2D SEISMIC REFLECTION DATA INTERPRETATION, PETRO PHYSICAL ANALYSIS OF FIMKASSAR AREA, UPPER INDUS BASIN, PAKISTAN USING SEISMIC AND WELL LOG DATA

By

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(2016-2020)

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CERTIFICATE OF APPROVAL

This dissertation submitted by **Rohail Khan** is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the requirement for the award of degree of BS Geophysics.

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EXTERNAL EXAMINER

DEDICATION

Every challenging work needs self-effort as well as guidance of elders especially those who were very close to our heart. My humble effort I dedicate to friends and family. I dedicate it to a place where much of this was invented, elaborated, or pondered and where a friendship developed that even the writing could not spoil.

Acknowledgement

First praise is to Allah, the most Beneficent, Merciful and Almighty, on whom ultimately we depend for sustenance and guidance. I bear witness that Holy Prophet Muhammad (PBUH) is the last messenger, whose life is perfect model for the whole mankind till the Day of Judgment. I thank Allah for giving me strength and ability to complete this study.

I am especially indebted to my honorable supervisor **DR. Aamir Ali** for giving me an initiative to this study.

I specially acknowledge the prayers and efforts of my whole family, specially my parents for their encouragement, support and sacrifices throughout the study. I also wish to thank the whole faculty of my department for providing me with an academic base, which has enabled me to take up this study I pay my thanks to the employees of clerical office who helped me a lot and all those their names do not appear here who have contributed to the successful completion of this study.

Abstract

The dissertation work includes seismic data interpretation, seismic attribute analysis, petrophysical analysis using well logs data; identification of possible resource plays as well use of seismic inversion to estimate physical properties of rocks.

Seismic and well log interpretation are used in the dissertation to study the structural style, physical properties of rocks and identification of possible petroleum system in Fimkassar area (Upper Indus Basin) Pakistan. The data is interpreted with Kingdom Suit (8.8) software. Two horizons are marked namely Sakesar and Patala Formations. Time and a depth contour maps shows faulted anticline structures in study area. Petrophysical analysis of wells Fimkassor-02 is carried out for Sakesar Formation in order to depict the probable hydrocarbon producing reservoir. Seismic attribute analysis is then applied to confirm both structural and stratigraphic interpretation. Petrophysical results suggest that Sakesar Formations is hydrocarbon bearing zone with shale (35% by volume) and limestone (10% porosity). Seismic inversion results are also demonstrating that Sakesar Formation acts as a reservoir. The post stack color inversion is performed to identify the possible hydrocarbon accumulation via variation in acoustic impedance that agrees with petrophysical analysis.

Contents

Chapter-01

Introduction

1.1 Introduction

Pakistan has a very high potential of hydrocarbons in its northern (Potwar, Kohat) and southern (Badin, Mari etc.) parts. The dissertation is a result of exploration of hydrocarbons in Fimkassar oil field which lies in Chakwal a city of Punjab province. The 2D seismic survey is helpful in interpreting subsurface structural trending and occurrence of hydrocarbons in deeper zones of sedimentary basin.

Seismic Reflection Method most commonly used in hydrocarbon exploration in petroleum geology. Petroleum system comprises of three main components as given below.

1. Source rocks (which contains organic materials responsible for generation of hydrocarbons)
2. Reservoir rock (which offer suitable accumulation for hydrocarbons it migrates from source rock)
3. Seal or trap rock (which stops the upward movement of hydrocarbons)

The Indus basin, including the Kohat-Potwar (study area) depression, belongs to the class of extra-continental downward basins. The Potwar basin has mostly structural traps with in responsible for hydrocarbon accumulation.

Investigation of earth through geophysical method involves taking measurement in order to check the variation in the physical properties of the earth both laterally and horizontally to interpret structure.

Petrophysics use all kinds of logs, core and production data to obtain physical properties of reservoir such as volume of shale, porosity, water and hydrocarbon saturation which help in identifying probable zones of hydrocarbon. After getting Petrophysical results we get more clear understanding of rock properties and detect more meaningful results.

1.2 Fimkassar oil field's exploration history

The Fimkassar oil field is the concession area of Oil and Gas Development Company Limited (OGDCL). The Fimkassar oil field is located in the eastern part of the Potwar sub-Basin and is about 75km away from SW of Islamabad. Fimkassar, formerly Parhal, field is in Southern Potwar on OGDC's Fimkassar concession in Punjab's Chakwal District. Gulf Oil company (GOC) declared Fimkassar IX an oil discovery in June 1981. The well is an oil producer from Chorgali limestone at 2,891-3,081 m. Original reserves were 30 million bbl, and 1994 production was 2,562 b/d of oil. Because of low production it was sold to OGDCL. OGDCL drilled a well that encountered the same formations and penetrated a fracture that produced 4700 barrels of oil per day.

OGDCL drilled the Fimkassar-01A well and abandoned the well due to technical difficulties. The Fim-1-ST well is the highest oil volume producing well to date and produced 4000 barrels/day. A third well, the Fimkassar-02 was drilled in 1990. This initially produced 1960 barrels of oil per day.

1.3 Objectives of dissertation

The main goal of dissertation is to present a subsurface model, estimate the reservoir properties and to categorize the new well location. All objectives are given below in points.

1. Delineation of subsurface structural image and 2D seismic reflection data favorable for hydrocarbons accumulation.
2. Seismic attributes analysis to confirm the presence of hydrocarbons within identified structures and also to confirm interpretation.
3. Petrophysical evaluation of the lithology encountered in the well for reservoir characterization**.**
4. Seismic post-stack coloured inversion to analyse the variation of acoustic impedance at reservoir level

1.4 Data used

Seismic and borehole data provided by DGPC is given in Table 1.1.

Seismic line	Direction
96-PW-03	Dip line
96-PW-06	Dip line
884-FMK-103	Strike line
FIMKASSOR-02	developed(oil & gas)

Table 1.1 Seismic lines and well used in the study.

1.6 Data formats

Seismic reflection data which consist of following formats:

1. SEG-Y
2. LAS
3. Navigation

All data sets used were provided by Directorate General of Petroleum concession (DGPC), Government of Pakistan upon the request of Chairman Department of Earth Sciences, Quaid-i-

Azam University Islamabad. The detail of well data is given in table 1.2 along with Formation tops in table 1.3.

Well Names	Well Depth	**Formation Tops(Sakesar)**	**Status of Wells**	**Discovery**
Fimkassar-02	3067	2946	Development	Oil & Gas

Table 1.2 Table shows the detail of Fimkasar-02 well.

FORMATION NAME	FORMATION TOPS(meter)	FORMATION THICKNESS(meter)
NAGRI	0	595
CHINJI	595	948
KAMLIAL	1543	160
MURREE	1703	1199
CHORGALI	2902	44
SAKESAR	2946	121
PATALA	3067	14

Table 1.3 Table showing Formation tops of Fimkassar-02

Chapter 2

General Geology and Stratigraphy of the Study Area

2.1 Introduction

Information about the geology of an area is necessary in order to precisely interpret seismic data. The interpretation of seismic data in geological terms is the objective of seismic project. Therefore seismic data interpretation is based on the stratigraphy and structural geology of the area.

This chapter deals with a brief description of the tectonic setting, structural geology and stratigraphy of the study area (Fimkassar) and adjoining areas of upper Indus Basin.

2.2 Tectonic history of the study area (Potwar area)

In the Potwar area, the deformation appears to have occurred by south verging thrusting, with tight and occasionally overturned anticlines separated by broad synclines. The major thrust faults dip to the north and are normally associated with south dipping conjugate back thrusts, which have resulted in the formation of popup structures. The main faults detach on the regional plane of decollement i.e. Salt Range Formation.

The tectonic map of Pakistan is shown in figure. 2.1. The eastern Potwar region represents the most strongly deformed part of the Potwar fold and thrust belt, with large low angle detachment faults accommodating more shortening than elsewhere in the Potwar fold and thrust belt. The area is dominated by over thrust tectonics, where the formations have been compressed into fold and fault dominated structures. In eastern Potwar, most of the folds trend NE-SW, in contrast to the EW trending folds in the central region. Conventional imbricate thrusts, popup structures, and triangle zones are commonly developed in this area (Aamir and Siddiqui, 2006).

2.3 Geological boundaries of the study area

The Potwar basin is bounded to the south by Salt Range escarpment, to the north by the Main Boundary Thrust, to the east by the Jhelum transform fault, and to the west by Kalabagh transform fault (Aamir and Siddiqui, 2006) as shown in figure 2.2.

2.4 Stratigraphy of the Study Area

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 figure 2.3.

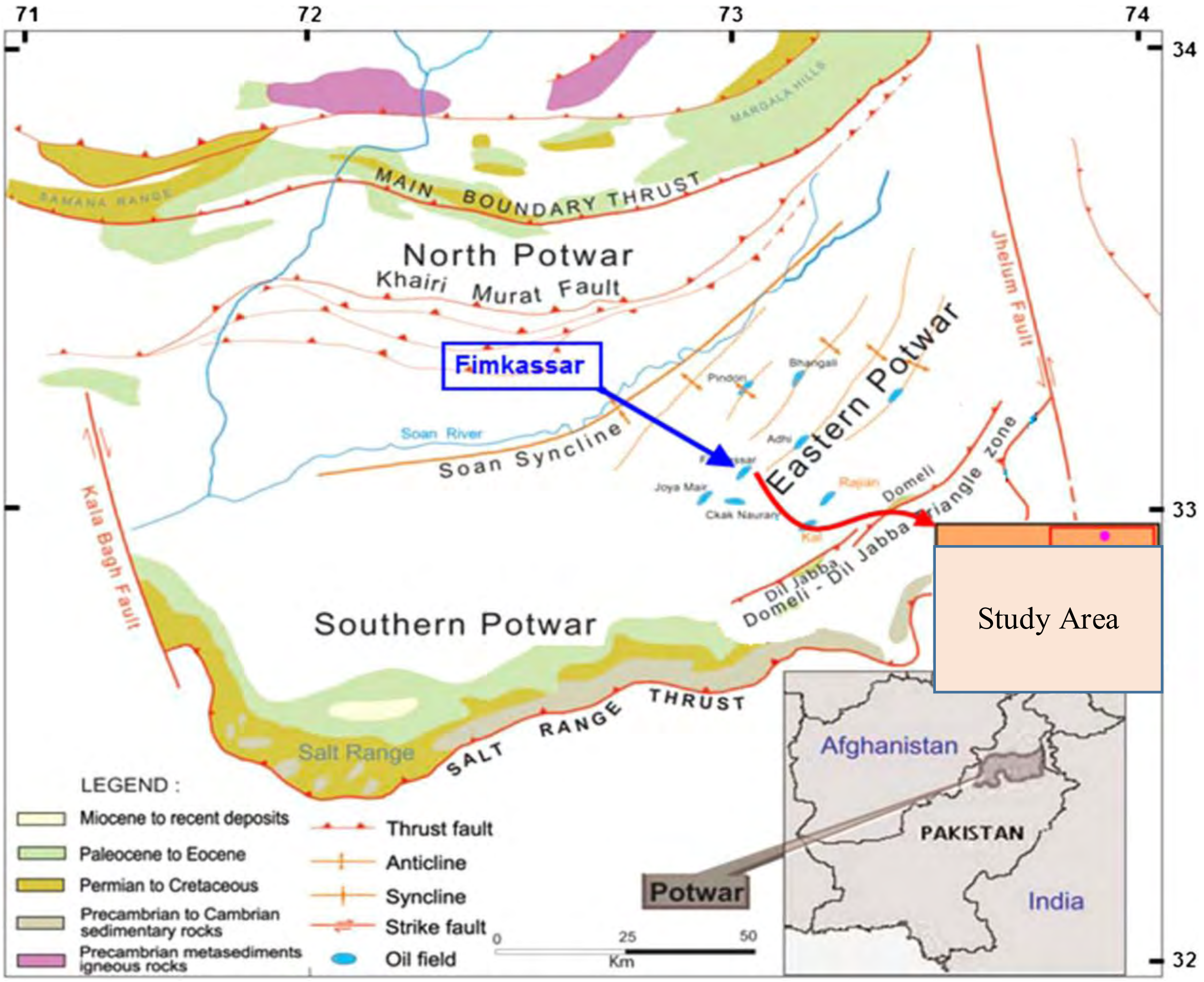

Figure 2.1 Map showing the study area (Ali et al., 2015)

These unconformities are not easily identified in the seismic profiles due to complex thrusting. The Potwar sub-basin is filled with thick infra-Cambrian evaporate deposits overlain by relatively thin Cambrian to Eocene age platform deposits followed by thick Miocene-Pliocene molasses deposits. This whole section has been severely deformed by intense tectonic activity during the Himalayan Orogeny in Pliocene to middle Pleistocene time. (Aamir and Siddiqui, 2006). The oldest formation penetrated in this area is the Infra- Cambrian Salt Range Formation, which is dominantly composed of halite with subordinate marl, dolomite, and shales. The Salt Range Formation is best developed in the eastern salt range. The salt lies unconformable on the Precambrian basement. The overlying platform sequence consists of Cambrian to Eocene shallow water sediments with major unconformities at the base of Permian and Paleocene. The Potwar Basin was uplifted during Ordovician to Carboniferous; therefore no sediments of this time interval were deposited in the basin (Aamir and Siddiqui, 2006).

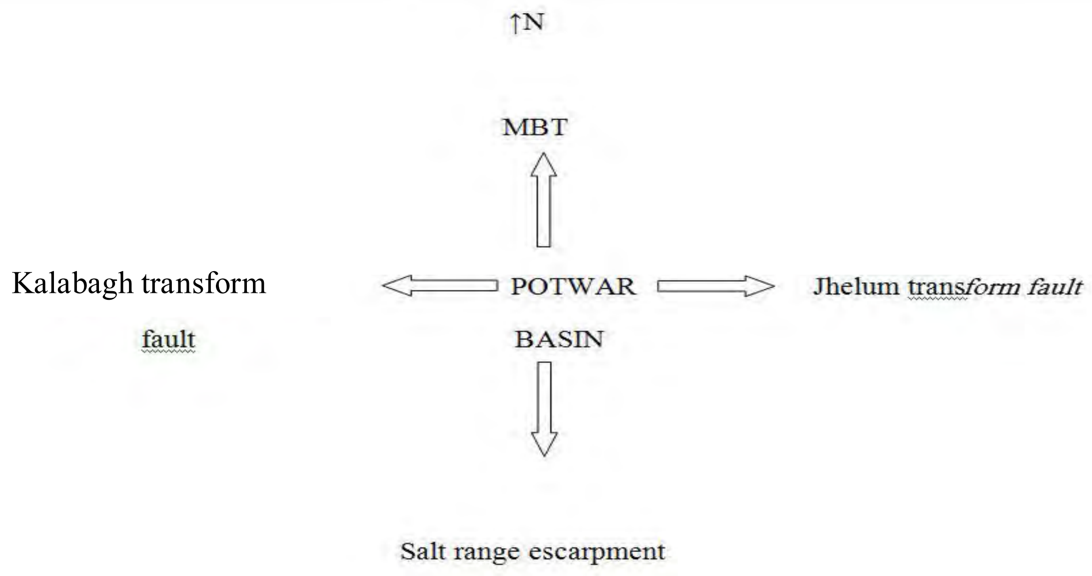

Figure 2.2 Geological boundaries of the study area.

The second abrupt change to the sedimentary regime is represented by the complete absence of the Mesozoic sedimentary succession, including late Permian to Cretaceous, throughout the eastern Potwar area. In Mesozoic time the depocenter was located in central Potwar, where a thick Mesozoic sedimentary section is present (Aamir and Siddiqui, 2006). Stratigraphy of the eastern Potwar is shown below in figure 2.3.

