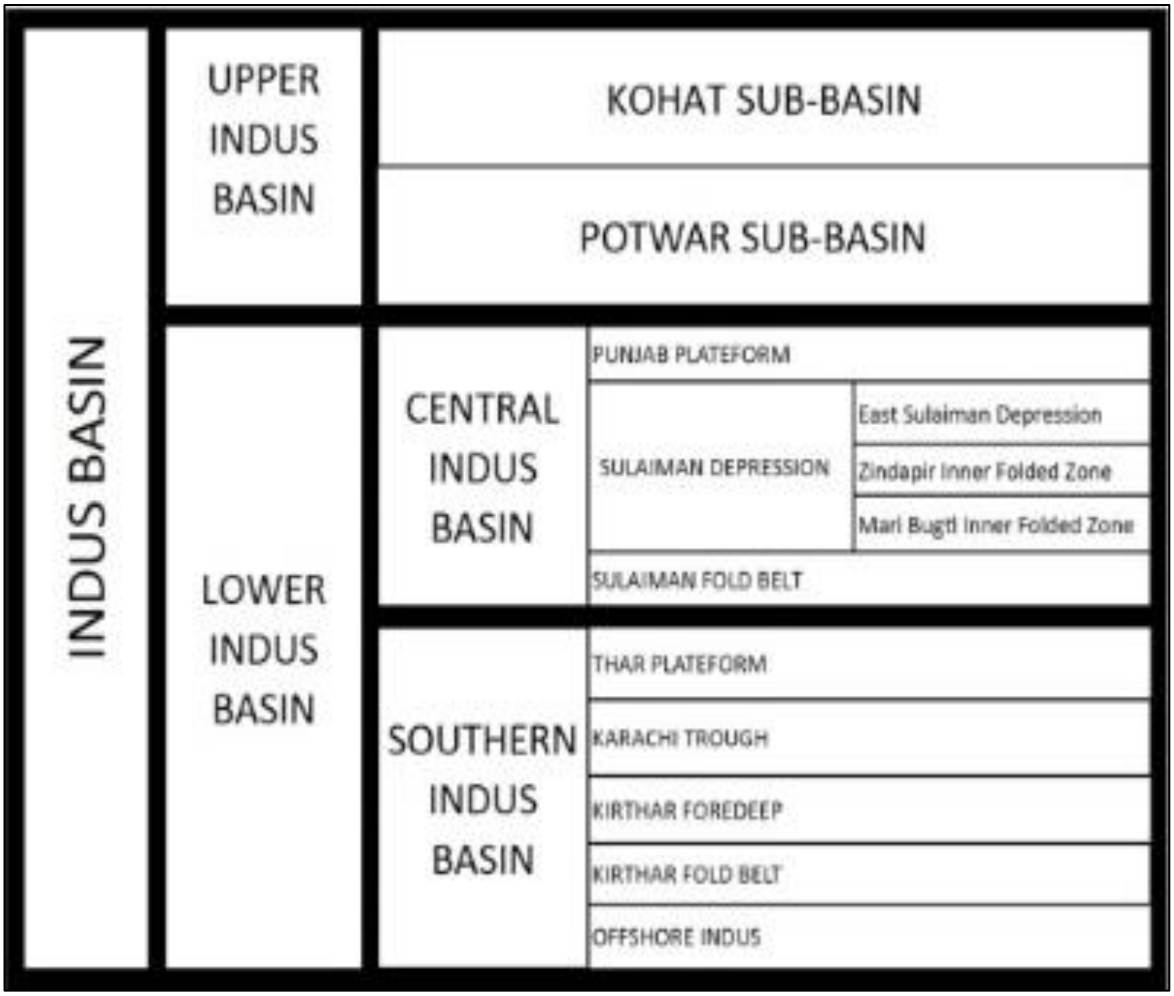

Figure 2.1 Division of the Indus Basin (Kadri, 1995).

2.2 Tectonics of Upper Indus Basin

The upper Indus basin is separated by the Sargodha High from the Lower Indus basin. The northern and eastern boundaries coincide with the Main Boundary Thrust (MBT). The western boundary of the basin is marked by the uplift of pre-Eocene sediments that are eastward directed and are thrusting to the west of Bannu shown in figure 2.2.

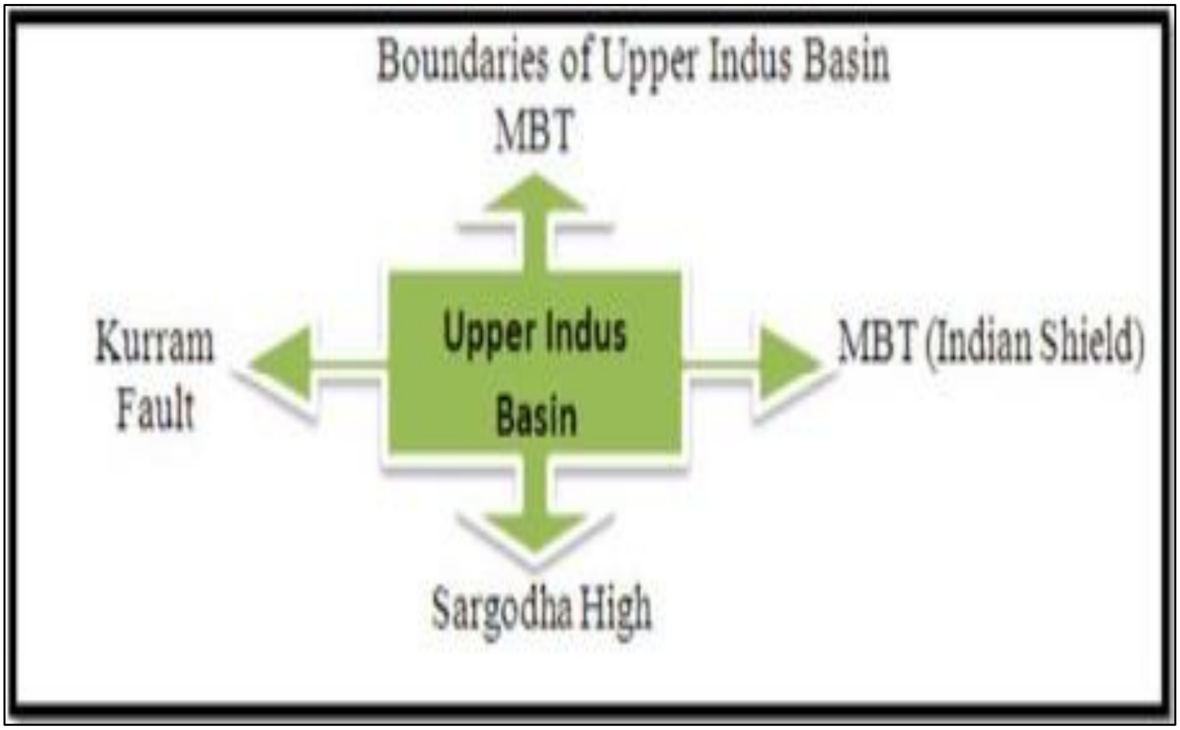

Figure 2.2 The geological boundary of Upper Indus Basin.

The basin is subdivided in the Potwar sub-basin in the east, and Kohat sub-basin in the west by the River Indus. These sub-basins although not much larger in size, depict important facies.

2.2.1 Potwar Sub-Basin

Potwar sub basin preserves sediments from Precambrian to Quaternary age in subsurface, with them being exposed in the Salt. Potwar is a Fore-land fold and Thrust belt of Himalaya Orogeny that is bounded by Kala-Chitta and Margallla Hills to the north, Indus River and Kohat Plateau in the west, Jhelum River and Hazara Kashmir Syntaxis in the east and Salt Range Formation in the south (Kadri, 1995).

2.2.2 Kohat Sub-Basin

In Kohat sub-basin, Eocene rocks through the Siwalik strata are involved in a complex fold and thrust belt in which Eocene Salt occupies the cores of many of the anticlines. Paleocene and Eocene stratigraphy is more complete in the Kohat sub-basin (Kadri, 1995).

The major unconformity present in both the sub-basins is between Carboniferous to Ordovician and Permian ages.

2.3 Stratigraphy of Upper Indus Basin

Stratigraphy of Upper Indus Basin includes formation from Infra-Cambrian to Miocene time. Some of the formations which are not encountered in Qazian-01X, those are either Pinched out or terminated before reaching the well. Following figure 2.1 shows stratigraphic division of Upper Indus Basin.

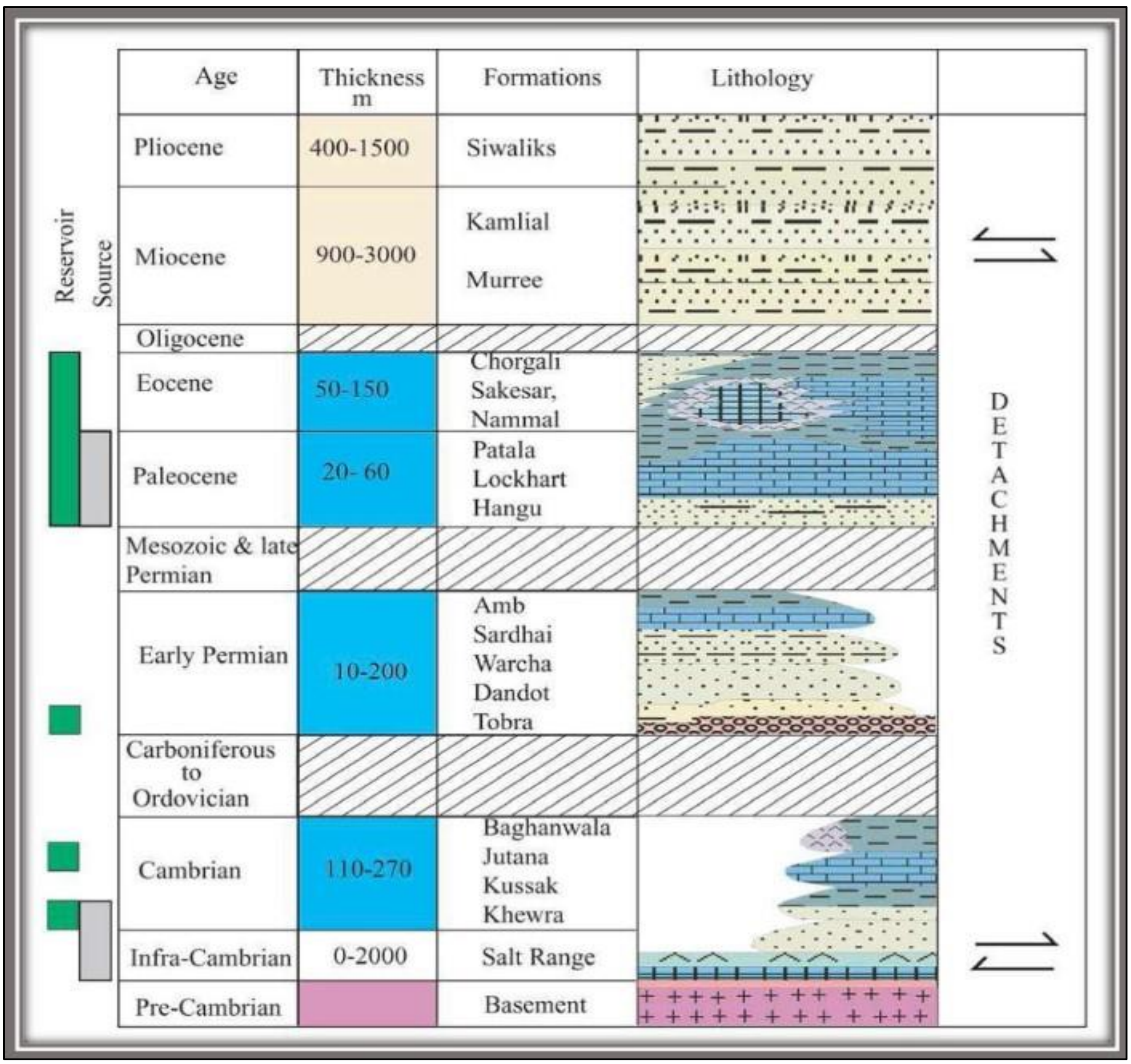

Fig.2.1 Stratigraphy division of upper Indus Basin (Aamir and Siddique, 2006).

The oldest stratigraphy unit drilled in the Qazian-01X is the Infra-Cambrian Salt Range formation which is followed by Khewra, Kussak, Jutana and Baghanwala formation in Cambrian age. The Cambrian age is then followed by Dandot and Tobra formation in Early Permian which is then followed by Patala formation in Paleocene sequence. This is then followed by Eocene and Miocene sequences (Shah, 2009).

The stratigraphic column is divided into three unconformity-bounded sequences. These unconformities in the study area are Ordovician to Carboniferous, Mesozoic to Late Permian, and Oligocene in age. These unconformities are not easily identified in the seismic profiles due to complex thrusting.

The Formation tops were initially picked at the well site, which were further refined / confirmed by the electric logs. A list of final formation tops and thickness drilled in Qazian-01X are presented in a table 2.1.

Table 2.1 Formation Tops

Formations	**Formation tops (m)**
Chinji	0
Kamlial	1031
Murree	1199
Chorgali	2062
Sakesar	2107
Namal	2182
Patala	2196
Dandot-Tobra	2225
Baghanwala-Jutana-Kussak	2258
Khewra	2343
Salt range	2457

2.3.1 Salt Range Formation

Khewra Gorge in the eastern Salt Range has been designated as the type section. It is about 5m thick. The lower part of salt range formation is composed of red coloured marl with thick seams of salt, beds of gypsum, dolomite, greenish clay and low grade oil shale are the constituents of the upper part (Shah, 2009).

2.3.2 Khewra Formation

Khewra formation was formalized as Khewra Sandstone by Stratigraphic Committee of Pakistan. The type locality is in Khewra Gorge near Khewra Town, Salt Range. The formation consists of purple to brown fine-grained sandstone. The lower most part of the formation is red, flaggy shale. The thickness in type locality is about 150m (Shah, 2009).

2.3.3 Baghanwala Formation

The type section of this formation is located near Baghanwala Village in the eastern Salt Range. The formation is composed of red shale and clay with alternate beds of flaggy sandstone. Sedimentary structures such as ripple marks and mud cracks are common. Near Baghanwala, its thickness ranges from 100 to 116m (Shah, 2009).

2.3.4 Dandot-Tobra Formation

The type locality of Tobra formation is located near Tobra village in the eastern Salt Range. The formation at the type locality is 20m thick. This formation composed of boulders of granite with fragments of quartz, feldspar, magnetite, garnet, claystone, siltstone, gneiss and bituminous shale. The type locality of Dandot formation is near Dandot Village, eastern salt range. The lithology at the type locality consists of light grey to olive green sandstone with thin pebbly bed of shales. The maximum thickness of the formation has been recorded in Makrach Valley, where it is about 50m (Shah, 2009).

2.3.5 Patala Formation

The term Patala Formation was formalized by the stratigraphic committee of pakistan for the Patala shale and its usage was extended to other parts of the Kohat-Potwar and Hazara formations. The formation includes Tarkhobi shale and part of Hill limestone. The section exposed in Patala Nala (lat. 32° 40´ N: long. 71° 49´ E) in the Salt range has been designated as type section. In the salt range formation consists of shale and marl with subordinate limestone and sandstone (Shah, 2009).

2.3.6 Nammal Formation

The section exposed in Nammal Gorge (lat. 32° 40´ N: long. 71° 07´ E) is the type section. The formation throughout comprises shale, marl and limestone. The shale is grey to olive green , while the limestone and marl are light grey to bluish grey. The formation is well developed in Salt and Surghar range. It is 100m thick in the Nammal Gorge (Shah, 2009).

2.3.7 Sakesar Formation

Sakesar peak (lat. 32° 31´ N: long. 71° 56´ E) in the Salt Range has been designated as type locality. The units consists dominantly of limestone with marl. The limestone and marl are cream coloured to light grey. In the Salt Range thickness varies between 70m and 150m (Shah, 2009).

