STRUCTURAL SEISMIC INTERPRETATION INTEGRATED WITH PETROPHYSICS AND COLORED INVERSION FOR MEYAL AREA, UPPER INDUS BASIN, PAKISTAN

By

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(2016-2020)

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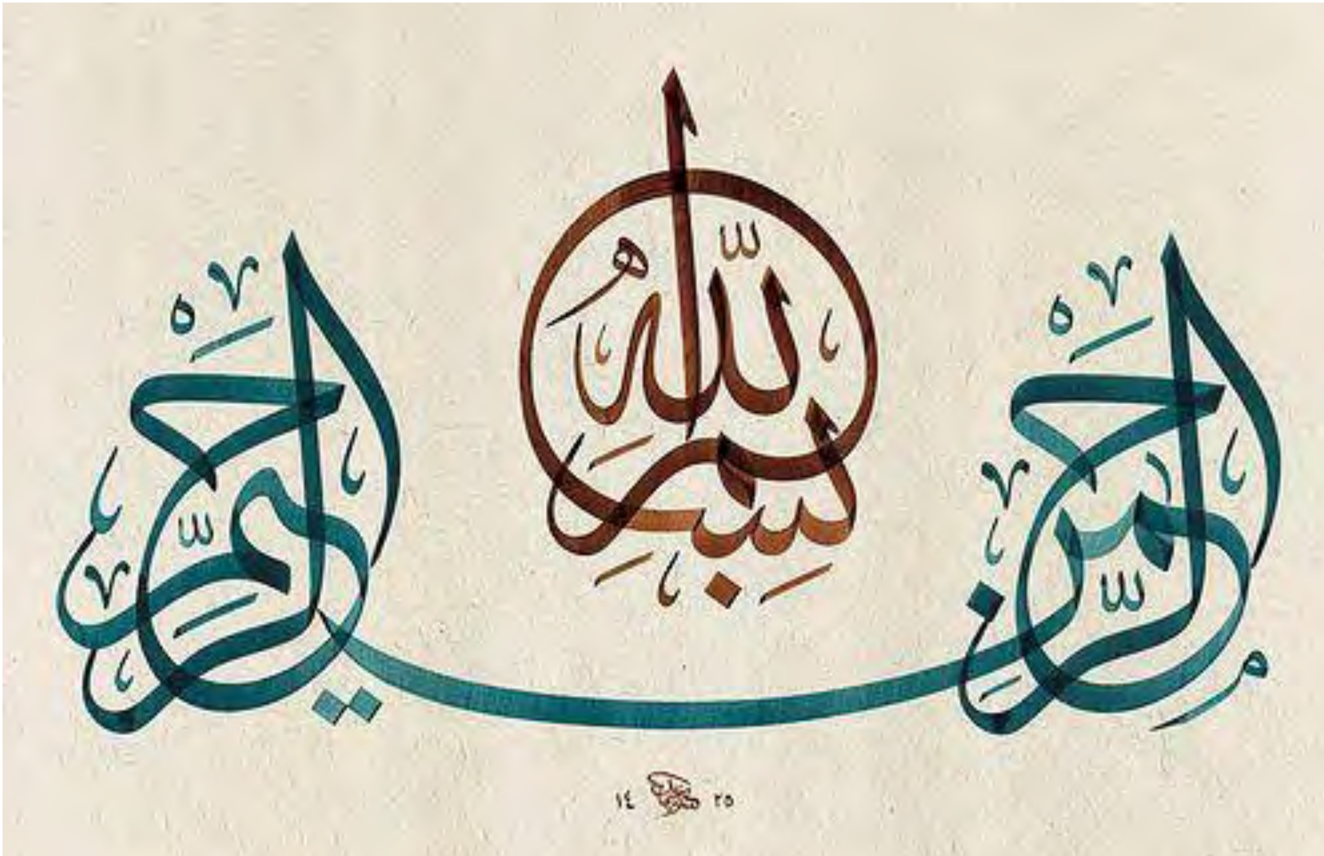
بسم الله الرحمن الرحيم


اللهم صل على محمد وآل محمد

ACKNOWLEDGEMENT

In the name of **ALLAH**, The Most Gracious and the Most Merciful, Beneficent Alhamdulillah. I bear witness that Holy Prophet **Muhammad (PBUH)** is the last messenger, whose life is perfect model for the whole humankind till the Day of Judgment. I am very thankful to ALLAH for the strengths and blessings.

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ABSTRACT

This study aims for the interpretation of seismic lines, wire line logs and colored inversion for better visualization of promising zones of hydrocarbon of Meyal Area. The study area lies in Upper Indus Basin of Pakistan. The area is a part of Potwar sub-basin which is known for its hydrocarbon structural traps due to tectonic activity. Datta and Patala Formations act as source rocks, Chorgali and Sakesar Formation are the two main reservoir rocks whereas Kuldana and Murree Formations act as seal/cap rocks.

Seismic data for this study consists of four seismic lines; three dip lines and one strike line. Overall interpretation of seismic lines shows pop-structure and proved presence of structural trap in area. Trace envelop, average and instantaneous phases seismic attributes are applied to aid the interpretation results and faults marking of prominent horizons.

Facies analysis of Well Meyal-9P is carried out. Petro-physical analysis of well Meyal-9P for Chorgali and Sakesar Formations in order to depict the favorable zones for hydrocarbon accumulation and their reservoir characteristics, Chorgali and Sakesar formation have 92.58% and 83.50% hydrocarbons saturation respectively. Colored Inversion is used for developing the relationship between seismic data and well logs, to improve resolution and to calculate accurately rock properties. Inversion result shows low acoustic impedance which proved presence of hydrocarbons in marked horizons.

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CHAPTER 01

INTRODUCTION

1.1 Introduction to Hydrocarbon Exploration

The search for hydrocarbon exploration in Pakistan was started in 1868, when the first drilling was made at Kundal near Mianwali, that is sustain till present. The first merchandising was achieved in 1915, with the successful drill of Khaur-01. In Pakistan, most of the sedimentary rocks are rich in petroliferous content. For exploration purpose structural and stratigraphic traps are very important as these are places where most of the hydrocarbons accumulate. In Pakistan these structures are present in areas of intense folding and faulting i.e. Potwar area. There is likelihood of major discoveries, either in on-shore or off-shore areas, is considered quite resourceful (Shami and Baig, 2002).

1.2 Aims and objective of this study

The core purpose of my work is as follow in general:

- Structural and stratigraphic interpretation for finding hydrocarbon traps.
- To aid structural and stratigraphic traps interpretation using seismic attributes.
- To identify the leads.
- Petro-physical analysis for reservoir characteristics.
- Facies analysis to support petro-physical results.
- Post-stack inversion to confirm subtle prospect zones by generation of low impedance model.

1.3 Seismic Data

1.3.1 Availability of seismic data

Seismic data was obtained by the Department of Earth Sciences, Quaid-i-Azam University, Islamabad. This was acquired and processed by Pakistan Oil Limited (POL). This data was acquired in such a way that the trend of Dip lines is SE-NW and Strike lines are SW-NE trending. The seismic data is listed below in the Table-1 in this table following features are mentioned, name of lines, second column defines the nature of lines i.e. Dip or Strike, line orientation defines the geographic orientation of lines, in the last column wells are represented in front of lines at which they are present.

Line Name	Line Nature	Line Orientation	Well
97-MYL-02	**DIP**	**N-S**	
97-MYL-05	**DIP**	**N-S**	
97-MYL-12	**STRIE**	**E-W**	
93-MYL-04	**DIP**	**N-S**	**MEYAL-9P**

Table 1: Seismic data line used in study of Meyal area.

1.3.2 Seismic and well data format

The data formats for the dissertation constitute of:

- SEG-Y (seismic data)
- LAS (Well data)
- Navigation

Seismic data is available in format that has been defined by Society of Exploration Geophysicists (SEG) such that in SEG-Y format. LAS file, that contain all information regarding formation tops and logs etc. Navigation file that aid in exact coordinates of lines etc.

1.4 Base Map

The base map is very important as it shows the spatial position of each picket seismic section. For a geophysicist, base map shows the location of seismic lines along with their coordinates, well location and the points on which data is acquired. Simply, it shows the dip and strike lines on which seismic survey being is carried out. Figure-1.1 shows the base map of Meyal area, lines 93-MYL-04, 97-MYL-02 and 97-MYL-05 are the dip lines trending N-S while 97-MYL-12 is the strike line E-W trending. Well MEYAL-9P (green color) is represented on line 93-MYL-04. Symbol N representing the northward direction. X and Y coordinates are shown, which are in meters. To compare the size of the area scale is shown on the bottom.

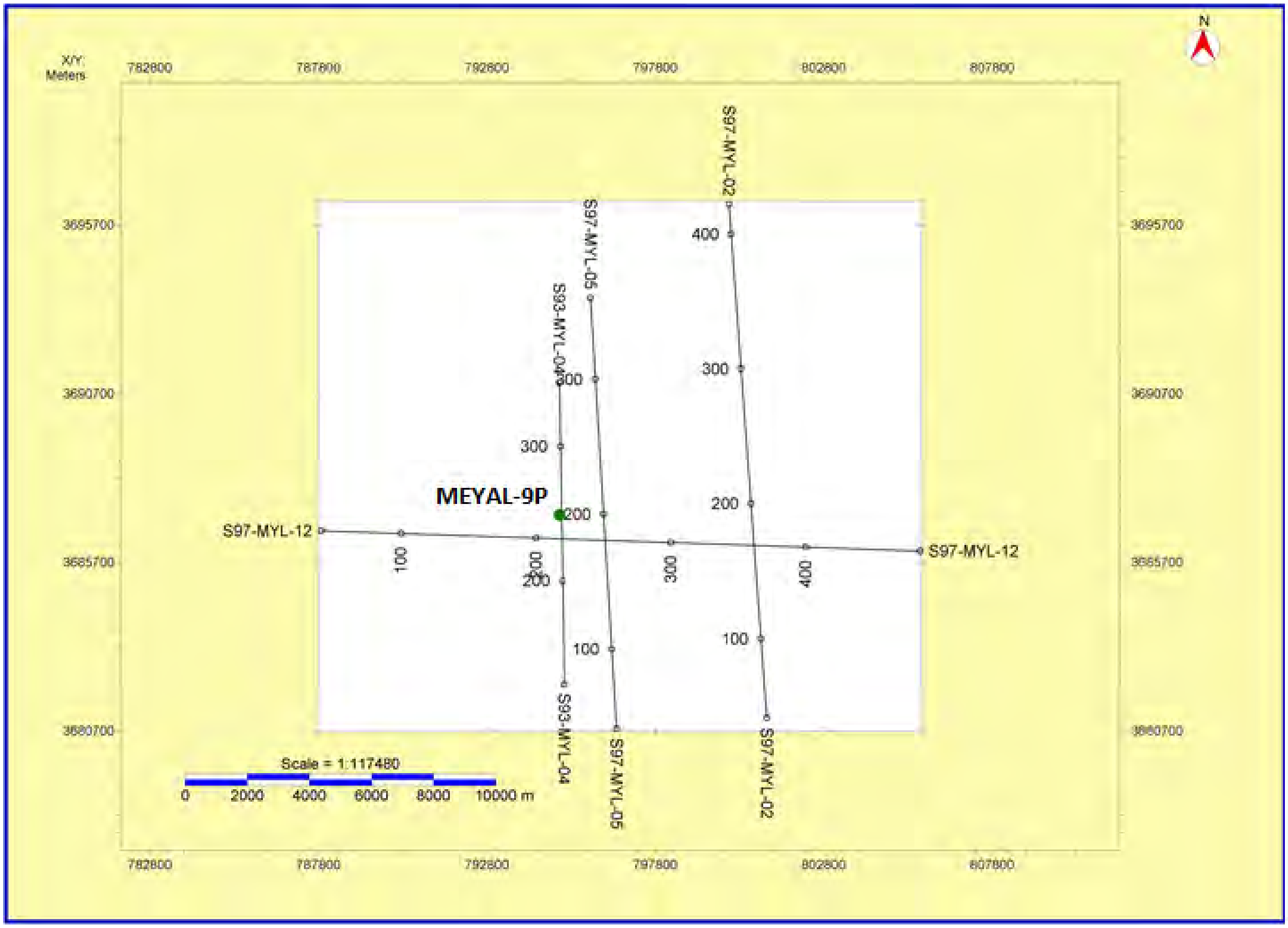

Figure 1.1 Base Map showing observed seismic lines and well location.

1.5 Information regarding study area

Meyal concession is situated in Pindi Gheb of District Attock in Punjab Province, at Latitudes 33° 20‘ 01.1” N - 33° 15‘ 36.1” N and Longitudes 72° 02‘ 53.2” E - 72° 15‘ 21.3” E. Meyal field is part of Meyal block which lies in central part of Potwar plateau of Upper Indus basin. The Indus River and the Jhelum/Soan rivers are passing on its western and eastern sides respectively. The Kalachitta-Margalla Ranges are in the north and The Salt Range is in the south. This area of the Potwar Basin has active surface and sub-surface structural features (Hasany and Saleem,.2001).

1.6 Climate of area

Climate of study and its surrounding area is semi-arid with rainfall of less than 25 centimeters per year. The higher elevations of the northern part of the area receive more than 100 centimeters of rainfall per year. Minimum and maximum mean temperatures in study area at an elevation of 510 meters are 14.8 and 28.9

degrees Celsius respectively (Nyrop et al., 1975).

1.7 Exploration history of Meyal

The Burma Oil Company was the first to acquire Meyal concession in 1916, and they drilled three wells, but unfortunately, they were all dry, till 1924. Later the area was granted to Attock Oil Company and they drilled their first well during 1942 – 44 which was abandoned due to 8 5/8" casing collapse. They drilled second well at the same site and abandoned due to the fact that the well had crossed the thrust entering downthrown block at 8000 ft. Their third well was to be abandoned at 8100 ft due to mechanical problems.

1.8 Currently producing wells

POL wells Meyal 6P, 8P, 12P, and 17 are currently producing oil and gas. Well Meyal– 6 was drilled down to 13424 ft (Jurassic sandstone), initially completed as dual producer from Paleocene and Jurassic, but production from Jurassic was ceased later in 1982 and currently producing from Paleocene. Well Meyal –12 was deepened down to 13622 ft (Triassic) and producing oil/gas from Chorgali/Sakesar. Well Meyal–08 is producing from Eocene/Jurassic. Meyal–17 was the last well drilled down to 13660 ft in Jurassic and now producing from Paleocene.

1.9 Methodology

Seismic data is loaded in software along with navigation files to plot seismic lines on base map. Las (well-logs) were updated. Well data is used to mark horizons. Discontinuities were observed within horizons that were present due to geological history. Faults were marked on given seismic lines. Fault polygons were generated and shown on base map as well to form fault boundaries. Time and depth contour maps for chorgali and Sakesar were built. Attributes are applied to aid interpretation of marked zones. Petrophysics and facies analysis is done using well data. Colored Inversion is also applied at the end. In the end all of the work is concluded and discussed.

CHAPTER 02

GEOLOGY OF THE AREA

2.1 Regional Geological Settings

Geological information of study area is important as from this we can have better understanding of phenomenon that we may encounter during subsurface exploration. The Indian Ocean and the Himalayas, both are product of the geodynamic processes of seafloor spreading, continental drift and collision of tectonics plates. A plate of the earth's crust carrying the Indo-Pakistan landmass rifted away from the super continent known as Gondwanaland followed by sea-floor spreading and the opening up of the Indian Ocean. Triggered by geodynamic forces the Indian plate traveled approximately 5000 Kilometers north and at last collided with Eurasian plate. This collision resulted in formation of the Himalayan Mountains and other surrounding mountain ranges. Pakistan possesses the northwestern boundary of the Indian lithospheric plate. Pakistan has been divided into two broad geological zones, which are as follow:

- Gondwanaland Domain.
- Tethyan Domain.

Pakistan is unique in as much as it is located at the junction of these two diverse domains. The southern part of Pakistan belongs to Gondwanaland Domain and is sustained by the Indo-Pakistan Crustal Plate. The northern most and western region of Pakistan fall in Tethyan Domain and present a complicated geology.

2.2 Tectonic Zones

Two broad geological divisions of this region the Gondwanaland and the Tethyan domains are discussed. In this scenario Pakistan is unique as it is located at the junction of these two diverse domains. The southeastern part of the Pakistan belongs to Gondwanaland domain and is sustained by the Indo-Pakistan crustal plate. The northern most and western regions Pakistan fall in Tethyan domain and present a complicated geology and complex crustal structure. Figure 2.1 showing tectonic division of study area. On the basis of plate tectonic features, geological structure, orogenic history (age and nature of deformation, magmatism and metamorphism) and lithofacies, Pakistan may be divided into the following broad tectonic zones.

- Indus Platform and fore deep.
- East Balochistan fold-and-thrust belt.

- Northwest Himalayan fold-and-thrust belt.
- Kohistan-Ladakh magmatic arc.
- Karakoram block.
- Kakar Khoarasan flysch basin and Makran accretionary zone.
- Chagai magmatic arc.
- Pakistan offshore.

