CERTIFICATE OF APPROVAL

This dissertion submitted by ALIZA TAHIR D/O TAHIR MEHMOOD 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 BS degree in Geophysics.

RECOMMENDED BY

Dr.M.GULRAIZ AKHTAR ____________________

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EXTERNAL EXAMINER ____________________

2D-Integrated Seismic Interpretation with Petrophysical Analysis, Rock Physics Based Facies Analysis and Velocity Modeling of MissaKeswal Area Upper Indus Basin of Pakistan

BY

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2016-2020

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Certificate of Approval

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بسم الله الرحمن الرحيم

To start with the greatest name of Almighty Allah. Most gracious and merciful,with Him is the knowledge of Hour,He sends down the rain,and knows that which is in the wombs. The One whose blessings are unlimited and The One whose blessings are eternal and the Knower of unseen and peace be upon Muhammad (S.A.W.W),

DEDICATION

Dedicated to my beloved parents and my brother whose love ,encouragement, guidance and prayers make me able to achieve such success and honor.

Acknowledgement

In the name of Allah, the most beneficial and merciful. All praises to Almighty Allah the creator of universe .I bear witness that there is no God but Allah and Holy Prophet Muhammad (P.B.U.H) is the last messenger of Allah, whose life is a perfect model for the whole mankind till the day of judgement .Allah blessed me with knowledge related to earth. Without the blessing of Allah, I could not be able to complete my work as well as to be at such a place.

I am indebted to my honorable supervisor **Dr.M.Gulraiz Akhter** for giving me an initiative to this study .I express my sincerest appreciation to my advisor Dr.Khalid Amin Khan (Oil and Gas Development Company Ltd), for his guidance in preparation of this thesis. He helped me in all aspects of work, moral and technical support which was very valuable for my work.

I specially acknowledge the prayers and efforts of my whole family who supported me throughout the study.

I would like to thanks wholeheartedly to my friends Aiman Nisar and Muzammil Riaz with whom I spent the best days and for always being there for me whenever I wanted.

Aliza Tahir

November 2020

Abstract

MissaKeswal area is a part of Potwar sub-basin of Upper Indus Basin of Pakistan which is known for hydrocarbons and structural traps. The present study pertains to integrated seismic interpretation, petrophysical analysis coupled with rock physics techniques with facies analysis and subsurface velocity model building of MissaKeswal area. Work has been done on three lines along with nine seismic lines of group fellows along with their navigation and velocity data and well logs data of one well. .For Interpretation of seismic data Licensed softwares are used .Three formations have been marked on prominent wiggles and named as Lockhart ,Chorgali and Sakesar along with the faults marking to examine the subsurface structures. Pop-up structures can be seen in marked seismic section. Time and Depth contour maps are generated to view the resulting picture of interpreted horizons. Pop-up structures act as a trap in the area, which is considered best for hydrocarbon accumulation.

Petrophysics and Rock physics analysis along with facies modeling are performed on MissaKeswal-03 and different zones of interest are identified where there is a chance of presence of hydrocarbon. Finally RSM Seismic Velocities have been used to generate a complex velocity model that has been used in 2D Seismic modeling.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Hydrocarbons plays vital role in the growth of any country and have wide uses at smaller scales in everyday life as well. Geophysicists have been trying for hydrocarbon exploration since a long time ago and developed many techniques in this regard. Seismic method is direct result evaluating and accurate geophysical method used for litho-structural analysis especially; Seismic Reflection Method has greater precision than seismic refraction method for deep hydrocarbon exploration in petroleum geology .Petroleum geology refers to the specific set of geological disciplines that are applied to search for hydrocarbons.

The seismic method is rather simple in concept. In which an energy source is used to produce seismic waves (similar to sound) that travel through the earth and the motion or pressure variations to electricity which is recorded by electronic instruments (Gadallah & Fisher, 2009).

Pakistan has a high potential of hydrocarbons and consists of three major sedimentary basins (covering more than $2/3^{rd}$ of its area) namely, Indus Basin in the east, Baluchistan Basin in the west and Pishin basin in the northwest. Indus and Baluchistan basin are separated by Ornach Bela transform fault zone and the Pishin basin lies between Indus and Chamman transform fault. A variety of sub-basins, fold belts and monoclines with variable structural styles resulting from diverse geodynamic conditions have been identified in Baluchistan Basin and Indus Basin (Kadri, 1995). Indus is the only producing basin of Pakistan where 83 oil and gas fields have been discovered. The Indus Basin covers an area of about 533,500 Km^2 and contains more than 15,000m thick sediments ranging in age from the Precambrain to recent. This giant basin has been divided into three compartments based on structural highs namely, The Jacobabad Khairpur High, Mari Khandkot High (Sukkur Rift) and the Sargodha High (Kazmi & Jan, 1997). Indus basin is divided into Upper Indus Basin, Middle Indus or Central Indus Basin and Lower Indus or Southern Indus Basin.

The first commercial discovery made in Potwar sub-basin in 1914, was the Khaur Field by Attock Oil Company. Since then this area has been viewed as an area of great interest for hydrocarbon exploration (Kemal et al.,1991). The MissaKeswal field was discovered in June 1991 and came on a regular production from December 1992. Geologically, it lies in the Upper Indus which is characterized by large numbers of thrust and normal faults producing asymmetrical structures (anticlines/ synclines).

1.2 Introduction to study Area

The geographical location of MissaKeswal is near Dina 17.7 kilometers north west of city of Jhelum on longitude of 73’58‖E and latitude of 33’2‖N.It is linked with Dina on one side and Rawalpindi on the other by the Grand Trunk Road and the north western railway both running from Peshawar to Lahore. The climate of the area is hot in summer and dry cold in winter. The imagery has been obtained from the Image Base databank developed using the Projection Independent Multi-Resolution Imagery Tiles Architecture (PIMRITA) (Khan et al., 2008) (Fig 1.1)

Fig 1.1: Satellite image of Pakistan showing MissaKeswal area (Khan et al; 2008)

1.3 Objectives

The main objectives of this dissertation based on interpretation of seismic section are:

- 2-D Structural interpretation to find out the structural traps and horizons of the formation.
- Petrophysical analysis for the identification of the hydrocarbon bearing zones.
- Rock Physics analysis for computation of elastic properties and facies modeling.
- Create subsurface Velocity model that can be used for 2D seismic modeling.