2.3.8 Chorgali Formation

The term Chorgali beds has been formalized as chorgali formation by Stratigraphic Committee of Pakistan. The formation also represents Passage beds in Attock area, Bhadhrar beds in Salt range and Lora formation in Hazara area. The section exposed in the Chorgali Pass (latitude 33° 26´ 30´´ N: longitude 72° 41´ E) in the Khair-e-Murat Range, has been chosen as the type section. The formation is composed of shale and limestone. In the Khair-e-Murat Range, it is dividible into two distints units. The lower unit comprises dolomitic limestone and shale. The dolomitic limestone is white to light grey and yellowish grey and medium bedded while shale is grey in colour. The upper part of formation is composed of shale with one thick bed of dark grey limestone (Shah, 2009).

2.3.9 Murree Formation

The name is derived from murree hills in the Rawalpindi Districts. A section exposed to the north of Dhok Maiki (lat. 33° 25´ N: long. 72° 35´ E) in the Attock District has been designated as the type section. The formation is composed of dark red and greenish grey sandstone. The formation ranges in thickness between 180 and 600m in the northern salt range (Shah, 2009).

2.3.10 Kamlial Formation

A section southwest of Kamlial (lat. 33° 15´ N: long. 72° 50´ E), Attock district has been designated as the type section. The formation consists of purple-grey sandstone with interbeds of purple shale and yellow conglomerate. This formation is 90m thick at Kamlial, 580m at Khaur (Shah, 2009).

2.3.11 Chinji Formation

The section south of Chinji Village (lat. 32° 41´ N: long. 72° 22´ E) in the Attock district has been designated as type section. This formation consists of red clay with ash grey sandstone. Th formation is 750m thick in the type area and more than 1800m thick in the Shinghar Range (Shah, 2009).

2.4 Petroleum play of study area.

2.4.1 Source Rock

The organic rich shales of the Paleocene (Patala formation) can be considered as the main formation which is acting as source to the Potwar basin. Due to buckling of basin floor the organic shale of Paleocene age were partly deposited in anoxic conditions. The oil shale intervals contain in Precambrian Salt Range Formation, which show potential of source rock.

2.4.2 Reservoir Rock

Marine sedimentary rocks of Paleozoic-Tertiary form petroleum systems in Potwar and are exposed in Salt Range along the Frontal Thrust. The Sakesar and Chorgali Formations have fractured carbonates that are major producing reservoirs in Missa kaswal.

2.4.3 Seal Rock

Due to thin-skinned tectonics Traps have been developed, which has produced faulted anticlines, pop-up and positive flower structures above Pre-Cambrian salt. The clay and shale of the Murree Formation also provide efficient vertical and lateral seal to Eocene reservoirs wherever it is in contact.

CHAPTER 3

2D SEISMIC INTERPRETATION

3.1 Introduction

In this chapter synthetic analysis is performed by loading well data which includes navigation of well, formation tops and td loading. Interpretation is done to interpret resultant data and to delineate areas in the subsurface which could hold hydrocarbons. This includes structure, stratigraphy, subsurface rock properties etc.

The main application of the structural analysis of seismic section is in the search for structural traps containing hydrocarbons. A structural trap is a type of geologic trap that forms as a result of changes in the structure of the subsurface, due to tectonic, diapiric, gravitational and compaction processes. Whereas The main aim of the stratigraphic analysis of seismic section is in the search for stratigraphic traps containing hydrocarbons. Stratigraphic traps are formed when there are changes in lithology, nature of the strata or depositional pattern. They prevent continued migration of hydrocarbons within reservoir beds (Onajite, 2014).

3.2 Methodology of Interpretation

The following steps were followed for interpretation purpose (figure 3.1).

- Loading of SEG-Y and navigation data
- Preparation of base map
- Generation of synthetic seismogram
- Fault identification and marking
- Horizon marking
- Construction of fault polygon
- Gridding and contouring

In flow chart form, above steps can be represented as;

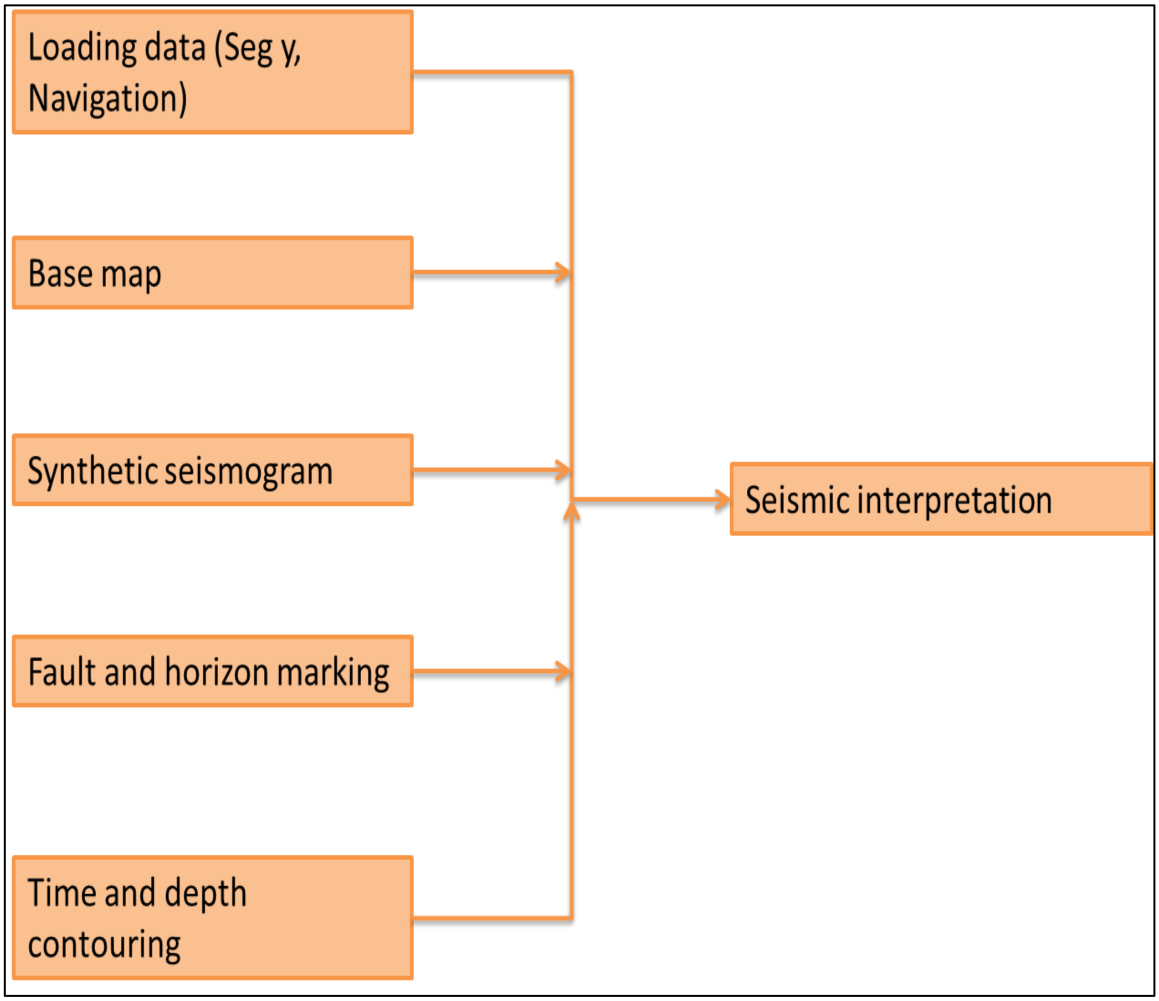

Figure 3.1 Interpretation flow chart.

3.3 Data Loading

Kingdom software is used to load SEG-Y data. Six seismic lines are given. Our well that is Qazian-01X is located near line GO-994-GNA-09, it is vertical well.

3.3.1 Seismic Data Loading

First of all projection is adjusted. The Zone 42N and UTM projection is used. Then seismic data is loaded which is 2d seismic lines with line navigation. A small window of short point data file will pop-up, skip first 50 lines for required data then select line name, shot point, X and Y. Now import SEG-Y file into single 2Dor 3D survey. Then select survey, data type name (amplitude), define trace numbers (trace sequence number by counting), set time boundes (sample interval, no. of traces, start and end time of imported trace and scale(1)). Then set output data format that is 16-Bit, seismic line has been loaded now assign 2D shot points to traces (starting shot points are 103 and trace per shot is 1).

3.3.2 Well Loading

Then well is loaded which includes navigation of well, formation tops and TD loading. The navigation of Qazian-01X are given as (DMS system) 33º 12´ 09.70´´ N and 73º 20´ 19.50´´ E. The well is abundant well. Well data includes well name (Qazian-01X), well number (01X), borehole name (main), location unit (decimal deg), UWI (035), well symbol, latitude (33.202694), longitude (73.338750), start depth (30.48m), end depth (8150m), surface elevation (0), total depth (8150m). We use the UTM coordinate system and define the position of the Qazian-01X.

Now select tops option in menu bar, import formation tops. Browse file then import formation top data in line order, use UWI as it exist in import data. Now short window of formation file will pop-up, lines to skip (1), select formation top name and depth. Then select well and borehole for data and depth type (MD).

For loading LAS file , import single LAS file. A short window will pop-up, browse file name, select well name, borehole name, UWI matching criteria, merging operation (add new curve only).

3.3.3 T-D chart

For generating synthetic seismogram, TD values are extracted and TD chart is created. Formation tops depth are given. From that depth we subtracted KB value which is 459.6200m. Then all that depths are located on TD and DT log is used to extract time for given formation at given SRD depth.

3.3.3.1 Flow Chart

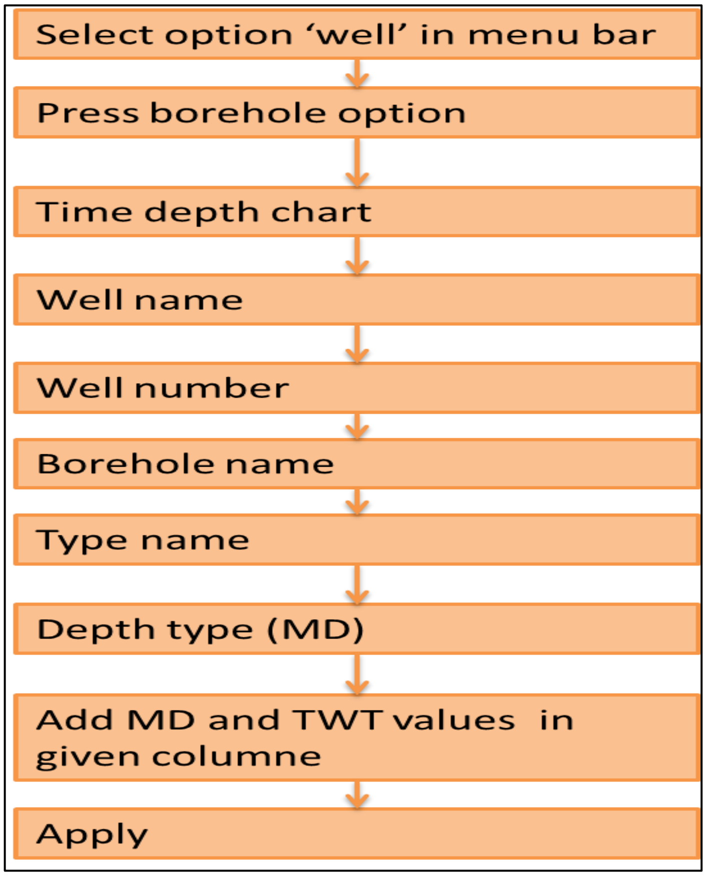

Figure 3.2 Steps adopted for TD loading.

Extracted TD values are used before subtracting the KB value from depth. For finding velocity Eq (3.1) is used ; (Rider, 2002).

$$V=\frac{1}{DT} \qquad (3.1)$$

Units are also converted from micro seconds per feet to meter per second using [(10^6) / (3.28)].

After that, velocities are computed to find Time by using Eq(3.2) mentioned below ; (Rider, 2002).

$$\text{Time}= \frac{\text{Depth}}{\text{Velocity}} \qquad (3.2)$$

From this time, two way travel time (TWT) is calculated by using Eq (3.3) (Rider, 2002).

$$\text{TWT}= \text{Time}*2 \qquad (3.3)$$

3.3.4 Synthetic Seismogram

Once the TD chart is created, synthetic seismogram is generated. Synthetic seismogram is a seismic trace created from sonic log and density log and it is used to compare the original seismic data collected near the well location. The prerequisites of synthetic seismogram are TD chart, Density log and sonic log. DT is a sonic log, provides direct information about the borehole. RHOB is density log, measures the density of the borehole.

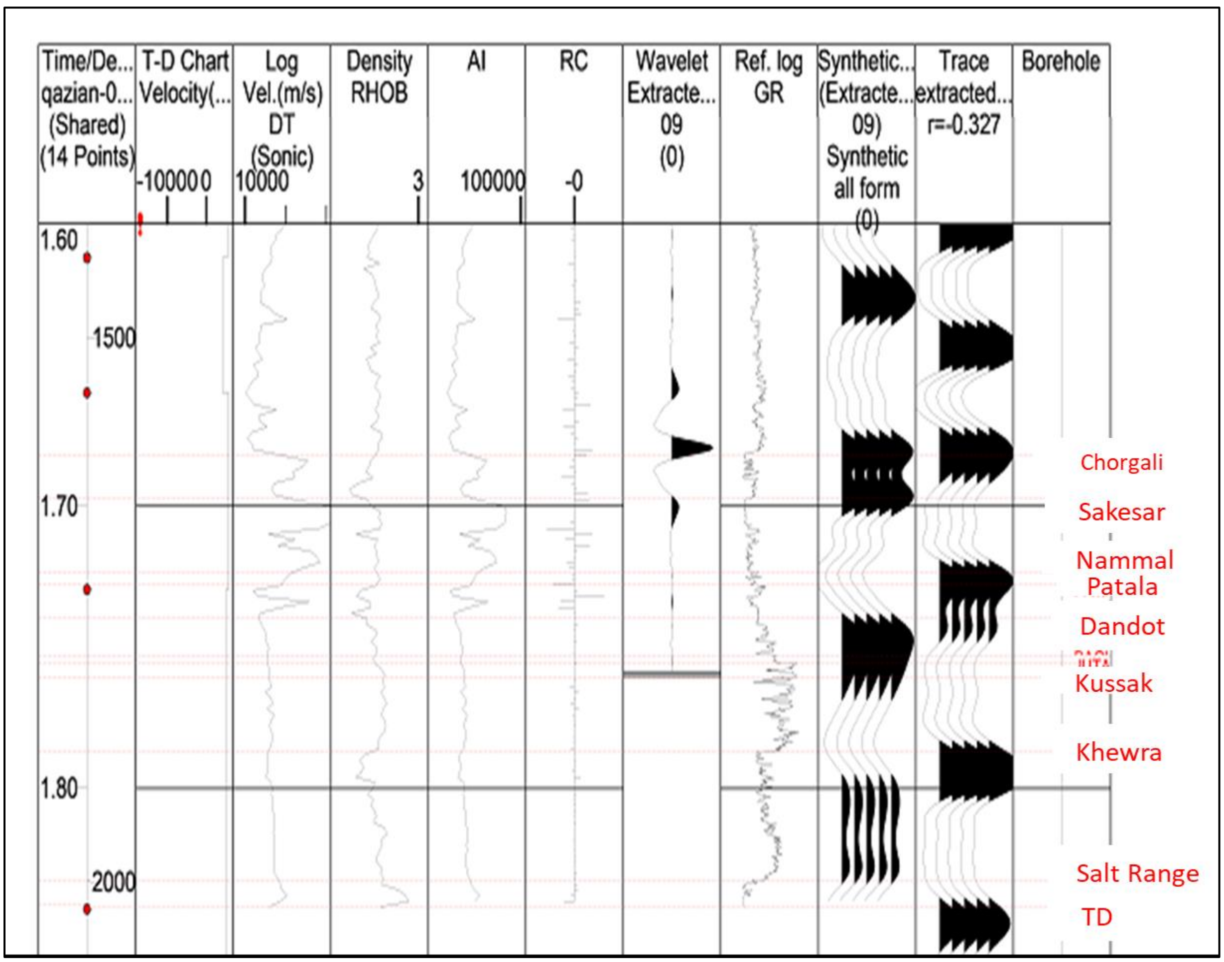

Figure 3.3 Shows synthetic seismogram.

Figure 3.3 shows synthetic seismogram. Chorgali and Patala Formation are chosen on the basis of hydrocarbon properties and hydrocarbon analysis will also be done on these formations.