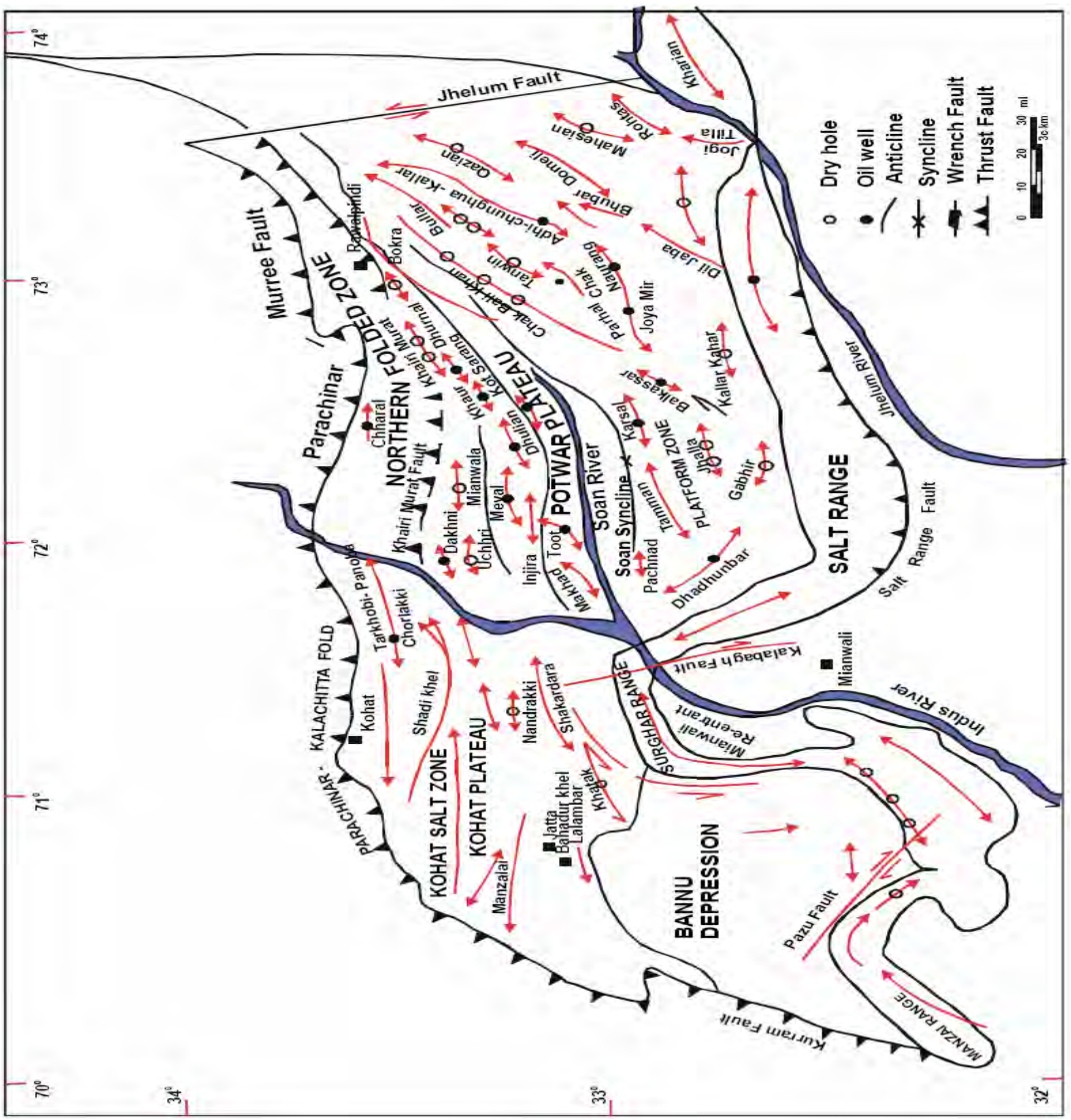

Figure 2.1: Tectonic division of our study area and surrounding such that Potwar Basin (Shami and Baig, 1998).

2.3 Sedimentary Basins:

Basin is an area characterized by regional subsidence and in which sediments are preserved for the longer periods of time. In a basin a receptacle or container, which is basin's substratum is called the Basement. The container fill or content, which is the accumulation of sediments resting on the basement, is called a Sedimentary cover. The gradual settling of the basin is called Subsidence. The point of maximum sedimentary accumulation is called the Depocenter. The Depocenter may not correspond to the zone of maximum subsidence.

Pakistan comprises of following three sedimentary basins.

- Indus Basin.
- Balochistan Basin.
- Pishin Basin.

2.4 Indus Basin

Indus Basin includes the 25000 square Km of South-East of Pakistan. It includes the Thar-Cholistan desert and Indus Plain. It has 80% of Pakistan population. Tectonically it is much stable area as compare to other tectonic zone of Pakistan. It comprises of buried ridges, platform slop, zone of up warp and dawn warp (Kazmi & Jan, 1997).

Structurally Indus Basin divided into two main parts;

- Upper Indus Basin (North).
- Lower Indus Basin (South).

Upper Indus Basin is further divided into two sub basin.

- Potwar sub-Basin.
- Kohat sub-Basin.
- Central Indus Basin (North).
- Southern Indus Basin (South).

2.5 Upper Indus Basin

It is in the northern Pakistan and separated from the lower Indus Basin by the Sargodha High. In its north MBT, while in east and west strike slip faults Jhelum and Kalabaugh is located, Upper Indus basin is subdivided into Potwar and Kohat Basins along the Indus River (Kazmi & Jan1997). Main boundary thrust runs along Kala Chitta, Kohat ranges and Margalla hills. In the Upper Indus Basin Deposition started from Pre-Cambrian. It is only on basin in Pakistan which receive the deposition from Pre-Cambrian time, these depositions are exposed in Salt Ranges.

2.6 Potwar Sub-Basin

2.6.1 Geological Boundaries

This sub-basin is located in north of Pakistan. 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. Potwar Plateau has undulating topography. It is characterized by a series of parallel ridges and valleys, generally trend in the E-W direction. Geologically, it forms part of the foreland zone of the NW Himalayan Fold-and-Thrust belt.

Structurally Potwar Basin is divided into North Potwar Deform Zone (NPDZ) in the north, Soan Syncline and Southern Potwar Deformed Zone (SPDZ) in the south. Potwar basin is covered by the molasse sediments ranging in age from Miocene to Pleistocene. Precambrian to Quanternary sequence is exposed along the ranges in south. (Shami et al, 2002).

Potwar Sub Basin is Characterized by an unconformity between Cambrian and Permian. Mesozoic sediments are exposed around the basin. Figure shows the tectonic zone of Potwar Basin.

2.6.2 Structural Division

The tectonic depression of Potwar sub-basin is formed as result of continent-to-continent collision at the northwest margin of the Indian Plate. Presently two-fold division is envisaged for the Potwar sub-basin. On the basis of the deformation style:

- Northern Potwar Deformed Zone (NPDZ).
- The Platform Zone.

Figure 2.2 is showing the structural distribution of study area and surroundings. The platform area is mainly covered with thick fluvial sediments of Siwalik group (Chinji, Nagri and Dhok Pathan Formations). These sediments have been folded along with underlying marine sediments of the Indian Plate as the rest of the latest tertiary tectonic movements. The folded structures are generally oriented in sub-latitudinal fashion.

The Platform is further divided into three parts:

- The eastern Platform Zone.
- The central Platform Zone.
- The western Platform Zone.

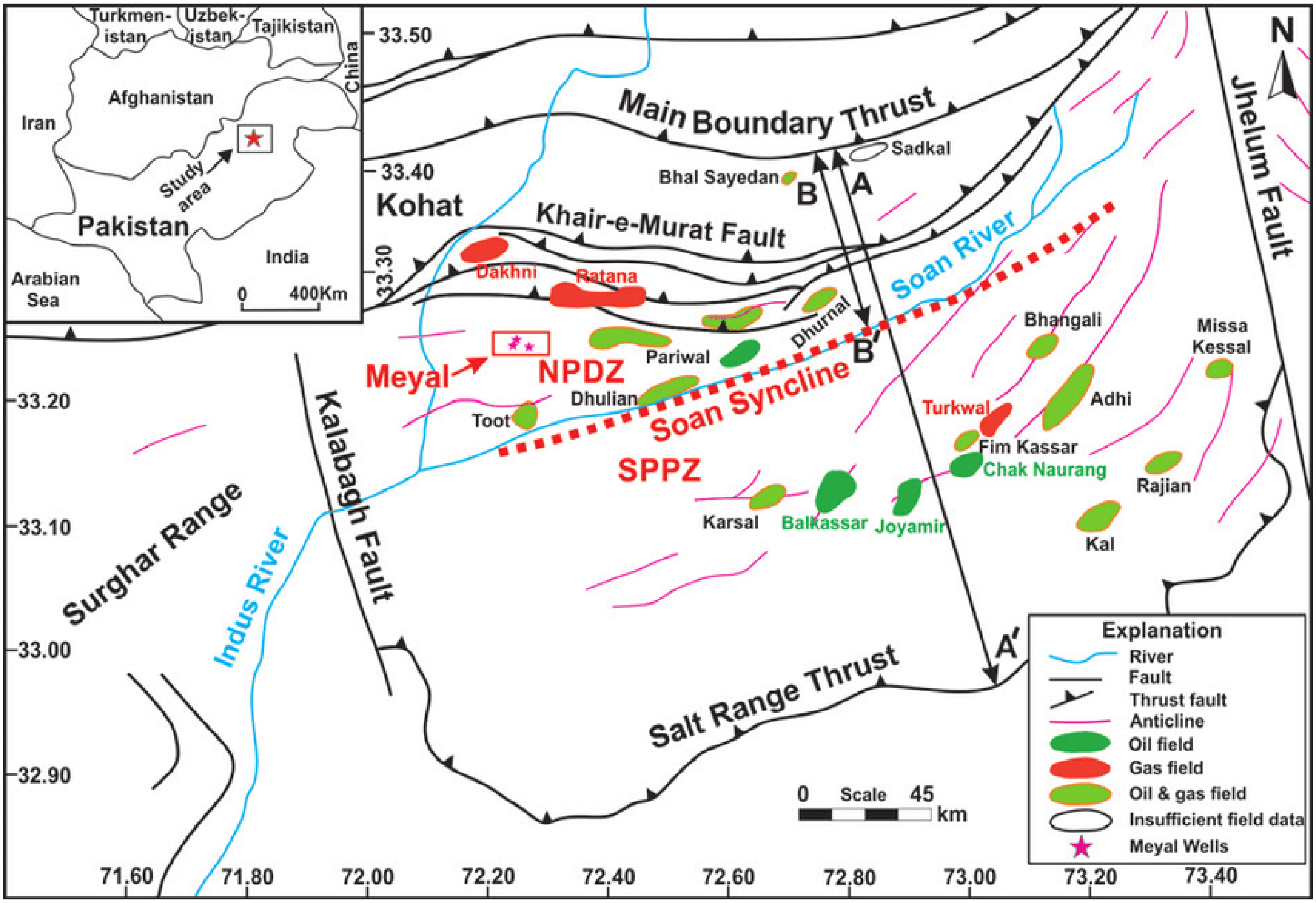

Figure 2.2: Map showing major structural features of the Kohat-Potwar plateau including Meyalfield. (Riaz et al., 2019)

2.7 Faults and Folds in Potwar Basin

As we have studied about geology of our study area that it's highly deformed area that consist of faults and folds.

2.7.1 Major Faults in Potwar Basin

- Khairi-Murat Fault (KMF).
- Kanet Fault (KF).
- Sakhwal Fault (SF).
- Dhurnal Back Thrust (DBT).
- Mianwali Fault (MF).
- Riwat Fault (RF).

2.7.2 Major Fold in Potwar Basin

- Soan Syncline.
- ChakNaurang Anticline.
- Adhi-Gungril Anticlines.
- Joya Mair Anticline
- Mahesian Anticline.
- Tanwin-Basin Anticline.
- Dhurnal Anticline.

2.8 Stratigraphy of Study Area

Stratigraphy of this area is very well defined with help of outcrops in the Salt range, which is also well supported with data obtained from wells that have been drilled across the Salt range Potwar foreland basin (SRPFB) and also in the Jhelum plain. Much of the thin-skinned tectonics in SRPFB are lubricated by evaporates of the Salt Range Formation (Shami and Baig, 2002). Here, Pre-Cambrian Salt Range Formation is overlain by Cambrian to Eocene platform sequence, like Peninsular India. Jhelum Group includes littoral to shallow marine Khewra and Kussak of Cambrian age. We have regional unconformity during Ordovician to Carboniferous in Upper Indus Basin, due to uplifting (Shami and Baig, 2002).The stratigraphic chart of Potwar sub-basin is shown in Figure 2.3 along with the regional unconformities and lithological symbols. Two time of chronostratigraphic details are shown i.e. time scale represents age as well as epoch.

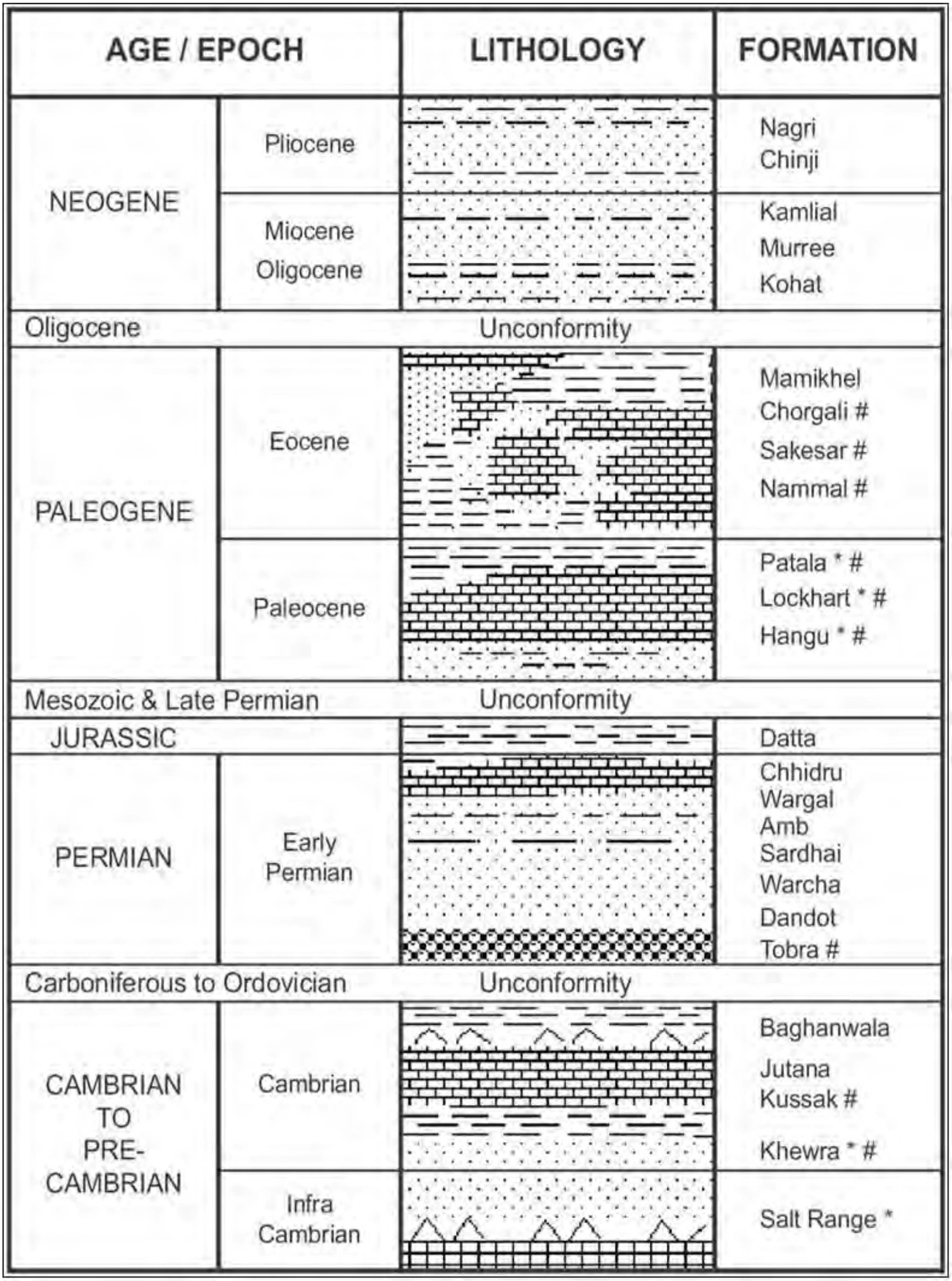

Figure 2.3 Stratigraphic chart of study area (Zaidi et al., 2012)

2.9 Petroleum Geology

The SRPFB belongs to the area of extra continental down wrap basins. This basin has complete package needed for petroleum. It has several suitable hydrocarbon accumulation features, including continental margin, thick marine sediment sequence of Eocene age, potential source, reservoir and cap rocks. The thick molasses sediments of 3047 m provide enough burial and geothermal gradient for oil formation. Average geothermal gradient is2^{0}C/100 m form oil window at the depth of 2750-5200m (Shami and Baig, 2002). Due to presence of complete package of source, reservoir and source we have Joyamair, Toot and Dhulian oilfields.

2.9.1 Source Rocks:

The gray shales of the Mianwali, Datta and Patala Formations are potential source rocks in this region. The oil producing shales of Eocambrian Salt Range Formation include 27-36% Total Organic Content (TOC), is isolated pockets of shales, considered as source rock in this area (Shami and Baig, 2002).

2.9.2 Reservoir Rocks:

In our study area such that Meyal; Chorgali, Sakesar, Ranikot and Datta formations are main producing reservoir rock. Cambrian, Jurassic, Permian, Paleocene and Eocene reservoir rocks are also producing hydrocarbons in Salt range Potwar foreland basin. The fractured carbonates of Chorgali and Sakesar formations are producing reservoir in Potwar basin. Chorgali formation is of creamy yellow to yellow gray, partly dolomitic and thin bedded limestone. Sakesar formation, limestone, is of light yellow gray that is partly dolomitized and contains cherts concretions.

2.9.3 Cap Rocks:

Kuldana formation (Eocene age) acts as cap for reservoir beds of Chorgali and Sakessar Formations in Salt Range Potwar Foreland Basin. Murree Formation of Pleistocene contain clay and shale also acts as a cap for Eocene reservoirs in this area as well as in Salt Range Potwar- Foreland Basin (SRPFB) where it is found to be in contact with.

2.9.4 Trap:

Due to high tectonic activity in the past, this area comprises of many structural traps. In Meyal, we have anticlinal structure due to movement along thrust sheets. Anticlinal structure are always good for trapping/accumulation of hydrocarbon.

CHAPTER 03

SEISMIC INTERPRETATION

3.1 Seismic Interpretation

The main objective of seismic data interpretation is to get all about sub-surface data. Once seismic data is ready after being processed and all noise has been removed, it is ready for interpretation. In this technique we generally convert seismic data into meaningful information such that it becomes structural/stratigraphic model of subsurface; a whole package of subsurface along with lithologies and structural variations. In seismic section we try to locate the anomalous zones (N.C Nanda, 2016). The correctness or incorrectness of an interpretation can be ascertained as from seismic data subsurface actual geology is rarely well known.

For good seismic data interpretation; knowledge of local geology (surface and subsurface), gravity as well as magnetic data and well information is important. Apart from this good geology and geophysical information are keys for perfect interpretation. The final objective of interpretation is to convert seismic section into the geological section, provides a somewhat realistic subsurface picture of that area, both structurally as well as strati-graphically (Badley, 1985).

3.2 Types of Interpretation

Seismic section can be interpreted by structure or stratigraphy analysis.

3.2.1 Structural Interpretation

In structural interpretation our main aim is to find structural traps in our area. For this purpose studying tectonic setting of area is important. For this type of interpretation, time (Two-way-time) maps are generated to display the geometry of selected reflection event. A deviation from regular pattern corresponds to regions of structural complexities. Structural traps are important for accumulation of hydrocarbons. Structural traps include the folds (anticline, syncline), faults (normal, reverse), pop-up and duplex structures etc (Sheriff, 1999). Pakistan, which has many oil and gas reserves that are obtained from structural traps, so this techniques plays a major role. In our study we have pop-up structure as area lies in compressional regime. So, structural interpretation helps to identify and marking faults and structures, as they accumulate hydrocarbon.