2.4.1 Eocene age

The following formations which are acting as major reservoir rocks in the study area are Sakesar Formation, Chorgali Formation, and Nammal Formation.

2.5 Reservoir character and production history of study area

Fractured limestones of the Chorgali and Sakesar formations are developed throughout the Surghar Range. These are the primary reservoirs in the Potwar basin. The Sakesar Formation is primarily represented by foraminiferal micritic facies whereas Chorgali Formation comprises thin interbedded shales, limestone and anhydrites. Limestone of both Chorgali and Sakesar formations generally considered to be tight but the fractures in the folded and faulted structures provide sufficient secondary porosity. Its outcrops are densely jointed and fractured. Evidence from the cores taken from wells at Dhulian field indicates that Sakesar reservoir is highly fractured with very low matrix porosity.

2.6 Reservoir rocks of Potwar Basin

The effective reservoir at Fimkassar oil field lies within the Sakesar and Chorgali formations, Palaeozoic-Tertiary dominantly marine sedimentary rocks form petroleum systems in Potwar are exposed in Salt Range along the frontal thrust and the fractured carbonates of Sakesar and Chorgali formations are the major producing reservoirs in the study area.

Chorgali Formation

The formation consists of massive dolostones, marls, nodular, extremely fissile varicoloured shales, and evaporate collapse breccia. It is 80 to 90 m thick and is early middle Eocene in age. There is very slight primary porosity and appears as vughs in certain layers and the process of dolomitization has produced certain porosity.

Sakesar Formation

It is major formation, acting as reservoir producing both Oil and Gas in Fimkassar area. It is a fractured reservoir, having negligible porosity It is about 70 to 300 m thick and is early to middle Eocene in age (Bender and Raza, 1995).

2.7 Source Rocks of Study Area

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 (Bender and Raza, 1995). Along that the grey shale's of Mianwalli and Datta, formations are potential source rocks.

2.8 Traps/Seal rock of Study Area

The clays and shale's of the Murree Formation provide efficient vertical and lateral seal to Eocene reservoirs wherever it is in contact.

The Kuldana formation acts as a cap for the reservoirs of Sakesar and Chorgali formations in SRPFB. The clays and shale's of Muree formation also provide vertical and lateral seal to Eocene Reservoirs in SRPFB wherever it is in contact.

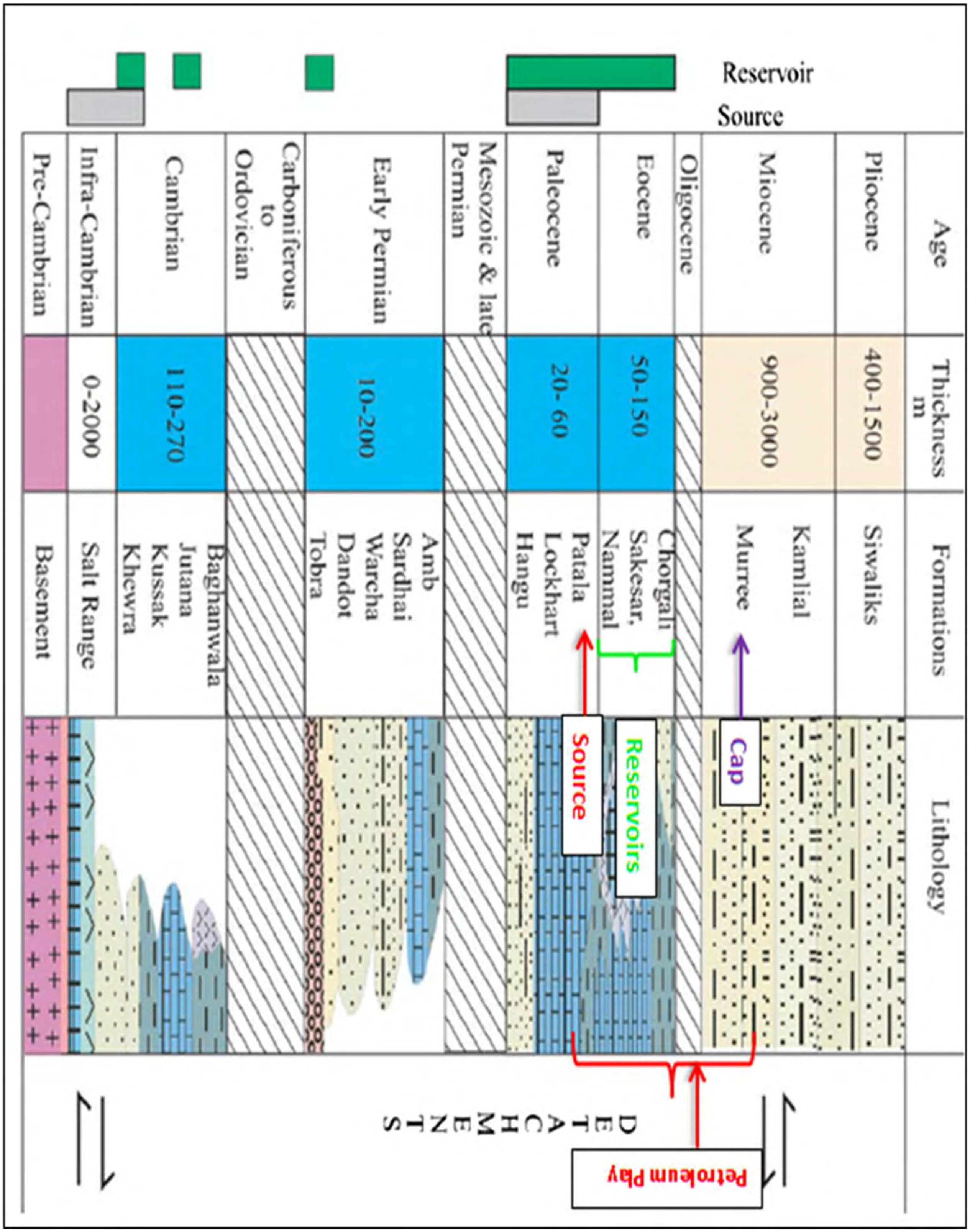

Figure 2.3 Schematic stratigraphic column of eastern Potwar (Ali et al., 2015).

CHAPTER 03

Seismic data interpretation

3.1 Introduction

The Seismic interpretation is the process of determining information about the subsurface of the earth from seismic data. It may determine general information about an area, locate prospects for drilling exploratory wells, or guide development of an already-discovered Field (Coffeen, 1986).

To meet the challenges of exploring ever increasingly complex targets, the seismic method has thus, evolved into a computationally complex science. The computer based working (Processing & Interpretation) is more accurate, precise, efficient and satisfactory which provides more time for further analysis of data. The generalized workflow of interpretation is shown in figure (3.1).

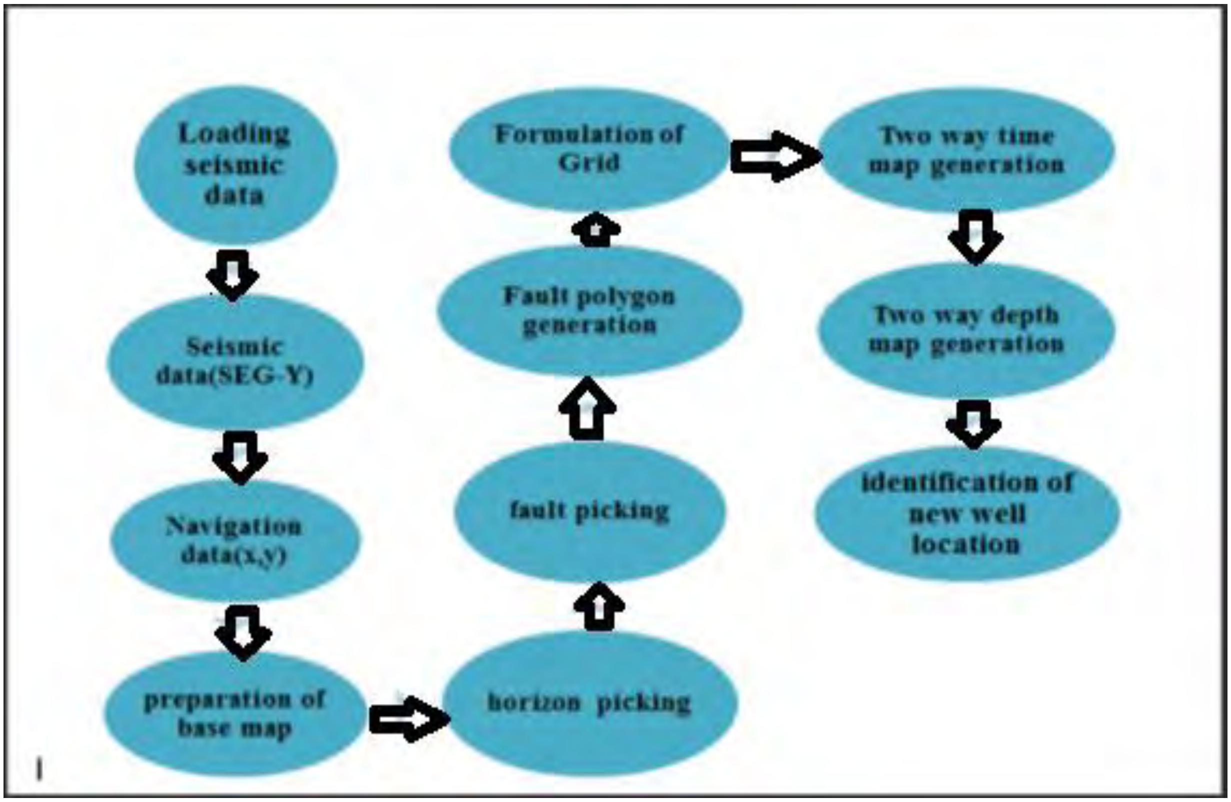

Figure 3.1 Interpretation work flow (Ali et al., 2015).

3.2 Structural Interpretation

Seismic data interpretation is mainly done on the basis of available information and stratigraphy of the area. Seismic is correlated with the formation tops penetrated in the wells using well tops if available. In this study, seismic interpretation is done by picking horizons and reflector is continued in all other seismic lines. Major faults are picked on the dip lines and their parts are correlated across the strike lines to map the structures throughout the area. Two way time (TWT) maps are generated using fault polygons in order to describe the structural inclination at different levels. The study area is in compressional regime, pop up and snaked head structures.

Navigations and SEG-Y of given lines of Fimkassar area are loaded in software and following procedure is adopted as shown figure.3.1

1. Preparation of base map.
2. Marking of seismic horizons
3. Fault identification and marking of faults. Fault polygon generation.
4. Contour maps generation (Time & Depth)
5. Identification of leads

3.3 Base map

Base map is a map which shows orientation and location of the seismic lines and wells. The map consists of dip and strike lines as shown in figure (3.2). A base map typically includes location of concession boundaries, wells, seismic survey points and length of seismic spread, longitude and latitude of the study area.

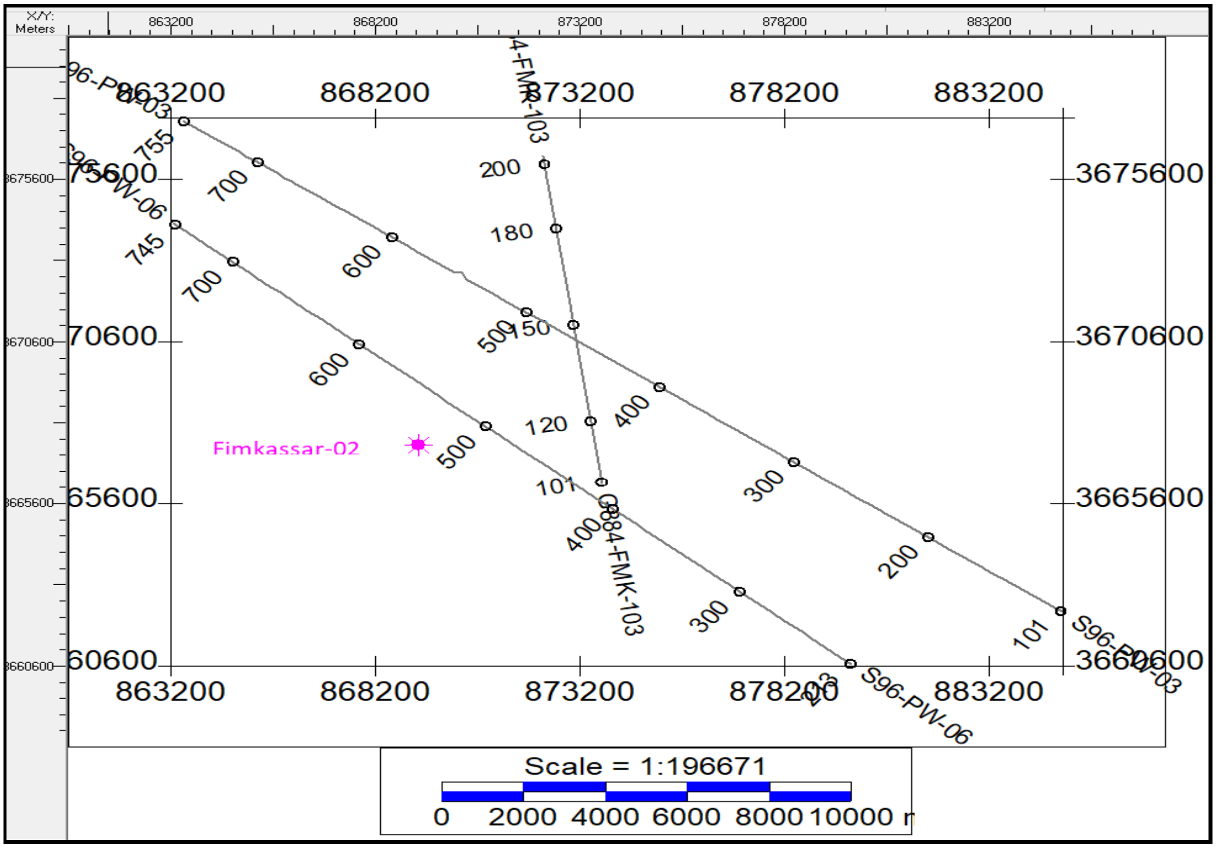

Figure 3.2 Base map of the study area.

3.4 Generation of Synthetic Seismogram

Velocity data from the sonic log (and the density log if available) are used to create a synthetic seismic trace. These logs are acquired in the borehole. We use this velocity and density data to compute a series of reflection coefficients called reflectivity series. Then a source Ricker wavelet with a dominant frequency of 15Hz is generated. The reflectivity series is convolved with the source wavelet to get a synthetic seismogram figure (3.3). Synthetic seismogram is matched with the seismic section at the well point to correlate the succession of reflectors.