3.3.5 Seismic Horizons

The main task of interpretation is to identify various reflectors or horizons as interfaces between geological formations. This requires good structural and stratigraphic knowledge of the area. Thus, interpretation involves marking of horizons and faults on the seismic section. The seismic data was provided in digital SEG-Y format. Three horizons are marked on the basis of available information. The horizons are named on basis of well tops of the well Qazian well. Well tops are used in order to identify and name the horizons.

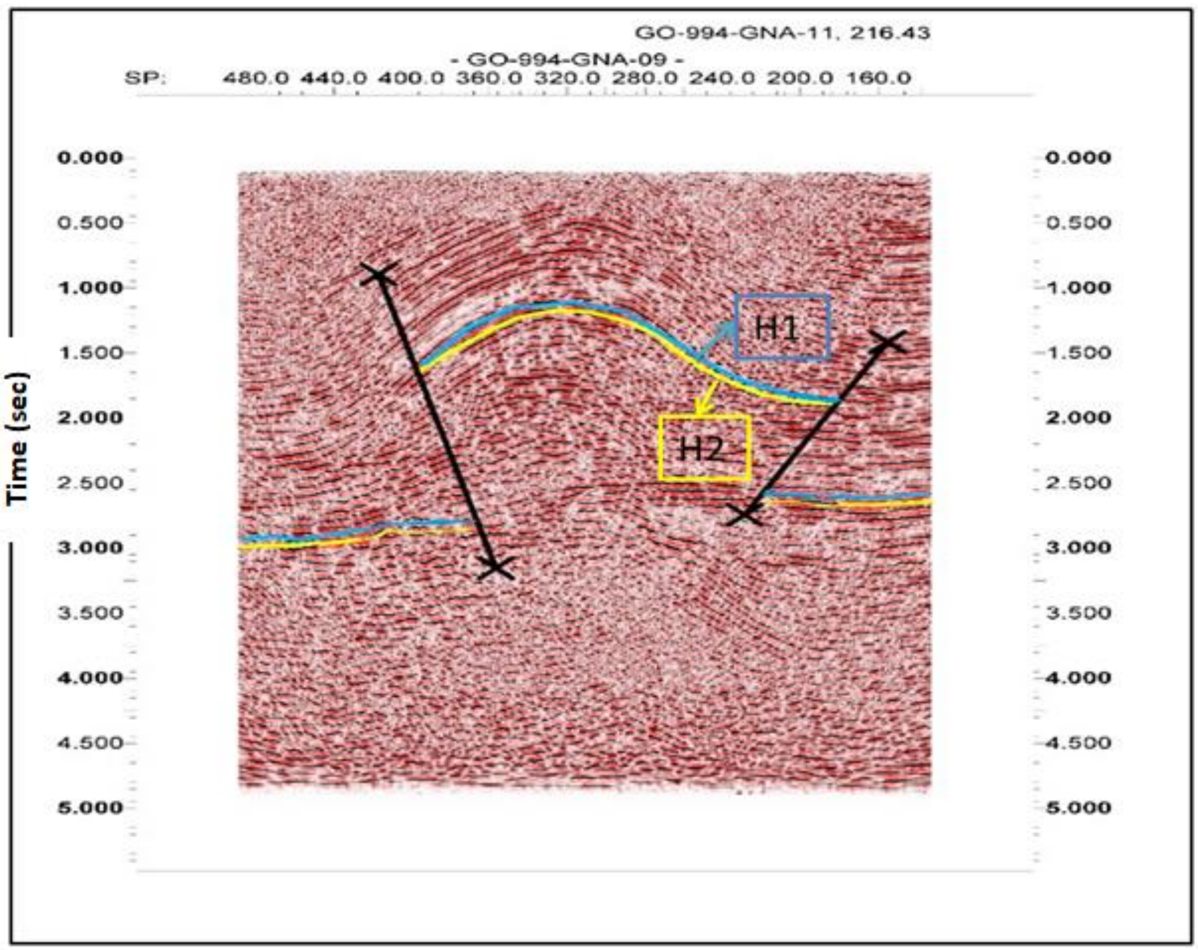

Figure 3.4 Horizons of interest marked on GO-994-GNA-09 (NW-SE).

Two horizons are chosen on the basis of hydrocarbon properties. Zone of interest comprises two horizons i.e Chorgali and Patala. In figure 3.4, blue colour shows Chorgali formation denoted in a figure as H1 and light yellow colour shows Patala formation as H2 in above figure.

3.3.6 Fault Marking

Faults are picked on the seismic section to delineate the geological structural trend in the study area. some of the clues to look for on seismic data to recognize faults are Termination of reflections, Offset in stratigraphy markers, Abrupt changes in dip, abrupt changes in seismic pattern, Associated folding and Coherency (Onajite, 2014).

Two reverse faults (F1, F2) are marked as shown in figure 3.5. They results to form anticlinal structure.

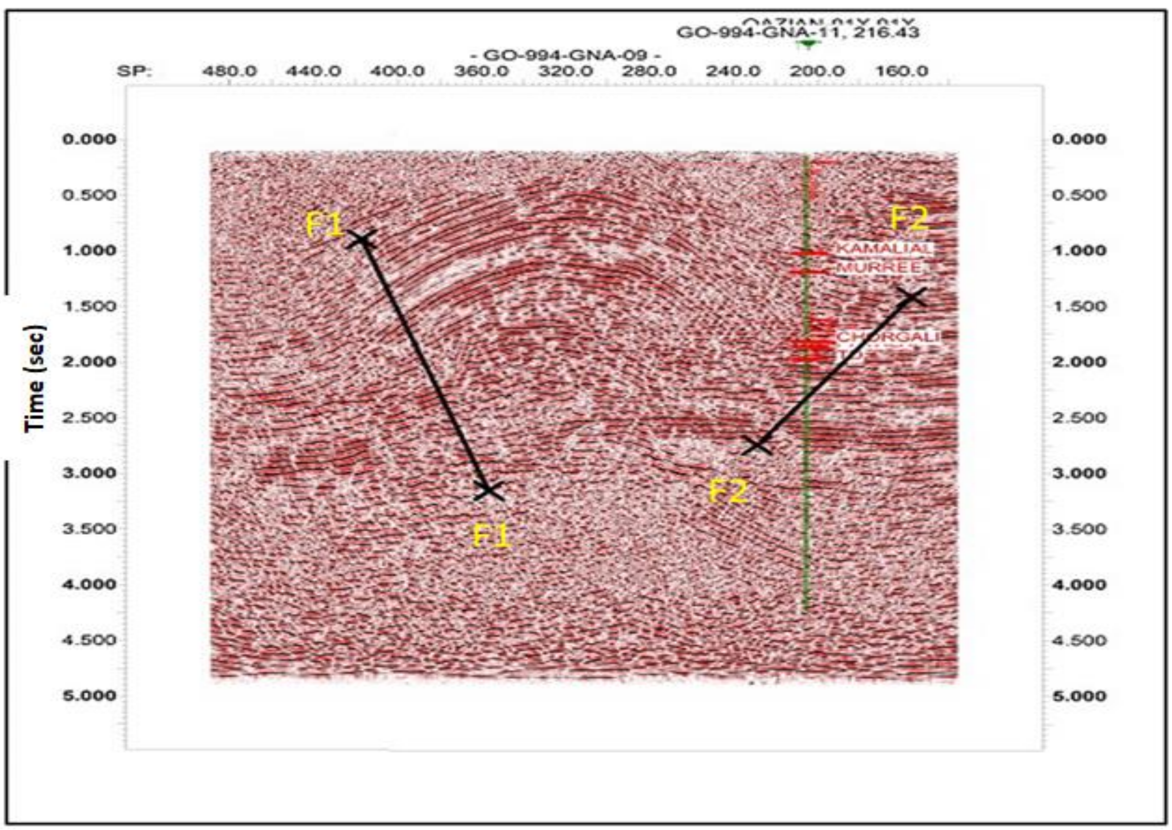

Figure 3.5 Faults marked on control line GO-994-GNA-09 (NW-SE).

3.3.7 Jump Correlation

Jump correlation process is used to overcome any discontinuity of the reflections along seismic gaps.

3.3.7.1 Interpretation Of Seismic Lines

Three dip lines GO-994-GNA-09, GO-994-GNA-10, GO-994-GNA-15 and one strike line GO-994-GNA-11 is interpreted. On dip line both the faults and horizons are marked but on strike line just horizons are marked because structural features can not be formed on strike line. Horizons of interest were marked on these lines using blue colour for Chorgali and light yellow colour for Patala formations. Seismic lines of interest are presented below in figure (3.6 to 3.9), H1 shows first horizon named as Chorgali and H2 shows second horizon named as Patala formation.

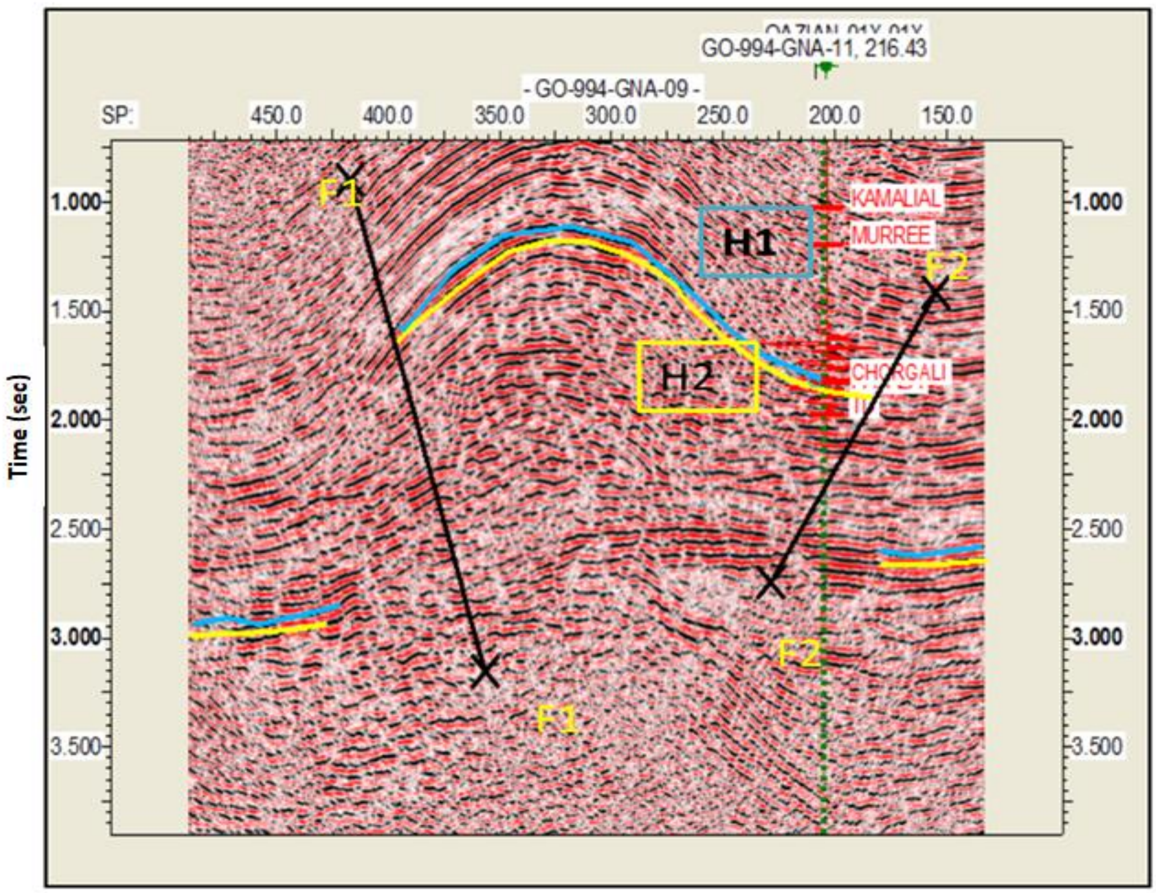

Figure 3.6 Interpretation of dip line GO-994-GNA-09 (NW-SE).

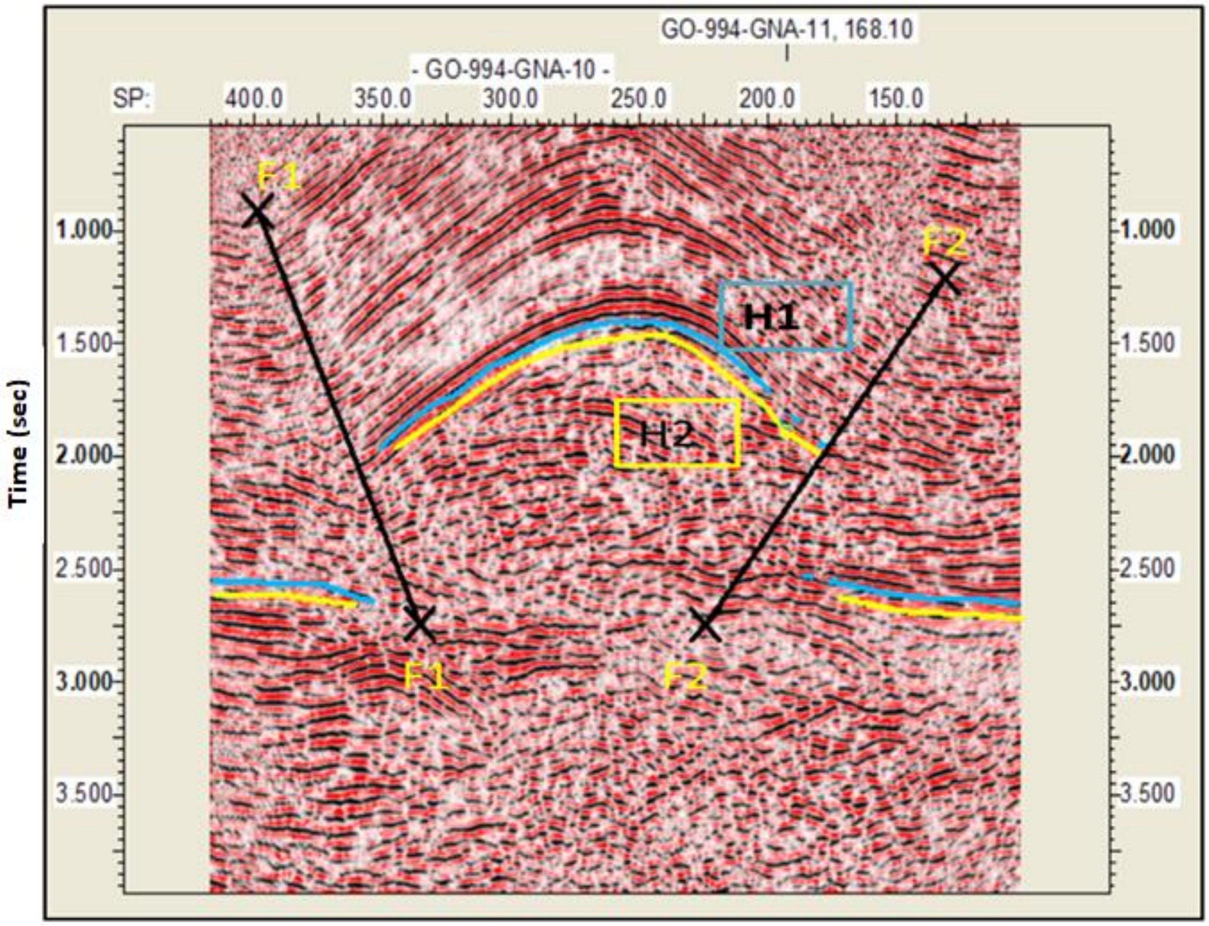

Figure 3.7 Interpretation of dip line GO-994-GNA-10 (NW-SE).