3.2.2 Stratigraphic Interpretation

In this type of analysis describing the seismic sequence that are present the different depositional units, recognizing the seismic facies characteristic which suggest depositional environment and analyzing the reflection characteristic difference to locate the stratigraphy change and hydrocarbon depositional environment. Amplitude, frequency, velocity and change in shape of wave are good indicator of hydrocarbon accumulations. Hydrocarbons can also be indicated on the basis of variation in amplitude with offset. Unconformities are marked on the basis of change in drainage pattern and which helps in developing the depositional environment. Lenses, unconformities and reefs are examples of stratigraphic traps (Serra, 1988).

3.3 Synthetic Seismogram

Synthetic seismogram is generated by convolving Sonic, density with source wavelet (extracted from well data). It is an artificial seismic trace. This helps us in correlating borehole data with seismic data. Well logs such as density and sonic give us estimation of the density and velocity of the sub-surface layer. Synthetic seismogram helps us in identifying the origin of reflectors within the seismic section. Well tops were also imposed on the synthetic seismogram and formation tops were shown correspondingly.

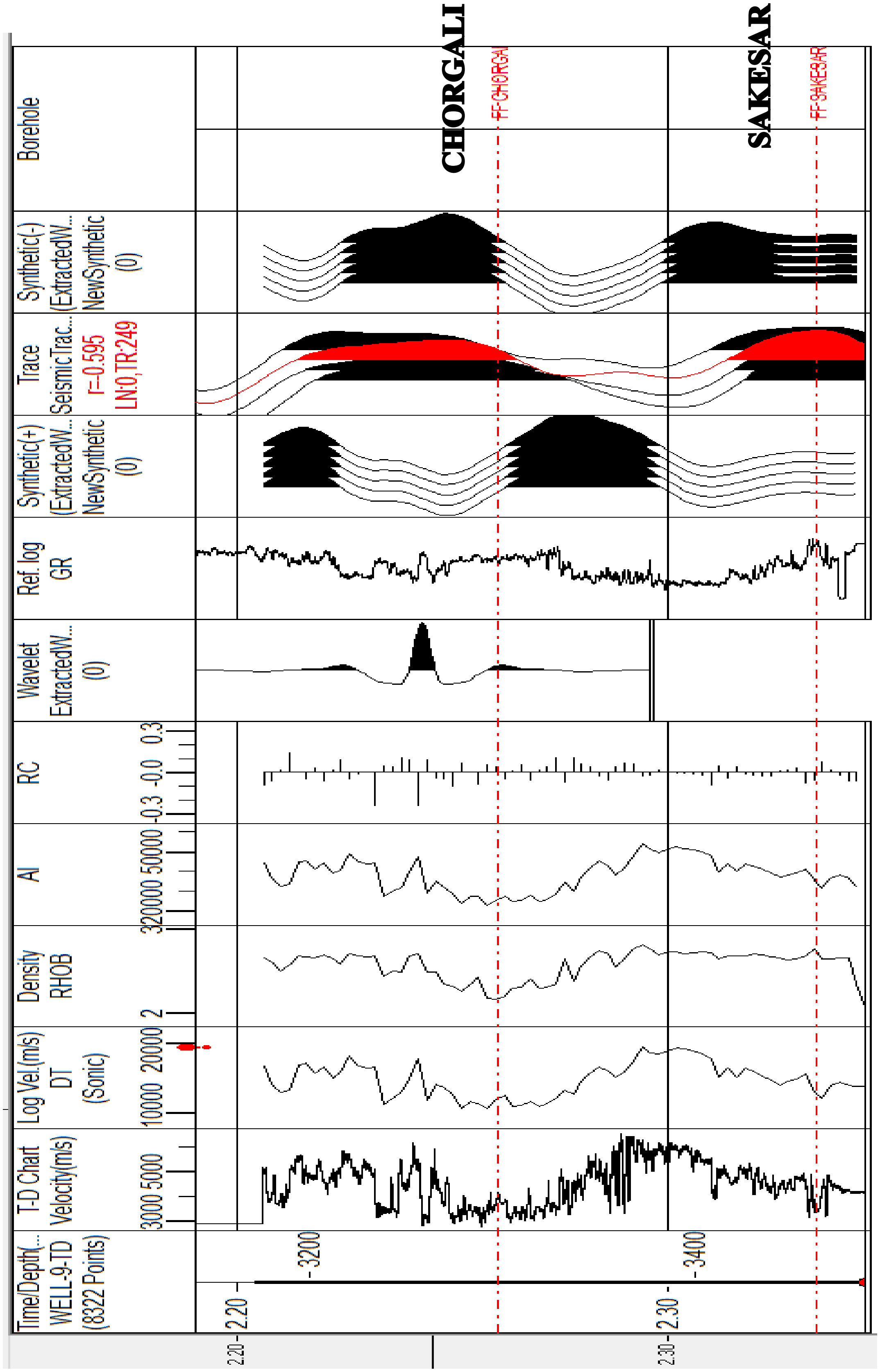

Figure 3.1 Synthetic Seismogram showing details

3.4 Marking of Horizon

Horizons are identified and marked with help of well data that are close seismic line as these are control line and from tying this line horizons are marked on other lines also. Horizons were identified on the seismic line with help of formation tops data and well data. Sonic logs are used to define the one way time (OWT) to the tops of the formations. Well-9P data was used to mark horizon on line 93-MYL-04. In figure 3.2, shows the horizon /along with two reverse faults F1 and F2.

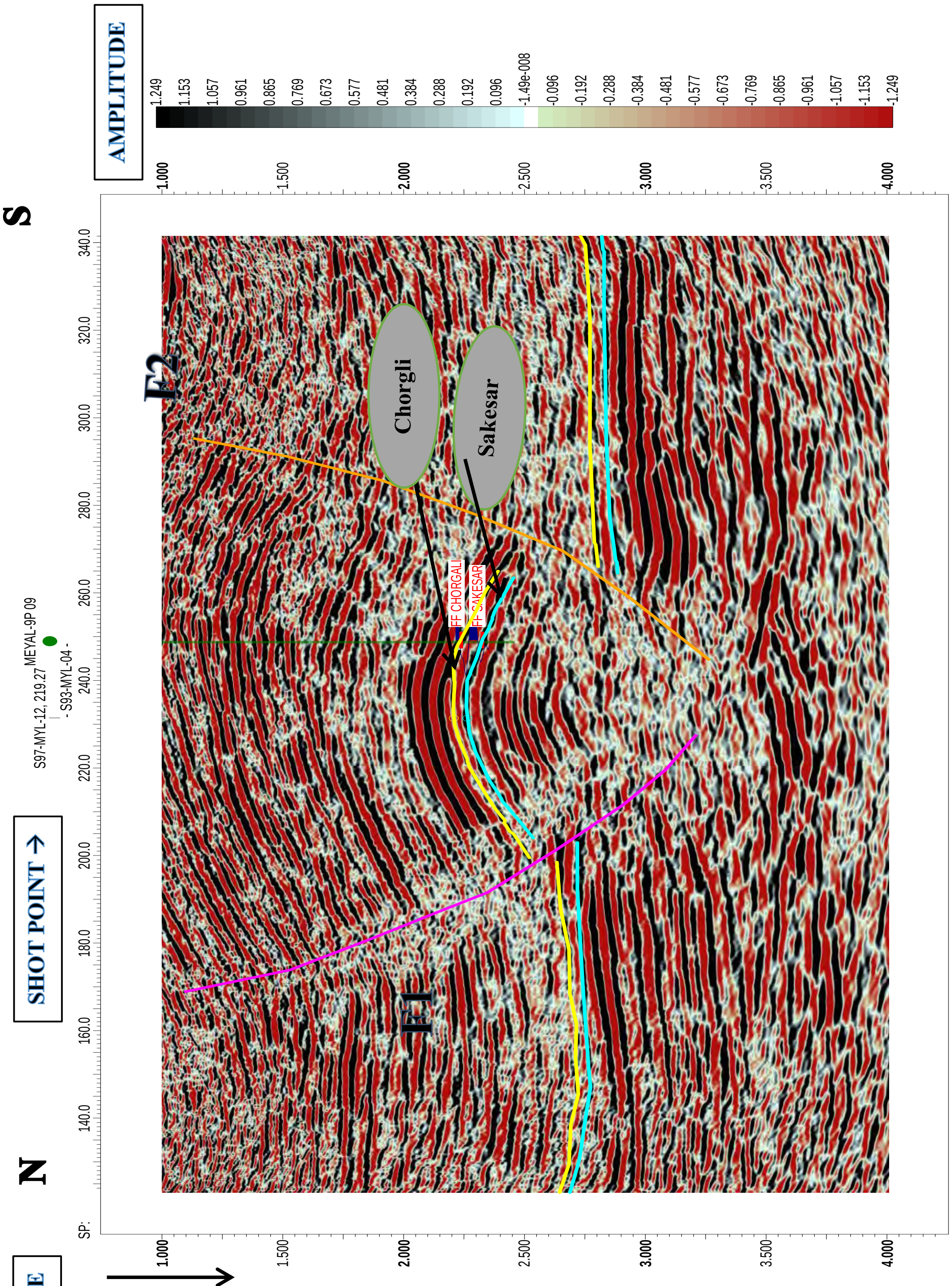

Figure 3.2 Seimic line 93-MYL-04 with marked faults and well Meyal-9P

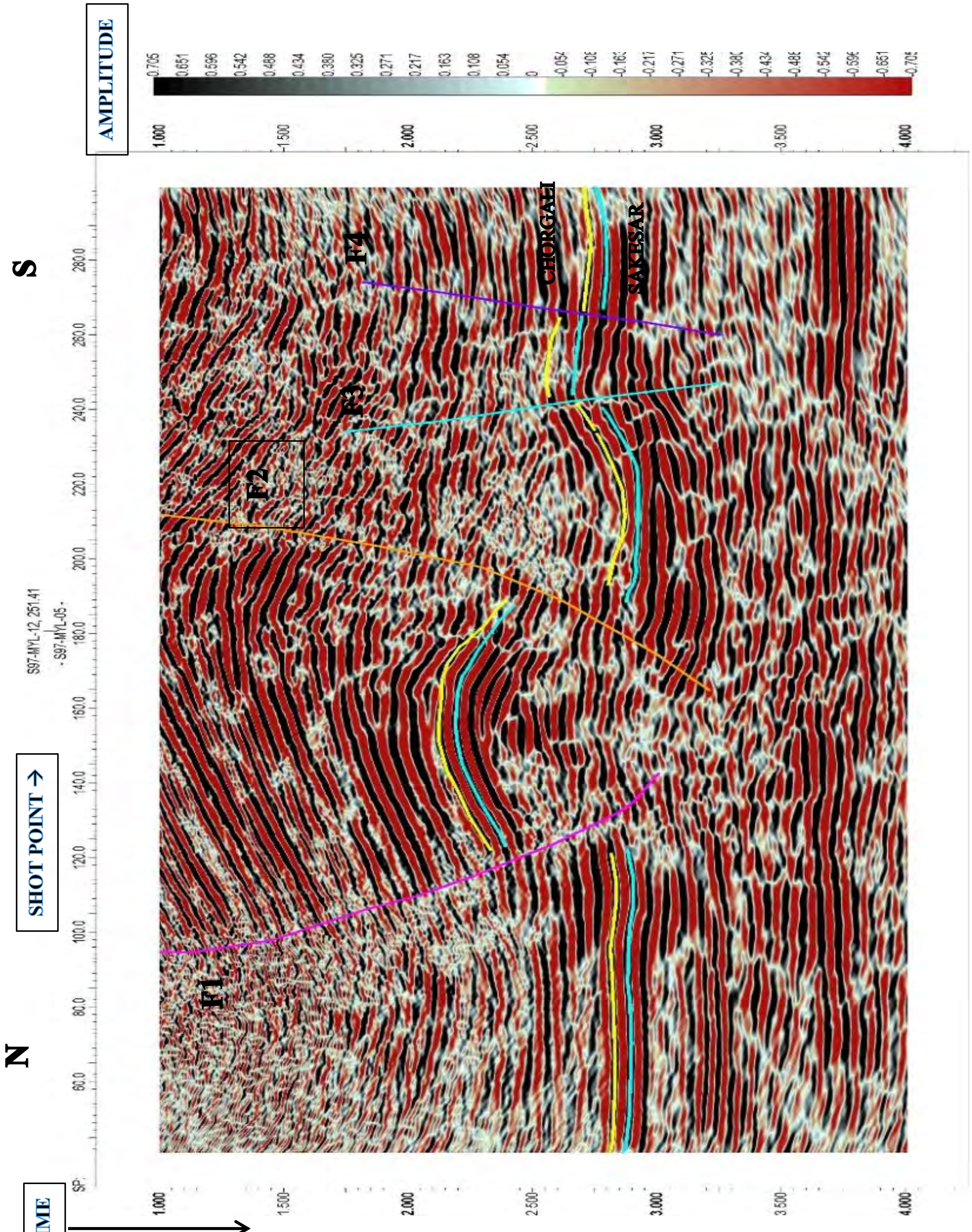

Figure 3.3 Dip Line 97-MYL-05 with marked horizons and faults

In above figure 3.3 shows the horizon marking on dip line 97-MYL-05 of Chorgali and Sakesar along with four reverse faults F1, F2, F3 and F4 respectively due to compression in the area. There is a visible pop-up anticlinal structure formed due to conjugate faults.

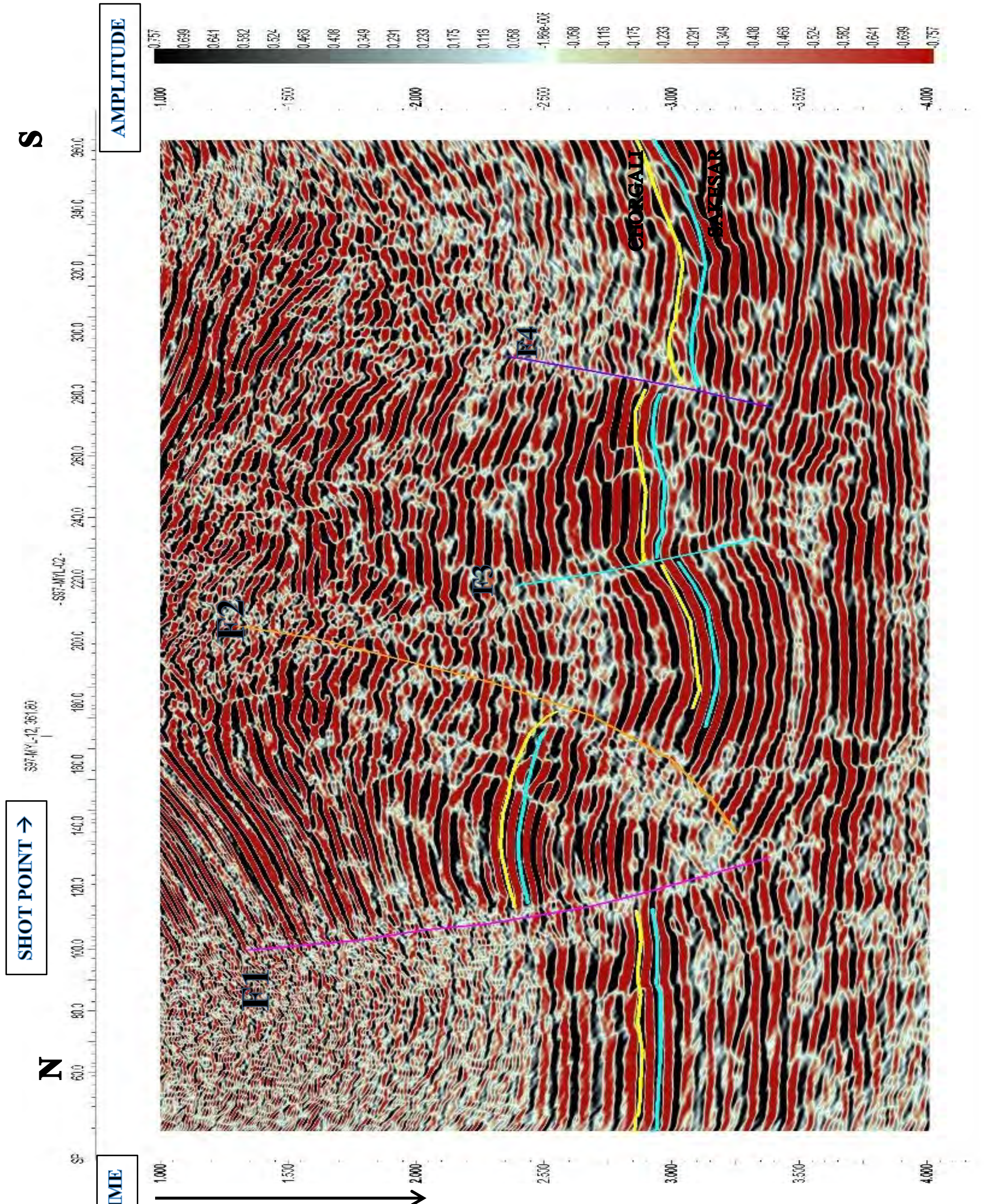

Figure 3.4 Dip line 97-MYL-02 with marked horizons and faults

In above figure 3.4 shows the horizon marking on dip line 97-MYL-02 of Chorgali and Sakesar along with two reverse faults F1, F2, F3 and F4 respectively due to compression in the area. There is a visible pop-up anticlinal structure formed due to conjugate faults.