1.4 Data used

Three seismic lines were selected for study the area. The data was acquired by OGDCL in Sep 1999. Table 1.1 shows the seismic lines that were used in the study and Table 1.2 gives the well details.

Table 1.1. Seismic lines provided for interpretation

Line Name	Line Type	Line Orientation
GNA- 10	Dip Line	NW- SE
GNA-16	Dip Line	NW- SE
GJN-15	Strike Line	NE–SW

1.5 Data Format

The data set used extensively in preparing this dissertation contained data regarding.

- SEG-Y
- LAS
- Navigation
- Velocity Data.

1.6 Base Map

The base map is important component of interpretation, as it shows the spatial position of each picket of seismic section. For a geophysicist a base map is that which shows orientations of seismic lines and specify points at which seismic data were acquired or simply a map which consist of number of dip and strike lines on which seismic survey is being carried out. A base map typically includes location of lease and concession boundaries wells,seismic survey points and other cultural data such as building and roads with geographic reference such as longitude and latitude.

Following 2-D reflection seismic lines are used to construct the Base map of 2-D seismic survey for given study area as shown in Fig 1.2.

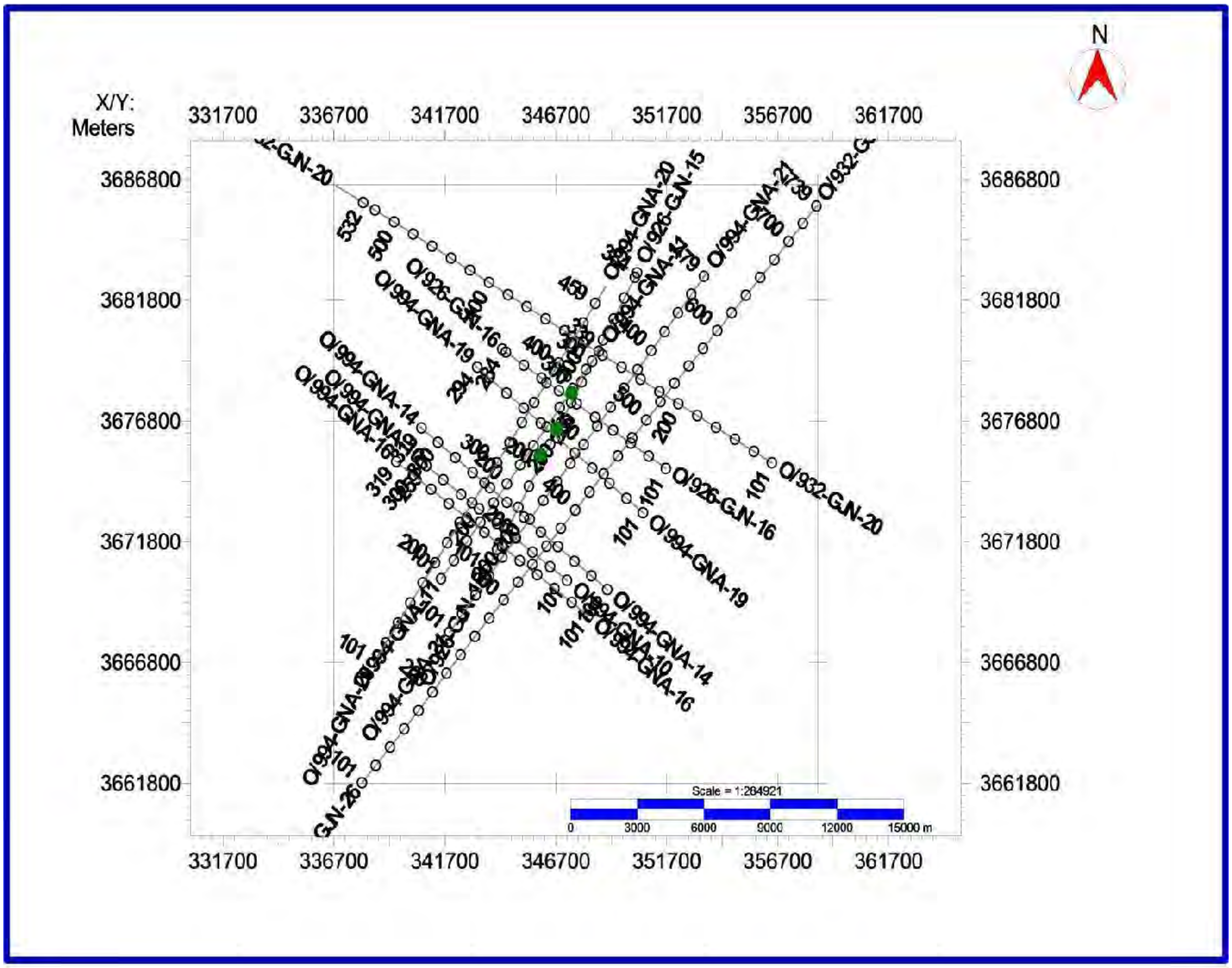
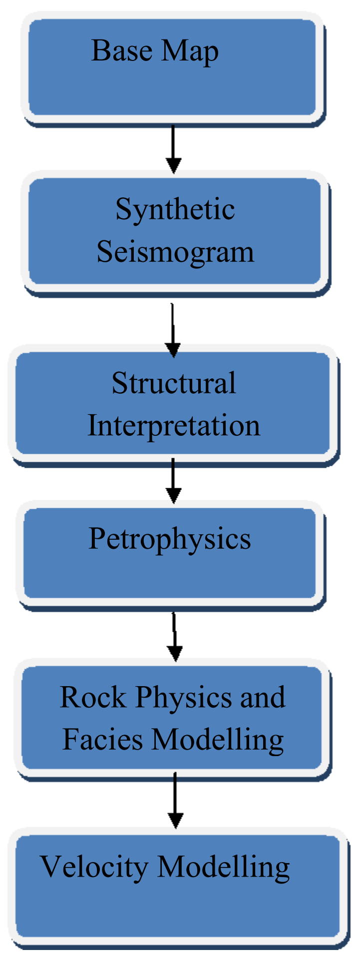