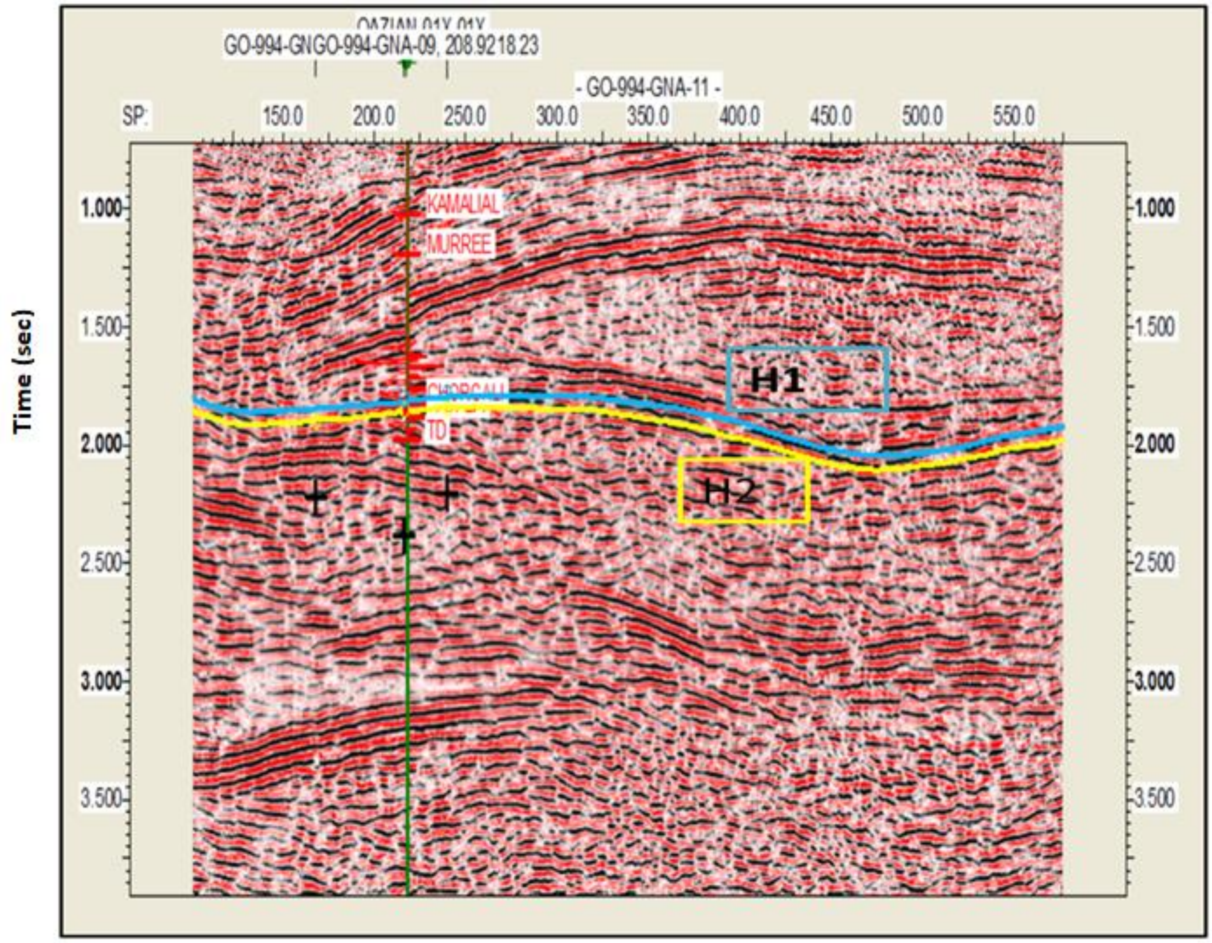

Figure 3.8 Interpretation of strike line GO-994-GNA-11(NE-SW).

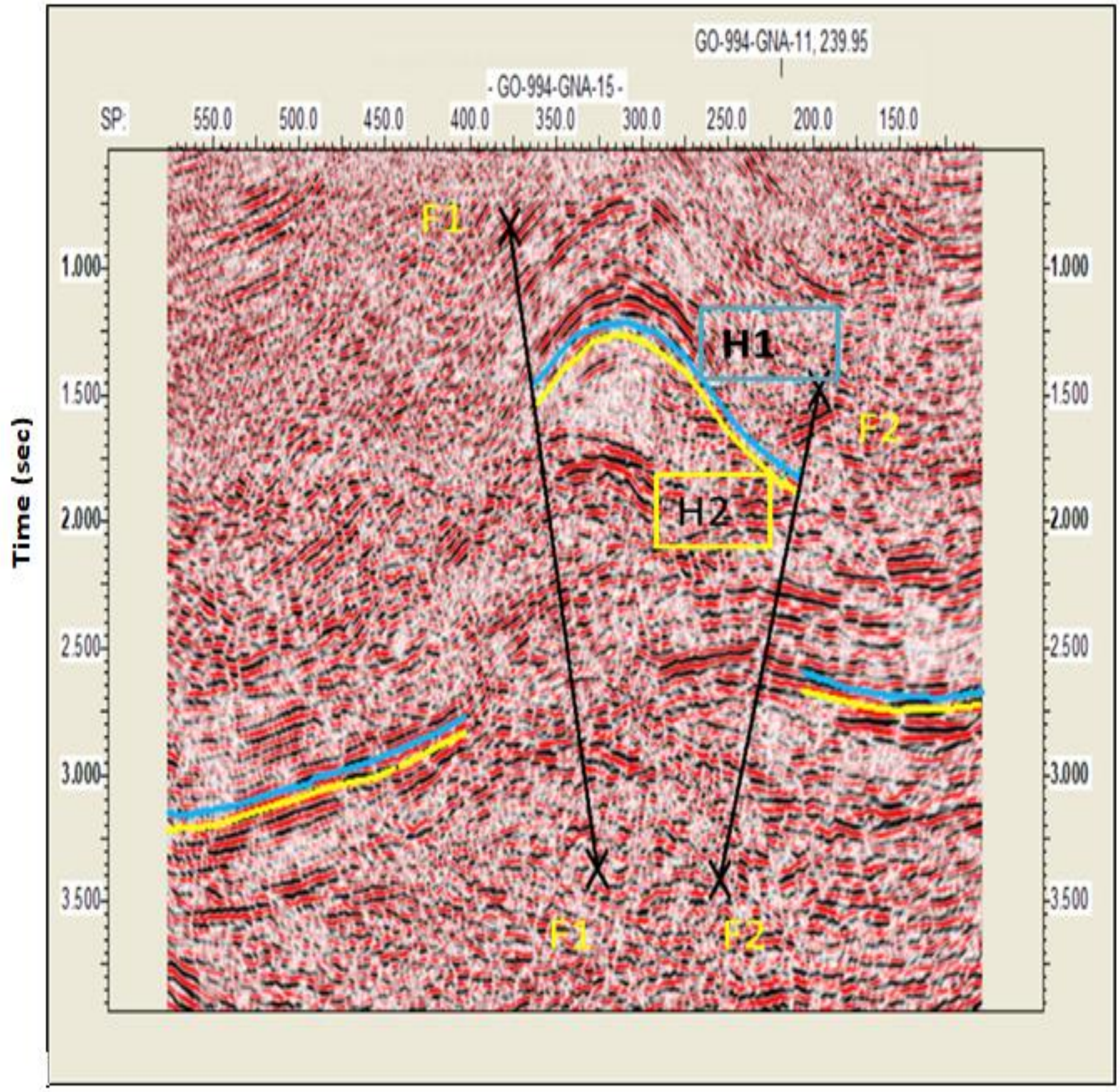

Figure 3.9 Interpretation of dip line GO-994-GNA-15(NW-SE).

3.3.8 Grid/Contour Maps

Contouring is the main tool used in the seismic interpretation. After contouring it becomes obvious that what sort of structure is forming a particular horizon. In the end of interpretation, time and depth contour maps were generated. Velocity contour maps were not generated dur to data limitations.

3.3.8.1 Time Contour Maps

Time contour maps are manualy generated using kingdom software. Figure 3.10 and 3.11 shows the time contour maps of Chorgali and Patala Formation. These time map shows that there is anticlinal structure is present, bounded by two reverse faults.

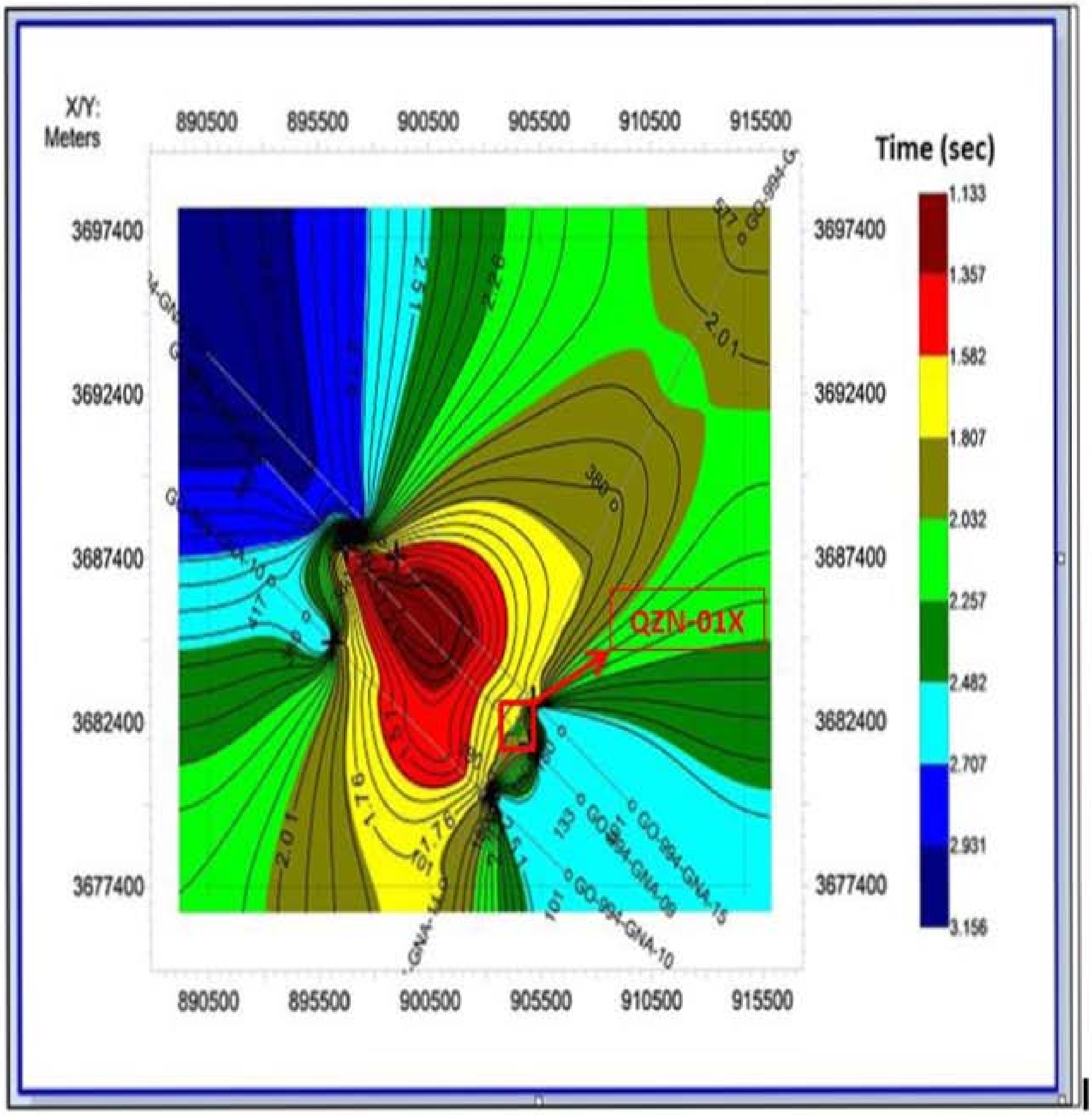

Figure 3.10 Time contour map of Chorgali Formation.

The structural variation in these contours can be interpreted by using color bar. Time contour map of Chorgali formation shows horizons are dipping towards NW direction. Contour interval is 0.25 sec. Brown colour shows shallow region (less time) and dark blue colour shows deepest region.

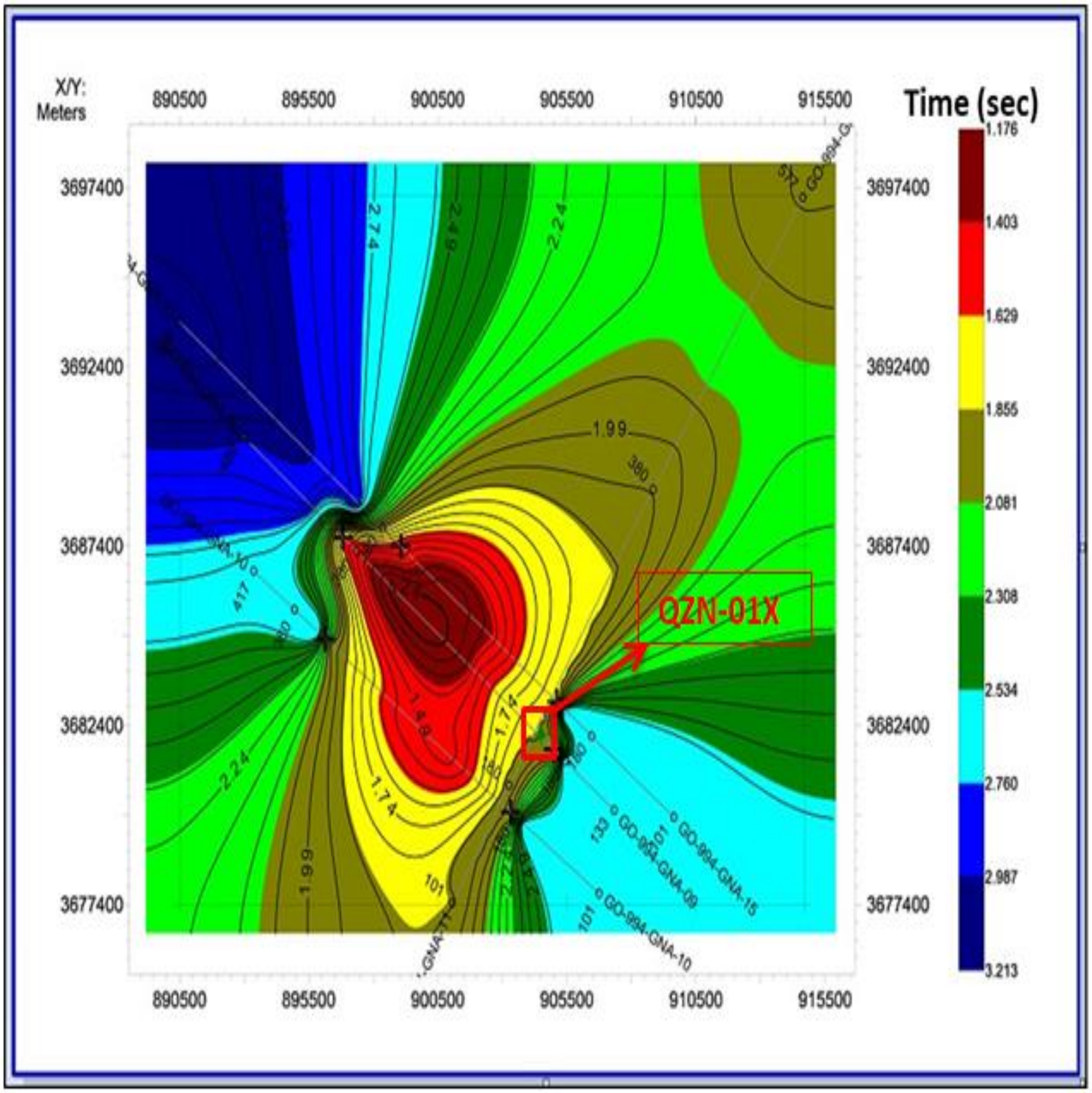

Figure 3.11 Time contour map of Patala Formation.

Time contour map of Patala formation shows horizons are dipping towards NW direction. Contour interval is 0.25 sec. Brown colour shows shallow region (less time) and dark blue colour shows deepest region.

3.3.8.2 Depth Contour Maps

Depth contour maps are generated by picking interval velocities of interested horizons from synthetic seismogram. Then using extended maths calculator (shown in figure 3.12) on kingdom, depth contour maps were generated using formula S= $\frac{VT}{2}$.