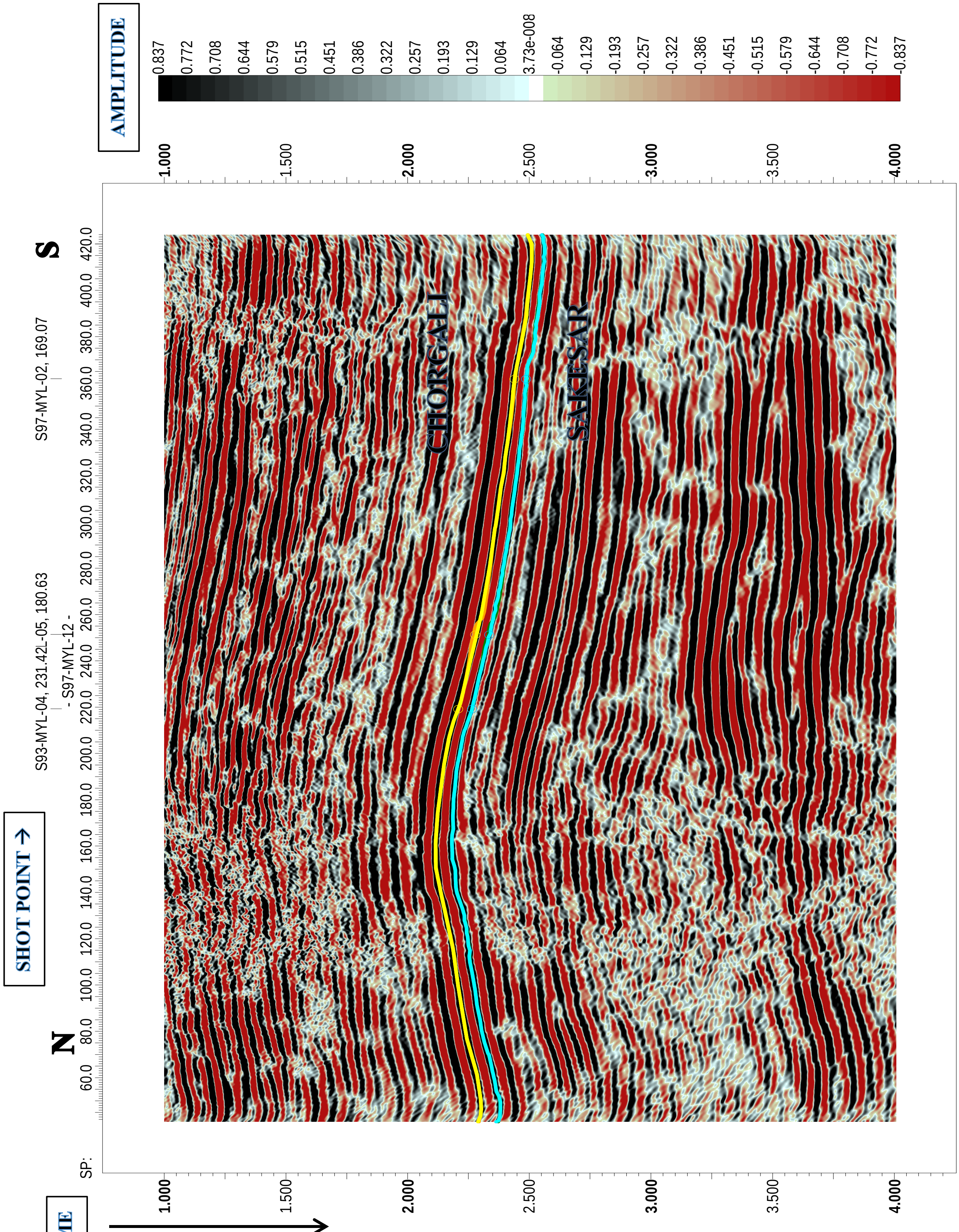

Figure 3.5 Strike line 97-MYL-12 with marked horizons

In above figure 3.5 shows the horizon marking on strike 97-MYL-12 of Chorgali and Sakesar.

3.4 Fault Marking and Fault Polygon Generation

Faults can be interpreted on seismic section when there is a break or discontinuity in bedding or rocks. When fault undergoes certain tectonic forces, movement will occur which is known as fault displacement. For marking and understanding nature of faults of an area, previous geology knowledge plays a vital role. Different direction of forces applied on fault cause different type of displacement. Normal faults are generated when forces pull apart tension and Reverse faults are caused when forces push together compression. In our study area faults can be easily marked on seismic section because there was visible displacement and anticlinal pop-up structures were observed easily due to sudden stepping out of their corresponding bedding planes.

Fault polygons represent the lateral extent of dip faults or strike faults having the same trend. This can helps us in identifying sub-surface discontinuities by observing the displacement in contours. Fault polygons can be constructed manually or can be generated automatically. Fault polygons are important for time and depth and contouring of formations.

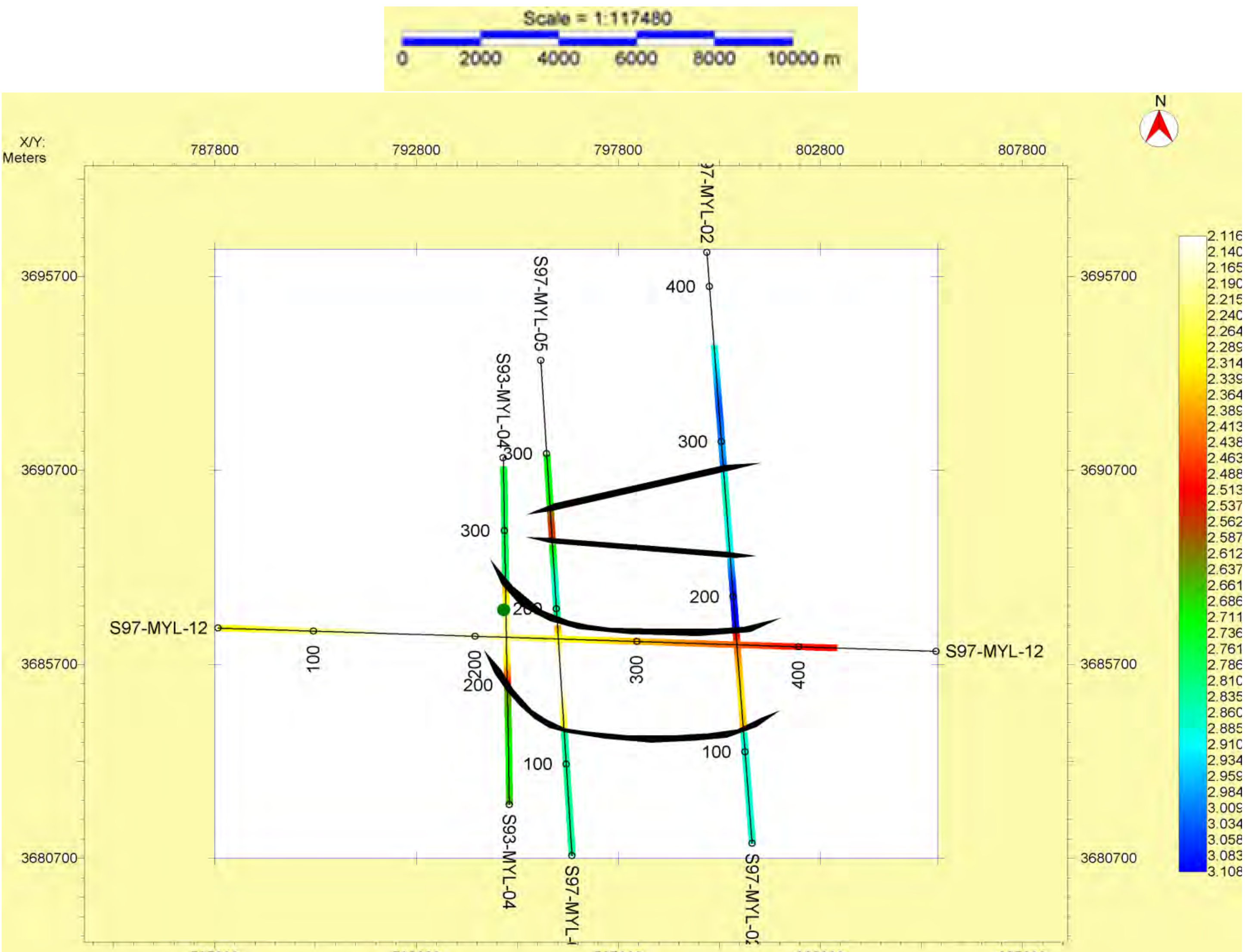

Figure 3.6 Fault polygons are showing on Base Map

3.5 Contour Maps

A line that joins the points of equal value is called contour line. Contour maps are used to display how much a slope is steep or elevated. These maps are used to show structural relief, elevation top of sub-surface of the sedimentary rock layer and also two-way-time (TWT) of our horizon. The contours are the lines of equal time and depth wandering around the map as dictated by data (Coffeen, 1984).

3.5.1 Time Contour Maps of Chorgali and Sakesar Formations

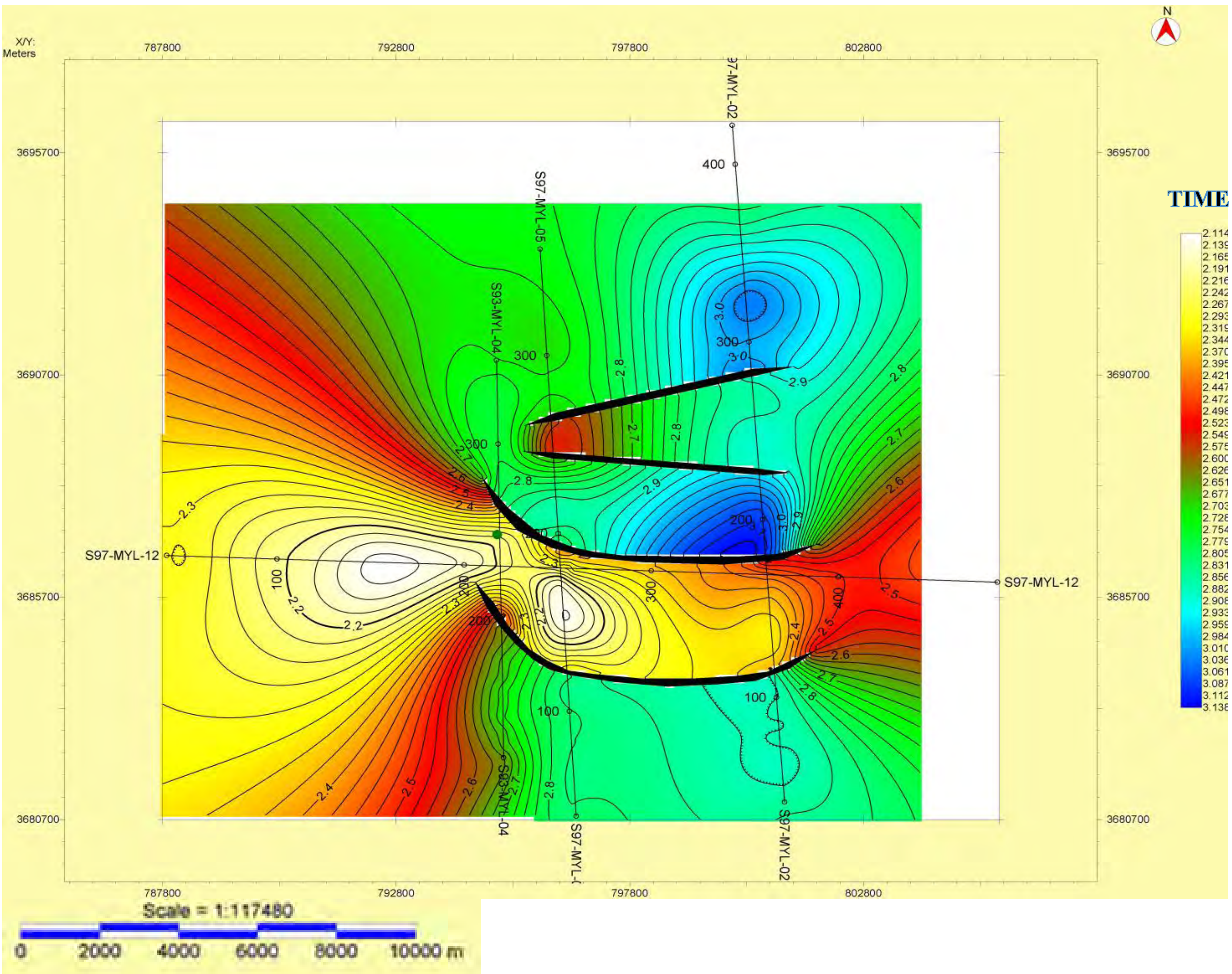

Figure 3.6 Time Contours of Chorgali Formation

Figure 3.6 shows time contour map of Chorgali formation along with four fault polygons. Contour interval is 0.02 seconds. It illustrates the pop-up anticlinal structure as interpreted in the above seismic sections. In between faults F1 and F2 time values are low which indicates shallow area and there is a well in this area.

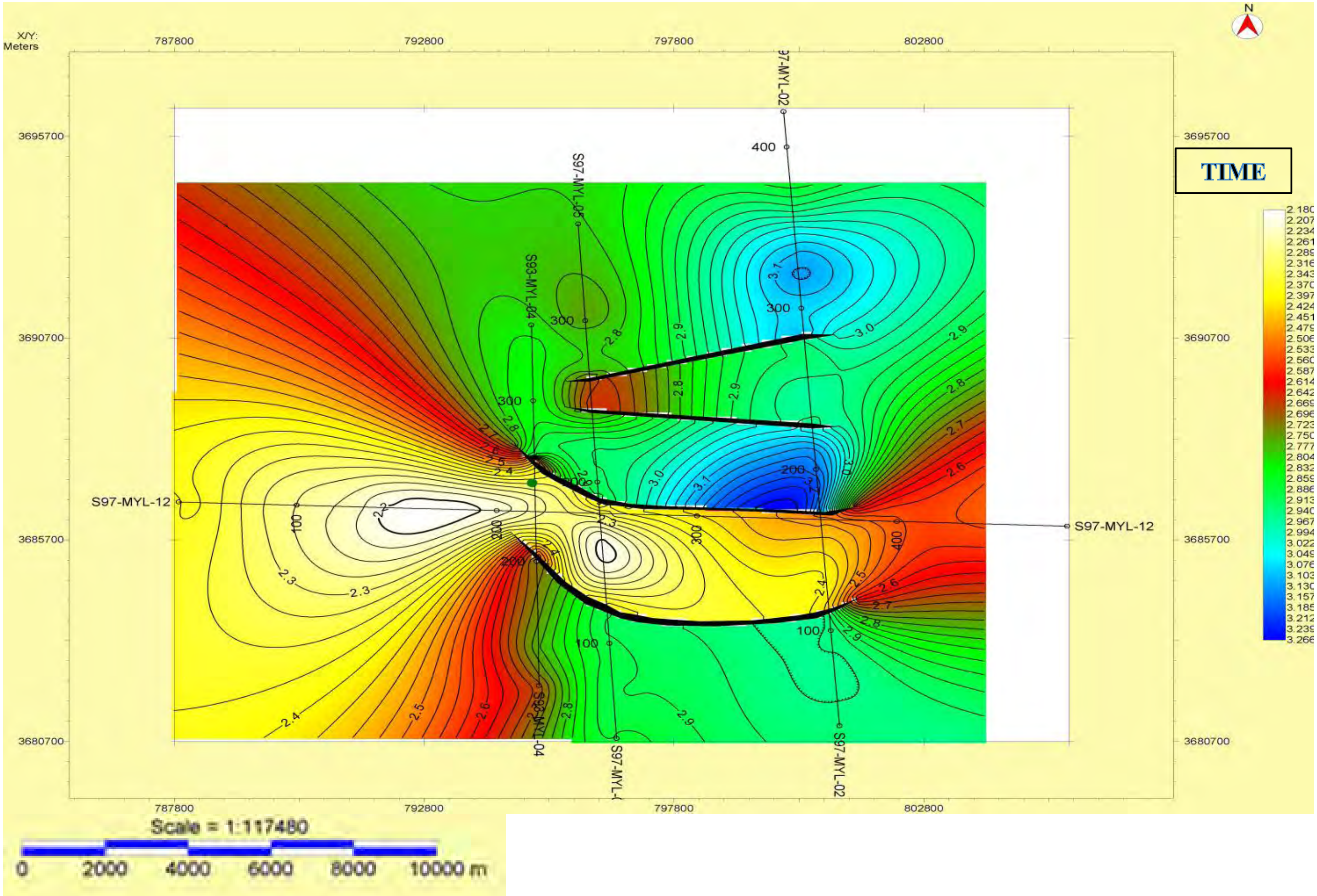

Figure 3.7 Time Contours of Sakesar Formation

Figure 3.7 shows time contour map of Chorgali formation along with four fault polygons. Contour interval is 0.02 seconds. It illustrates the pop-up anticlinal structure as interpreted in the above seismic sections. In between faults F1 and F2 time values are low which indicates shallow area and there is a well in this area.