Fig 1.2: Base map of study area

1.7 Methodology

Seismic reflection data of the Upper Indus Basin of MissaKeswal area is given in order to interpret the sub surface structures and other properties. In this practice, software **Kingdom 8.8** was used for structural interpretation. For this purpose seismic lines data were uploaded on kingdom, synthetic seismogram was generated, from well. After that faults and horizons were marked on seismic section, polygons were developed and time and depth contours were made. Petrophysical analysis have been done by using software **Geographix** for the identification of hydrocarbon bearing zones. Rock physics and Facies modelling were performed using **Wavelet** software. Velocity models were developed using software **K-tron X-Works**. Root mean square velocities were used for generating velocity models. The brief methodology workflow is shown below.



Workflow of analysis carried out in this study

1.8 Softwares tools and Applications

The following software tools have been used for interpretation, analysis and workflows carried out in this thesis.

1.8.1 SMT Kingdom 8.4

- Structural Interpretation
- Synthetic Seismogram

1.8.2 Geographix

- Petrophysical Analysis

1.8.3 Wavelets

- Rock physics
- Facies Modelling

1.8.4 K-tron X Works

- Velocity Analysis
- 2D Seismic Modelling

Chapter 2

General Geology and Stratigraphy of the Area

2.1 General Geology of Potowar Plateau

Pakistan possess the northwestern boundary of Indian lithospheric plate. The under thrusting of Indian plate beneath Eurasian plate is producing compressional thick skinned tectonic features since Eocene time on north and northwestern fringes of Indian plate .The continued under thrusting of Indian plate since cretaceous produced the spectacular ranges of the Himalaya and a chain of foreland fold-and-thrust belts as thick sheets of sediments thrusted over Indian craton.

In Northern Pakistan, the Himalayan trend is divided into four major subdivisions. Karakoram ranges and Hindukush lie in north of Main Karakoram Thrust (MKT). South of MKT and north of(MMT) Main Mantle Thrust lies the Kohistan-Ladakh block. Low ranges of Swat, Hazara and Kashmir that are analogous to the Lesser Himalayas of India lie between MMT and Main Bounding Thrust (MBT). The outlying potowar plateau bounded on the south by the Salt Range Thrust (SRT) represents the marginal foreland fold-and-thrust belt of Indo-Pak Subcontinent.

Thrusting in Indian plate is certainly the main accommodation method of shortening in the Himalayas Fault plane solutions of earthquakes gives evidence that these are linked to thrusts .However ,in the northwestern Himalayas (the study area is a part of which) complications arise as earthquake fault planes do not follow the thrusts which change in orientation suggests that other accommodation features besides simple thrusting are occurring in the northwest Himalayas.

2.2 Regional Geology

Pakistan comprises of three main geological subdivisions referred to as Laurasian ,tethyan and Gondwanaland domains (Kazmi,et,al,1997). Late Paleozoic is considered to be their origin.All the Continents had drifted apart to form a super Continent known as Pangea .By late Triassic ,Laurasia drifted to north and and Gondwana to south separated by Tethys seaway resulting in split up og pangea . Pakistan is located at junction of Gondwanian and Tethyan domain.

2.2.1 Tectonic framework of Pakistan

Tectonics of Pakistan is characterized by two active convergent boundaries;

(a) In the northeast there is an active continent-island arc-continental collision boundary .the west end of Himalayan origin.

(b) In the southwest there is an active boundary of oceanic lithosphere subducting arc trench gap sediments and continental sediment , the oceanic part of Arabian plate passing under the Makran arc-trench gap.

These two convergent boundaries are connected by a very large displacement north-south left lateral strike slip faults of Chaman-Transform Zone.

2.2.2 Tectonic zones of Pakistan

Based on plate tectonic features, geologic structure, orogenic history and lithofacies, Pakistan may be divided into following tectonic zones.

(a) Indus platform and foredeep, East Baluchistan fold-and-thrust belt.
(b) Northwest Himalayan fold-and-thrust belt
(c) Kohistan-ladakh magmatic arc
(d) Karakoram block
(e) Chagai magmatic arc
(f) Pakistan offshore