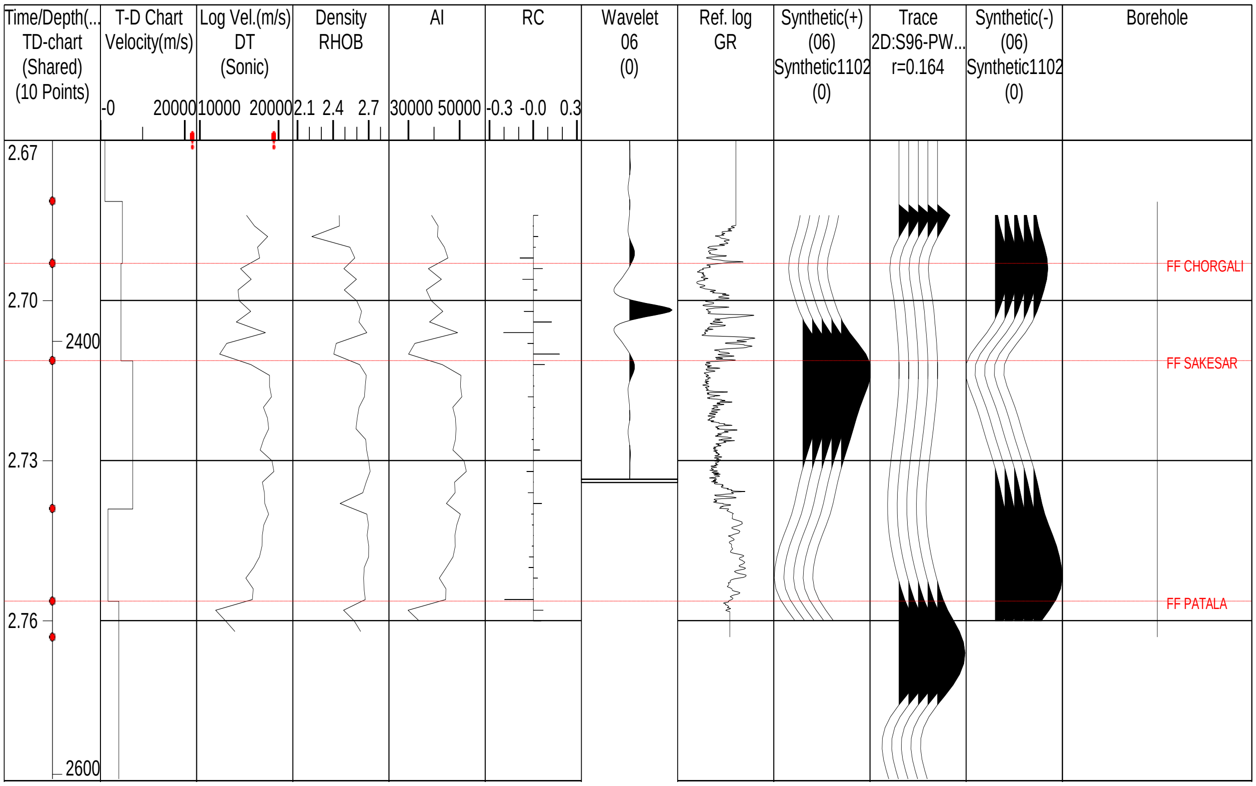

Figure 3.3 Synthetic seismogram.

3.5 Seismic section

Seismic section is the outcome of the seismic reflection survey. The seismic section shows the high values of traces in vertical line which are called recorded peaks in the cross section. Most importantly it points out some the features of a geologic cross-section. These high value traces in seismic section is filled in with black shows the wiggle-variable area. The seismic section display or plot the data of the seismic line. The vertical scale in the seismic section displays the arrival time (Two way travel time).Seismic section plots or displays seismic data along a line. The vertical scale is usually arrival time but sometimes depth and the Horizontal axis shows the shot points and CDP.

3.6 Fault Marking and Horizon Picking on Seismic Section

Two horizons are picked on the basis of available information (well data and generalized stratigraphic map). The horizons picked are named on basis of well top of the Fimkassar-02 the Sakesar and Patala showing high reflections on a seismic section making it easier to be picked. On the basis of the geology of the area, it is evident that the area under study lies in compressional regime. This background knowledge helps to identify that reverse and thrust faults should be marked on the seismic section.

3.7 Interpreted Seismic Sections

The two dip lines i.e. S96-PW06, S96-PW03 are interpreted are shown in figure (3.4) and figure (3.5) respectively. Two seismic horizons namely; Sakesar of Eocene age and Patala of Paleocene age on the basis of well tops and further more confirmed by synthetic seismogram. Along these seismic horizons; faults are also picked shown in figure (3.4) and figure (3.5).The horizon are also marked in line G884-FMK-03 shown in figure (3.6).Total two horizons namely Sakesar of Eocene age and Patala of Paleocene age are marked. Along these seismic horizons, faults are also picked shown in figure (3.1) and figure (3.2).These seismic sections pop-up structures bounded by thrust faulting. These pop-up structures may be suitable place for the hydrocarbons.

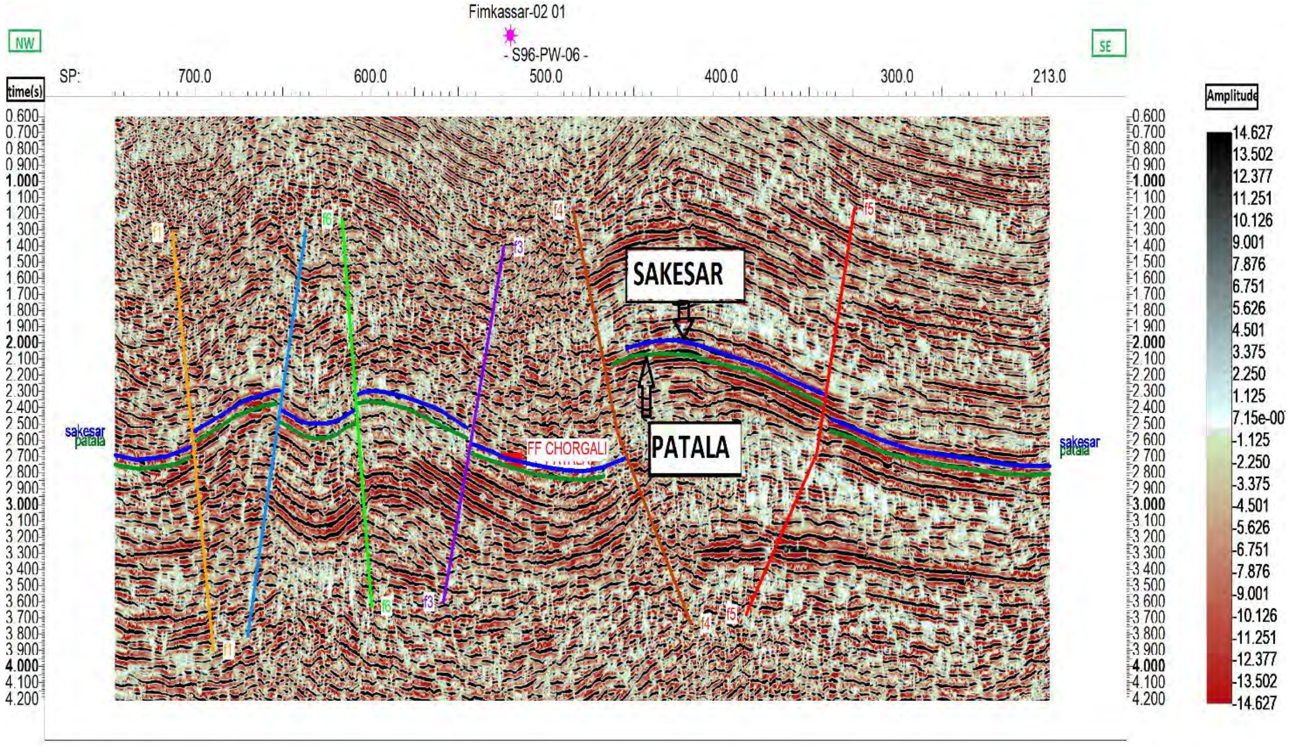

Figure 3.4 Interpreted seismic line PW-06. Line is oriented NW-SE

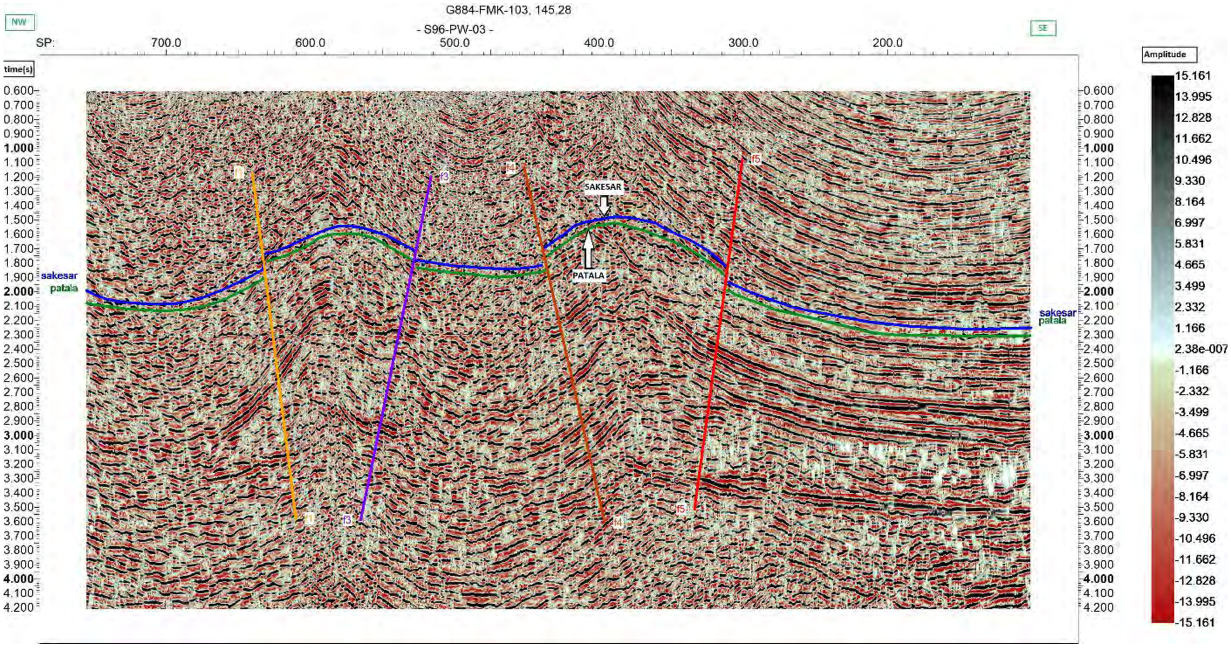

Figure 3.5 Interpreted seismic line PW-03. Line is oriented WN-SE

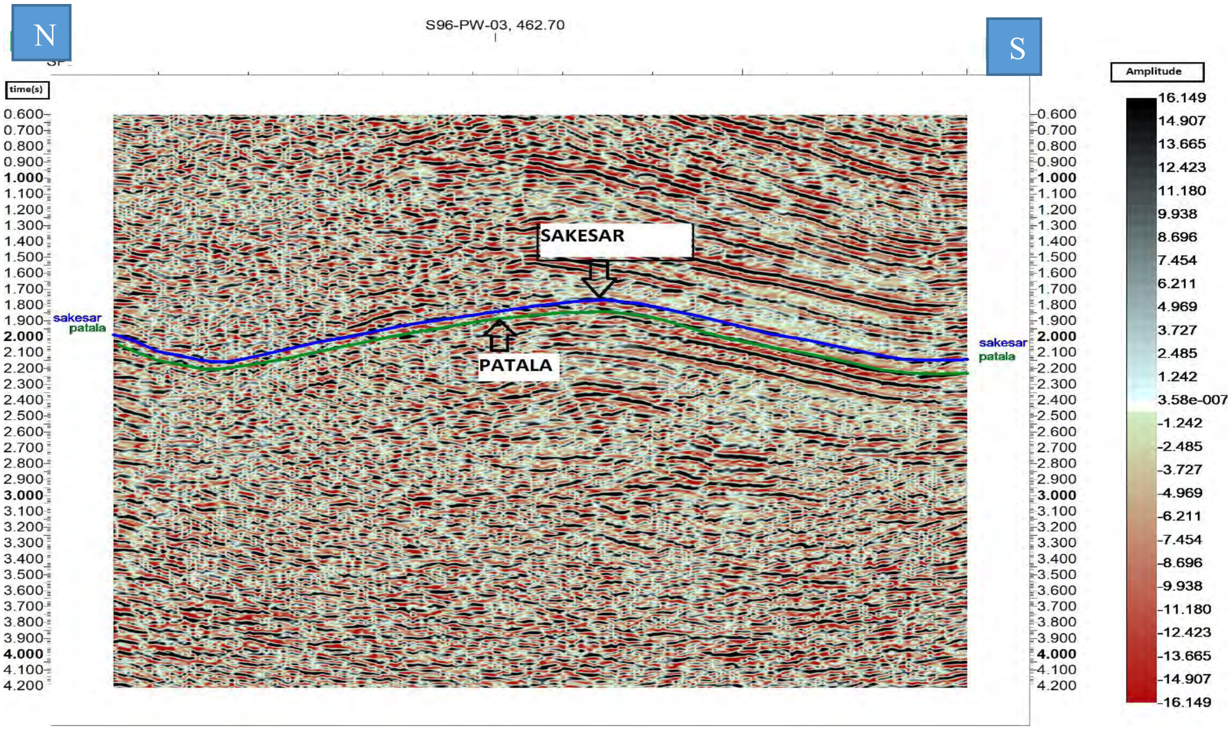

Figure 3.6 Interpreted seismic line FMK-103. Line is oriented N-S

3.8 Seismic attributes analysis

A seismic attribute can be defined as, anything or any information which can be obtained from seismic data either by direct measurement or by logical or experience based reasoning. These seismic attributes are now an integral part of seismic interpretation and mostly used for lithological analysis, Petrophysical analysis an as well as confirmation of structural interpretation. Here some of the post stack attribute are discussed below.

The Trace Envelope

The trace Envelope shown in figure (3.7) is a physical attribute and it can be used as an effective discriminator for acoustic impedance contrast, bright spots, and sequence boundaries.

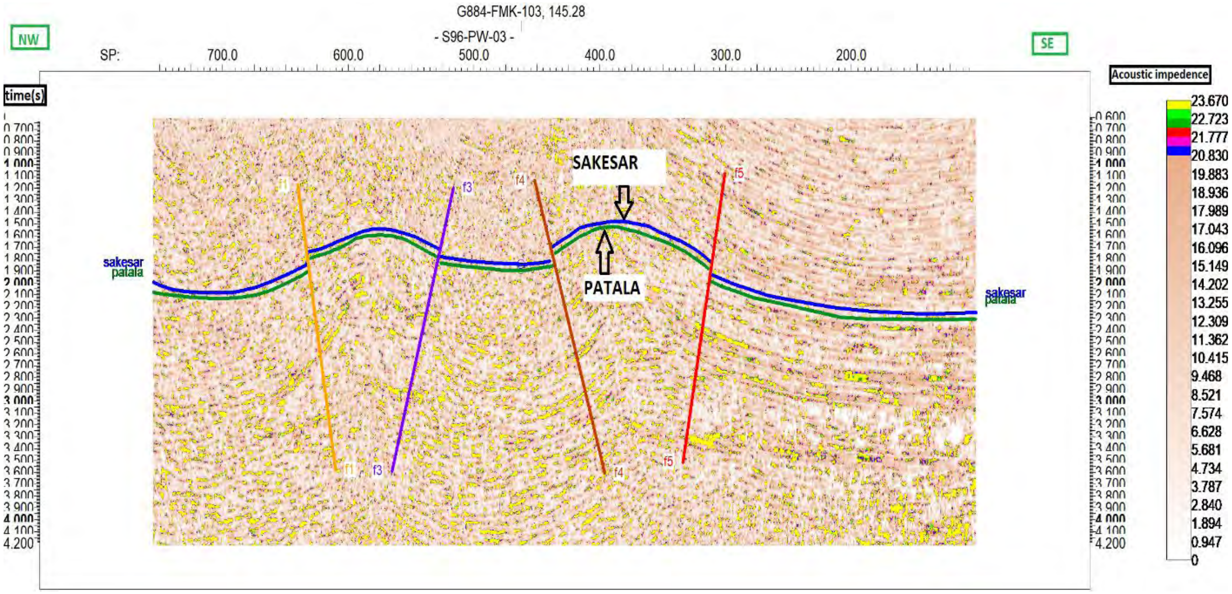

Figure 3.7 Trace envelope attribute showing acoustic impedance contrast. Line is oriented NW-SE

Average energy

Average energy is a post-stack wavelet attribute, in which, within a specified window the square root of the sum of squared amplitudes is calculated and divided by their number of samples. The attribute has a blocky response and individually highlights the seal, reservoir and source rocks as shown in Figure (3.8).