3.5.2 Depth Contours for Chorgali and Sakesar Formation

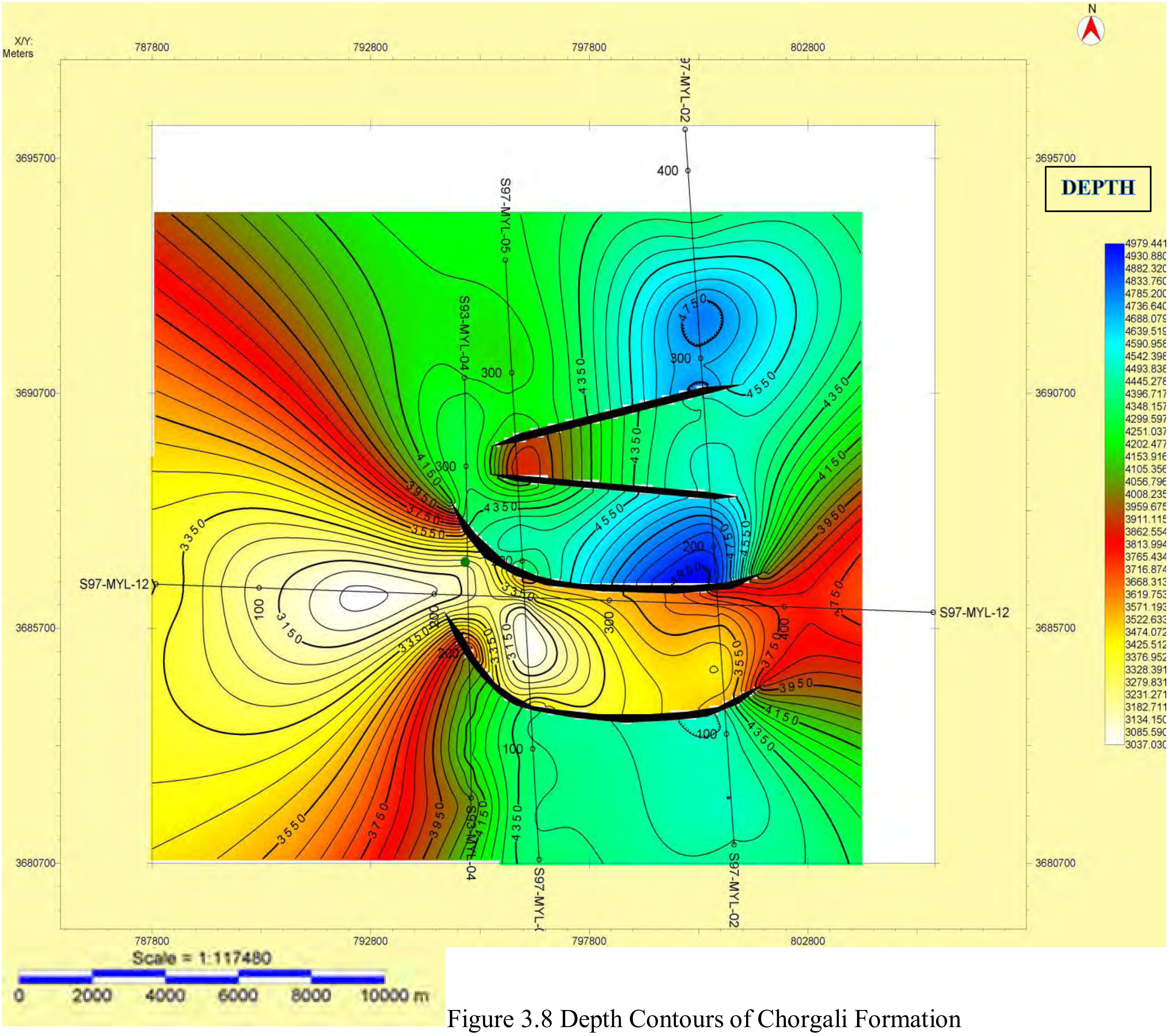

Figure 3.8 Depth Contours of Chorgali Formation

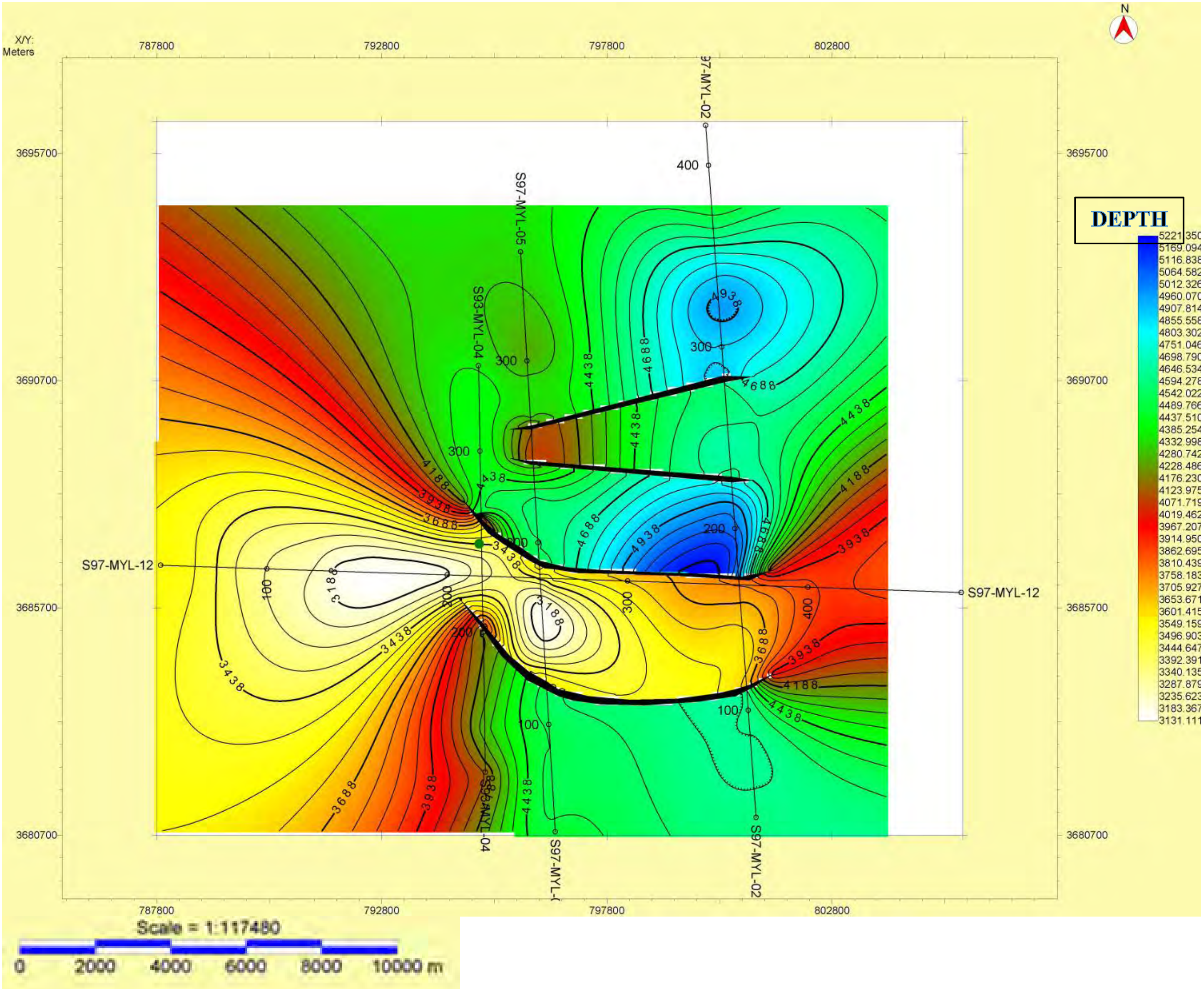

Figure 3.9 Depth Contours of Sakesar Formation

Figure 3.8 and 3.9 shows depth contour maps of Chorgali and Sakesar formation along with four fault polygons. Contour interval is 40 m. It illustrates the pop-up anticlinal structure as interpreted in the above seismic sections. In between faults F1 and F2 time values are low which indicates shallow area and there is a well in this area.

CHAPTER 04

SEISMIC ATTRIBUTES

4.1 Introduction

Attributes are intrinsic properties of a seismic wave signal derived from seismic data. Attribute can be defined as quality ascribed to any person or thing. Seismic attributes provide the qualitative information that facilitates structural and stratigraghic (channels, clinoform progradation, meanders, etc.) interpretation as well as it also provides lithology clues and fluid content estimation with a potential benefit of detailed reservoir characterization. In Seismic, it can be defined as any information or properties that can be extracted from seismic data. This can be done either by direct measurements or by logical or by experience based reasoning (Taner, 2001).

4.2 Classification of Seismic Attributes

The main attribute of seismic data is amplitude. Interpreters have one main goal to obtain good sound knowledge of sub-surface from seismic data and there are no limits to achieve their goal. So, there are no rules governing how attributes are computed. Any quantity calculated from seismic data can be considered as attribute thus any method that leads to the explorations goal is attribute. Classifications of attributes are:

- Physical attributes.

  They are related to physical properties, qualities or quantities. Mostly used for classifying lithologies and for reservoir characterization.

- Geometric attributes.

  They describe the spatial and temporal relationship of all attributes. Mostly used for stratigraphic interpretation.

- Seismic data domain based.
- Pre-Stack attribute.

  These are calculated from CDP ordered data while processing of seismic data. Such type of attributes' computation generates huge amount of data which is difficult to handle. Pre-stack data contains offset and azimuth information.

- Post-Stack attribute.

Post-Stack attributes are obtained from the seismic data that has been stacked. After stacking data offset and azimuth related information is eliminated. Attributes are applied and information can be extracted with ease as data isn‘t huge like in pre-stack.

- Computational characteristics based.
    - Instantaneous attribute: computed sample by sample in trace, gives instant variations.
    - Trace-to-Trace attribute: By trace-to-trace correlation, represent lateral continuation.
    - Interval Attribute: they‘re computed over time window in trace.

4.3 Envelope of Trace

This attribute mainly represents the acoustic impedance contrast, total instantaneous energy of the complex trace which is independent to phase such that remains always positive and calculated as the modulus of complex trace. The Hilbert transform of the real seismic trace generates the imaginary trace, by using both real and imaginary traces the envelope trace is computed (Taner, 2001). This attribute is mainly helpful in identifying (Chopra et al, 2006):

- Bright spots gas accumulation
- Major change in lithology.
- Sequence boundaries.
- Lateral changes.

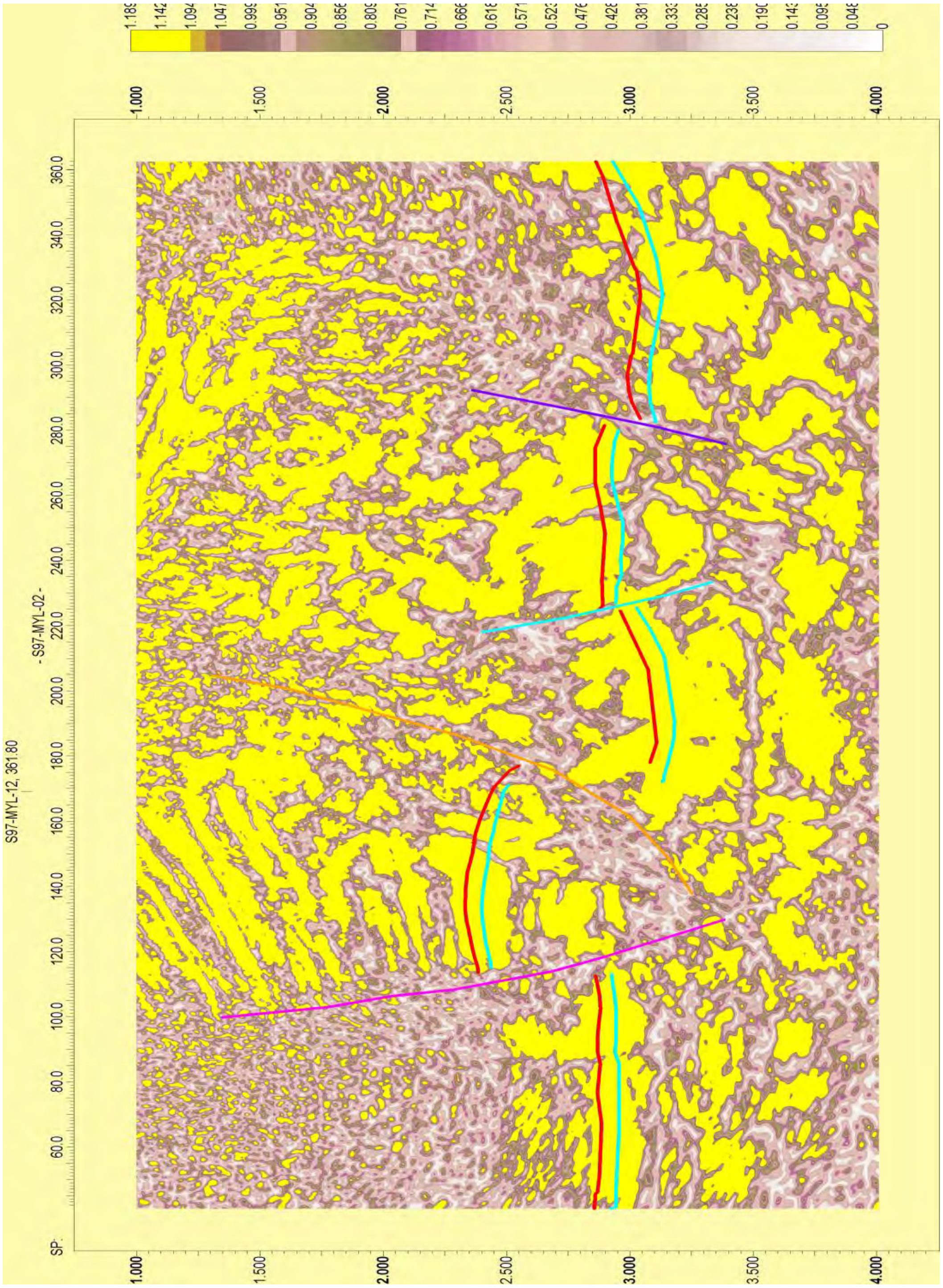

Figure 4.1 Line 97-MYL-02 Showing results of envelope trace

4.4 Instantaneous Phase

An instantaneous phase section shows the phase of a reflection wave form at the time corresponding to peak, trough and zero crossing. It is independent of amplitude, does not vary with strong or weak reflections and conveys lateral continuity of reflection event (N.C Nanda, 2016). This attribute can be helpful for (Chopra et al, 2006):

- Indication of lateral continuity of beddings.
- Quantifying the instantaneous frequency and the acceleration.
- Detailed display of geological bed configuration.
- Relating the waves‘ components to the propagation of seismic waves.
- Representing every event clearly.

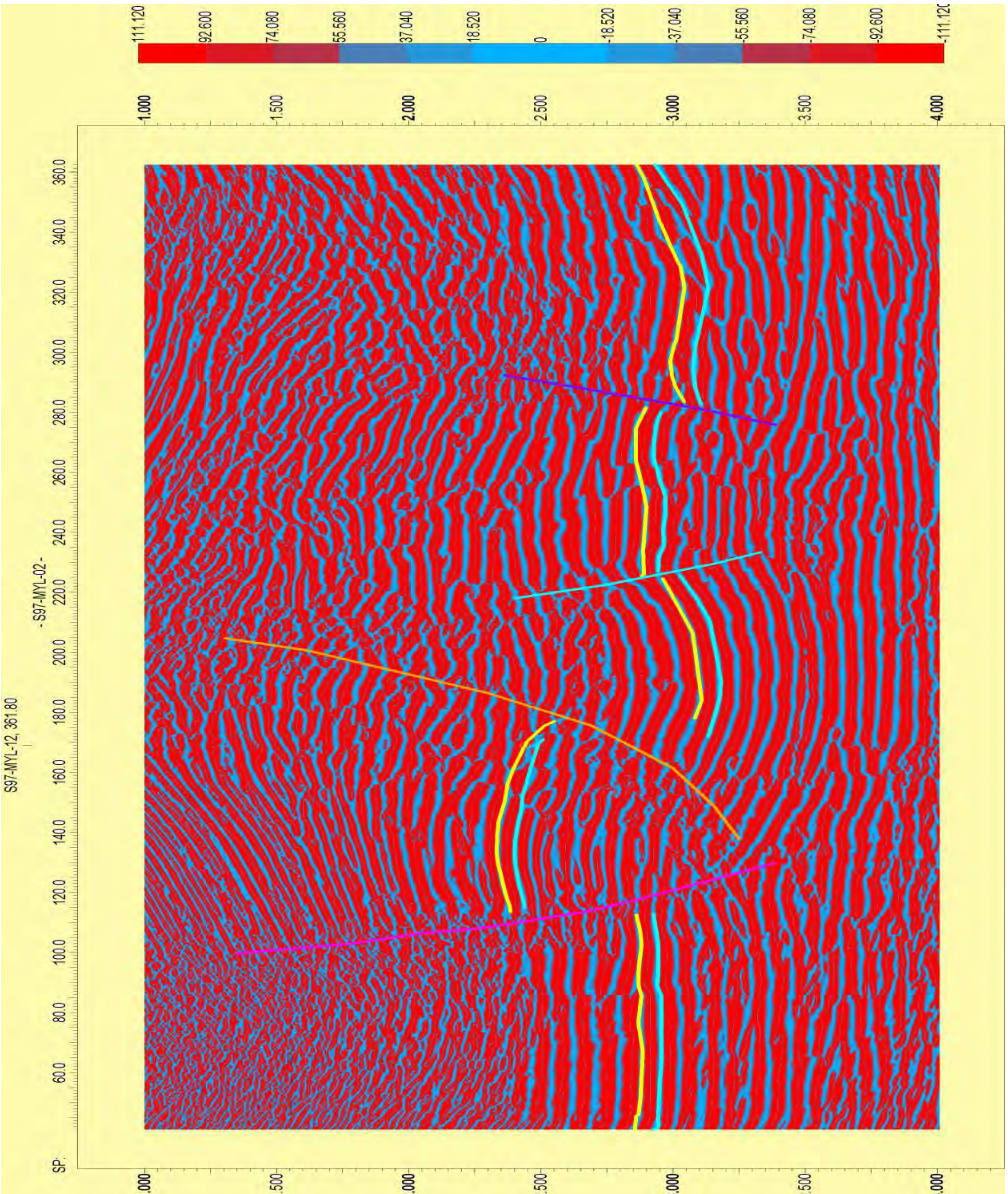

Figure 4.2 Line 97-MYL-02 Showing results of Instantaneous

4.5 Average Energy

Average energy attribute is a post-stack attribute. This attribute computes the sum of the squared amplitudes and divides them by the number of samples within a specified window. This help in:

- Mapping of DHI(direct hydrocarbon indicators).
- Highlights reservoir and source rock clearly.

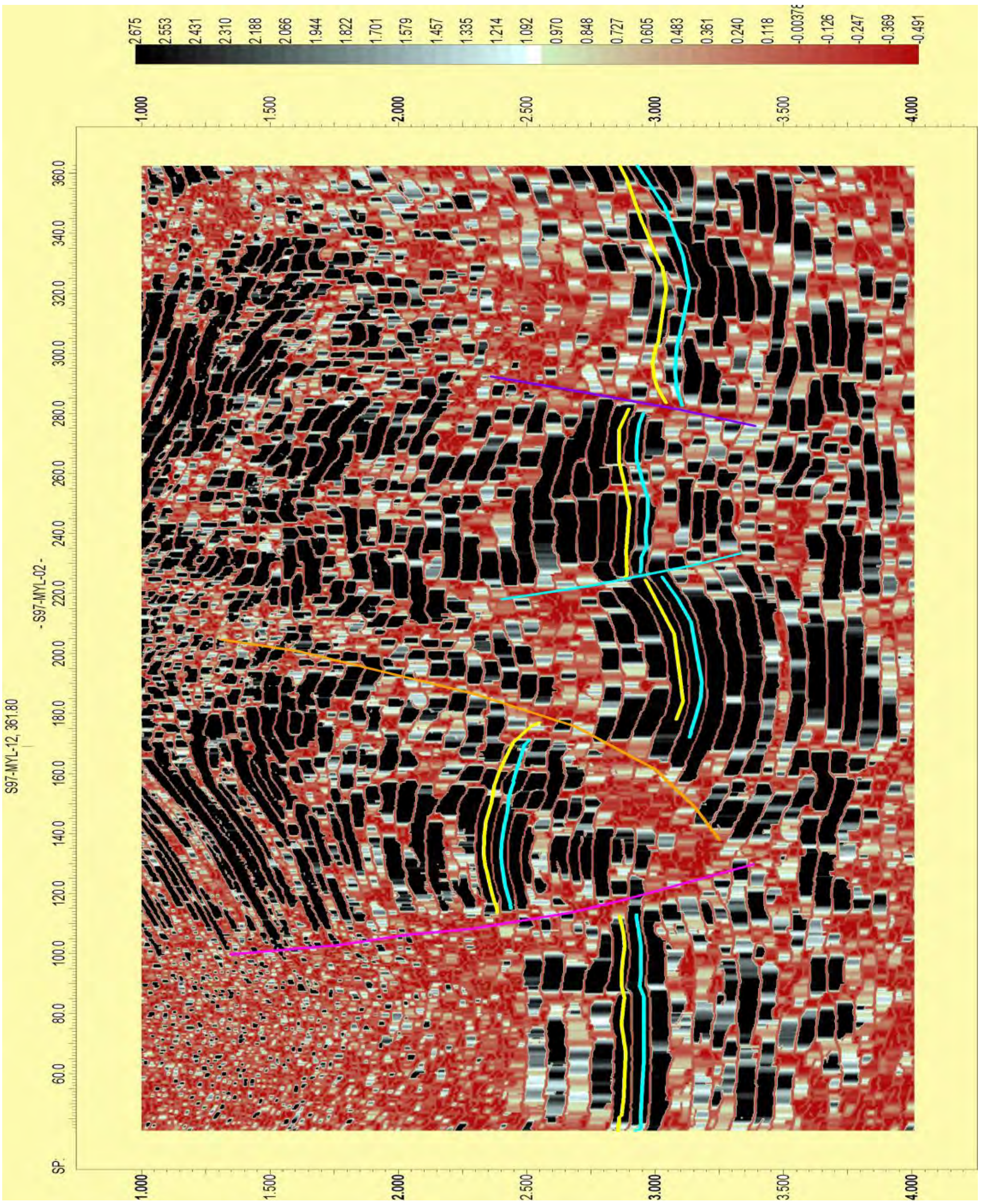

Figure 4.3 Line 97-MYL-02 Showing results of Average energy.