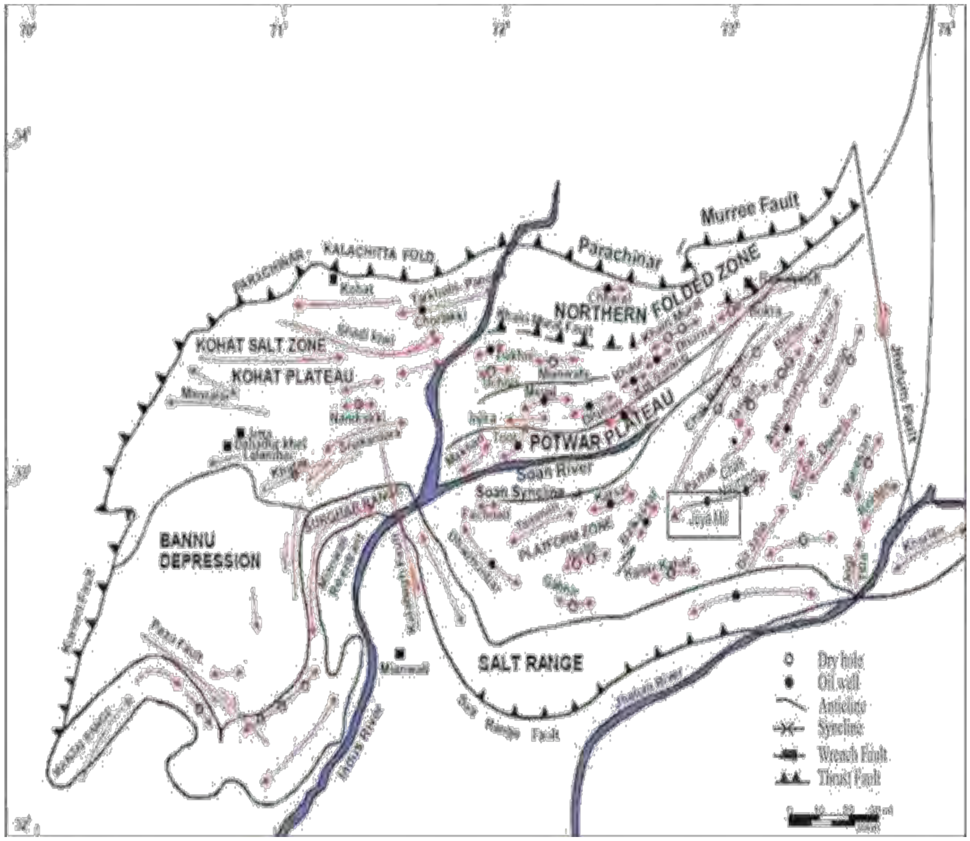


Fig 2.1: Tectonic division of potowar basin

2.3 Sedimentary Basins

Basin is an area characterized by regional subsidence in which sediments are preserved for the longer period of time. Basins' receptacle or container, which is basin; substratum, is known as its basement. The Container is filled with the sediments accumulated that rest on basement are known as sedimentary cover. The gradual setting of basin is called subsidence. Sediments originate at a certain place. These sediments may be deposited at the same place or may be transported to some other place by transporting agents. The sediments deposited at the same place are called molasses deposits. The transported sediments rest on the basement of a basin and form a sedimentary cover.

2.3.1 Indus Basin

The geological history of Indus basin goes back to Precambrian age. The Paleotopographic features, shown on the gravity map, influenced, to a large extent, the depositional processes throughout the basin development. These features also marked the limit of the basin and its divisions. The ongoing tectonic processes further enhanced and modified the configuration and gave rise to sonic new ones creating an array of modern basis. The first split up of the super continent Pangea which disturbed the equilibrium happened in Jurassic. Indus Basin is classified as follows;

(a) Upper Indus Basin

(i) Kohat sub-basin

(ii) Potwar sub-basin

(b) Lower Indus Basin

(i) Central Indus basin

(ii) Southern Indus basin

2.3.2 Upper Indus Basin

The basin is located in the northern Pakistan and is separated from the Lower Indus basin by Sargodha High. The northern and eastern boundaries coincide with the Main Boundary Thrust (MBT) the southern most of the major Himalaya thrust. The MBT runs through the Margalla Hills, Kala Chitta and Kohat Ranges. Western boundary of the basin is marked by an uplift of Pre-Eocene sediments and eastward directed thrusting to the west of Bannu. The basin is further subdivided into Potwar, to the east and Kohat, to the west by river Indus. Regardless of the small size of the Potwar and Kohat sub-basin they depict facies variation (Khan et al., 1986).

Potwar sub-basin preserves the sediments from Precambrian to Quaternary age in the subsurface and all of these are exposed in the Salt Range, a southern most thrust. The Tran-Indus ranges in south of the Kohat sub-basin expose sediments from Cambria to Pliocene age. Both Kohat and Potowar sub-basin are characterized by an unconformity between Cambrian and Permian. Mesozoic sediments are also exposed around the basin rim. However, this presence is governed by Pre-Paleocene erosion which progressively cut into older sequence from the Trans-Indus Ranges in the west to east Potwar through Salt Range. In Kohat sub-basin, west of the Potwar sub-basin, Eocene through Siwaliks strata are involved in a complex fold and thrust belt in which Eocene Salt occupies the cores of many of anticlines (Khan et al., 1986).

2.4 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:

(a) Northern Potwar Deformed Zone (NPDZ).

(b) The Platform Zone.

The NPDZ is in the south of Kalla Chitta Margalla Hills. It is structurally complex zone. In these areas Tertiary rocks are exposed along a series of south verging thrust faults (Khan et al., 1986). 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 (Khan et al., 1986). The Platform is further divided into three parts:

(a) The eastern Platform Zone.

(b) The central Platform Zone.