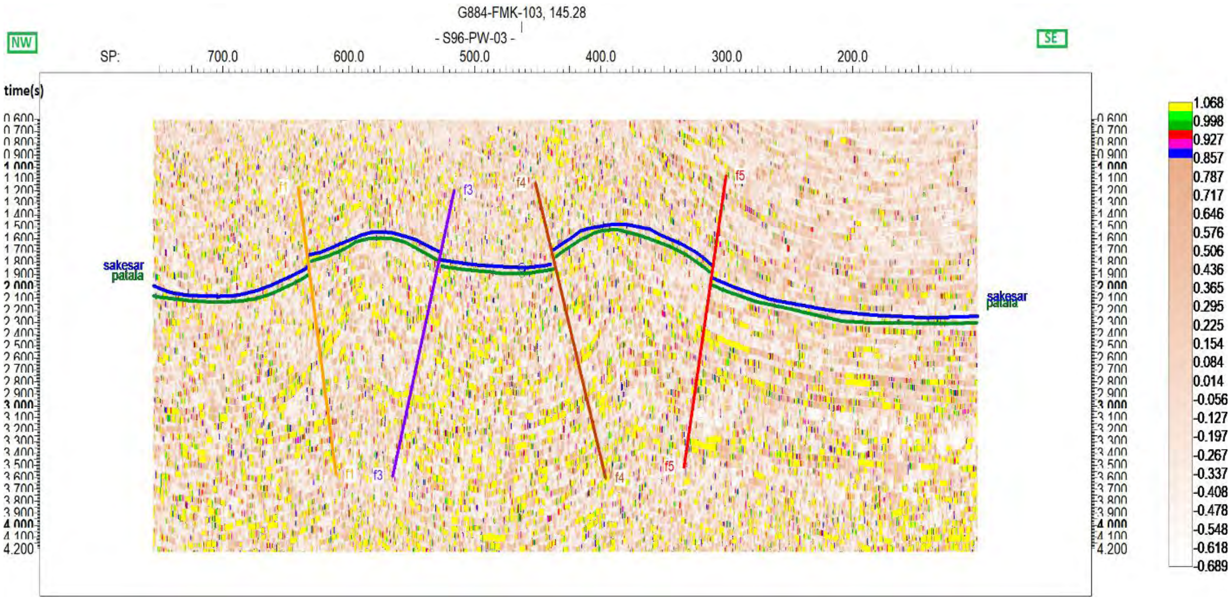

Figure 3.8 Average energy attribute showing energy absorbed at reflectors. Line is oriented NW-SE

Instantaneous phase

The phase information shown in figure (3.9) is independent of trace amplitude and relates to the propagation of phase of the seismic wave front. .

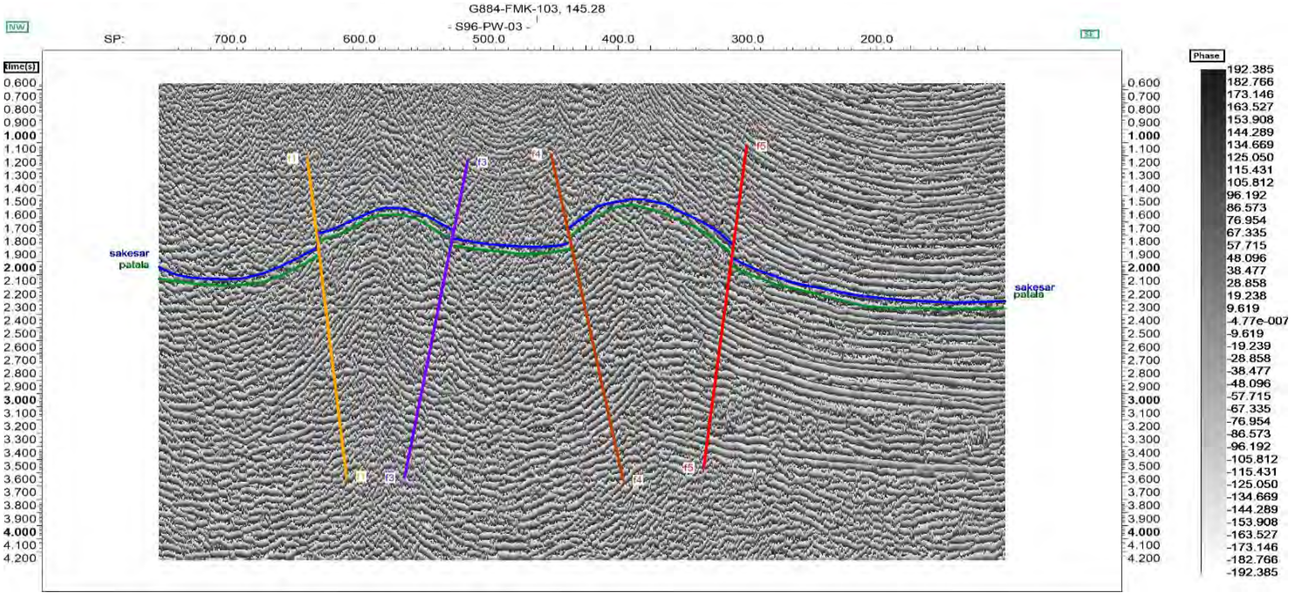

Figure 3.9 Instantaneous phase attributes showing the deeper horizons. Line is oriented WN-SE

3.9 Fault polygon construction

Fault polygon at Sakesar and Patala Formations shown in figure (3.10) and figure (3.11).

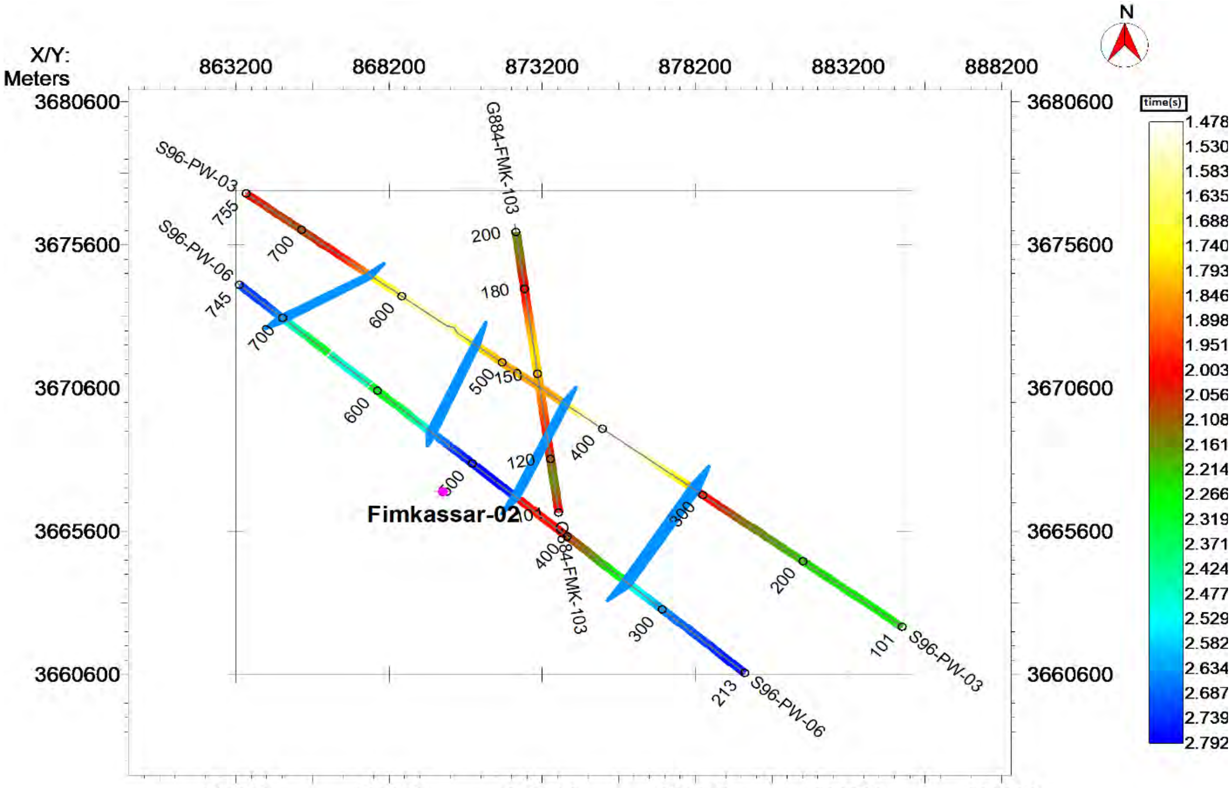

Figure 3.10 Polygon's orientation of Sakesar Formation on base map.

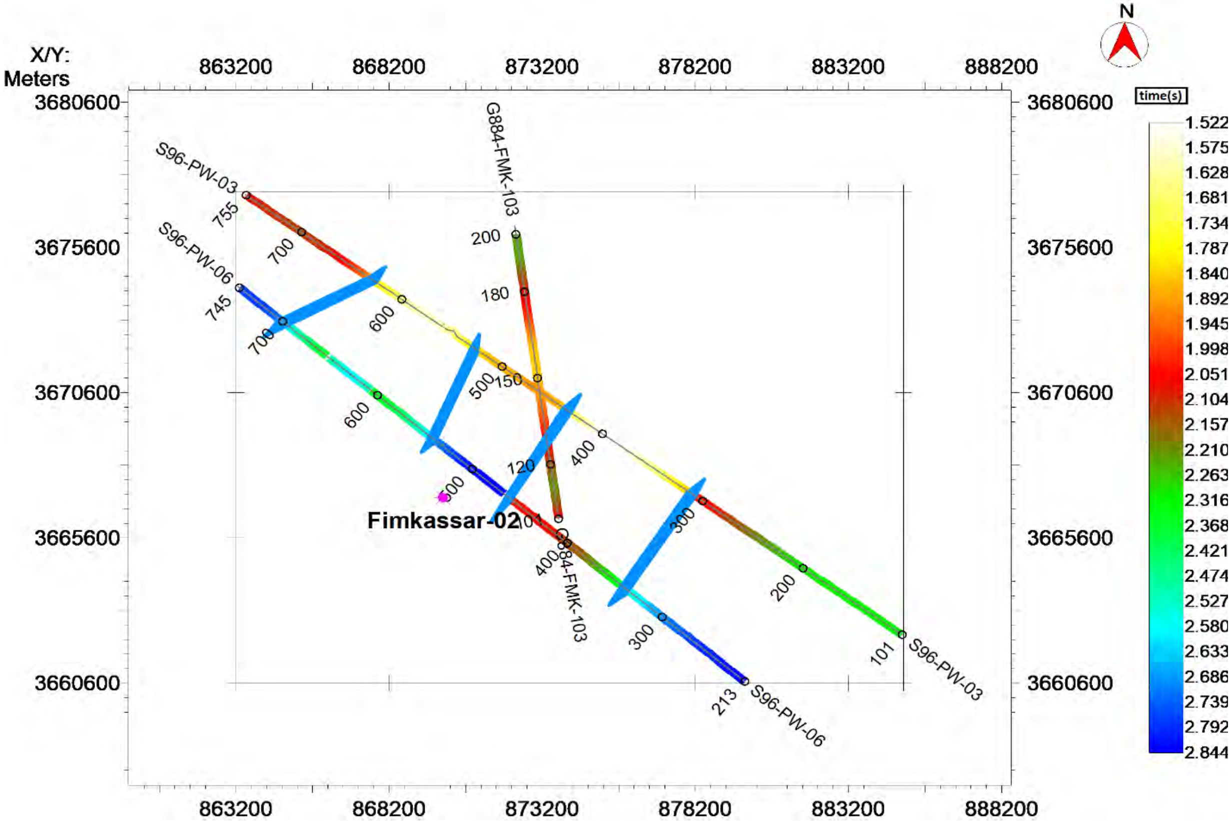

Figure 3.11 Polygon's orientation of Patala Formation on base map.

3.10 Contour maps

A line that connects the line of equal values is called a contour line. Such maps show us steepness of slopes, elevation top of the subsurface of the sedimentary rock layer and also the two way travel time of the horizon in milliseconds.

1. Time Contouring
2. Depth Contouring

3.10.1 Time contouring

Time was taken from the seismic section. The next step was the generating the time contour map. The time contour map and time surfaces of Sakesar and Patala are discussed under.

3.10.2 Depth contouring

The depth contour map marks the depth of structure. The depth contour map in the subsurface mainly shows the faults, anticline and folds.

So after marking the time contour map the depth contour map is being generated by using the following formula.

$$S=V*T/2 \tag{3.1}$$

So we have the time and depth of the given formation (Sakesar and Patala Formations). First we find velocity of each formation by using the formula.

$$V=2*S/T \tag{3.2}$$

Then put it in the equation (3.1) to calculate the depth of each formation then using it for depth contour mapping.

3.11 Time and depth contour map of Sakesar formation

The time and depth map of Sakesar Formation are generated on the base map along with wells and their corresponding fault polygons shown in figure (3.12) and figure (3.13). The structural variation in these contours can be interpreted by using color bar and legends, yellow color ranges shows the shallowest parts and blue shows the deepest parts in figure (3.12). While blue color ranges represent the shallowest parts in figure (3.13). The contour map helps us to mark the zone of interest and gives hint about the location of second well. Sakesar Formation is the second zone of interest and one of the major potential reservoirs after Chorgali. Here at this level similar fault polygon are observed which indicates a presence of same faults on both Formations. Hence yellow portion shows the highest peak or elevated part i.e. most favorable area for hydrocarbon extraction.