CHAPTER 05

PETROPHYSICAL INTERPRETATION

5.1 Introduction

Petrophysics is the technique which is used for the identification of reservoir characterization. This study enables us in the identification and quantitative measurements of reservoir fluid. It is the study of the physical and chemical properties that describes the occurrence and behavior of rocks, soils and fluids. To accurately characterize an oil or gas reservoir, measurements such as density and resistivity are made, effective porosity, saturations and permeability can be quantified.

5.2 Well Logging Techniques:

The main purpose of Well logging is to determine the various properties of different lithologies like porosity, fluid saturation etc., the actual depth of specific lithology, its thickness and interval velocity.

The petrophysical analysis has been done with help of wire-line logs of Meyal-09:

- Caliper Log
- Density log (RhoB)
- Spontaneous Potential (SP)
- Neutron Log (NPHI)
- Resistivity Logs (LLD & LLS)
- Gamma ray (GR)

5.3 Classification of geophysical well logs

Geophysical well logs can be classified into three categories:

- Lithology logs
- Resistivity logs
- Porosity logs

5.3.1 Lithology Logs

Lithology log are mostly used to identify the boundaries between the permeable and non-permeable formation, information about the permeable formations provide lithology data for the correlation with other well logs.

- Caliper (CALI)
- Spontaneous potential (SP)

- Gamma Ray (GR)

a) Caliper (CALI)

Caliper logs measure the diameter of the borehole. It records the cavities where the well is caved in, and also the hardness of the rock cut during drilling. Where there is the porous material, mud cake will be formed that cause the hole diameter to become smaller. Variation in the diameter of the borehole influences the record of the different logs. Therefore, it is important to consult with the caliper logs any artifacts (Asquith et al., 2004).

b) Gamma Ray Log

Gamma ray logs are lithology logs that are used to measure the natural radioactivity of a formation. The radioactive material's concentrations are present in shale, as shale has high gamma ray reading. Therefore, shale free sand and the carbonates have low gamma ray reading. Volume of shale can be calculated by the following formula, (Asquith et al, 2004)

$$\mathbf{Igr} = \frac{\mathbf{GR_{LOG} - GR_{min}}}{\mathbf{GR_{max} - GR_{min}}}, \tag{5.1}$$

where GR_{min} is minimum value and GR_{max} is the maximum value of the gamma ray, Igr is the gamma ray index an Gr log represent the gamma ray log. Gamma ray logs are used to identify lithology, the volume of the shale and the correlation between the formations (Asquith et al., 2004).

5.3.2 Resistivity well logs

Resistivity well logs give the thickness of the formation, accurate value for the true formation resistivity and information for the correlation purposes. All these logs are plotted on the logarithmic scale due to more variation in resistivity (0.2 to 2000 ohm) with depth.

Resistivity well logs are

- Deep laterolog (LLD)
- Shallow laterolog (LLS)

a) Deep laterolog (LLD)

Deep laterolog is the electrode logs and are designed to measure formation resistivity in the borehole filled with saltwater muds (R_{mf}).The effective depth of the laterolog investigation is controlled by the extent to which the surveying current is focused (Asquithet al., 2004).

b) Shallow laterolog (LLS)

Shallow laterolog measure the resistivity of in the invade zone (R_i). In water-bearing zone, the shallow laterolog records a low resistivity because mud filtrate resistivity (R_{mf}) is approximately equal to mud resistivity (R_m), (Asquith et al., 2004).

5.3.3 Porosity well logs

Porosity well logs are providing the data through which the water saturation can be determine, provide the accurate lithologic and porosity determination and provide data to distinguish between oil and gas.

Porosity well logs are

- Sonic/Acoustic (DT)
- Neutron Porosity (NPHI)
- Density (RHOB)

Sonic/Acoustic (DT)

Sonic logs measure the interval transit time (delta t) of the compressional sound wave through the formation. The interval transit time is related to the porosity of the formation. The unit of measure is the microseconds per foot or microseconds per meter

Porosity of the formation can be calculated by using the following formula (Asquith et al., 2004):

$$\emptyset_s = \frac{\Delta t_{log-} \Delta t_m}{\Delta t_f - \Delta t_m} \tag{5.2}$$

where $\emptyset_s$ represent the calculation that derived from the sonic log, Δt_m is the interval transient time of the matrix, Δt_{log} interval transient time of formation, represents the transient time of the fluid (salt mud=185 and fresh mud=189).the interval transient time of the formation depends upon the matrix material, its shape and cementation (Wyllie et al , 1956).If fluid (hydrocarbon or water) is present in the formation, transient interval time is increases and this behavior shows increase in porosity which can be calculated by using sonic log (Asquith et al , 2004).

Neutron Porosity (Φ_n)

Neutron log is the porosity log that measure hydrogen ion (HI) concentration in a formation (Asquith et al , 2004).In the shale free formations where the porosity is filled with the water, the neutron log is related to the water filled porosity (NPHI).In gas reservoir, porosity measured by the neutron log is low then the formation true porosity as the hydrogen ions concentration are less in gas reservoir then that of oil and water (Asquith et al, 2004).It is the one limitation of neutron log that is known as the Gas effect.

Density (RHOB)

Density log is the porosity log that measure electron density of the formation, (Asquith et al, 2004). Formation electron density is related to bulks density of formation. It is the sum of fluid density multiplies its relative volume plus matrix density time relative volume.

Relation for the calculation of the porosity from the Density log ($\emptyset_d$)

Density log can be used to find out the correct porosity of the formation, if the matrix densities in the formation or rock type are known (Asquith et al, 2004). The rock type in my research work is limes tone and shale. By using following mathematical relation, density porosity can be related as

$$\emptyset_{\mathbf{d}} = \frac{\rho_m - \rho_b}{\rho_m - \rho_f} \qquad (5.3)$$

where,

- $\emptyset_d$ represent porosity derived from the density log
- $\rho_b$represent bulk density of formation
- $\rho_m$represent matrix density and for limestone it is 2.71 g/cm^3
- ρ_f represent density of fluid.

The main purpose of present petrophysics is to obtain calculation about porosity, saturation of water and hydrocarbon.

5.4 Average porosity calculation

Sum of the porosities that are obtained from the different logs divided by number of logs from which porosity is calculated. The relation is given below through which average porosity is calculated.

$$\emptyset_{\mathbf{avg}} = \frac{\Phi n + \emptyset_d + \emptyset_s}{3}, \qquad (5.4)$$

where,

- $\emptyset_{avg}$ is the average porosity calculated from the available porosities
- Φn represents neutron porosity
- $\emptyset_d$ represent the density porosity
- $\emptyset_s$represent the sonic porosity.

5.5 Effective porosity ($\emptyset_e$)

This will define as "the ratio of the volume of interconnected pore spaces in a rock unit to the total volume of the rock by removing shale effect that rock unit". The zone which rich in the shale, effective porosity will be zero. Effective porosity is used to mark the saturated zone. The effective porosity can be calculated by the following formula (Asquith et al, 2004).

$$\emptyset_{\mathbf{e}} = \emptyset_{\mathbf{avg}} \times (\mathbf{1} - \mathbf{Vsh}), \qquad (5.5)$$

Where,

- $\emptyset_e$ effective porosity which to be calculated
- $\emptyset_{avg}$ represent the average porosity
- Vshrepresent volume of the shale.

5.6 Mathematical relation for Water Saturation (S_w)

Water saturation in the formation can be defined as "The percentage of the pore volume filled by water in the formation". The saturation of water in the formation can be calculated by the following Archie equation

$$S_w = \sqrt[n]{\frac{F \times R_w}{R_t}}, \tag{5.6}$$

where,

- F is formation factor which is

$$F = \frac{a}{\emptyset^m} \tag{5.7}$$

- R_w represent the resistivity of water
- R_t represent the true formation resistivity
- n represents the saturation exponent
- a is the constant and its value is 1 in case of limestone
- $\emptyset$ represent effective porosity
- m represents the cementation factor and it value is taken 2 for the limestone.

Mathematical relation for Hydrocarbon Saturation (S_h),

$$S_h = 1 - S_w \tag{5.8}$$

Hydrocarbon saturation can be defined as "the pore in formation is filled with hydrocarbon". It can be calculated by using the following mathematical relation

Where S_w represent Hydrocarbon saturation, S_h represent hydrocarbon saturation.

5.7 TABLE FOR MARKED ZONES

S.NO	ATTRIBUTES	ZONE 1(Chorgali)	ZONE 2(Sakesar)
1	VOLUME OF SHALE	30%	27%
2	DESNITY POROSITY	2.9%	2.1%
3	EFFECTIVE POROSITY	3.06%	1.7%
4	TOTAL POROSITY	4.36%	2.36%
5	WATER SATURATION	7.42%	16.50%
6	HYDROCARBON SATURATION	92.58%	83.50%

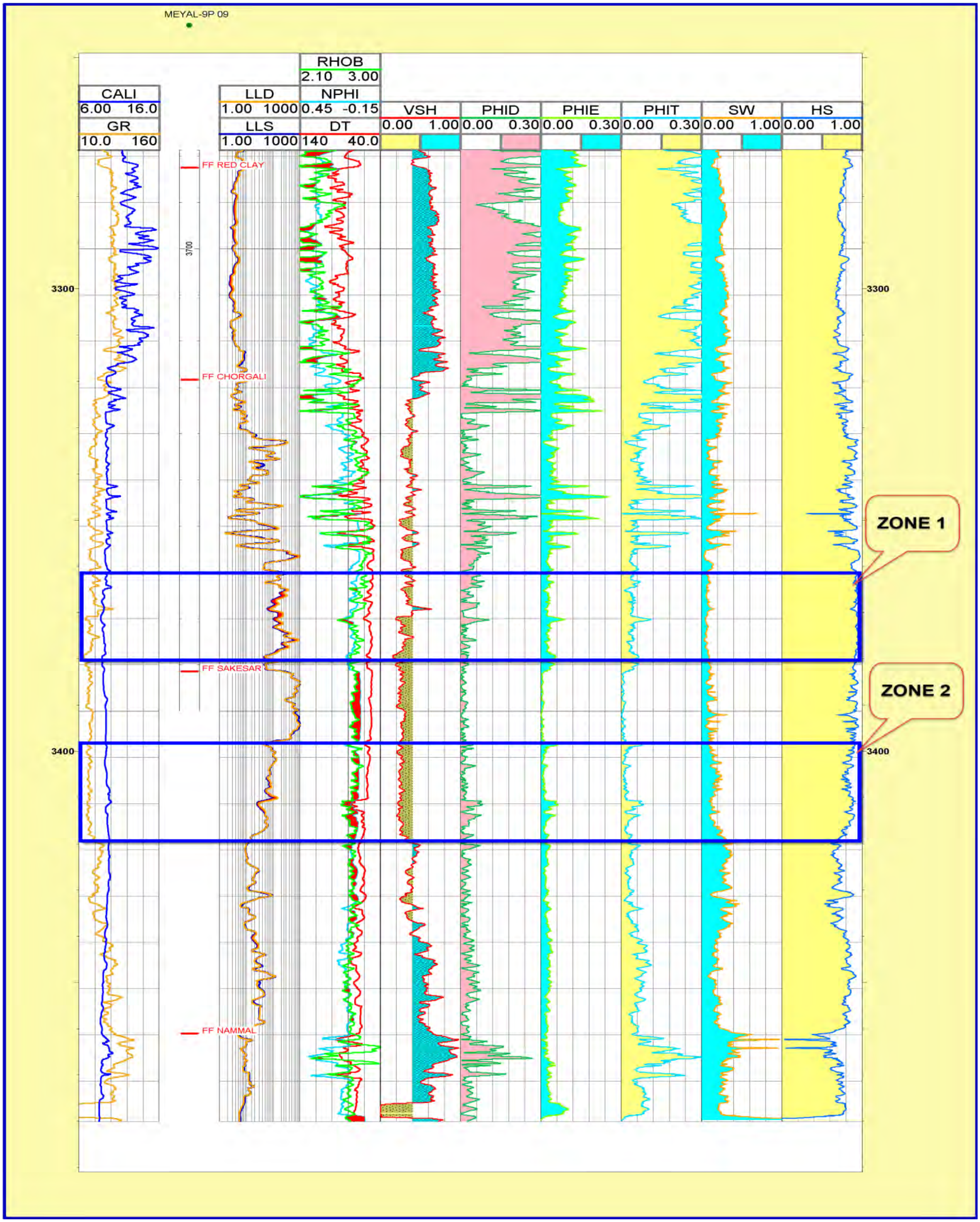

Figure 5.1 Marked zones of interest with logs of MEYAL-09

Petrophysical Results

GR log is on lower side caiper is stable. There is a separation between LLS and LLD logs and Cross-over form between RhOB and NPHI. Vsh shows low values also porosities are higher while water saturation is low and hydrocarbon saturation is high in the marked reservoir zones. This indicates the presence of hydrocarbons in the zones of interest of Chorgali and Sakesar.

5.8 FACIES ANALYSIS

5.8.1 Introduction

The term Facies was introduced in 1838 by a Swiss geologist and paleontologist named Amanz Gressly. In the field of geology, the term ―Facies" is a rock body that has some specific characteristic which distinguish it from the other. Facies are different aspects of stratigraphic units which have mutually space distribution and clarify the relationship between facies and lithotopes (Mutti et al, 1978). Facies analysis is a technique that is being used widely to for characterization of reservoir.

The Facies are related to the certain depositional environment. In certain or specific environment facies are deposited or formed. These environments could be Delta, Stream, Glaciers, Lakes, Abyssal Plain and Sea bottom etc. To differentiate between the sand and shale has been a challenging situation for scientist. In this process the key challenge is identifying the facies with help of data of well-logs and core data, and degree to which the shale content affect the reservoir properties. This gives the main indication about the productive zone in the reservoir.

Facies is a body of rock with specified characteristics, which can be any observable attribute of rocks, including their appearance, composition as well as condition of formation or the changes that may occur over the geographic area. All characteristics such as chemical, physical or biological features distinguish facies from surrounding rock (Parker, Sybil P. 1984).

5.8.2 Types of Facies

Sedimentary Facies:

These are distinctive rock unit that forms under certain condition of sedimentation and depositional environment.

Metamorphic Facies:

The sequences of minerals that develop during progressive metamorphism at progressively higher temperatures and or pressures define a Facies series.

Seismic Facies:

These are map able three-dimensional seismic units composed of reflection units whose parameters are different adjacent Facies units.

5.8.3 Walther's law of Facies

A geologist Johannes Walther (1860-1937), states that the vertical succession of facies reflects lateral changes in environment. Conversely, it states that when a depositional environment migrates laterally, sediments of one depositional environment come to lie on top of another. A classic example of this law is the vertical stratigraphic succession that typifies marine transgressions and regressions.

Transgression: Marine transgression is a geologic event during which sea level rises relative to the land and the shoreline moves toward higher ground, resulting in flooding and produce the fining upward.

Regression: Marine transgression is a geologic event during which sea level falls relative to the land and the shoreline moves toward lower ground, and it exposes former sea bottom and produce coarsening upward.

5.8.4 Facies Analysis

Fundamental to all subsurface geologic studies is an analysis of depositional facies. Development of a facies classification scheme is a particular challenging interplay between capturing enough information for environmental interpretation yet remaining simple. Particularly important is the characterization of Facies such that their recognition criteria relate to critical environmental thresholds such as sea level, normal wave base, and storm wave base. These physical environmental zones regulate sedimentary textures and biotic assemblages. A good understanding of pale ecology always strengthens the interpretation and such studies should be included as part of all depositional Facies studies. Depositional textures in turn affect porosity-permeability in carbonates. The vertical and lateral organization of Facies is an exercise essential to sequence stratigraphic interpretations (Lucia, 1995).