(c) The western Platform Zone

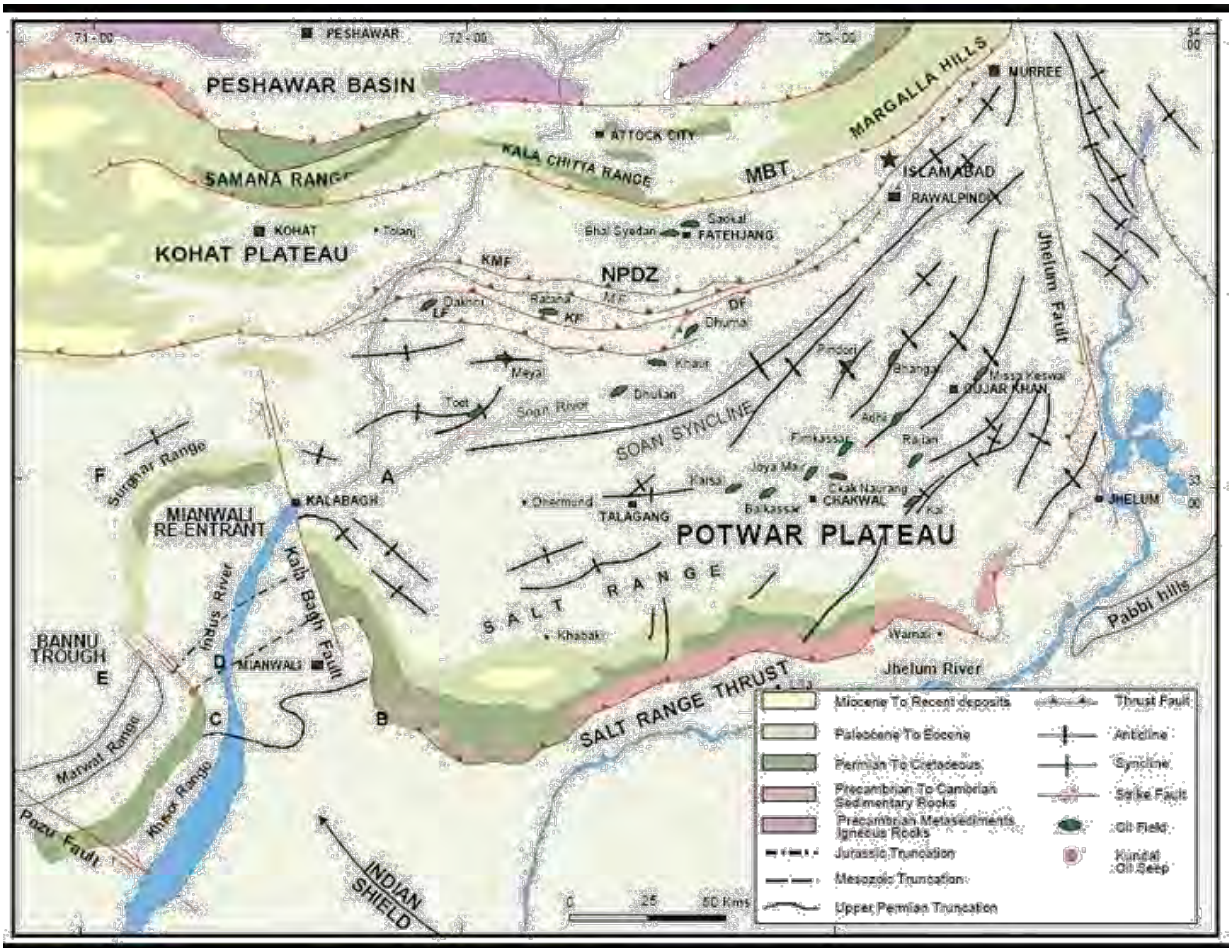


Fig 2.2: Geologic and structural division of Potwar Plateau(www.google.com)

2.5 Stratigraphy of the area

The Stratigraphy of the Salt Range and Potwar Plateau is well established from outcrops in the Salt Range. The stratigraphy in the NPDZ is not that well constrained due to lack of deep drilling. Surface outcrops along the MBT and seismic profile, however, suggest the stratigraphy of NPDZ is similar to that of the Salt Rang and Potwar Plateau. Stratigraphic succession of the Potwar Basin is characterized by thick Infra-Cambrian evaporite deposits overlain by relatively thin stratigraphic succession of the Eocene to Cambrian. Thick Miocene-Pliocene molasses deposits are related to severe deformation in Late Pliocene to Middle Pleistocene (During Himalayan orogeny).Formations, age, thickness and lithology is given in Fig 2.3.

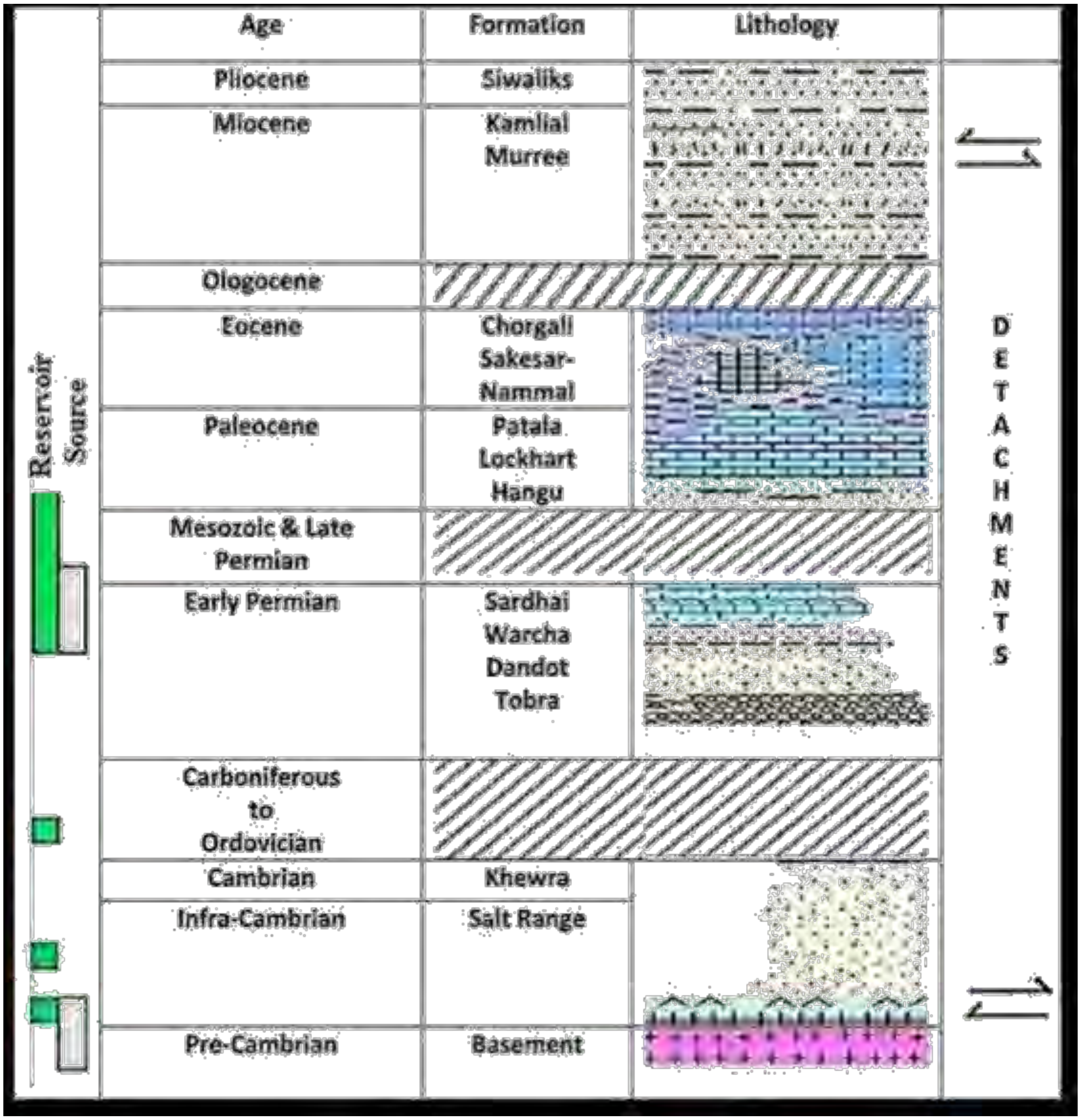


Fig 2.3: Stratigraphic column of upper Indus basin(google.com)