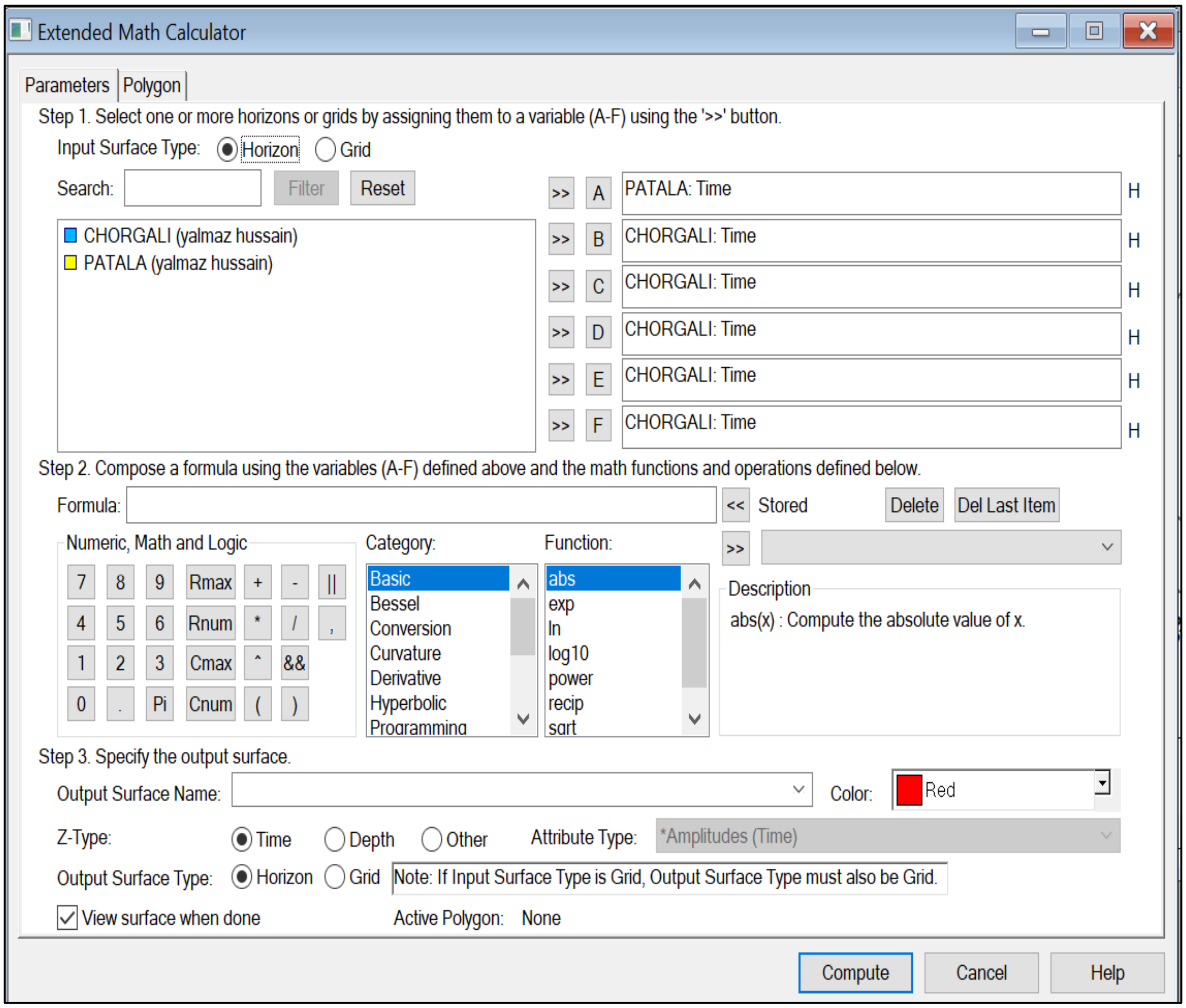

Figure 3.12 Time depth conversion.

Following are the depth contour maps of Chorgali and Patala formation. In Figure 3.13 and 3.14, brown colours shows shallow depth and blue colours shows deeper depth values. In depth contours of Chorgali and Patala Formation it is clear that there is aniticlinal structure bounded by two reverse faults.

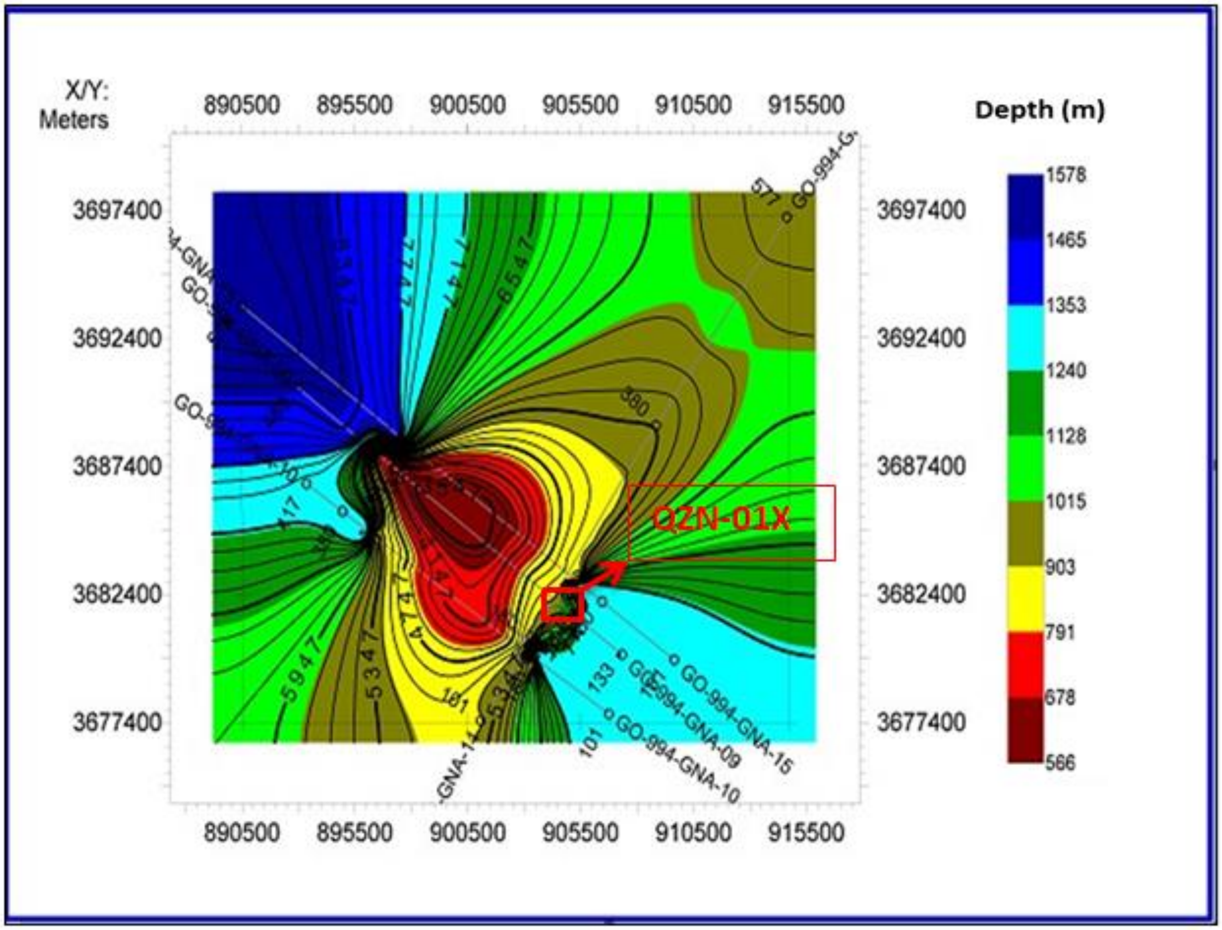

Figure 3.13 Depth contour map of Chorgali Formation.

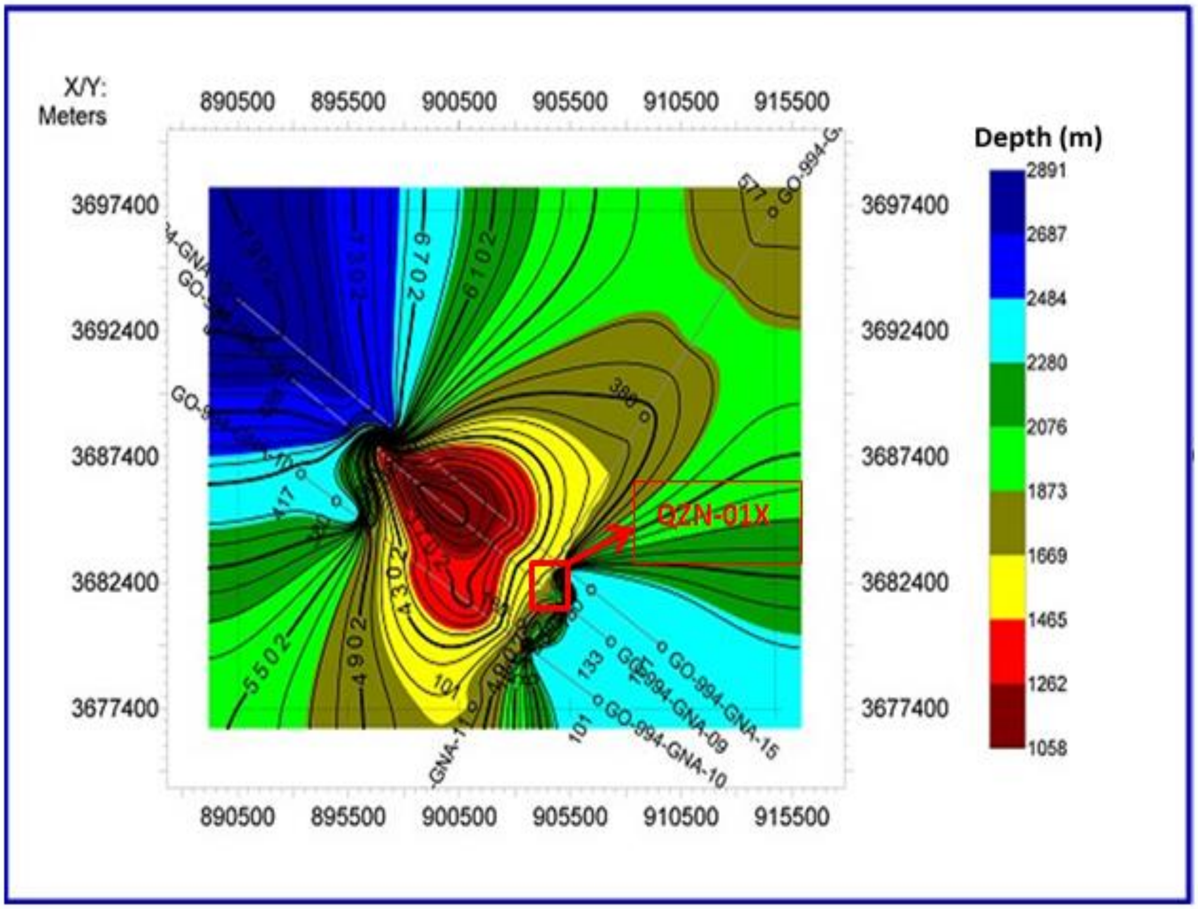

Figure 3.14 Depth contour map of Patala Formation.

In figures 3.13 and 3.14, brown colour indicates anticline (shallow) and blue colour shows deepness of reflectors. The contour interval in both depth maps is 600m.

CHAPTER 4

SEISMIC ATTRIBUTE ANALYSIS

4.1 Introduction

The history of seismic attributes began in the 1950s with the earliest efforts to extract geological information from seismic reflection character. Seismic attributes are filters that quantify properties of seismic images. The most useful seismic attributes are unique, comparable, easy to use, and geologically meaningful. Seismic attributes aid seismic interpretation by revealing hidden features, by identifying similar patterns, and by quantifying specific properties. Seismic attributes quantify properties of seismic data; seismic attributes describe seismic data. Attribute computations act as filters that remove some component of the signal to reveal another component (Barnes, 2016).

4.2 Types of Attributes

There are no rules governing how attributes are computed. Any quantity calculated from seismic data can be considered an attribute. Seismic Attributes can be classified as seismic data domain as:

I. Pre-Stack Attributes
II. Post-Stack Attributes

Main focus is on post stack attributes. Post stack attributes treat seismic data as images of the earth. Poststack attributes are derived through filters, transforms, and statistics. They quantify stratigraphic and structural properties and are easy to compute and apply (Barnes, 2016).

4.3 Attributes used

4.3.1 Relative Acoustic Impedence

This attributes remove the noise from the data, the main uses of this attribute are; it shows acoustic impedance contrast, porosity and Indicates discontinuities (Manual, 2014). In the figure 4.1, Relative acoustic impedence attribute is applied on the line GO-994-GNA-09. It confirms that both reflectors and faults are correctly picked. Chorgali Formation is marked on the high acoustic impedence shown by blue colour. Whereas Patala Formation is marked on low energy and low acoustic impedence shown by greenish blue colour.

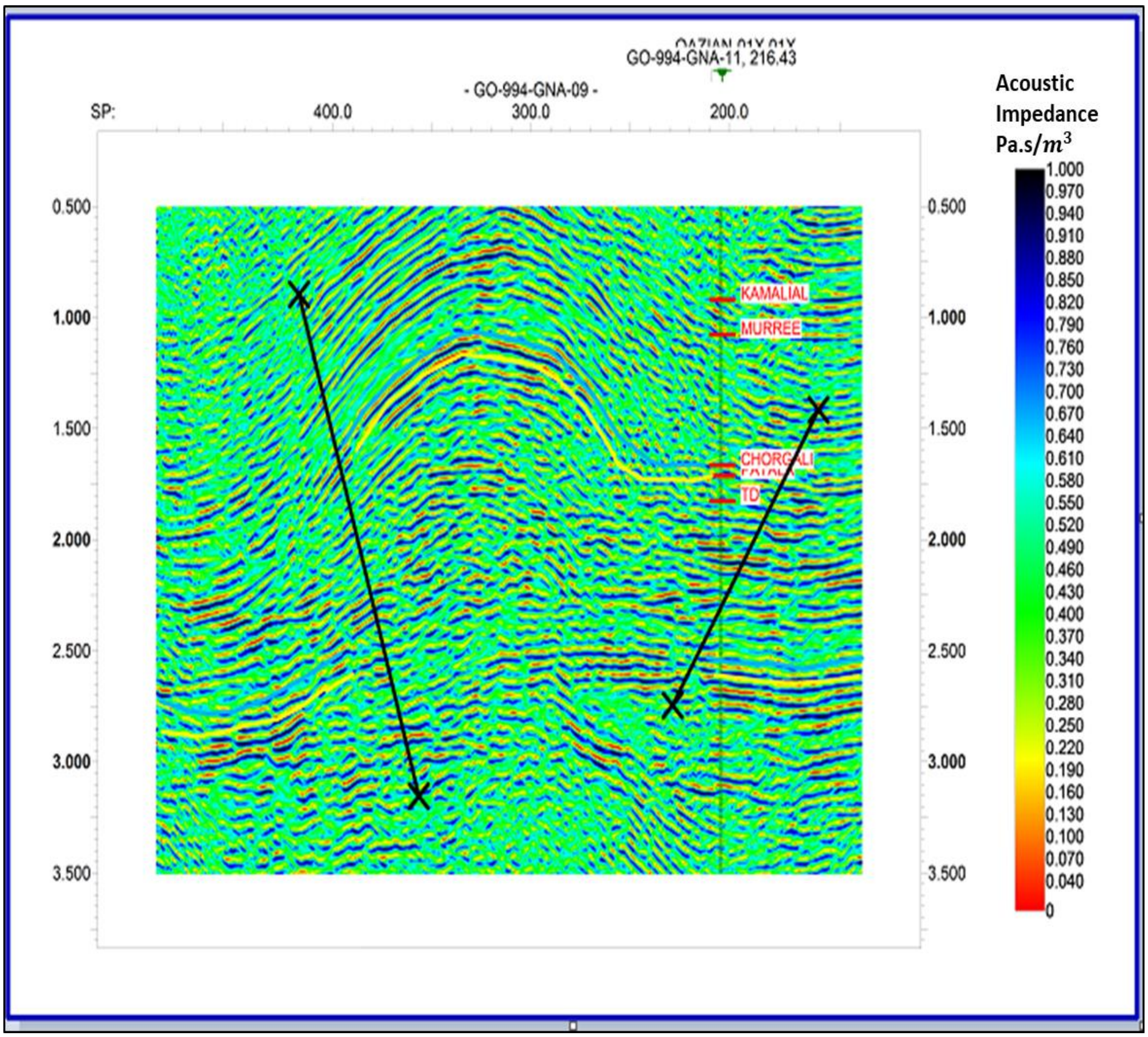

Figure 4.1 Relative acoustic impedence attributes on control line GO-994-GNA-09.