5.8.5 Cross plot between DT VS NPHI

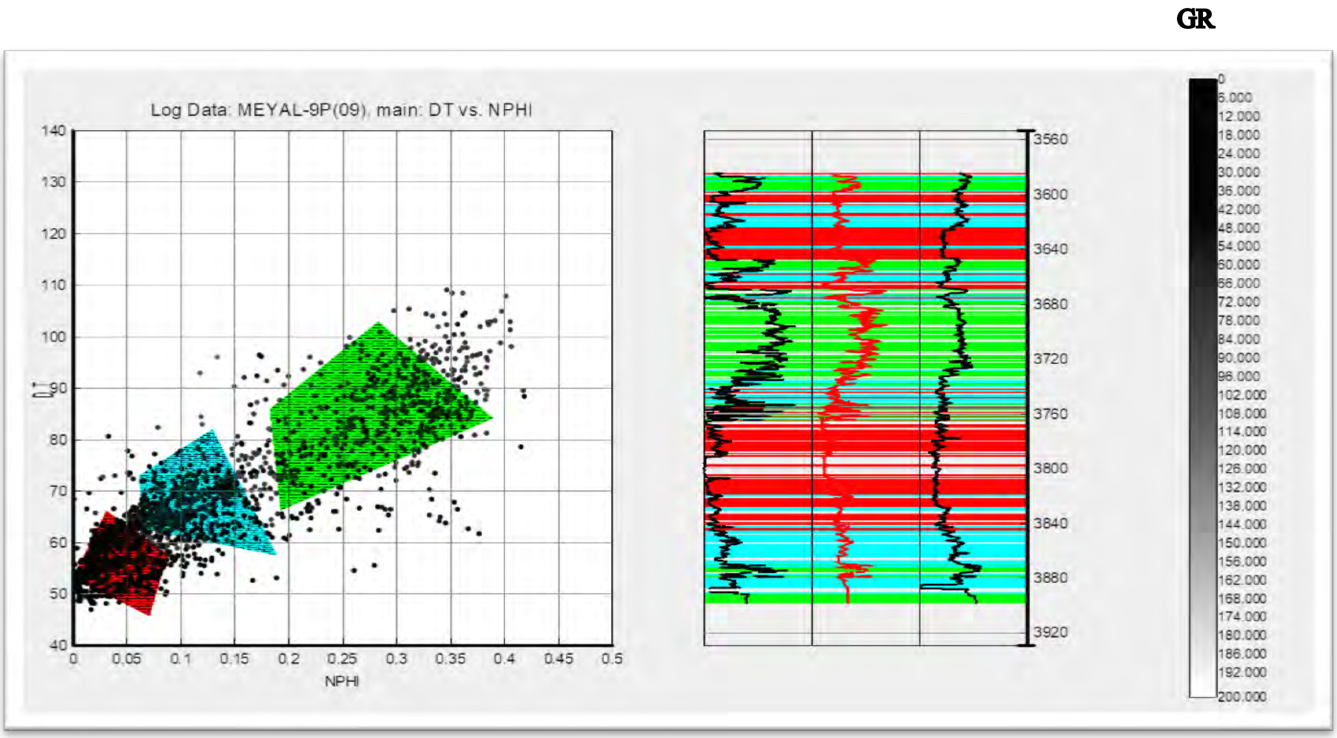

Figure 5.2 Cross plots between DT and NPHI

5.8.6 Cross plot between LLD VS RHOB

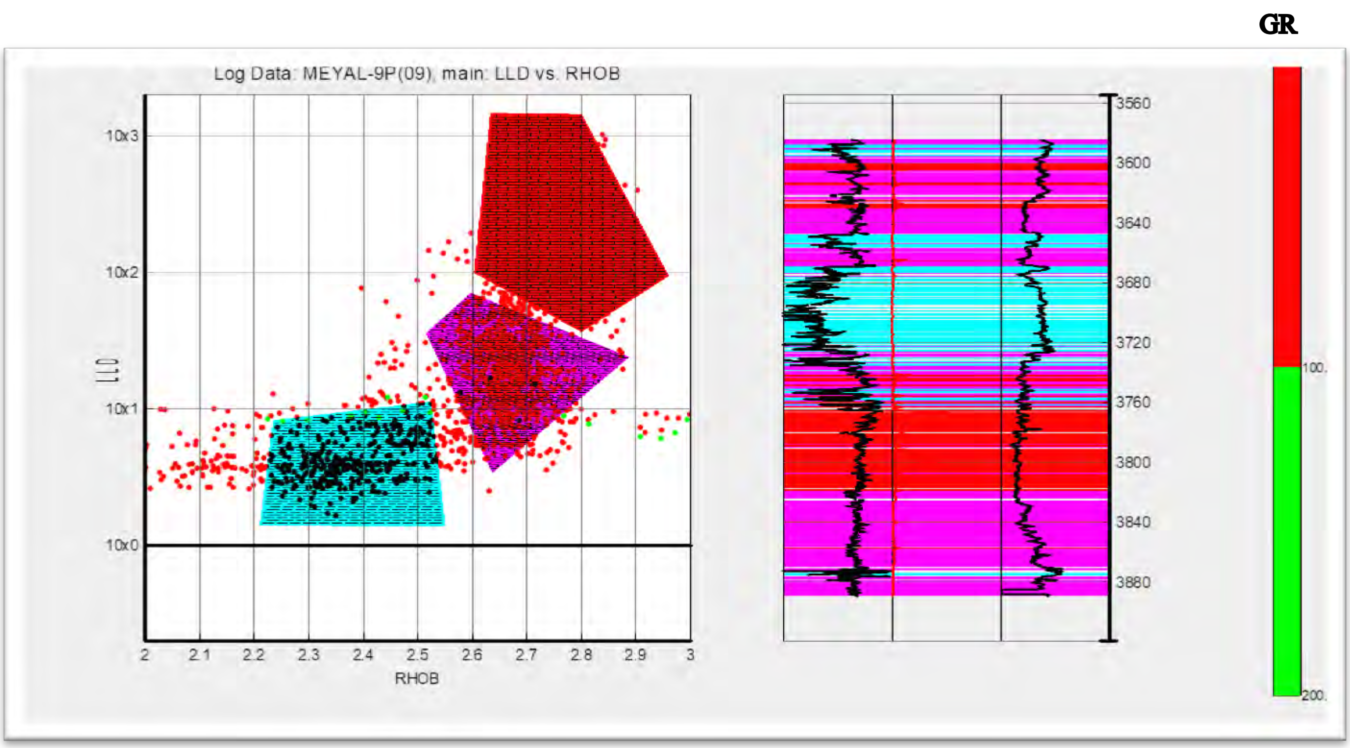

Figure 5.3 Cross plots between LLD and RHOB

Results

Cross plots of NPHI vs. DT and RHOB vs. LLD confirms three different lithologies including limestone, calcareous shale and shale. These are marked on the basis of their density values, resistivity range and slowness. The red polygon represents limestone. As we know that limestone is a compact lithology so it has high density, high resistivity (indicate hydrocarbon content). Low DT or slowness (high velocity). Low NPHI, indicating fracture porosity. And on the same basis calcareous shale and shale are marked.

CHAPTER 06

COLORED INVERSION

6.1 INTRODUCTION

Inversion is a technique in which we obtain the physical sub-surface structure and properties of earth with help of data obtained from the surface of earth. This is ―inverse" of forward modeling (Russell, 1988).

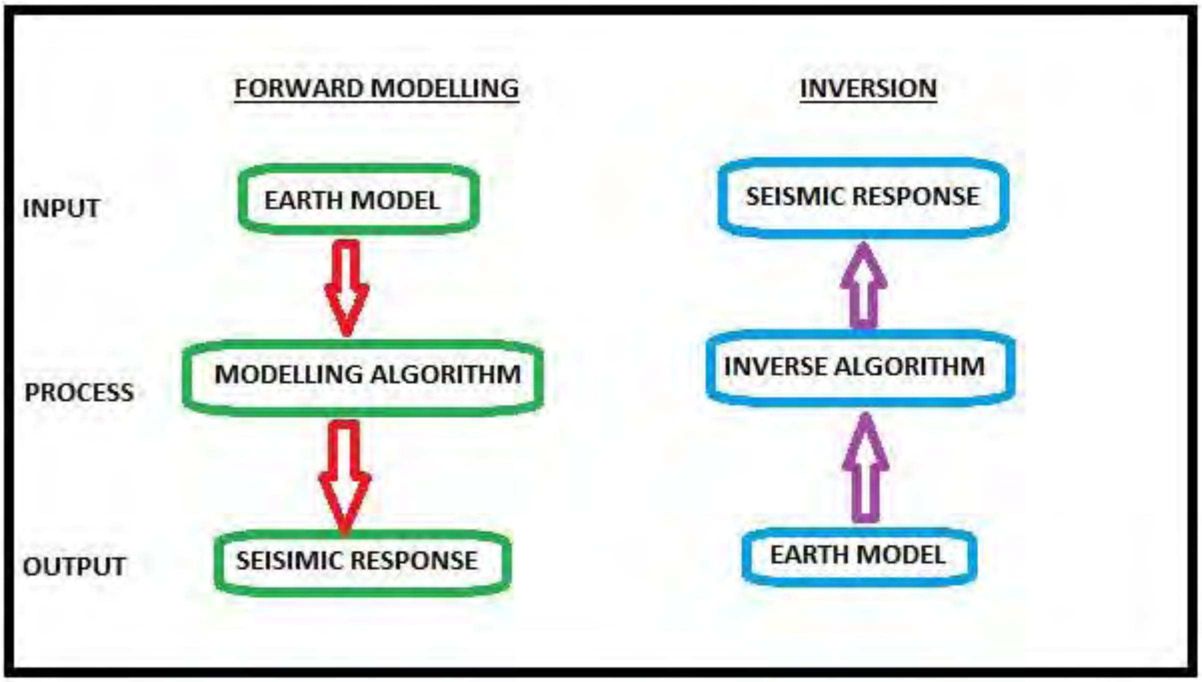

Figure 6.1 General Workflow of Inversion

To better understand, here is process of convolution

6.2 Convolution process

Time domain: S(t) = R(t) * W(t) + Noise

Where, S(t) is seismic trace in time domain which has been obtained by convolving source wavelet with R(t) i.e reflectivity.

Frequency domain: S(f) = R(f) x W(f) + Noise

Where, in frequency domain convolutional sign is replace by a multiplication sign.

Convolutional model helps us in understanding the change in rock properties with change in waveform. At geological boundaries the magnitude of change in rock properties i.e. reflection coefficient determines how much of wavelet‘s energy is reflected to surface

6.3 Acoustic Impedance and Wavelet

Acoustic Impedance or AI is defined as the product of seismic velocity with density, which gives the basic physical property of the rocks. With the help of this we can predict the nature of rocks and change in lithilogies. Seismic traces are converted into pseudo-reflection-coefficient time series by appropriate initial processing, then into acoustic impedance by inversion of time series using the recursive algorithm (Lindseth, 1979).

Wavelet is defined as the wave pulse approximation (mathematical function) for a seismic source contains many frequencies and is time limited. Wavelet is both time varying and complex in shape. As earth acts as natural filter which converts spike into a long band-limited wavelet. The computation of this composite wavelet from the data provides a close approximation of the reflectivity series following the technique described by Rice in 1962. Wavelet enhances resolution for better imaging inversion of post stack data is common practice now. In post-stack inversion the trace emulates a zero-offset seismogram. Seismic data contains noise and this problem should be solved by removal of noise. Three inverse problems were identified.

- Estimation of wavelet when the reflection coefficient is known.
- Estimation of reflection coefficient or acoustic impedance when the wavelet is known.
- Simultaneous inversion for acoustic impedance of wavelet.

Colored inversion performs significantly better than other technique such as recursive inversion, and benchmark well against unconstrained sparse-spike-inversion. In this technique inversion results are obtained very quickly and effectively.

6.4 Methodology

For colored inversion following methods were adopt:

To obtain acoustic impedance (AI) we convolve velocity and density, velocity and density data were obtained from sonic (DT) and density (RHOB) logs respectively.

- Cross-matched obtained acoustic impedance with the input reflection data.
- Derive a single optimal matching filter, convolving this filter with the input data.

The phase of the operator is a constant -90^o which agrees with the simplistic view of inversion and the concept of a zero phase reflection spike being transformed to a step AL interface, provided the data are zero-phase. As Walden and Hoskin 1984 empirical observation indicates that inversion can be approximated with a simple filter and that it may be valid over a sizeable area.

6.5 Wavelet Extraction

The wavelet is shown in Figure 6.2 is extracted based on 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 by applying different limitations.

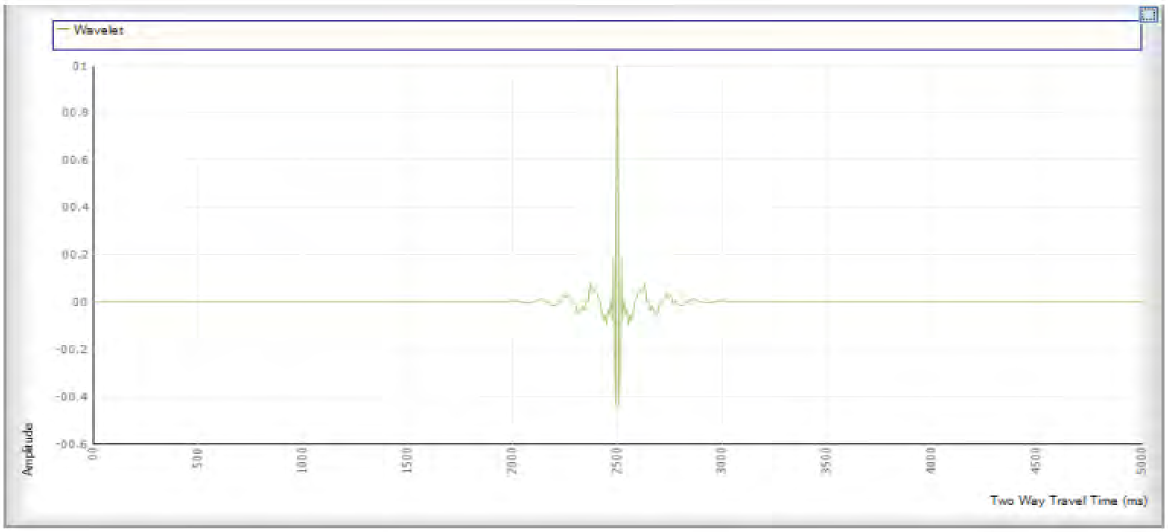

Figure 6.2 Extracted wavelet

6.6 Estimation of Impedance

Now we convolve the extracted wavelet with acoustic impedance such that reflectivity series. We assume that the as input given seismic cube is zero phase, which is not in general. The acoustic impedance is also computed from well log data. The impedance spectrum obtained is estimated after removing source wavelet and noise also.

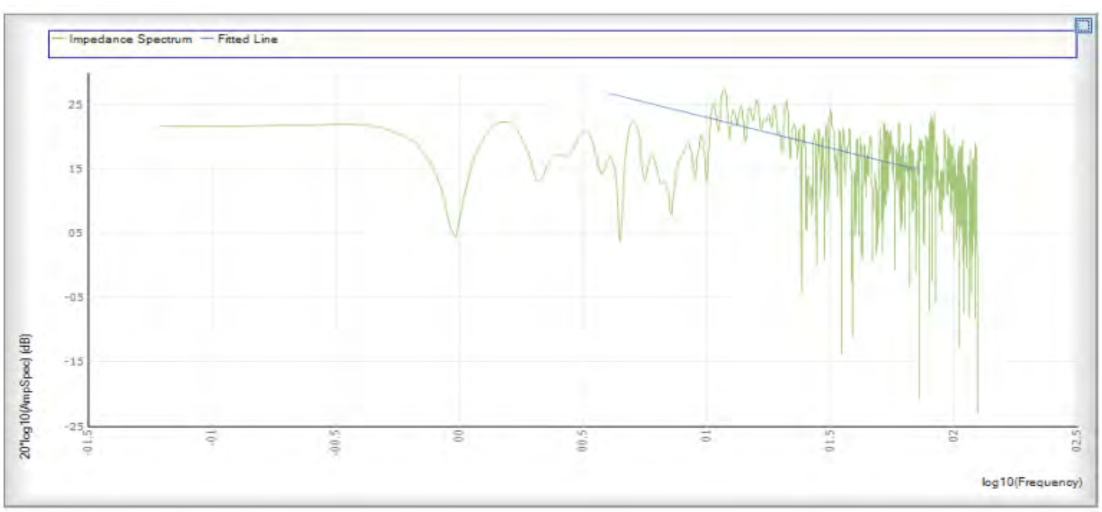

Figure 6.3 Impedance Spectrum

6.7 Butterworth Filter

The Butterworth filter is a type of signal processing filter designed to have as flat a 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.

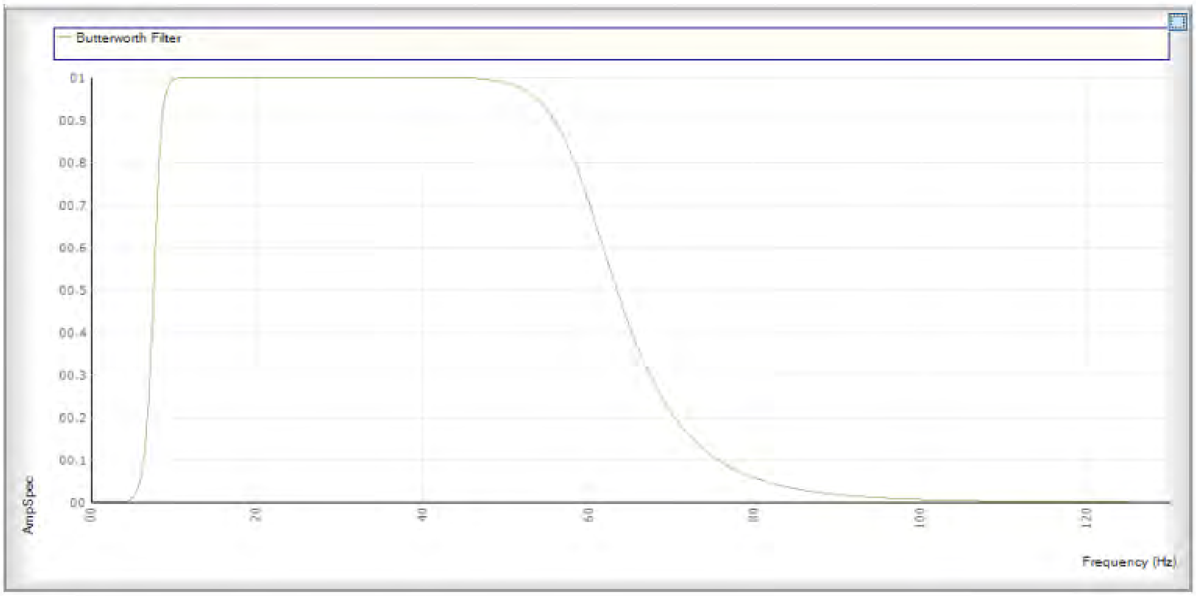

Figure 6.4 Butterworth filter

An operator is designed bringing the seismic amplitudes in correspondence with those seen in the well. This operator is subsequently applied to the whole seismic cube (Lancaster and Whitcombe, 2000). 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.

There are two spectrums shown in Figure 6.5 both are of different colors. The blue color shows the spectrum obtained from convolution of wavelet and acoustic impedance and the spectrum in blue color shows a desired spectrum. Now we need to obtain a spectrum of our desire for this purpose we must convolve this spectrum with another spectrum known as shaping spectrum which is obtained by applying Fourier transformation on expected spectrum. The shaping spectrum is shown Figure 6.6.