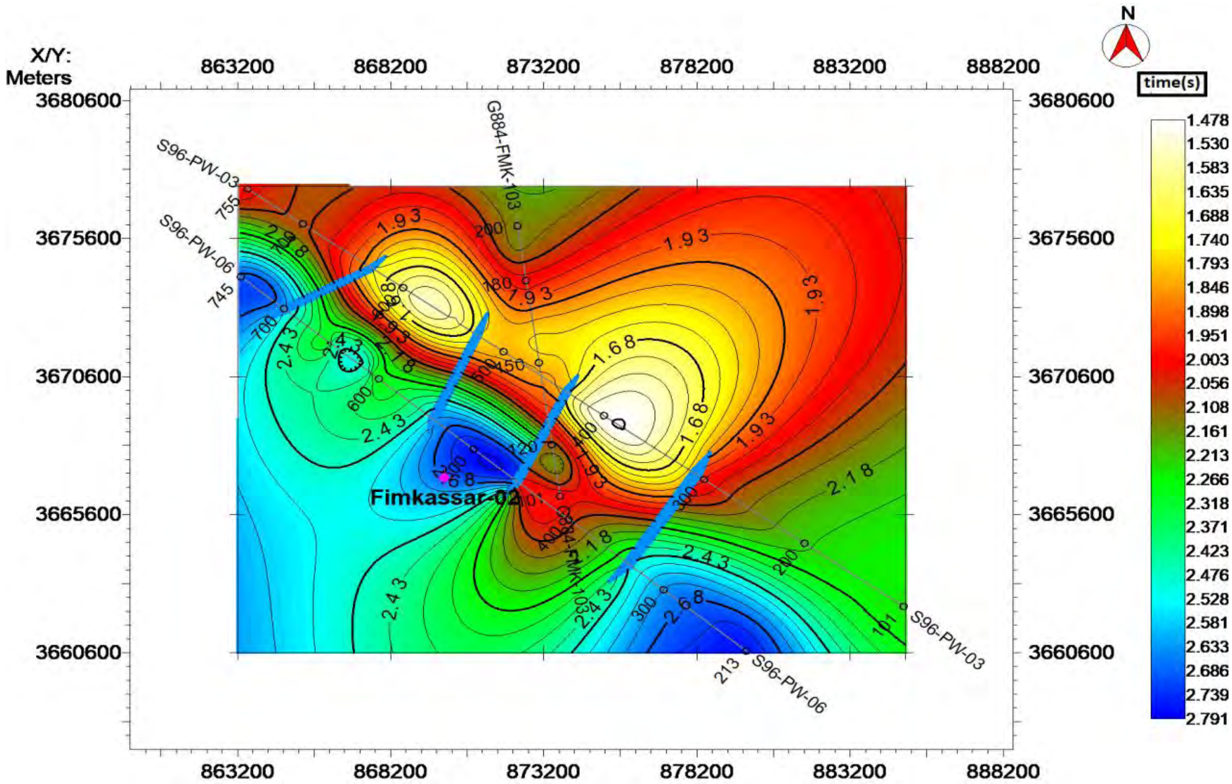

Figure 3.12 Time contours map of Sakesar Formation

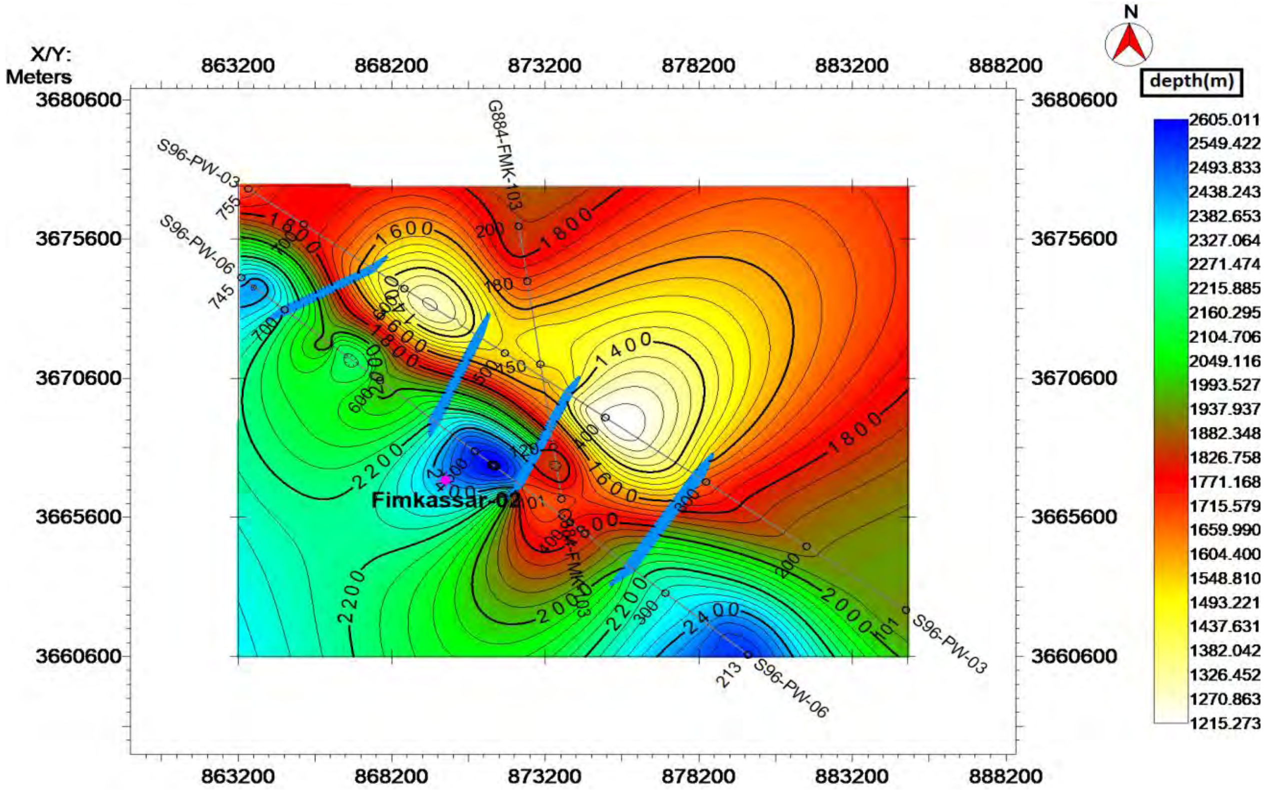

Figure 3.13 Depth contours map of Sakesar Formation

3.12 Time and depth contour maps of Patala Formation

Patala Formation acts both reservoir as well as source rock. The time and depth contour maps of Patala Formation is shown in figure (3.14) and figure (3.15). Blue colour shows the shallowest part or elevated part in our zone.

The TWT contour map can be interpreted from the colour bar. It is interpreted as pop-up structure because value of time is decreasing as we move outward. The depth map of Patala Formation can also interpreted by using colour bar. The depth value ranges from 1257-2720 meter. Yellow colour shows the shallowest while blue shows the deepest regions. The time ranges from 1.5-2.8 seconds.

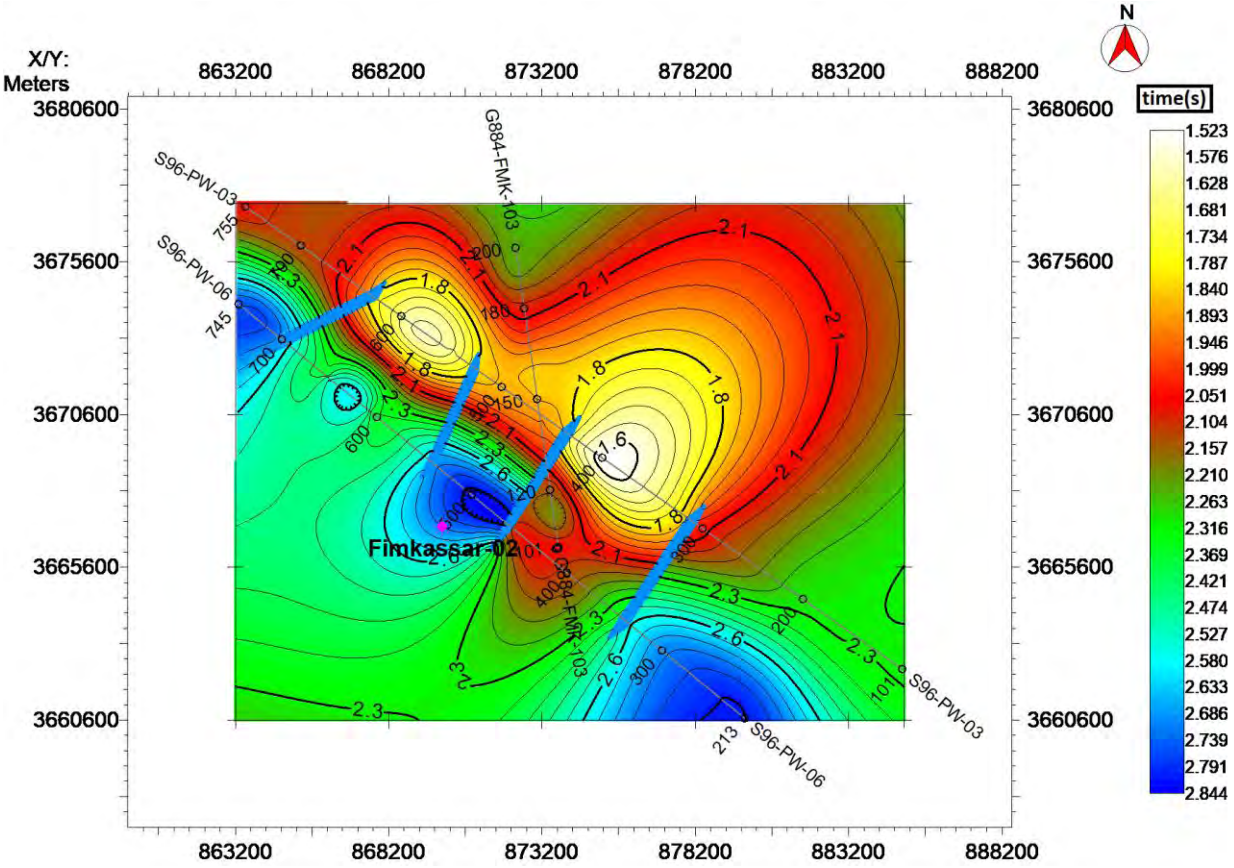

Figure 3.14 Patala Formation Time contours map

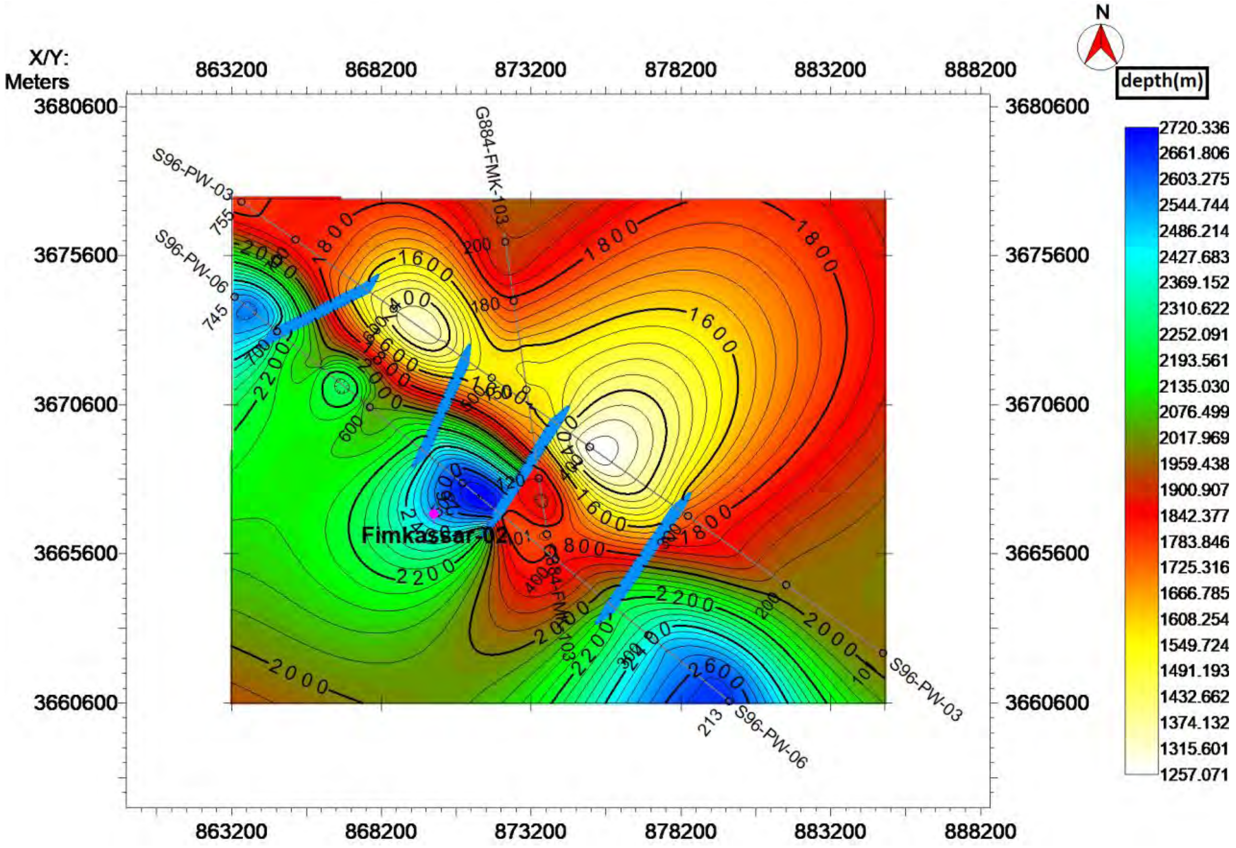

Figure3.15 Patala Formation depth contours map

3.13 Results

The seismic section shows the displaced popup anticlinal structure where the marked reflectors are named on the basis of well formation tops. The time and depth contour maps of Patala and Sakesar helps us to confirm the presence of anticlinal structure in the Fimkassar Area. Anticlinal structure acts as a trap in the area which is best for hydrocarbon accumulation.

Chapater04

Petrophysical Analysis

4.1 Introduction

This study facilitates in identification and quantification of fluid in a reservoir (Ali et al., 2014). Knowledge of reservoir physical properties like volume of shale, porosity, and water and hydrocarbon saturation is needed to define accurately probable zones of hydrocarbon. Petrophysics is apprehensive with using well measurements to subsidize reservoir depiction. . To accurately characterize oil or gas in a reservoir, measurements such as resistivity, porosity and density are made, from which volume of shale, average porosity water saturation and hydrocarbon saturation can be quantified.

4.2 Petrophysical analysis

The Petrophysics analysis has been carried out in order to measure the reservoir characterization of the Fimkassar area using the borehole data of Fimkassar-02. We used the log curves including spontaneous potential log (SP), Gamma Ray (GR), Sonic log (DT), Latero log deep (LLD), Latero log shallow (LLS), Neutron log, density log, Photo electric effect log (PEF).For Petrophysics analysis the following parameters are calculated for reservoir rock.

1. Volume of shale (by Gamma Ray log)

2. Porosity of reservoir (by SONIC, DENSITY and NEUTRON logs)

3. Water saturation (by LLD, LLS and SP logs)

4. Hydrocarbon Saturation

5. Permeability of reservoir rock (Ross Willey equation)

4.3 Estimation of volume of shale

The volume of shale can be estimated from the response of Gamma ray log. The response of Gamma ray must be known through different lithologies. The gamma ray log is the passive logging because we measure the Formation properties without using any source. Actually it is the measures the Formation‘s radioactivity. The gamma ray emits from the Formation in the form of the Formation in the form of the electromagnetic energy which are called the photon. When photon collides with the Formation electron hence they transfer the energy to the

Formation electron so the phenomenon of the Compton scattering occurs. Now these emitted Gamma rays reached to the detector of the gamma ray and counted and displayed as count per second which is termed as the Gamma ray. The volume of the shale is calculated by using (Asquith and Gibson, 2004) equation given below.

$$\mathbf{IGR}= \frac{\mathbf{GR_{log}-GR_{max}}}{\mathbf{GR_{max}-GR_{min}}} \qquad \mathbf{(4.1)}$$

where,
GR (max) = 100% shale.

GR (min) = 0% shale or clean Formation.

The Gamma ray log shows maximum value when shale is encountered and shows a minimum value when clean lithology like sand is encountered. These values are calculated from given log response and then volume of shale is estimated by using (Asquith and Gibson, 2004) equation. The volume of shale calculated in Fimkassar-02 is 35%.

4.4 Estimation of porosity

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.

4.4.1 Calculation of porosity from sonic log

Sonic log device consists of a transmitter that emit sound waves and a receiver that picks and record the compressional waves as it reach the receiver. This log is a recording verses depth of time (t) which is required by a compressional wave to go across 1 feet of Formation, called interval transient time Δt, while it is the reciprocal of the velocity of sound wave. This time (Δt) is depended upon lithology and porosity of the Formation (Asquith and Gibson, 2004). Sonic log can also be used for the following purposes in combination of other logs.