4.3.2 Dominant Frequency Attribute

It tells us about litholgy type that either it is consolidate or fluid exists. Figure 4.2 shows Dominant frequency applied on seismic line GO-994-GNA-09. Form figures it is clear that dominant frequency lies between 0.28Hz to 0.640Hz, this range shows low frequency and high amplitude. Blue colour (1Hz) shows high frequency. Chorgali Formation is marked on blue colour which means in Chorgali Formation, there is high frequency and in high freuquencies resistance is less so waves moves fastly so less time is taken which shows consolidated material exist. The reasons for high frequency are void spaces and data attenuation. In Patala Formation, there is low frequency, more resistance so more time will be taken so may be some fluid is present in this formation.

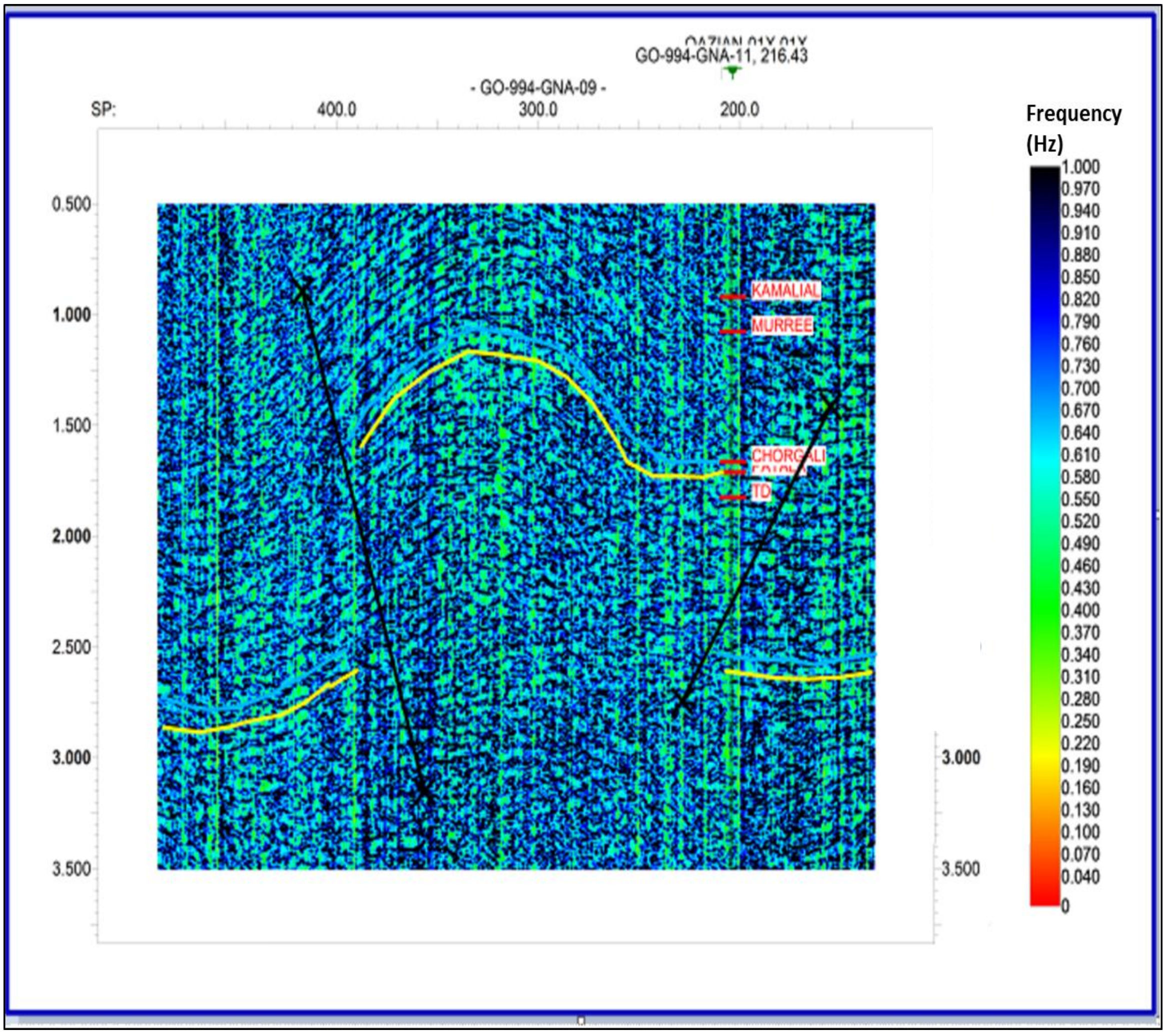

Figure 4.2 Dominant Frequency attribute on control line GO-994-GNA-09.

CHAPTER 5

PETROPHYSICS ANALYSIS

5.1 Introduction

Petrophysics is the study of rock properties and their interactions with fluids (gases, liquid, hydrocarbons and aqueous solutions). Petrophysical Analysis provide a method of deriving accurate values for the hydrocarbons and water saturation, the permeability, the porosity and the lithology of the reservoir rock. It aims at obtaining the physical properties such as porosity, saturations and permeability, which are related to production parameters shown in figure 5.1.

5.2 Flow Chart

For petrophysical analysis, proposed methodology covers following steps:

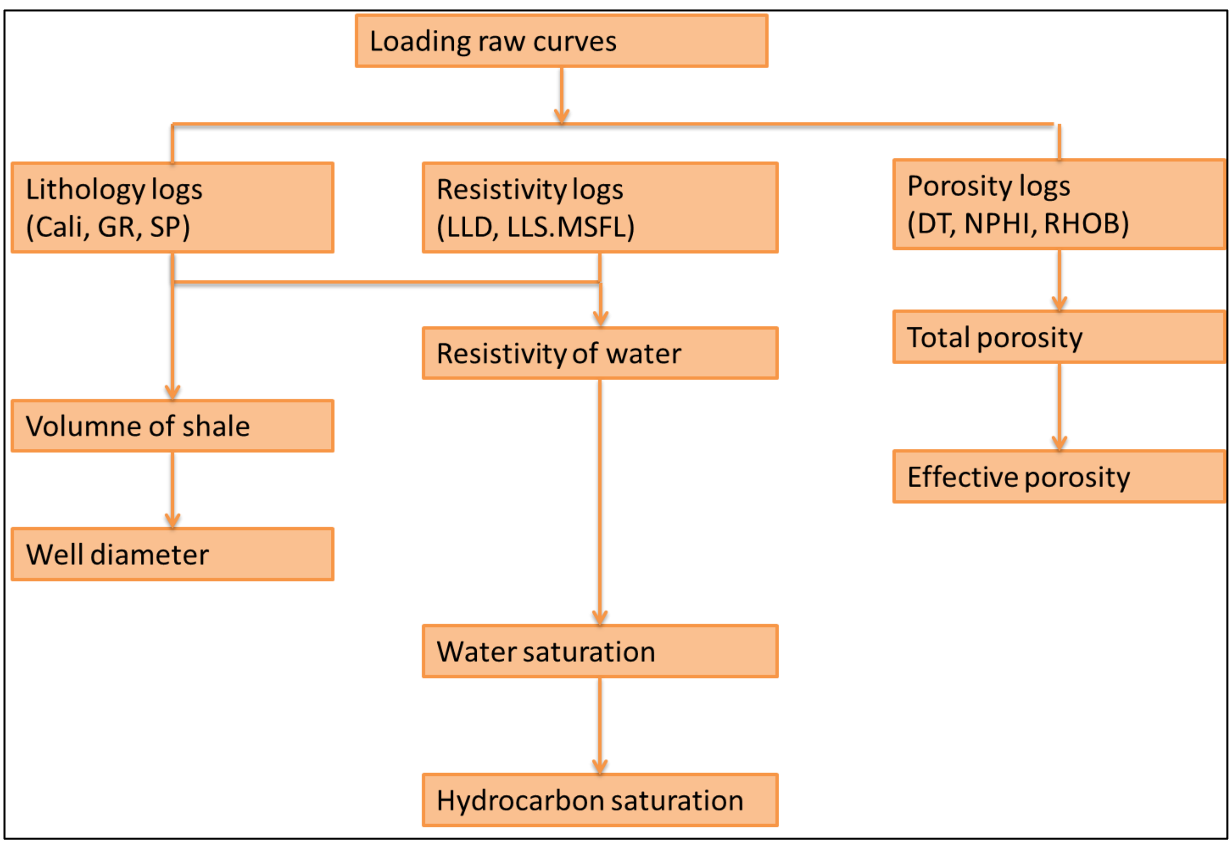

Figure 5.1 Basic steps followed for petrophysical analysis.

Petrophysics is performed by using different log curves. Petrophysical analysis is performed on the Chorgali Formation because it is reservoir formation.

Table 5.1 Thickness of Chorgali Formation

Formation	Formation top (m)	Formation base (m)	Thickness (m)
Chorgali	2062m	2106m	44m

5.3 Logs Used in Analysis

The logs are explained according to the tracks in which they are run.

5.3.1 Lithology track

In lithology track the following three logs are displayed which are explained as follow.

- Gamma ray (GR)
- Spontaneous Potential log (SP)

5.3.1.1 Gamma ray log

GR log is also known as shale log is measurement of formations radioactive contents. Since radioactive contents are present in shale so it gives deflection where shale is present that’s why it is best log for lithology identification.

5.3.1.2 Spontaneous potential log

SP log measures the naturally occurring potential of geological formations no artificial currents are injected. It gives deflection opposite to permeable beds since shale is impermeable so it gives straight line opposite to shale known as shale base line. It is used

- To indicate permeable zone
- Identify bed boundaries
- To calculate volume of shale.

 To calculate resistivity of formation water

5.3.2 Caliper log

Caliper log use to measure the borehole size. This log give us help to identify the cavity washouts and break outs. Hence this log is also called the quality check for other logs. Because if any where there is say wash out then in front of the wash out the porosity and resistivity log will not give the correct reading. Hence caliper log is very important in Petrophysical logs.

5.3.3 Porosity log

DT, RHOB, and NPHI are porosity logs which are used to calculate pore volume of formations. With the combination of resistivity logs they are used to calculate water saturation of formations. Porosity log contains

 Sonic log (DT)

 Density log (RHOB)

 Neutron Porosity log (NPHI)

5.3.3.1 Sonic log.

Sonic log produce compressional waves and measure the transient travel time of waves. Where travel time is higher it is indication of porous media because wave is name of progressive disturbance of media if media is porous travel time is higher. It is used

 Porosity (using interval transit. Time)

 Lithology identification (with Neutron and/or Density)

 Synthetic seismograms (with Density)

 Mechanical properties of formation with (Density)

 Abnormal formation pressures detection.

5.3.3.2 Density log

Gamma rays are bombarded on formation these are scattered from formation’s electrons higher the scattering higher the electron density and this electron density is related to bulk density of rocks. Lower the density higher the porosity of medium.

5.3.3.3 Neutron log

Neutron log tool emit high energy neutron and the only resistive substance to neutron are hydrogen ions. If value of this log is high it means high hydrogen ions concentration is present. Since hydrogen ions are present in pore space so neutron log measures porosity. If gas is present than value of l.g is low because concentration of hydrogen ion is low.

5.3.4 Electrical resistivity log

Basically there are different types of electrical Resistivity Logs. Logs of LLS and LLD can separate only when (oil) high resistive fluid is present in the formation. It is explained in detail in Petrophysical interpretation.

- Laterelog Deep (LLD)
- Laterelog Shallow (LLS)

5.3.4.1 Laterelog deep

Laterelog is used for deep investigation of the undisturbed zone (Uninvaded zone) and it is called Laterelog deep (LLD). This log is also used for saline muds also in case of fresh mud. This log is generally used for measuring the formation resistivity. IT having deep penetration as compared to the (LLS).

5.3.4.2 Laterelog shallow

Laterelog shallow (LLS), used for shallow investigation of the transition zone / invaded zone. Because the depth of the investigation is smaller than the LLD .

5.4 Petrophysical Properties

The parameters that were directly read from the log track are:

Formation depth (in ft), Bulk density of formation (RHOB) scale 1.95 to 2.95, Bulk resistivity of the formation (LLD) scale 0.2-2000 ohm.m, Spontaneous potential (SP) scale -80 to 20mv, Neutron porosity (NPHI) scale 0.45 to -0.15.

For calculating hydrocarbon saturation, following steps is performed:

5.4.1 Volume of Shale

Different logs such as resistivity, SP and Gamma-ray log is used to calculate shale volume in the reservoir. There are different methods to estimated volume of shale but in this study we used non-linear method consisting gamma ray log for volume of shale calculation.

Vsh can be calculated from gamma-ray response. The mathematical relation for the Volume of shale is calculated by Eq (5.1) (Rider, 2002).

$$Vsh = \frac{(\text{GR log} - \text{GR min})}{(\text{GR max} - \text{GR min})} \quad (5.1)$$

5.4.2 Calculation Of Porosity From Logs

Porosity is the ratio of volume of voids to total volume of rock. Porosity is calculated for different zones of interest by using the following logs:

- Sonic log
- Neutron log
- Density log

5.4.2.1 Neutron Porosity

It is obtained from Neutron log given in Qazian-01X well data.

5.4.2.2 Density Porosity

Density porosity is calculated from density log by using matrix density of the lithology of marked formation and density of fluid present in that formation. The mathematical relation for density derived porosity is mentioned below in Eq (5.2) (Rider, 2002).

$$PHID = \frac{(\text{RhoM} - \text{RHOB})}{(\text{RhoM} - \text{RhoF})} \quad (5.2)$$

Where, RhoM is matrix density, RHOB is bulk density and RhoF is fluid density.

5.4.2.3 Average Porosity

For calculating average porosity, Neutron and Density porosity must be known. Average porosity is calculated by using Eq (5.3) (Rider, 2002).

$$\text{Average porosity}(\Phi)= \frac{(\Phi N.D + \Phi D)}{2} \qquad (5.3)$$

where,

ΦN.D is Neutron porosity.

ΦD is Density porosity.

5.4.2.4 Effective Porosity

The effective porosity is the ratio between the pores volume of the rock and the total volume of the rock calculated after removing the effect of the shale. The effective porosity is used to estimate the water saturation. Formula used for calculating effective porosity is given in Eq (5.4) (Rider, 2002).

$$\Phi e=\Phi avg*(1-Vsh) \qquad (5.4)$$

5.4.2.5 Sonic Porosity

Sonic porosity is calculated from DT log by using transit time of matrix and fluid of formation. Formula used for calculating sonic porosity is given in Eq (5.5) (Rider, 2002).

$$PHIS = \frac{(DT - DTma)}{(DTfld - DTma)} \qquad (5.5)$$

5.4.3 Resistivity Of Water (Rw)

Computing the resistivity of the water is the initial step in finding the saturation of the water. Schlumberger log interpretation charts along with several equations were used to find out Rw for calculating saturation of hydrocarbons. Following parameters must be calculated for calculating Resistivity of Water.

- Geothermal gradient

Geothermal gradient is calculated by using Eq (5.6) (Rider, 2002).

Temperature Gradient= $\frac{(BHT-St)}{T.D}$ (5.6)

Where;

BHT is borehole temperature.

St is surface temperature.

T.D is total depth.

- Formation temperature

Ft is calculated by using Eq (5.7) (Rider, 2002).

Ft=(geothermal gradient*formation top)+surface temperature (5.7)

- Resistivity of mud filterate
- Equivalent resistivity of mud filterate
- SSP
- Equivalent resistivity of Water
- Calculation of Rw
- Water Saturation

Sw is the ratio of water volume to pore volume. Water saturation is calculated by using Eq(5.8) (Rider, 2002).

Sw= $\left(\frac{(F_R * R_W)}{Rt}\right)^{1/2}$ (5.8)

Where,

Rw is resistivity of water.

Rt is LLD log and

$F_R = \frac{1}{\Phi_e^2}$, Φ_e is effective porosity.

- Saturation Of Hydrocarbons

The fraction of pore volume filled hydrocarbons. Saturation of hydrocarbon is calculated by given Eq (5.9) (Rider, 2002).

S_{hc}= 1-S_w (5.9)

Where,

S_w is Saturation of water

S_{hc} is Saturation of hydrocarbon.