2.6 Petroleum Play of potowar

Potwar marine facies has great potential of hydrocarbon. Previous drilling was restricted up to Eocene carbonate. Recent discoveries in Potwar result in delineation of deep subsurface crest. (Kadri, 1995). Potwar region which is traditional oil producing area of Pakistan has the average geo-thermal gradient of the order of 2 degree celcius per100 meters. Hence the oil window lies between 2750-5200 meters. (Kadri, 1995).

2.6.1 Source and reservoir rock of potowar basin

Non-commercial oil has been encountered in the shale of Precambrian Salt Range Formation (in well drill in Dhariala, Kallar Kahar). In Cambrian the marine shale of Kussak, Jutana and also of Khisorformation has source potential for hydrocarbon. Oil is produced from Khewra Sandstone in Adhi field. In Permian, shale of Dondot and Sardhai and Limestone and Black shale of Zaluch group has source potential of oil. Reservoir potential of Permian is also good, as Adhi oil filed in Tobra/Dandot/Warcha., Dhurnal oil field in Amb and Wargal while Dhulian Well in Permian sandy Limestone. Triassic unit of Potwar having versatility in the environment of deposition that reason that can not act as a good source rock. Only the Khatkiara Member of Tredian Formation have good reservoir characteristic. In Jurassic the black clay and organic content of Data and some part of Shinawri Formation are believed to be good source rocks while Data is oil producing reservoir atMeyal, Toot and Dhulian oil field. Similarly Samana Suk Formation has also good reservoir characteristic. In Cretaceous Chichali Formation has good source potential due to abundant of organic material while Lumshiwal Formation is good reservoir having gas discovered in some area of Punjab Platform. In Paleocene Patala shale is major source in this region while the Paleocene reservoir is productive in all part of the Indus Basin like in Dhulian, Toot and Meyal. Early Eocene carbonate are good source and reservoir rock, Sakesar andChorgali having fractured Limestone having hydrocarbon potential in Adhi(PPL),Dhurnal(OXY), Dakhni(OGDCL) etc.

In Dhulian the Permian and Paleocene succession is quite thin. Carbonates of Chorgali and Sakesar Formations are major oil producing unit in this area. Moreover the sandstone of Murree Formation has also good potential. Sakesar is consisted of light gray, massive and partially dolomitized carbonated that locally contains the chert concentration. Chorgali Formation contains the creamy, yellow to yellow gray, silty,partially dolomitized and thin bedded limestone. Clay and shale of Murree Formation provides good vertical and lateral seal to these Eocene carbonates. (Geomodelling of Hydrocarbon of Potwar, (Shami & Baig, 1998).

2.6.2 Source rocks

The gray shales of the Mianwali (Triassic age), Datta (Jurassaic age) and Patala Formations (Paleocene age) are potential source rocks in Salt Range Potwar- Foreland Basin (SRPFB) (Khan et al, 1986). The oil shales of the Eocambrian Salt Range Formation include 27% to 36% total organic content (TOC) in isolated pockets of shales, and are considered as the source rock in SRPFB (Shami and Baig, 2003).

2.6.3 Reservoir rocks

The Cambrian, Permian, Jurassic, Paleocene and Eocene reservoirs are producing oil in Salt Range Potwar- Foreland Basin (SRPFB).Petroleum play reservoirs ranging in age from Infra-Cambrian to Miocene are present in the Kohat-Potwar foldbelt. The target reservoirs are clastics and carbonates of Infra-Cambrian, Lower Cambrian, Clastics of Permian, clastics of lower to middle Jurassic, clastic of lower Cretaceous, carbonates of upper Paleocene and lower Eocene and clastics of Miocene.

2.6.4 Cap rocks

Thick layers of evaporite and shale have good sealing potential for Infra-Cambrian reservoir. Interbedded shale, mudstone and siltstone provide seal to Cambrian reservoirs.Limetones and intraformational shales are the potential seals for the Cenozoic and Mesozoic reservoirs. Most of the fields discovered in Kohat-Potwar geological province to date are either due to overturned faulted anticlines, popup structures or fault-block traps. The latest trap-forming thrust event began at approximately 5 to 2 Ma (Jaswal, et al., 1997).

Chapter 3

SEISMIC INTERPRETATION

3.1 Seismic Interpretation

Interpretation is a technique or tool by which an attempt is made to transform whole seismic information into structural or stratigraphic model of the earth. Since the seismic section is the representative of the geological model of the earth, by interpretation, one tries to locate the zone of final anomaly (Sheriff, 1999).

Interpretation is the transformation of the seismic reflection data in to a structural picture by the application of correction, migration and time depth conversion (Dobrin and Savit, 1988). The computer based working (Processing & Interpretation) is more accurate, precise, efficient and satisfactory which provides more time for further analysis of data. This whole work is carried out using a combination of computer software products, which include all office Software suit and SMT Kingdom suit.

3.2 Types of Seismic Interpretation

There are two types of seismic interpretation

- Stratigraphical Interpretation
- Structural Interpretation

3.2.1 Stratigraphical Interpretation

Stratigraphy analysis involves the delineating of seismic sequences, which present the different depositional units, recognizing the seismic facies characteristic with suggest depositional environment and analysis the reflection characteristic variation to locate the both stratigraphy change and hydrocarbon depositional environment. Hydrocarbon accumulation is indicated by the amplitude, velocity, frequency or the change in wave shape. Variation of the amplitude with the offset is also an important hydrocarbon indicator. Unconformities are marked by drainage pattern that help to develop the depositional environment. Reef, lenses, unconformity are example of stratigraphy traps. (Sheriff, 1999).