Sonic log is also used in with combination with other logs to achieve our desired goals. The various combinations are given below.

1. Lithology identification (with neutron or density).
2. Synthetic seismogram (with density).
3. Mechanical properties of Formation (with density).

The mathematical relation used for calculating the porosity from sonic log is written below.

$$\boldsymbol{\varphi}\mathbf{s} = \frac{\mathbf{\Delta t_{log}-\Delta t_{mat}}}{\mathbf{\Delta t_{fl}-\Delta t_{mat}}} \qquad \mathbf{(4.2)}$$

The interval transient time of Formation increased due to presence of hydrocarbon known as hydrocarbon effect. This effect should be removed because it affects the values of calculated porosities.

4.4.2 Calculation of porosity from density log

In the density logging gamma ray collide with the electron in the Formation and scattered gamma ray (Compton scattering) received on the detector which indicate the density of the Formation increase in the bulk density of the Formation causing the decrease in the count rate and vice versa. Bulk density which is obtained from the density log is considered the sum of the density of the fluid density and the matrix density of the Formation.

If rock type is known then porosity is calculated by using (Asquith and Gibson, 2004) equation. The rock lithology is known by using gamma ray log in this case it is limestone. The following relation is used for calculating porosity.

$$\boldsymbol{\varphi_d = \frac{\rho_m - \rho_b}{\rho_m - \rho_f}} \qquad \mathbf{(4.3)}$$

where,

φ_d=Density Log porosity

ρ_m= Density of matrix (limestone= 2.7)

ρ_b= Bulk density of formation

ρ_f= Density of fluid (salt mud = 1.1, Fresh mud = 1)

4.4.3 Calculation of porosity from neutron log

This is the type of porosity log which measure concentration of Hydrogen ions in the Formation. Neutron is continuously emitted from chemical source in the tool of the neutron logging. When these neutron collide with nuclei in the Formation and results in loss of some energy. Hydrogen atom has same mass as that of neutron, maximum loss of energy occurs when electron collides with hydrogen atoms.

Hydrogen is an indication of the presence of the fluid in the Formation pores; hence loss of energy is related to the porosity of the Formation.

The neutron porosity is very low when the pores in the Formation are filled with the gas instead of the water and oil; the reason is that gas having les concentration of the hydrogen as compared to water and oil. This less porosity by the neutron PHI due to the presence of the gas called the gas effect (Asquith and Gibson, 2004).

4.4.4 Total porosity

The total porosity is the sum of all the porosities calculated from different logs divided by the number of logs used for calculating porosities. The total porosity is calculated for the reservoir which is Chorgali in this case. The mathematical relation is used for this purpose is given below.

$$\varphi_T = \frac{\varphi_d+\varphi_n+\varphi_s}{3} \tag{4.4}$$

where,

φ_T= Average porosity

4.5 Estimation of true resistivity

Basically there are different types of electrical Resistivity Logs. But in my work I have only two logs available in my data which are simply explained as follow. These logs are used to measure the resistivity of the subsurface, but actually they measure the resistivity of the Formation fluids. They are very helpful in order to differentiate between water filled Formation and the hydrocarbon filled Formations. Resistivity logs include the following.

1. Laterolog Deep (LLD).
2. Laterolog shallow (LLS).

4.5.1 Laterolog Deep (LLD)

Latero log deep is used for the deep investigation of the quietly undisturbed (Uninvaded zone) and it is called Laterolog 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 has deep penetration as compared to the (LLS).

4.5.2 Laterolog Shallow (LLS)

Laterolog shallow (LLS), used for shallow investigation of the transition zone / invaded zone. The depth of the investigation is smaller than the LLD. These logs are used to calculate the true resistivity.

4.6 Estimation of water saturation

Water saturation is the percentage of pore volume in rock that is occupied by water of Formation. To determine the water and hydrocarbon saturation is one of the basic goals of well logging. To calculate saturation of water in the Formation, a mathematical equation was developed by Archie shown below. All the parameters of Archie equation can be calculated from resistivity and spontaneous potential logs.

$$S_w = \sqrt[n]{\frac{R_w * F}{R_t}} \tag{4.5}$$

where,

R_w = Resistivity of water

R_t = True resistivity

F= Formation factor ($F = (\frac{a}{\phi m})$)

n = Saturation exponent (value varies between 1.8 to 2.5)

ϕ = Effective porosity

m = Cementation factor constant = 2

a = 1

4.7 Estimation of hydrocarbon saturation

The fraction of pore spaces containing hydrocarbons is known as hydrocarbon saturation. The simple relation used for this purpose is given below.

$$S_w + S_H = 1 \tag{4.6}$$

The saturation of hydrocarbons is percentage of pore volume occupied by hydrocarbon.

where,

S_H = Hydrocarbon saturation and

S_w = Water saturation

4.8 Well log interpretation of Fimakassar-02

The interpretation of Fimkassor-02 is shown in Figure 4.1. The Sakesar Formation is encountered at the depth ranges from (2946m-3067m). The Sakesar Formation is confirmed as a reservoir by different results obtained from well log. The Sakesar Formation is encountered at ideal depth which is required for hydrocarbon accumulation. The other logs like Gamma ray log shows low value of Gamma ray readings and resistivity logs shows high values. The volume of shale is far less than 50%. The neutron log shows good porosity values and density and sonic logs shows low values as well. These results are satisfactory thus we can interpret that Sakesar act as a reservoir.

4.9 Sakesar Formation (Fimkassar-02) results based on well logging interpretation:

Average volume of shale = 35%.

Total porosity = 10%.

Average water saturation = 41%.

Average hydrocarbon saturation = 59%

4.10 Results

The presence of possible hydrocarbon-bearing zones at Sakesar level has been identified by Petrophysical analysis of well logs from the well Fimkassar-02 (Figure. 4.1). The results show that the extension of probable hydrocarbon zone exists at the depth range of 2,946–2,991m within the Sakesar limestone.

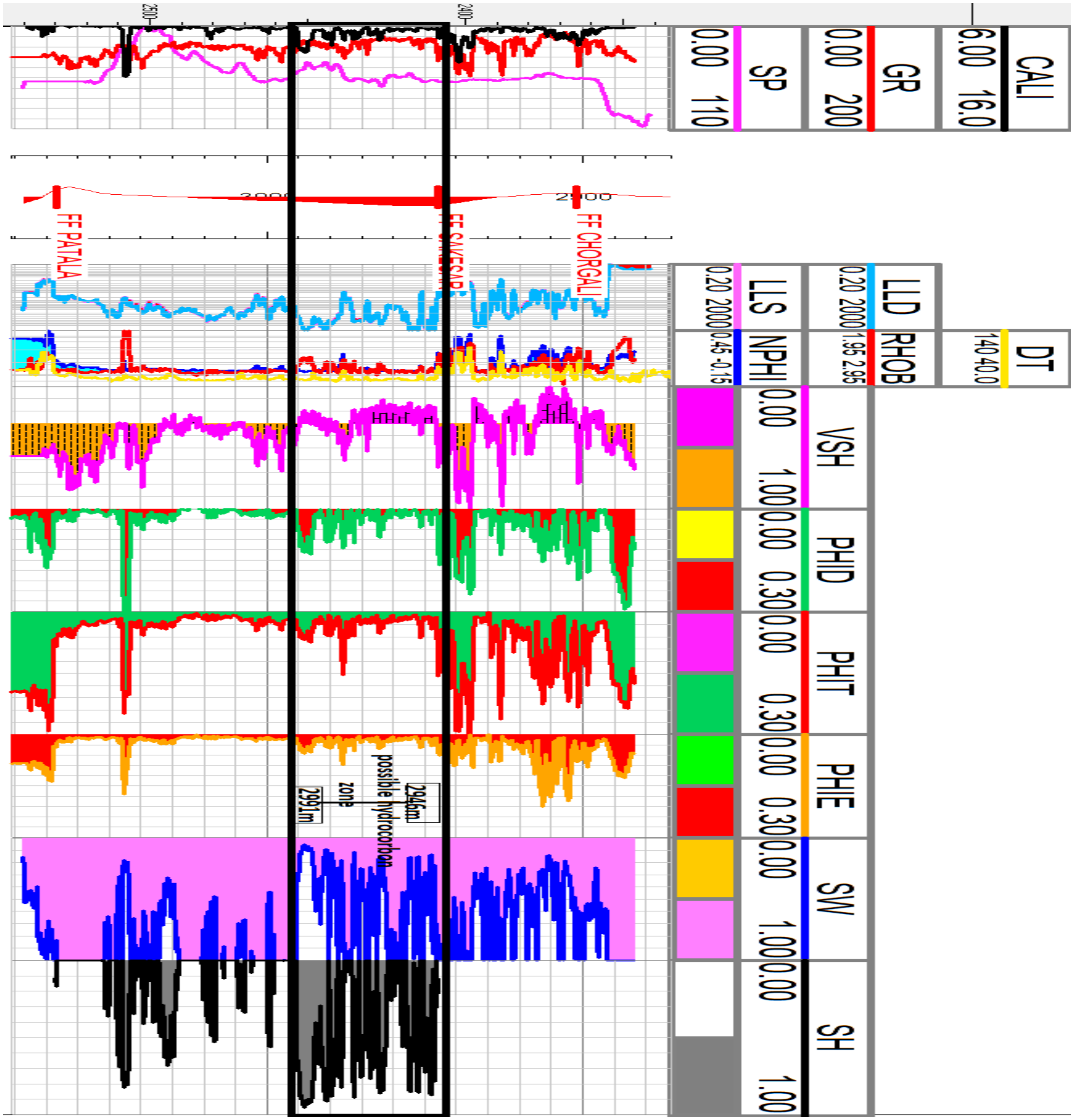

Figure 4.1 Well log interpretation of Fimakassar-02 the highlighted portion shows possible potential zone.

Chapter 05

Coloured Inversion of Post Stack Data

5.1 Wavelet and acoustic impedance

For many seismic processing applications, it becomes necessary to derive an estimate of the seismic wavelet. Because the character of wavelet is imprinted on seismic traces, it is important to understand its shape in order to decipher the properties of earth's interior from seismic traces. In spite of the fact the wavelet is time varying and is expected to be spatially varying, an overall knowledge of wavelet is crucial to enhancing resolution for better imaging of structure and predicting lithology and fluid content. The most common practice is to invert post-stack seismic data for wavelets. A post-stack trace emulates a zero-offset or normal-incidence seismogram, which can be simulated using convolution model assuming 1D earth model. Most seismic data contain noise this problem must be compensated.

In frequency domain, the convolution operation is replaced by a multiplication. Three inverse problems are identified.

1. Estimation of the wavelet when the reflection co-efficient is known.
2. Estimation of reflection co-efficient or acoustic impedances when the wavelet is known.
3. Simultaneous inversion for acoustic impedance of wavelet.

Inversion of seismic data to Acoustic Impedance is usually seen as a specialist activity, so despite the publicized benefits, inverted data are only used in a minority of cases. To help overcome this obstacle we aimed to develop a new algorithm which would not necessarily be best in class, but would be quick and easy to use and increase the use of inversion products with in BPA. This new technique, Colored Inversion', performs significantly better than traditional fast-track routes such as recursive inversion, and benchmarks well against unconstrained sparse-spike inversion.

Once the Colored Inversion operator has been derived it can be simply applied to the data on the interpretation workstation as a user-defined filter'. In this way inversion can be achieved within hours since the volume data do not have to be exported to another package, and no explicit wavelet is required. The inversion is understood simply by the flow chart of Figure 5.1.

5.2 Methodology

The well data and information of logs is required for the performing the colored inversion in Kingdom Software.

1. The velocity is obtained from sonic log and density is obtained from density log and values of densities are obtained from density log by convolving these values.

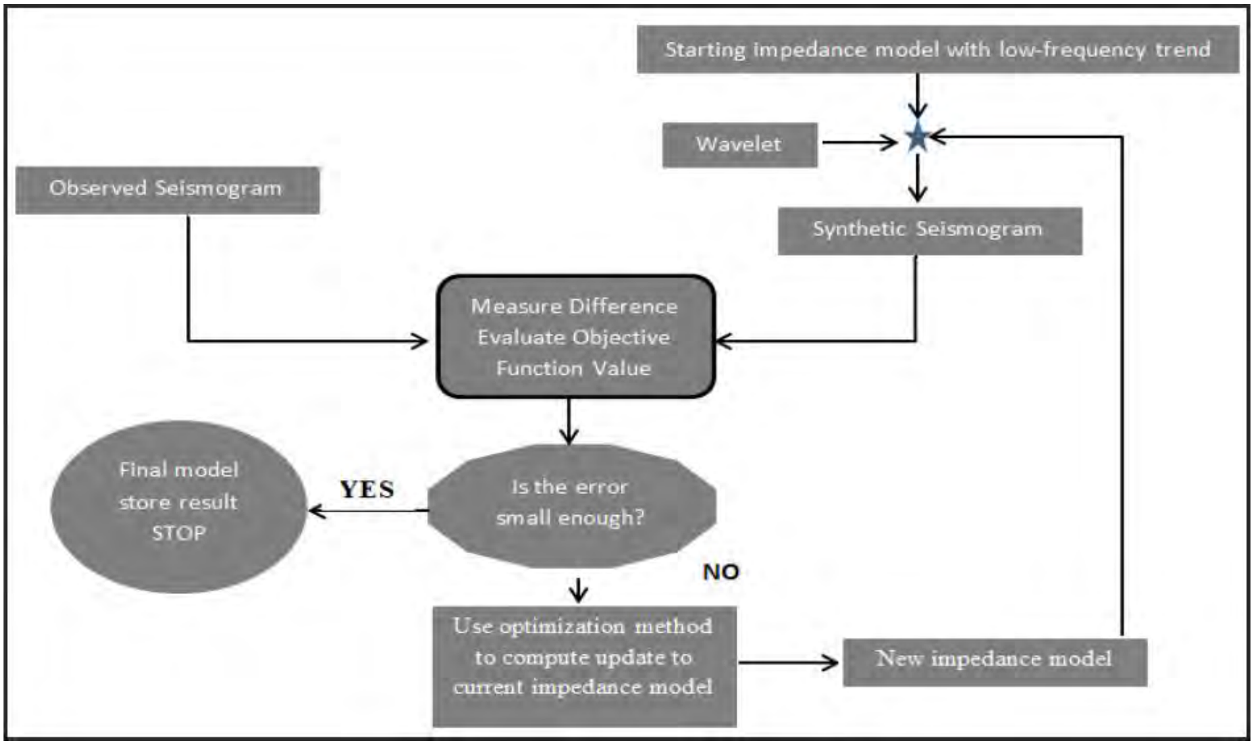

Figure 5.1 Flow chart showing impedance and wavelet extraction scheme (Badar Ali, 2017).

3. We get acoustic impedance by cross-matching these impedance data with the input reflection data.
4. We derive a single optimal matching filter Figure 5.8. Convolving this filter with the input data we see in Figure 5.7 that the result is very much similar, everywhere.
5. This Empirical observation indicates that inversion can be approximated with a simple filter and that it may be valid over a sizeable region.

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

Empirical observation shows that earth reflection coefficient series have spectra that exhibit a similar trend that can be simply described as constant function. The term is a positive constant and is frequency arrives at a similar observation theoretically may vary from one field to another but tends to remain reasonably constant with in any one field.

It therefore follows that if our seismic data are inverted correctly they too should show the same spectral trend as logs in the same area.