5.5 Log Trend of Chorgali Formation

Figure 5.2 shows log trend of Chorgali Formation. Track 1 on the left having GR and Caliper and SP log. Track 2 has resistivity logs and track 3 has DT, NPHI and RHOB log. Track 5 has volume of Shale shaded by pink and green colour. Green colour shows Limestone and Pink colour shows Shale. Track 6 has Effective porosity shaded by yellow colour. Track 7 has Water saturation shaded by blue colour and track 8 has Hydrocarbon Saturation shaded by brown colour.

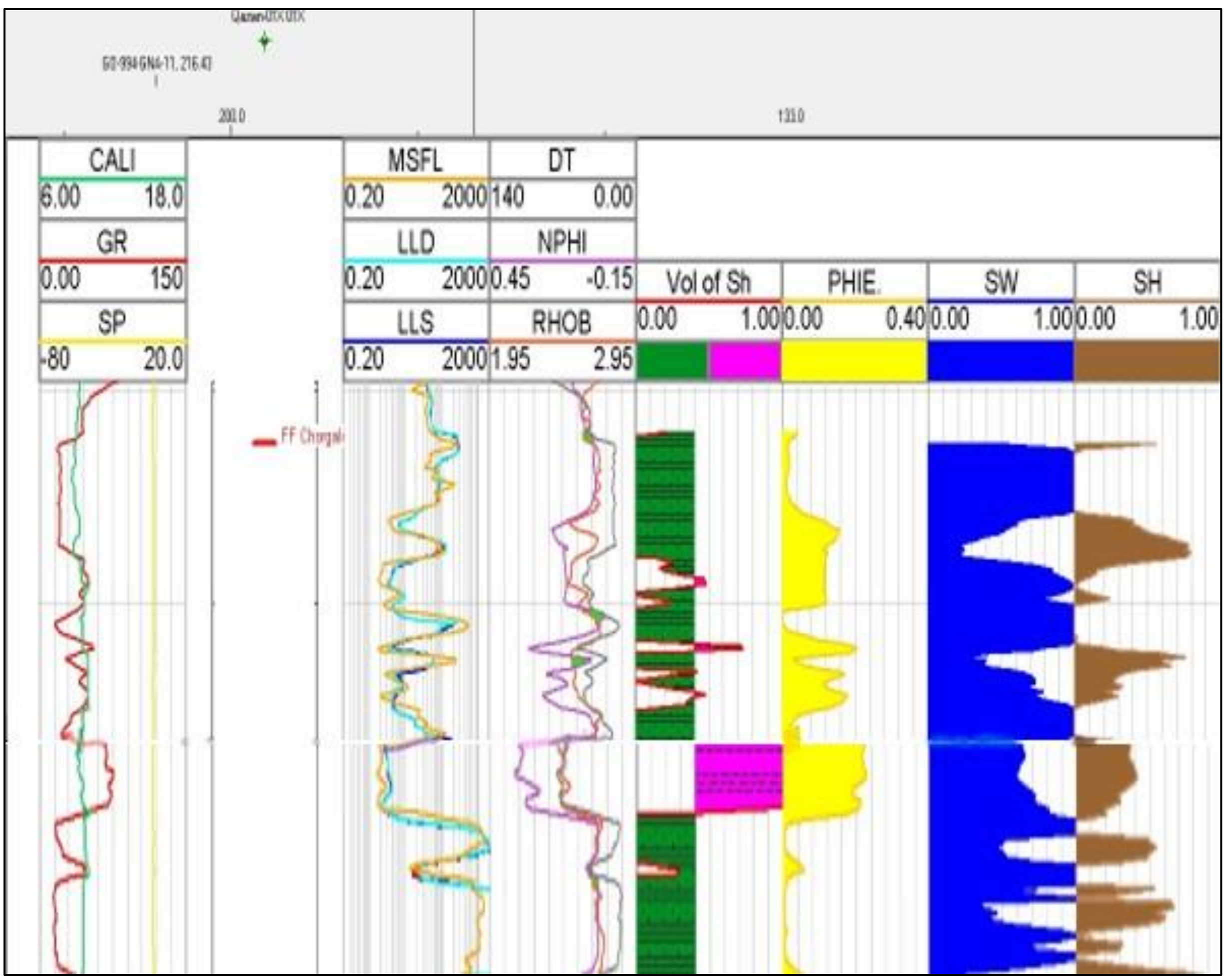

Figure 5.2 log trend of Chorgali Formation

5.6 Results

Table 5.3 Showing results calculated by petrophsical analysis.

Volume of Shale	Porosity	Water Saturation	Hydrocarbon Saturation
40%	7%	85%	15%

Petrophysical analysis is performed on the Chorgali Formation because it is reservoir formation. Chorgali mainly consist of limestone, whose porosity ranges from 7 to 8% so average porosity calculated from petrophysical analysis is 7%. Water saturation is 85% and hydrocarbon saturation is 15% because well is dry so water is predominantly present.

CHAPTER 6

FACIES ANALYSIS

6.1 Introduction

In geology, a facies is a body of rock with specified characteristics. Generally the facies is distinctive rock unit that form under certain condition of the sedimentation that reveals the environmental process.

In petrofacies analysis, cross plots between different logs are used to map lithology, porosity, density and minerals where it is available. When data points are connected in a cross plot then the properties like lithology, porosities can be predicted. A third variable can be presented at each point on the crossplot by assigning a color scale that is based on other well logs, often gamma ray or photoelectric effect etc (Watney, 1998).

6.2 Sedimentary Facies

The term facies is commonly used in diverse manner to denote almost any type of sedimentary deposit, with or without reference to defined stratigraphic unit. It refers to the combined product of past conditions, processes and events as recorded over some fraction of the earth's surface and representing some fraction of geological history (C.R. Longwell et al., 1948)

Sedimentary facies are defined as a really restricted, three-dimensional bodies of rock or sediment that are distinguished from other bodies by their lithology, sedimentary structures, geometry, fossil content, and other attributes. Lithofacies are defined solely on the basis of their lithology. Similarly, biofacies are defined based on their fossil content. Sedimentary facies analysis is based on the concept that facies transitions occur more commonly than would be expected if sedimentation processes were random.

6.3 Facies Analysis

The identification of a bed's lithology is fundamental to all reservoir characterization because the physical and chemical properties of the rock that holds hydrocarbon affect the response of every tool used to measure formation properties. Understanding reservoir lithology is the foundation from which all other Petro-physical calculations are made. To make accurate Petro-physical calculations of porosity, water saturation (Sw) and permeability, various lithologies of the reservoir interval must be identified and their implications understood. Lithology means the composition or type of rock such as sandstone or limestone.

6.4 Facies Analysis of Chorgali Formation

An effort has been made in this thesis to plot various logs and by means of geophysical knowledge of the logs, to mark the facies present in the subsurface. Facies analysis of only Chorgali Formation has been done. The results were as follows:

6.4.1 Cross plot of LLD and RHOB Logs

Since resistivity and density of limestone is higher than shale so limestone facies are marked at higher values. Since density of shale is highly variable and concentration of organic contents is less in shale therefore the density of limestone and shale can overlap so Gamma log is used as reference log for further separation of facies. Three facies are encountered, shale, shaly limestone and limestone facie (figure 6.1).

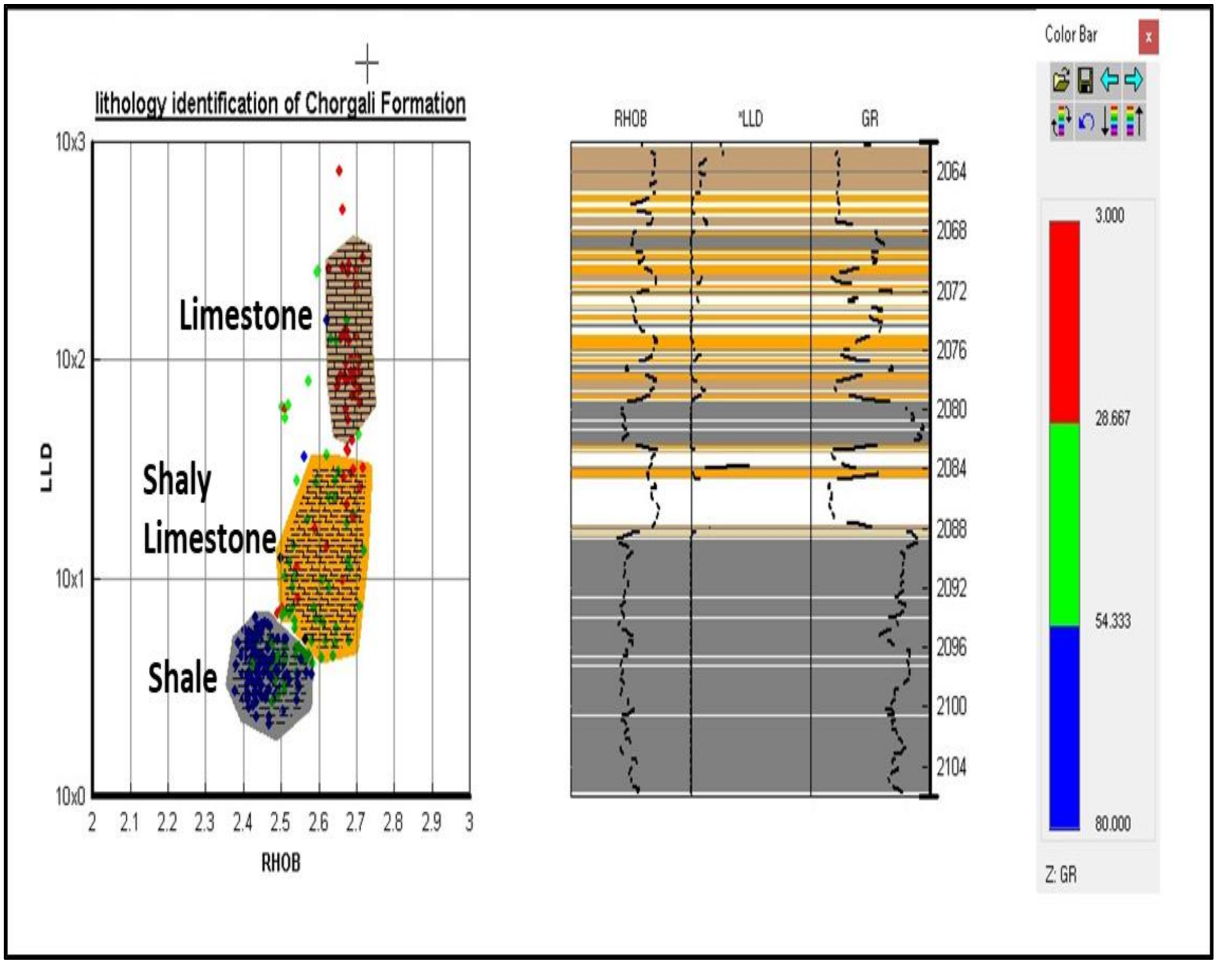

Figure 6.1 Cross plot between LLD and RHOB.

shale is indicated by grey colour, shaly limestone by golden colour and limestone by brown colour.

6.4.2 Cross Plot of NPHI and RHOB

There is a direct relation between NPHI and Shale. Greater volume of shale shows high value of NPHI. Limestone has high value of RHOB and Shale has low value of RHOB. NPHI is plotted along x-axis and RHOB is plotted along y-axis. Facies encountered are same as shown in figure 6.1, Brown color shows the Limestone and grey color shows the Shale (6.2).

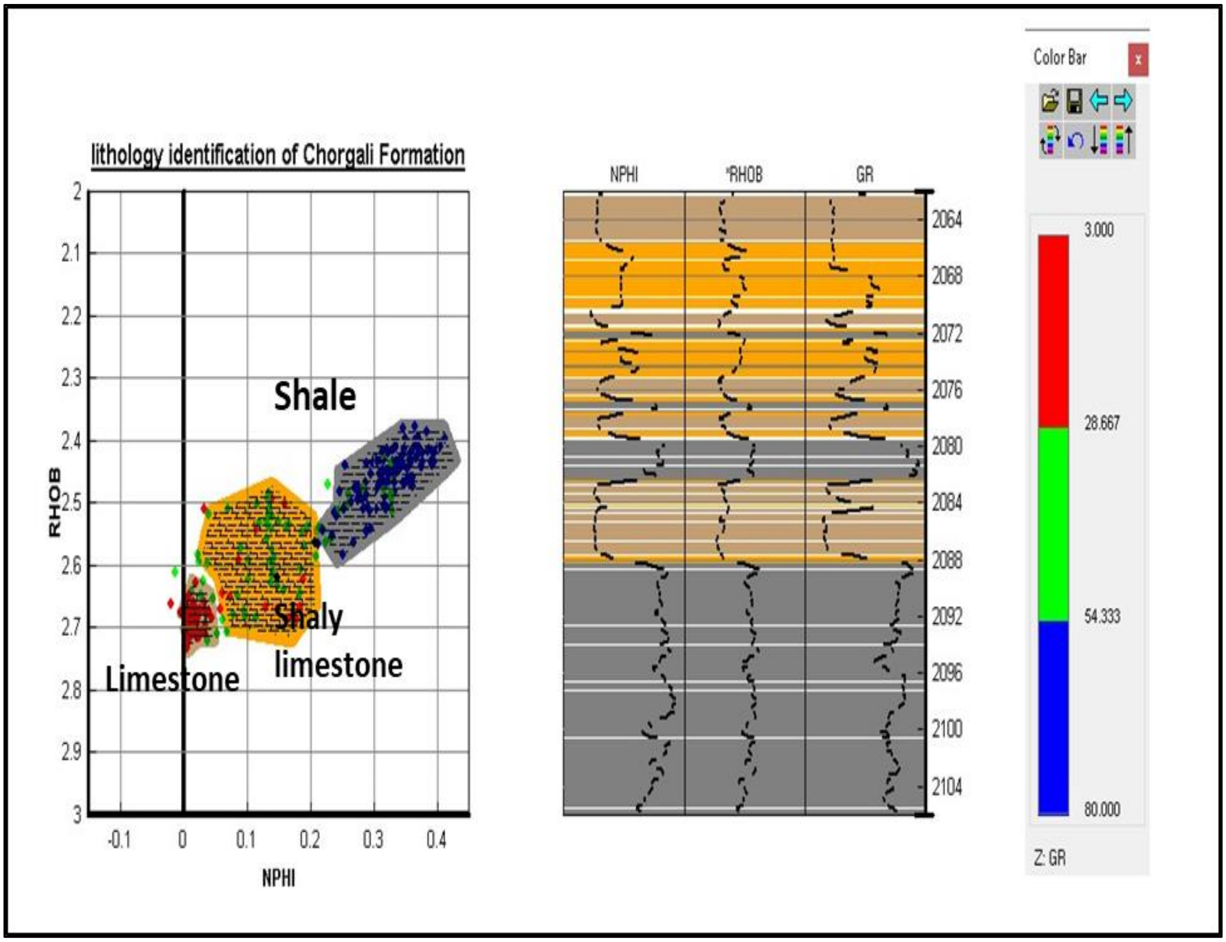

Figure 6.2 Cross plot between NPHI and RHOB.

6.4 Results

Lower Gamma Ray log values and higher Density log values clearly indicates the presence of limestone lithology. The reason for higher density log values is because of compactness of the limestone lithology. The lower resistivity values on the other hand show the presence of hydrocarbon which lowers the resistivity. Similarly lower NPHI values show presence of hydrocarbons.

Higher GR log values and comparatively lower density values show presence of shale. The comparatively higher Lateral Log Deep values show absence of hydrocarbons in the shale lithology. Higher NPHI log shows absence of hydrocarbons.

In between Shale and Limestone, Shaly Limestone is present with moderate GR values, density, resistivity and NPHI values.

CHAPTER 7

COLOURED INVERSION

7.1 Seismic Inversion:

Geophysical inversion involves mapping the physical structure and properties of the subsurface of earth using measurements made on the surface of earth. Another way to look at seismic inversion is to consider it as the technique for creating a model of the earth using the seismic data as input. As such, it can be considered as the opposite of the forward modelling technique, which involves creating a synthetic seismic section based on a model of the earth (or, in the simplest case, using a sonic log as a one-dimensional model).

7.2 Coloured Inversion

Coloured inversion is designed to approximately match the average spectrum of inverted seismic data with the average spectrum observed impedance (Lancaster and Whitcombe, 2000). The earth's reflectivity can be considered fractal, and the resulting amplitude spectrum favors high frequencies (spectral blueing). If there was no preferred frequency, then you would have a "white spectrum", but as there are some frequencies with more energy, then it is called "colored".