3.2.2 Structural Interpretation

In structural analysis main emphases is on the structural traps in which tectonic play an important role. Tectonic setting usually governs which types of the structure are present and how the structural features are correlated with each other, so tectonic of the area is helpful in determining the structural style of the area and to locate the traps. Structural traps include the faults, folds anticline, pop up, duplex, etc. (Sheriff, 1999)

Seismic section can predict the structure that scale up to few tens of kilometers. For large scale interpretation, we have to use the grids of seismic lines.

3.3 Interpretation Workflow

The Interpretation was carried out using different techniques and steps with each step involve different processes which were performed using the software tools as mentioned above. Simplified workflow used in the dissertation is given in Fig 3.1; which provides the complete picture depicting how the dissertation has been carried out by loading navigation data of seismic lines and SEG-Y in HIS kingdom Software, base map was generated. Faults and Horizons of interest were then marked manually. Identification of marked horizons was done with help of synthetic seismogram, generated with help of well data and faults were marked by keen observation on seismic section and knowing geologic history of study area.

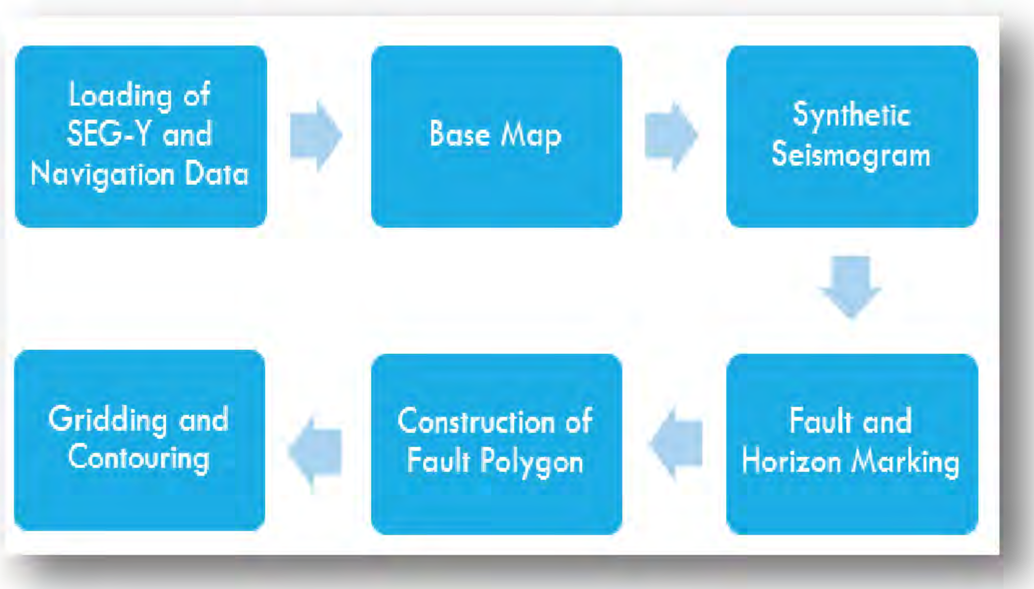


Fig 3.1 Workflow for seismic interpretation

3.4 Generation of synthetic seismogram

Synthetic seismograms provide a crucial link between lithological variations within a drill hole and reflectors on seismic profiles crossing the site. In essence, they provide a ground truth for the interpretation of seismic data. Synthetic seismograms are useful tools for linking drill hole geology to seismic sections, because they can provide a direct link between observed lithology's and seismic reflection patterns (Handwerger et al., 2004).

MissaKeswal-03 is the only well in our available data that having the DT and ROHB log to generate the synthetic seismogram. With the help of MissaKeswal-03 well, I construct the synthetic seismogram in order to mark the horizons.

The display of the synthetic seismogram is shown in the Fig 3.2.