5.3 Non uniqueness and convolution

The process of convolution for constructing a seismogram using a wavelet and acoustic impedance is performed to generate an operator. Note that wavelet is smoothly varying function, while the reflectivity is a series of delta functions placed at two-way normal time of each reflector (Cooke and Schneider 1983). We observe that wavelet is a band-limited, while reflectivity series is a broad-band. Because the convolution is equivalent to multiplication in frequency domain the spectrum of resulting seismogram is band-limited as well. We can imagine the complexity of the problem further we can take into account the loss of high frequencies of wavelet caused by attenuation. In other words series cannot be assumed to be stationary. Even under stationary conditions the data does not contain all the frequencies. The most common approach to deriving the wavelet is based on well-log data that produce a true reflectivity series.

5.4 Wavelet extraction

The wavelet is shown in Figure 5.2 is extracted on the basis of the well log data that provides the true reflectivity series (i.e. compressional wave velocity and density computed into acoustic impedance logs, which are mapped into normal incidence reflectivity series). An initial guess of wavelet is convolved with reflectivity series and synthetic normal incidence trace is generated. The difference between the observed and synthetic traced is minimized using a suitable chosen norm with smoothness constraints (Mrinal K. Sen).

5.5 Impedance estimation

Now our approach is to convolve this wavelet with acoustic impedance (reflectivity series). The acoustic impedance is also computed from well log data as described previously. The impedance spectrum is shown in Figure 5.3 is estimated after removing source wavelet; noise must be absent; all multiple reflections must be removed; spherical spreading including all plane reflections (Ghosh 2000)

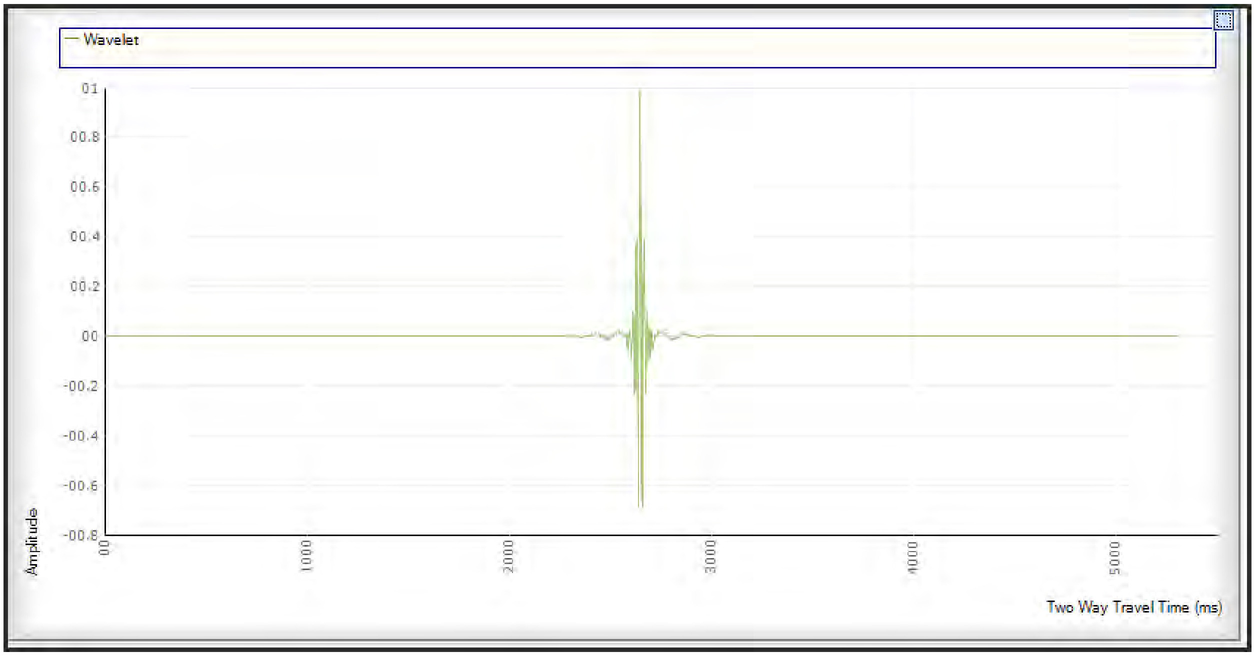

Figure 5.2 Extracted Wavelet

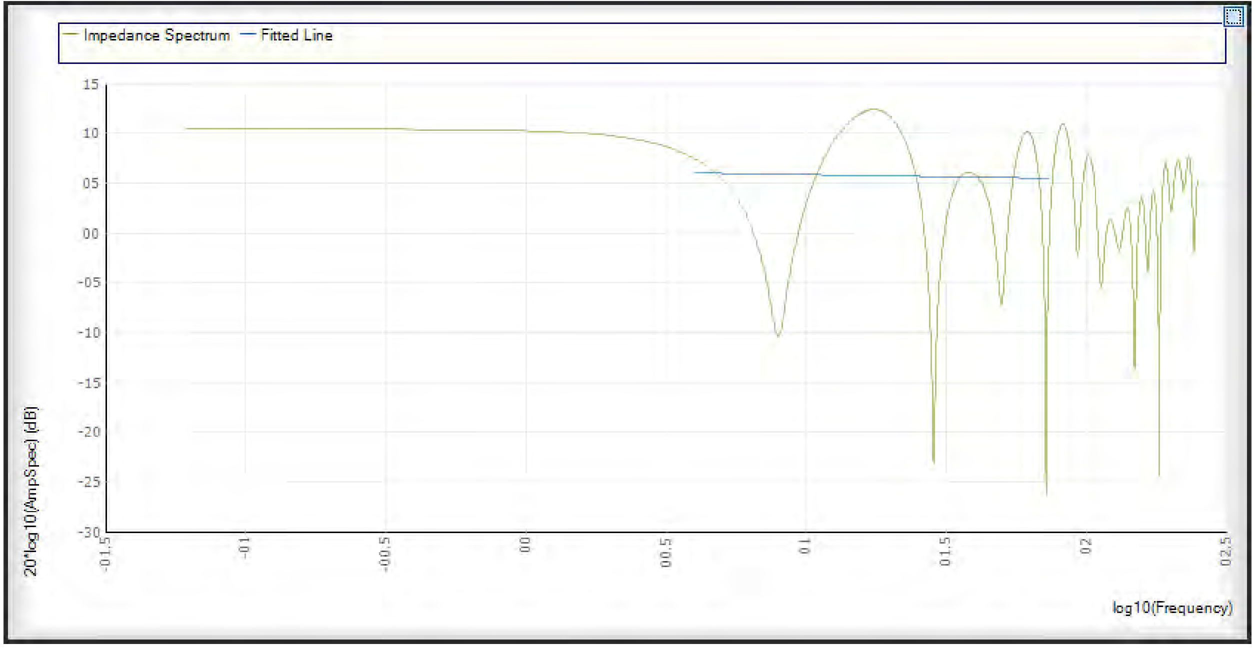

Figure 5.3 Impedance spectrum with fitted line.

5.6 Butterworth filter

The Butterworth filter is a type of signal processing filter designed to have as flat frequency response as possible in the pass band. It is also referred to as a maximally flat magnitude filter. It was first described in 1930 by the British engineer and physicist Stephen Butterworth in his paper entitled "On the Theory of Filter Amplifiers. An ideal electrical filter should not only completely reject the unwanted frequencies but should also have uniform sensitivity for the wanted frequencies. This filter is used here for convolution of the wavelet and reflectivity series for formulation of seismogram. The Butterworth filter is shown in Figure 5.4.

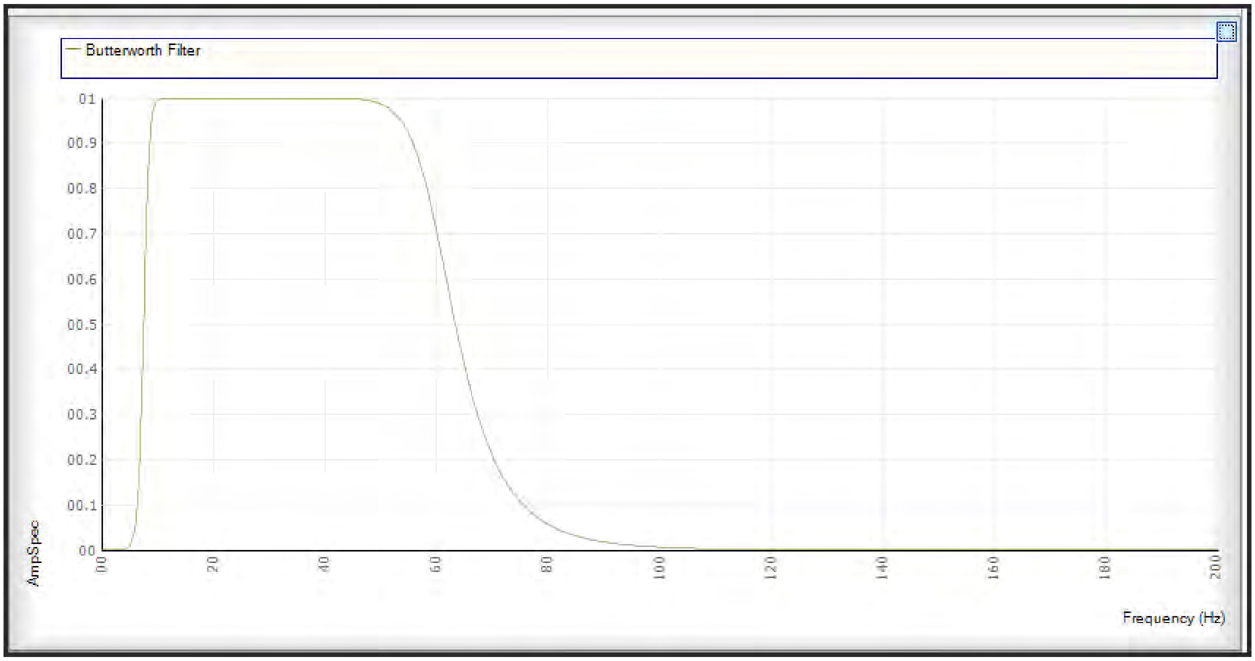

Figure 5.4 Butterworth filter.

After the process of convolution is performed we get the seismogram (operator). There is a vast difference between the seismogram of our desire and the seismogram we obtained from the convolution.

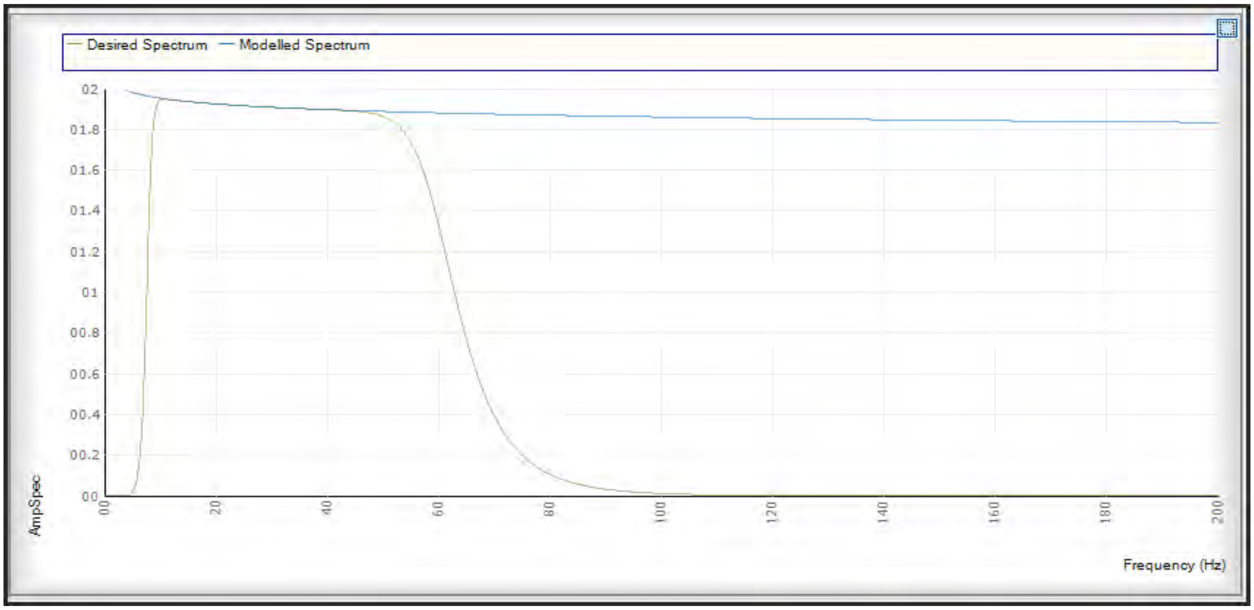

Figure 5.5 Desired and modelled spectrum.

There are two spectrums shown in Figure 5.5 both are of different colours. The blue colour shows the spectrum obtained from convolution of wavelet and acoustic impedance and the spectrum in blue colour shows a desired spectrum. Now we need to obtain a spectrum of our desire for this purpose we have to convolve this spectrum with another spectrum known as shaping spectrum which is obtained by applying Fourier transformation on desired spectrum. The shaping spectrum is shown in Figure 5.6.

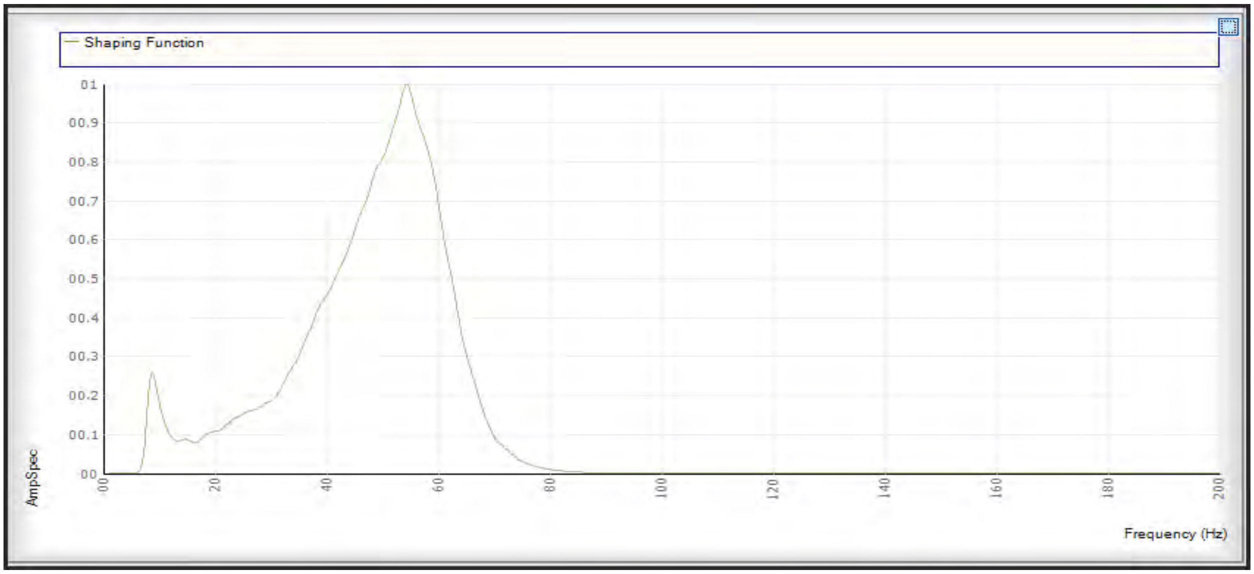

Figure 5.6 Shaping spectrum**.**

A seismogram for specific window (as values of acoustic impedance is obtained from well data) is developed now we develop a seismogram to invert whole section. For this purpose we convolve desired spectrum with seismic mean spectrum. After convolving seismogram with seismic mean spectrum we are able to apply it on whole seismic section. The Figure 5.8 shows seismic mean spectrum and desired spectrum.