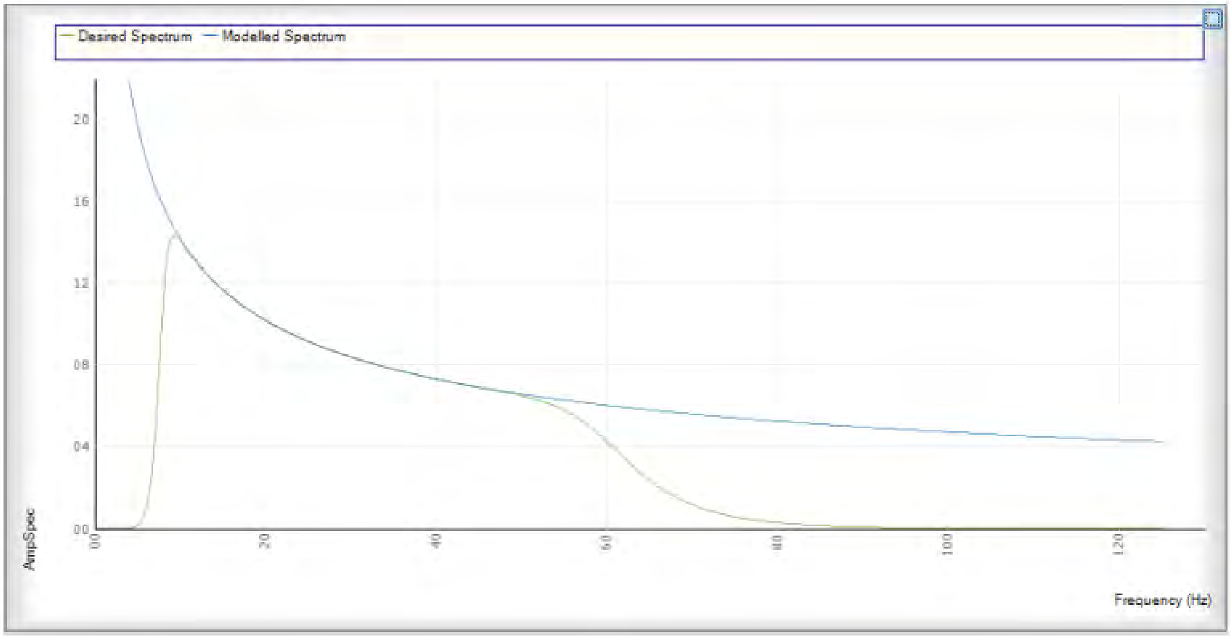

Figure 6.5 Expected and Modeled Spectrum

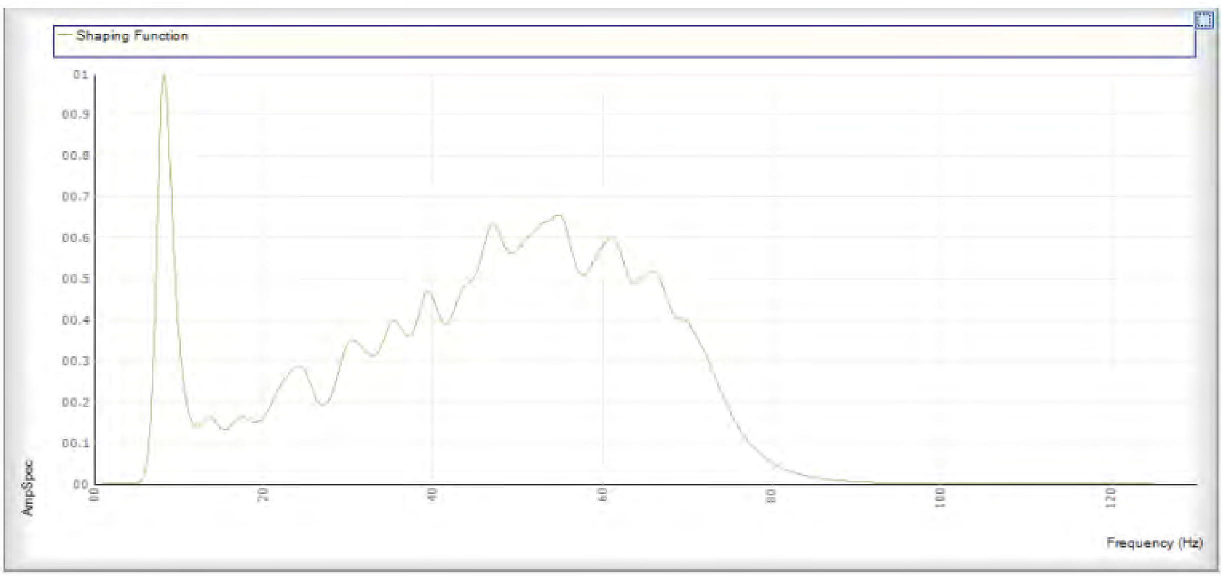

Figure 6.6 Shaping Spectrum that is obtained

A cross plot is made between the amplitude and the logarithm of the frequency to compute the operator. A linear fit is performed to calculate an exponential function and this serves as a shaping filter (Walden and Hosken 1985, Velzeboer 1981). The figure 6.7 shows us the shaped seismic spectrum and desired seismic spectrum

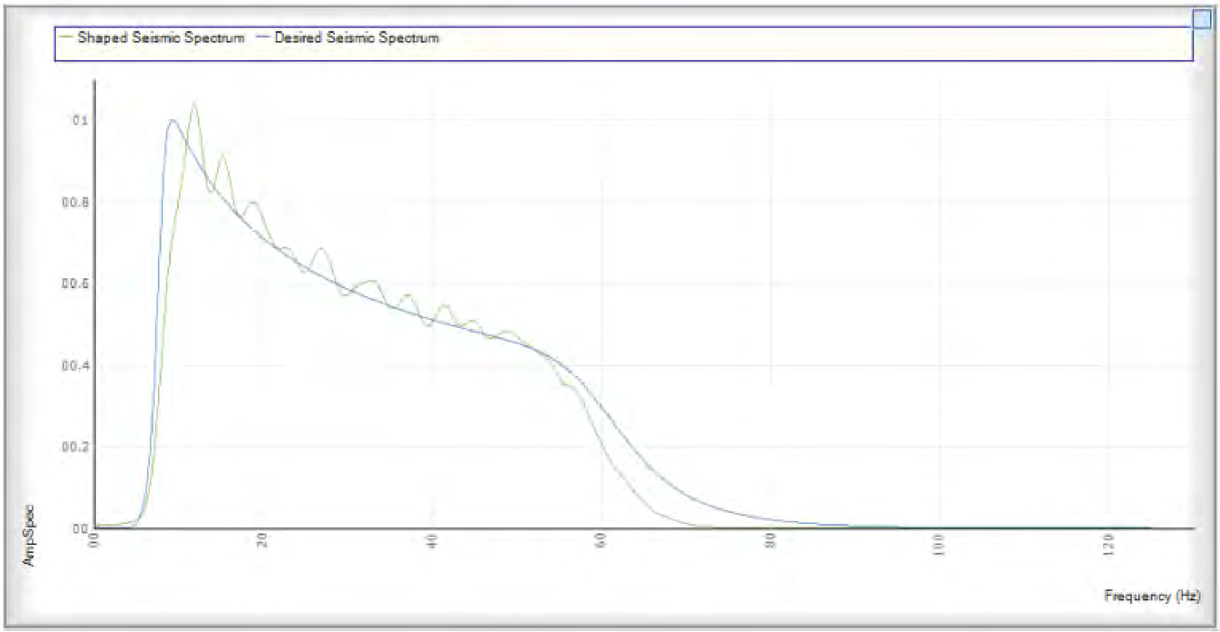

Figure 6.7 Seismic Spectrum and Desired Spectrum

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 7.8 shows seismic mean spectrum and desired spectrum.

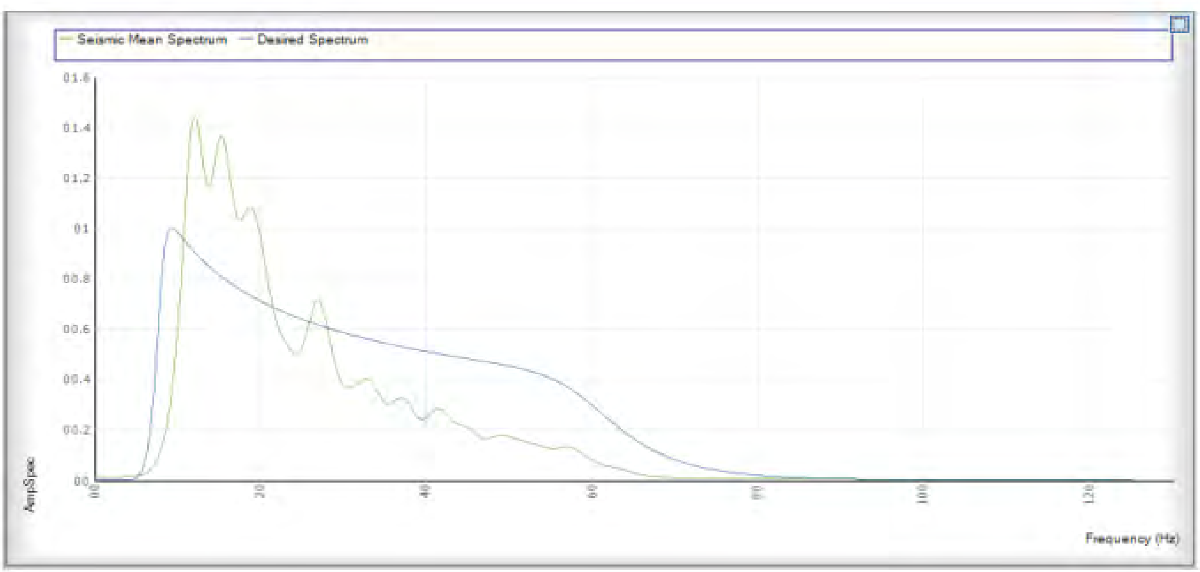

Figure 6.8 Seismic Mean spectrum and desired spectrum convolution

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 7.9

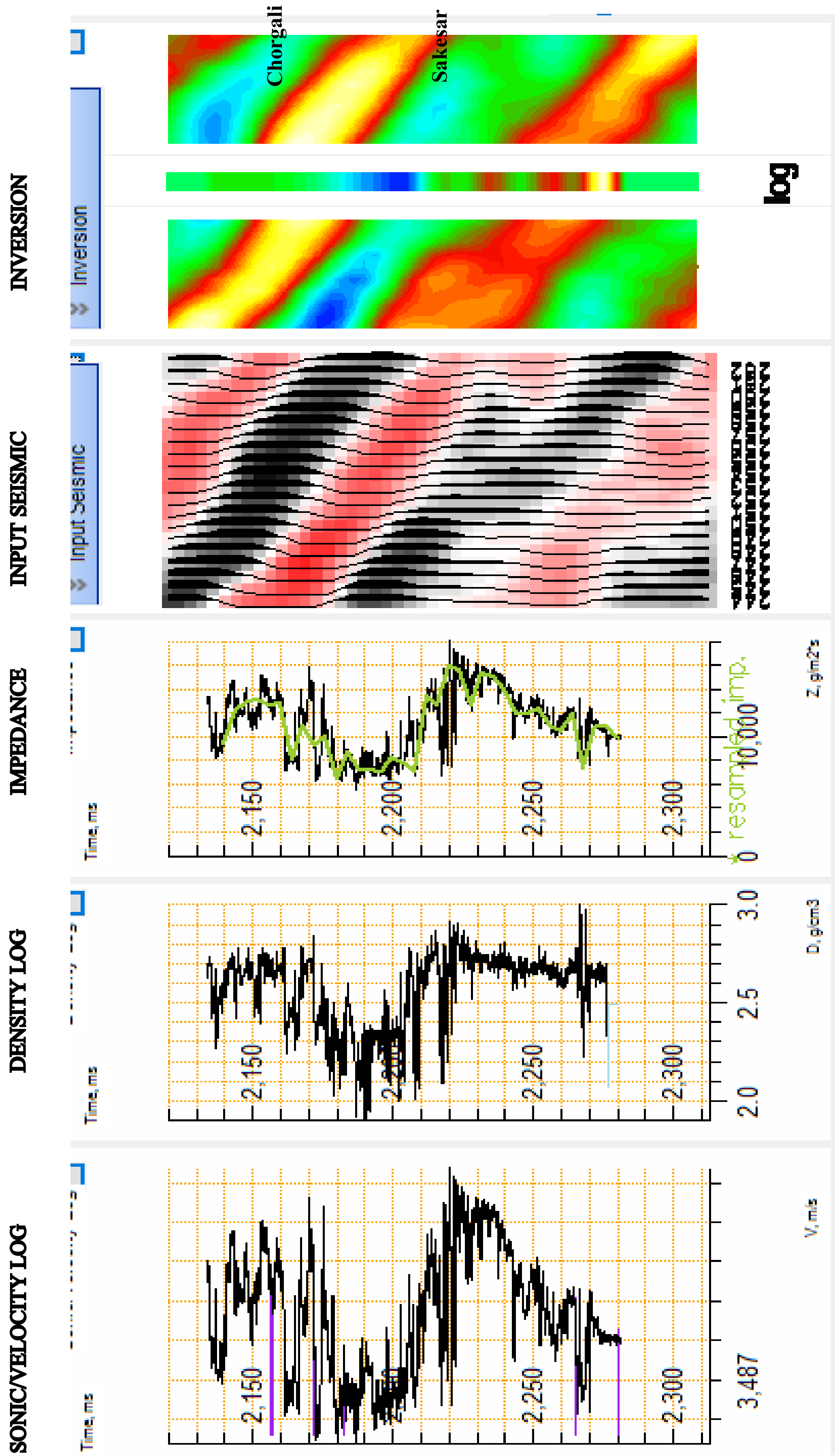

Figure 6.9 Input seismic trace, trace from well log and inverted section

In the above figure we have logs of sonic (DT) and density (RHOB), these are used for obtaining acoustic impedance (AI). 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. 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.

6.8 Interpretation of Inverted section

After convolution of seismogram with mean spectrum an inverted seismic section is generated as shown in the above Figure 6.9. The inverted section can be interpreted by using color bar. The white to yellow color shows high values of acoustic impedance and blue to green color 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 Chorgali Formation, which yields a response of low acoustic impedance it is related to presence of hydrocarbon accumulation it is also confirmed from Petrophysical results.

The Chorgali is interpreted as main producing reservoir in Meyal area. Because results obtained from seismic inversion shows low values of impedance with pop-up structure, these both conditions give indication for presence of hydrocarbons. Figure 6.10 also confirms our results.

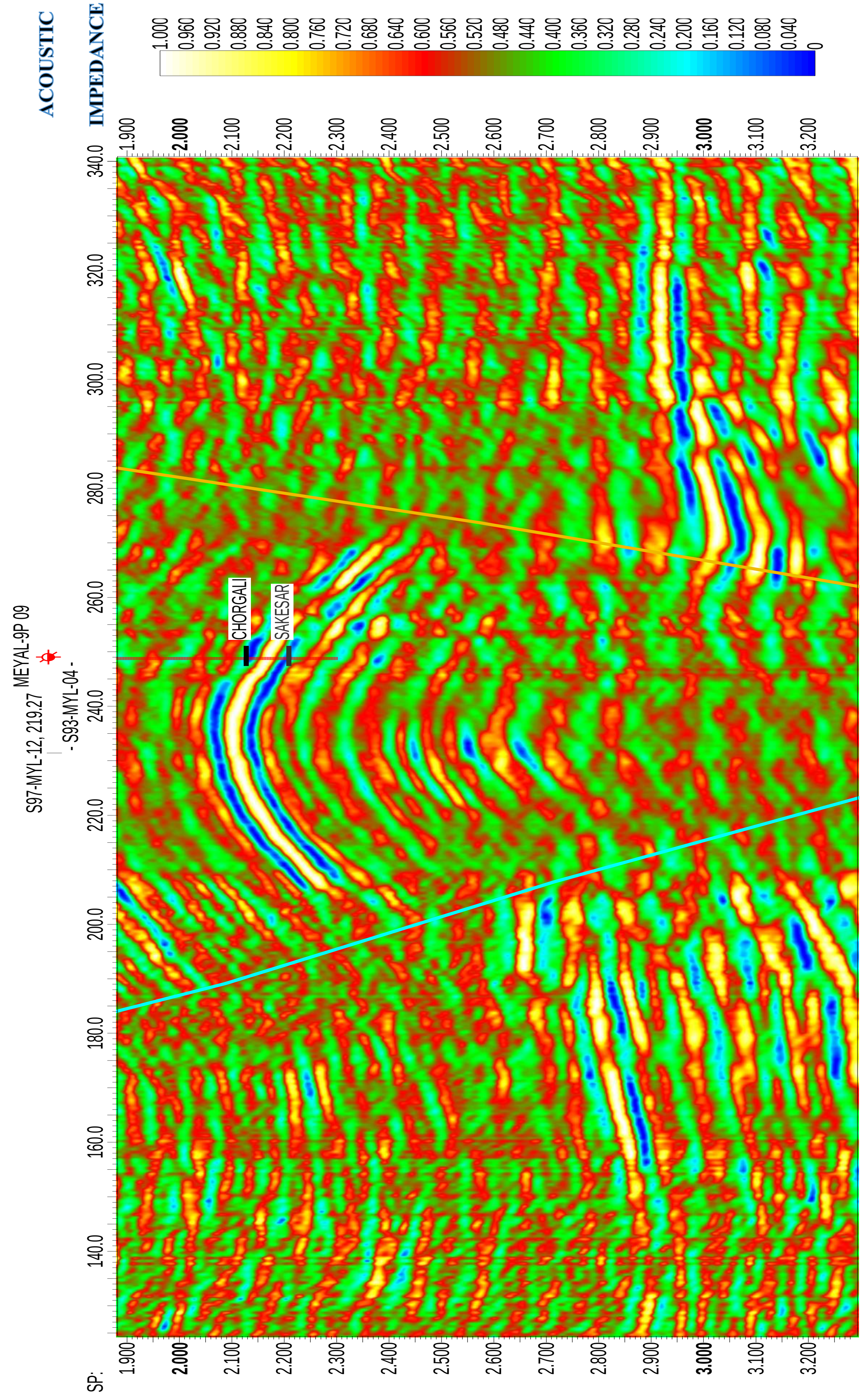

Figure 6.10 Inverted section of line 93-MYL-04 which shows contrast in impedance.

DISCUSSIONS AND CONCLUSIONS

Seismic data for this study gave us result of four seismic lines. Synthetic seismogram is generated using well logs and seismic data. Based on which two horizons were marked namely Chorgali and Sakesar. Overall interpretation of seismic lines shows pop-structure and proved presence of structural trap in area which is also confirmed by time and depth contour maps.

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 Meyal-9P for Chorgali and Sakesar Formations in order to depict the favorable zones and overall Chorgali has good reserves. Facies analysis of well Meyal-9P.

Colored Inversion is used for developing the relationship between seismic data and well logs, to improve resolution and to calculate accurately rock properties. Very clear low impedance has been achieved by inversion which proved presence of hydrocarbons in marked horizons.

Following result have been concluded:-

- On seismic section there is a visible pop-up structure interpreted.
- Attributes also aided the marked horizons.
- Petrophysical results have shown that Chorgali and Sakesar formation has good potential of hydrocarbons.
- Colored Inversion gave us very low acoustic impedance in marked horizons as well.

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