Coloured Inversion include preparation of the well logs, investigating relationships between impedance and reservoir properties and tying the well logs to the seismic figure 7.1. After tying to the seismic, the well log data is used to estimate a seismic wavelet. By application of zero phase deconvolution a broad-band zero-phase dataset is obtained which forms the input to colored inversion (Lancaster and Whitcombe, 2000). Coloured inversion converts the seismic data to a relative impedence data set. The advantages of coloured inversion are the speed of calculation and avoidance of artifacts that may be introduced by a model. Coloured inversion, whether acoustic or elastic impedence (Cannolly, 1999), is an excellent qualitative interpretation tool.

A method was developed by Lancaster and Whitcombe (2000) which called Coloured Inversion (CI). The CI method is a simple and fast technique to invert the band-limited seismic data to relative impedance and can be done by generating a single operator to match the average seismic spectrum to the shape of the well log impedance spectrum.

Coloured Inversion enhances the seismic signal and adds the auto-picker. Often it can enhance features such as bed resolution, minor faulting, fracture zones and discontinuities due to channels and possibly the presence of hydrocarbons.

7.3 Work Flow Adopted

Work flow adopted for coloured inversion is given below

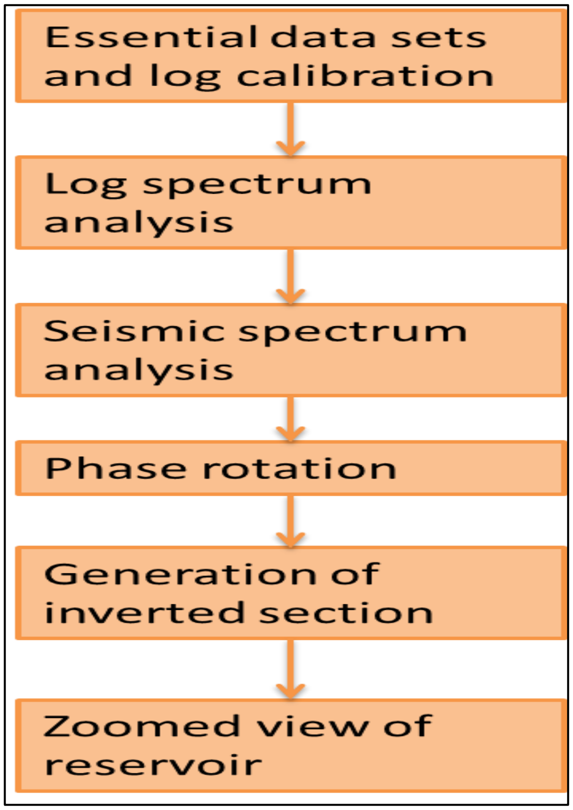

Figure 7.1 steps for coloured inversion.

7.4 Coloured Inversion Computation

The coloured inversion computation requires the following as input:

- DT log
- RHOB log
- Formation tops
- TD chart

The amplitude spectra of the impedance logs (velocity * density) derived for the window of interest can be calculated and displayed on a log-log graph from which a linear spectral slope can be estimated. The fitted line can be expressed as the exponential α in the equivalent representation of the spectral trend in the form A*fα.

Butterworth filter is used to smooth and constrain the impedance log spectrum. The Butterworth filter is a type of signal processing filter designed to have as a flat frequency response as possible in the pass band.

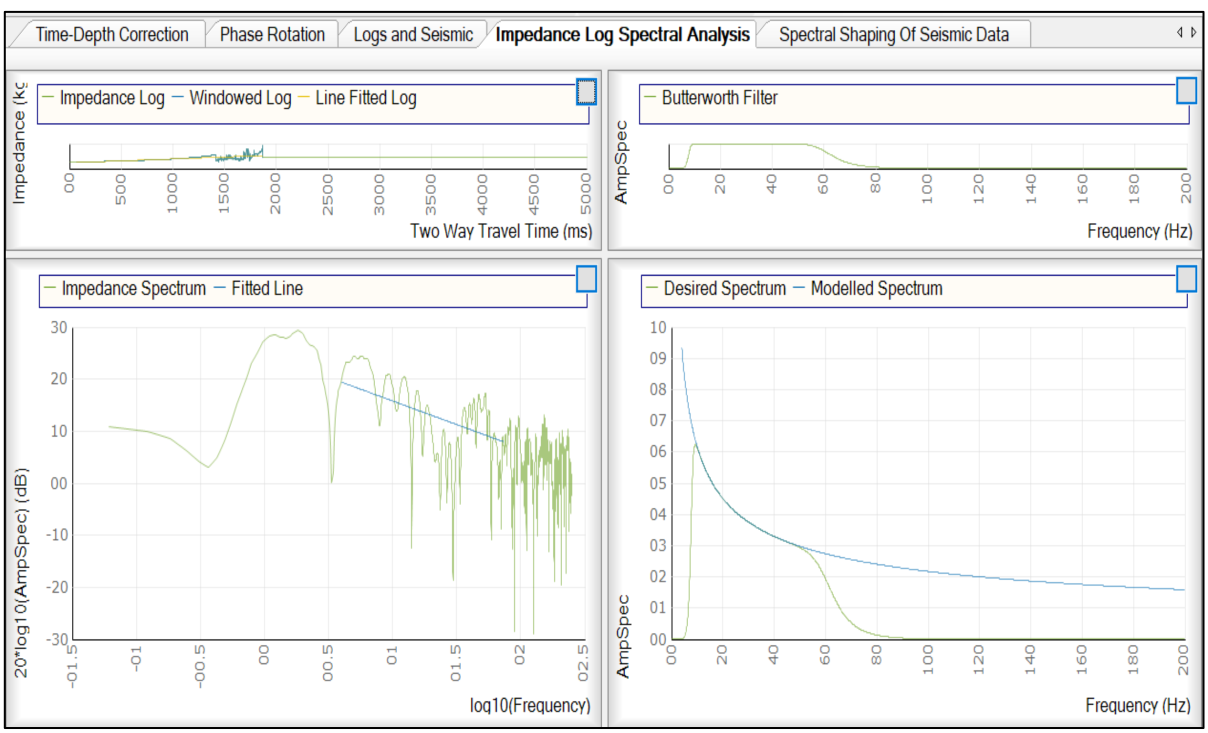

Figure 7.2 Impedance log spectral analysis.

The amplitude spectra are averaged and smoothed – to enable a smooth spectral shaping operator to be derived to operate on the data.

The phase of the operator is a constant -90° which is in agreement with the simplistic view of inversion to integration, and the concept of a zero-phase reflection spike being transformed to a step AI interface, provided the data are zero-phase.

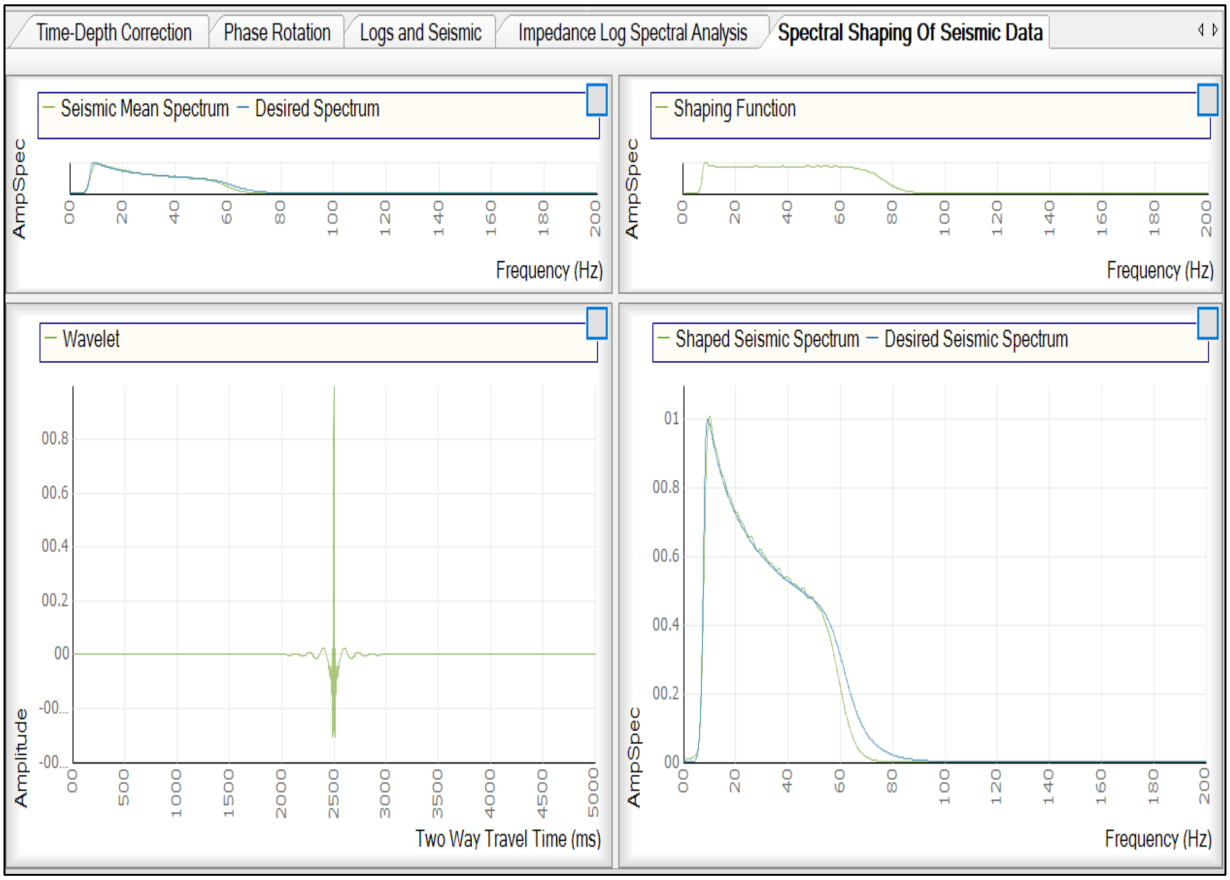

Figure 7.3 Spectral shaping of seismic data.

7.5 Coloured Inversion of control Line GO-994-GNA-09

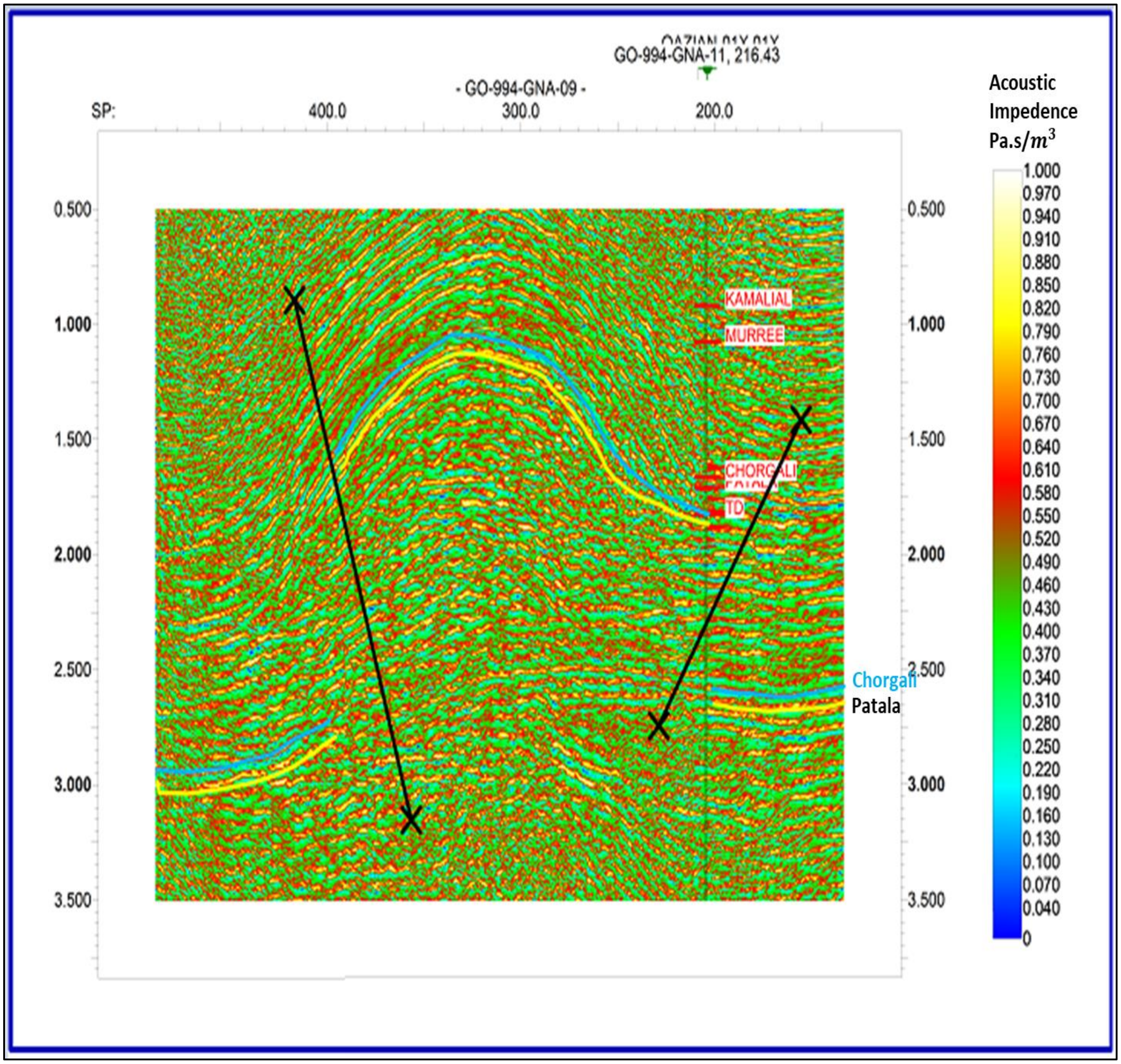

Figure 7.4 Coloured inversion on line GO-994-GNA-09

The area in green colour shows low acoustic impedence, which is favourable for Hydrocarbons. The reservoir Formation (Chorgali Formation) is marked on high acoustic impedence value (indicated by yellowish red colour), so there is no hydrocarbon potential in Chorgali Formation. This is the justification for the dry Qazian-01X well

DISCUSSIONS AND CONCLUSION

- Two horizons are chosen, Chorgali and Patala Formation on the basis of hydrocarbon potential. These are marked on one strike line GO-994-GNA-11 and three dip lines GO-994-GNA-09, GO-994-GNA-19-10 and GO-994-GNA-15, anticlinal structure is formed bounded by two reverse faults.
- Then grid contour map of Chorgali Formation is created in Time and Depth domain. Time Contour maps are generated manually and Depth Contours are created by using extended maths calculator, $S=\frac{V*t}{2}$ is used in calculator. The velocity used in this formula is interval velocity, picked from synthetic seismogram. Time Contour maps shows that the horizons are deepest in North-West direction and deeper in SE direction. Depth Contour maps shows that the brown colour shows shallow depth (anticline).
- In Attribute Analysis, relative Acoustic Impedence attribute and wavelet Dominant Frequency attribute confirms that the reflectors and faults are correctly picked, also show that the Chorgali formation has high acoustic impedence and frequency.
- The Petrophysics analysis is done on the Reservoir Formation which is Chorgali Formation, by loading lithology, resistivity and porosity logs and using different charts and formulas. Followig parameters are calculated by petrophysical analaysis, Volume of Shale 40%, effective porosity is 7%, Water Saturation 85% and Hydrocarbon Saturation 15%. As the water saturation is high so these results justify that there is no Hydrocarbon potential in Chorgali Formation and the well is dry. Facies Analysis is also performed.
- Facies Analysis confirms the lithology of Chorgali Formation that is Limestone with interbeds of Shale, by generating different cross plots between logs, so three facies are encountered, limestone Facie and shaly limestone facie and shale facie. Chorgali Formation has major portion consist of limestone and have some beds of shale. Coloured Inversion is performed on a control line GO-994-GNA-09, that justifies Qazian-01X is dry well, as the reservoir formation is marked on the high acoustic

impedence values so Vp and density in formation is high, which is not favourable for Hydrocarbons. Only low acoustic impedence is favourable for Hydrocarbons.

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