After completion of the process of generating synthetic seismogram, the section is inverted an acoustic impedance is shown on section instead of amplitude as shown in Figure 5.9.

This window displays sonic log and density logs. These logs are used to compute the acoustic impedance. If values of density log are missing then Gardner equation is used to estimate these densities. This equation is very popular in petroleum exploration because it can provide information about the lithology from interval velocities obtained from data these values are calibrated from Sonic and density well log information but in the absence of these, Gardner's constants are a good approximation for density.

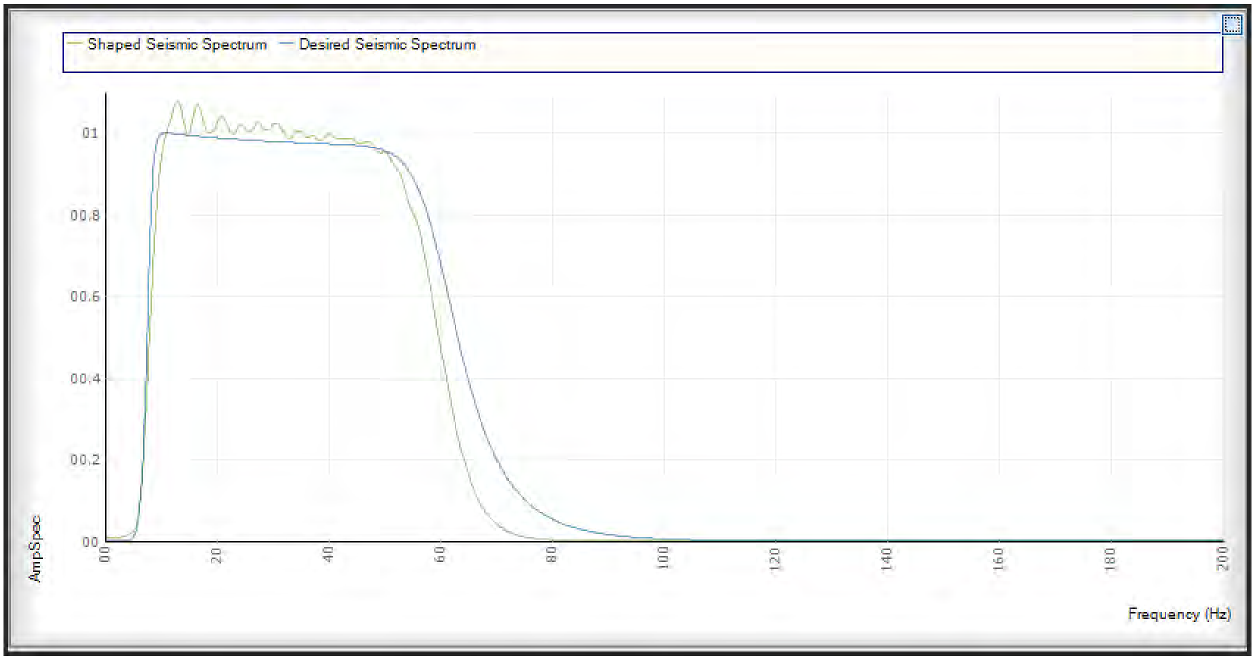

Figure 5.7 Convolution of shaped seismic spectrum and desired spectrum.

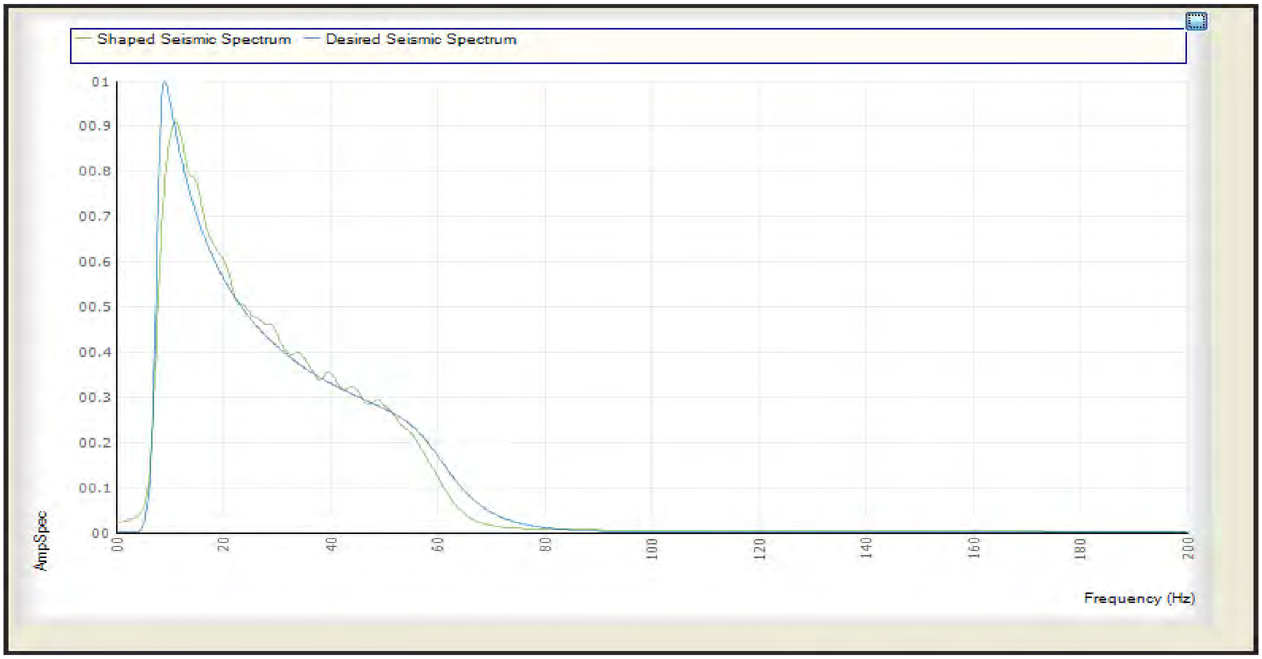

Figure 5.8 Convolution of shaped seismic spectrum and desired spectrum.

At the right corner of the window input seismic section is shown on left side and inverted section is shown on the right hand side. The inverted section is shown on the both sides of logs sides of the well the log is inverted to invert the seismic section.

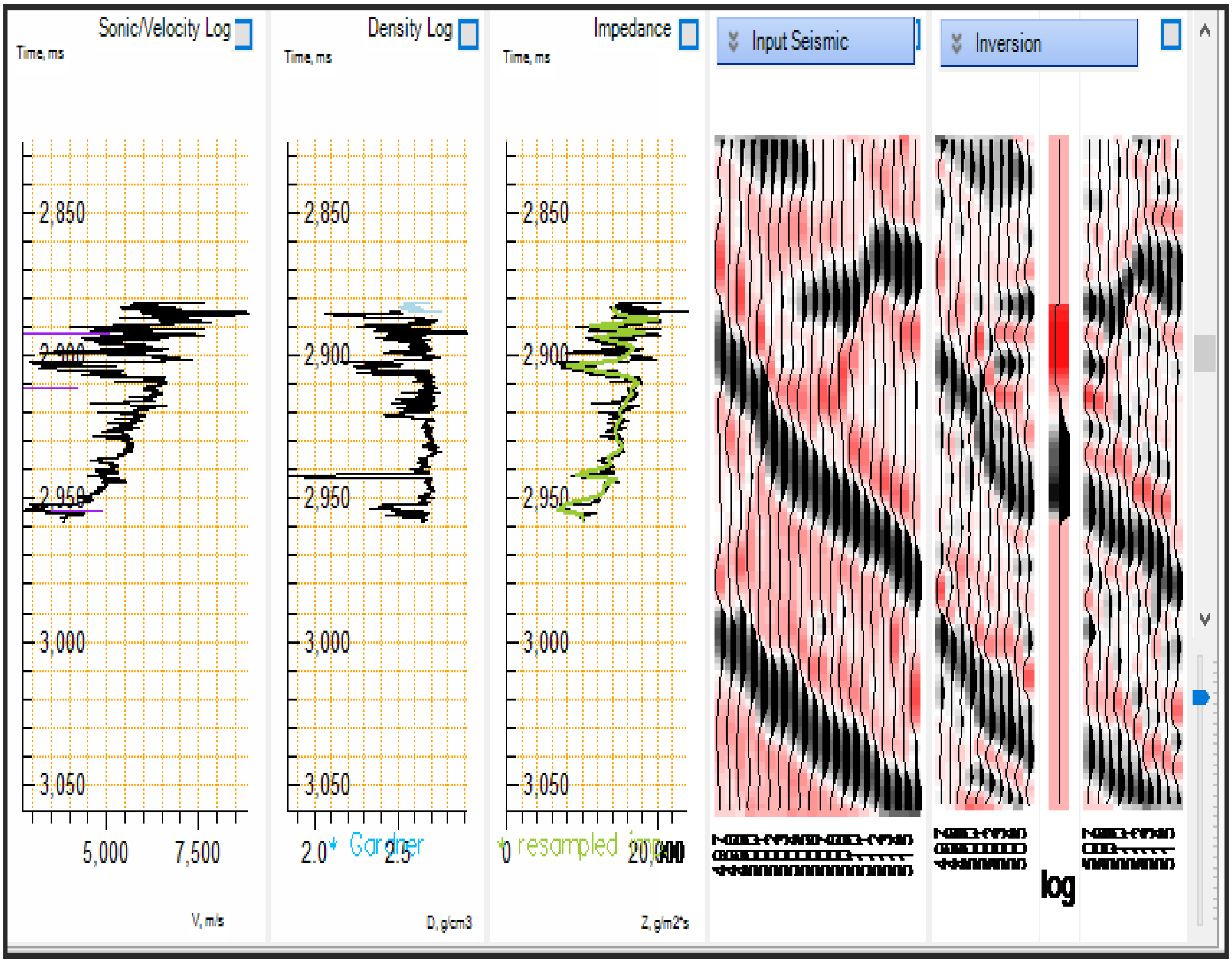

Figure 5.9 Input seismic section and inverted section along with logs.

Now inversion is applied to the whole section.

5.7 Interpretation of inverted section

After convolution of seismogram with mean spectrum an inverted seismic section is generated as shown in above Figure 5.10. The inverted section can be interpreted by using colour bar. The white to yellow colour shows high values of acoustic impedance and blue to green colour shows low impedance.

The hydrocarbons accumulation is associated with low acoustic impedance. The given inverted section is shown with T-D chart and it shows Formations as well. The Formation circled in Figure 5.10 is Chorgali and Sakesar it yields a response of low acoustic impedance it is related to presence of hydrocarbon accumulation it is also confirmed from petrophysical results

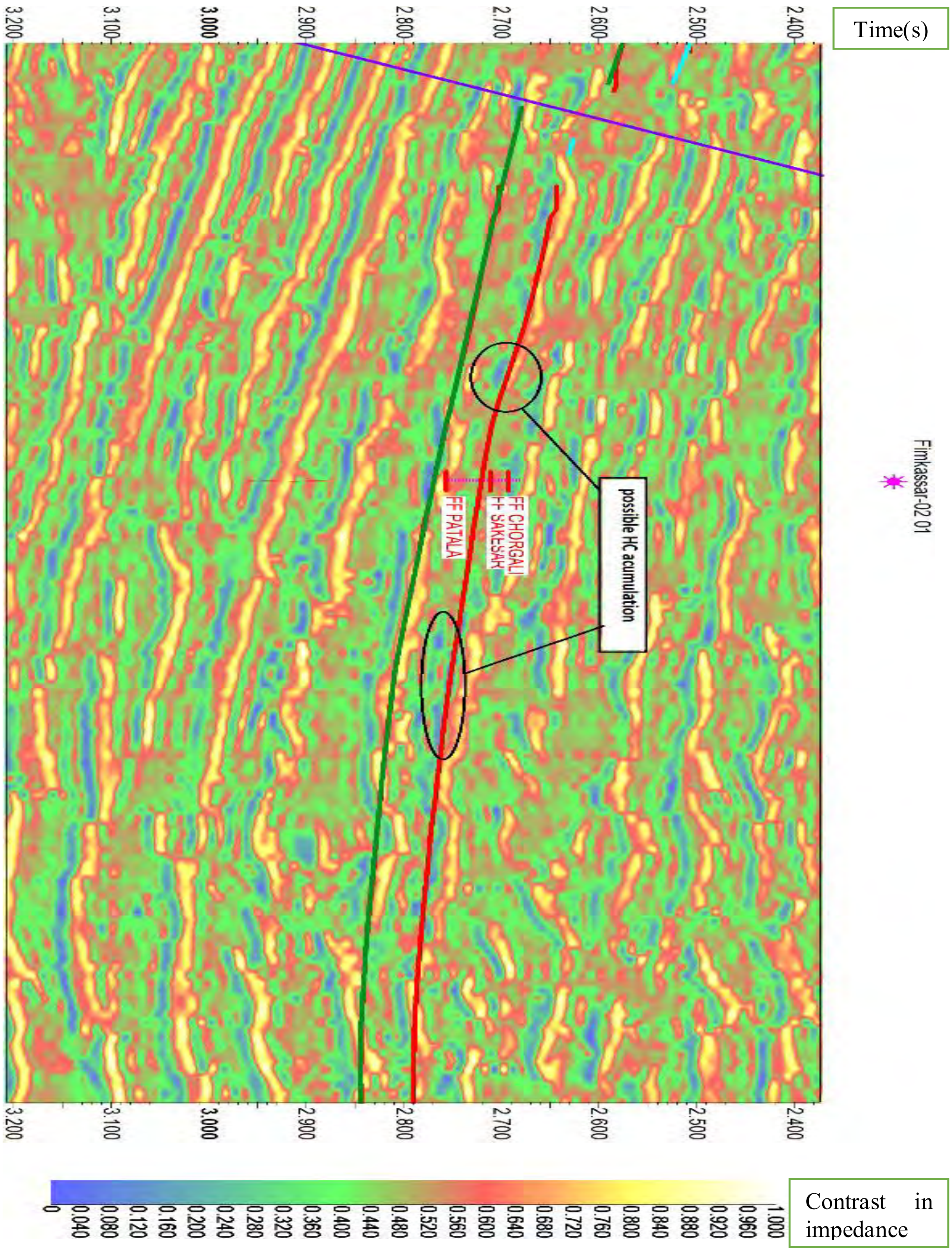

Figure 5.10 Zoomed view of inverted section.

Discussion and conclusions

Seismic interpretation of Fimkassar area gives us following results. Synthetic seismogram is generated using well logs and seismic data. Based on which two horizons are marked namely Patala and Sakesar along with six faults marked on seismic section. Overall interpretation of seismic lines shows pop-anticlinal structure.

- Time and depth contour maps are generated which delineates the results of structural interpretation.
- Seismic attribute analysis is carried out in order to confirm the results of seismic interpretation. Trace envelop, average and instantaneous phases seismic attributes were applied to aid the interpretation results and faults marking of prominent horizons.
- Petro-physical analysis of well FIMKASAR-02 for Sakesar Formation is carried out in order to depict the promising and overall Sakesar has good reserves. The average volume of shale found to be 35%, total porosity of 10%, average water saturation of 41%, average hydrocarbon saturation of 59%.
- Colored inversion is done in order to develop the relationship between seismic data and well logs, to improve resolution and to calculate accurately rock properties. Very clear low impedance map has been achieved by inversion which proved presence of hydrocarbons in marked horizons.

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