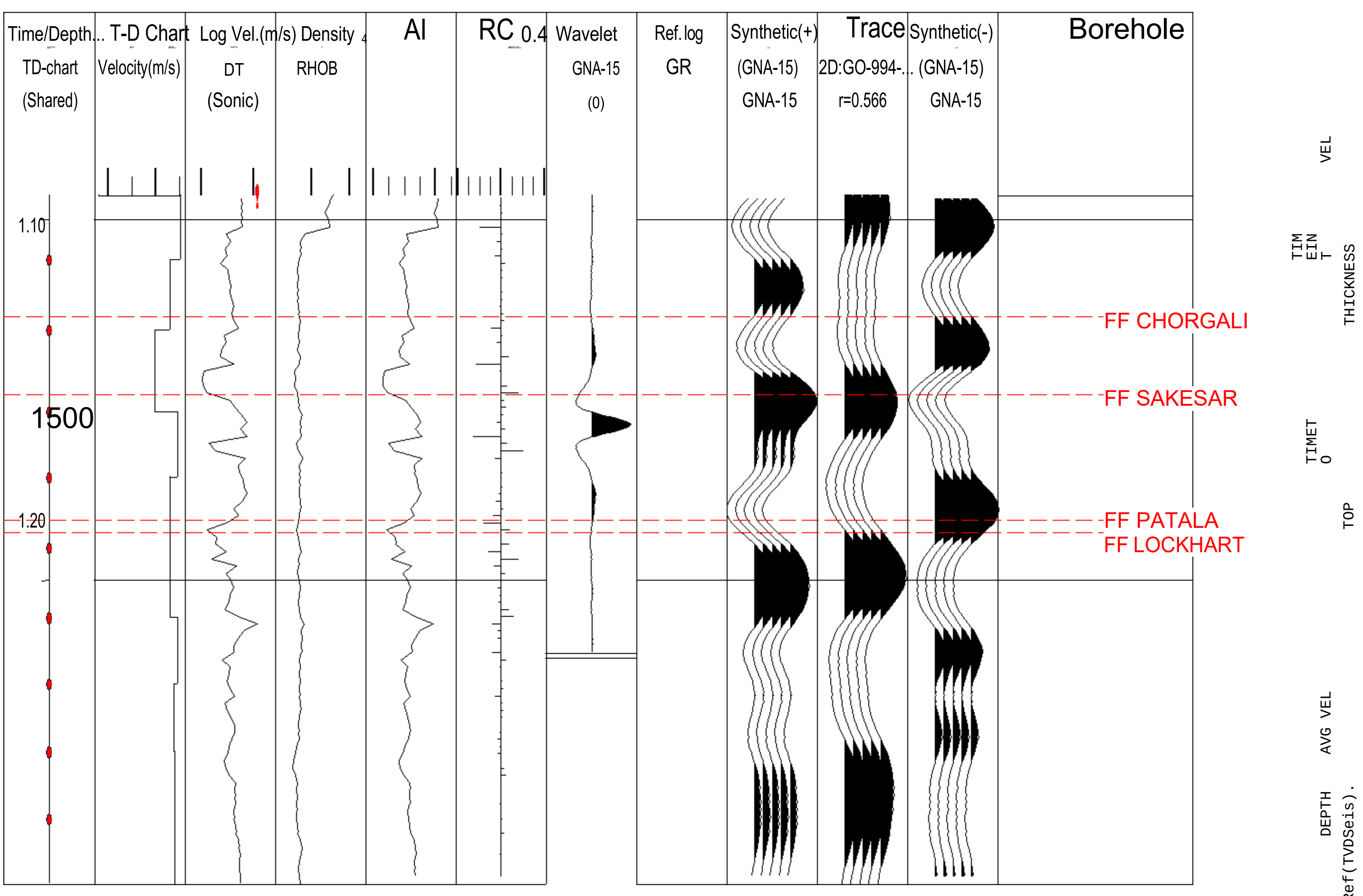


Fig 3.2 Synthetic Seismogram of Well MISSAKISWAL-03

3.5 Fault marking

Conventional seismic interpretations are the arts that require skills and thorough experience in Geology and Geophysics to be precise (Mc. Quillin et al., 1984). Fault marking on real time domain seismic section is quite a hard work to do without knowing tectonic history of Area (Sroor, 2010). Faults are marked on the basis of breaks in the continuity of reflection. This Discontinuity of the reflector shows that the data is disturbed here due to the passing of the faults. Reverse faults are seen in upper part of sections and Normal faulting in basement due to which anticline pop-up structures are formed which are good reservoirs of hydrocarbons.

3.6 Picking of Horizons

Interpreting seismic sections, marking horizons, producing time and depth maps is a task which depends on interpreter's ability to pick and follow reflecting horizons (reflectors) across the area of study (Mc. Quillin et al., 1984). Reflectors usually correspond to horizon marking the boundary between rocks of markedly different lithology but it does not always occur exactly at geological boundary of horizon which is sometimes important problem in seismic interpretations (Kemal et al., 1991). However basic aim in seismic section interpretation is picking a horizon, and mostly, reflections on the section represent a certain geological formation where change in acoustic impedance occurred and this is the seismic way to interpret subsurface stratigraphic features.

3.7 Interpreted Seismic Sections

The Prominent reflections that are present on the seismic section are marked, and then selected those that showed good characteristics and continuity and traced well over the whole seismic section.

Using well data of well MissaKeswal-03, Horizons are marked on seismic lines: Dip **line GNA-10,** Dip **line GNA-16** and Strike **line GNA-15**. The marked Horizons are CHORGALI, SAKESAR and LOCKHART formations on the basis of change in Acoustic impedance and also confirmed by Synthetic Seismogram.

The Interpreted seismic section of Dip line GNA-10 is shown in Fig 3.3.

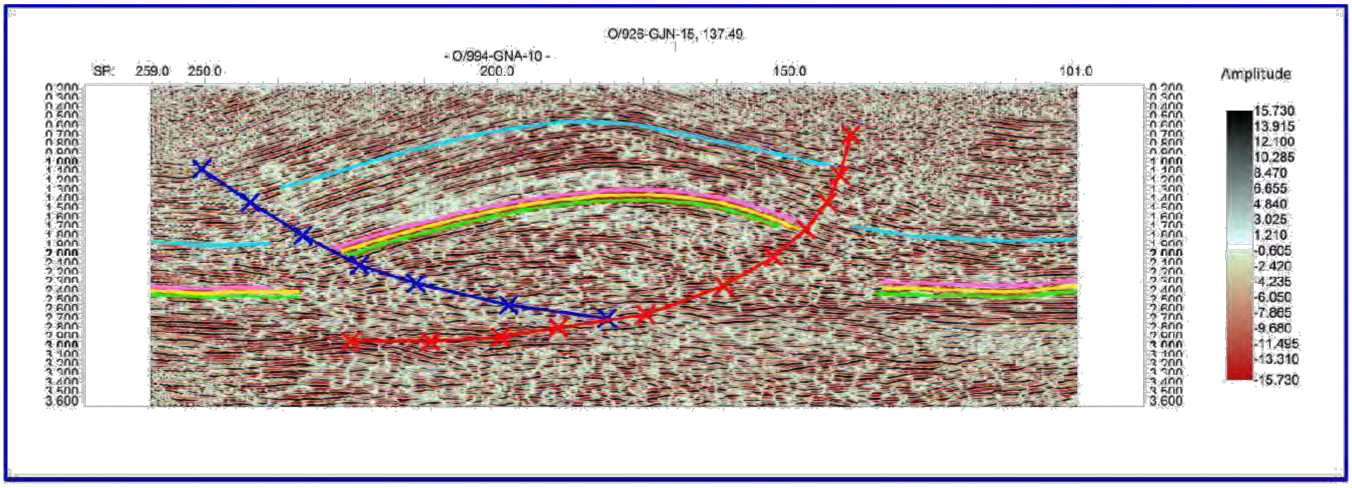


Fig 3.3 : Interpreted Seismic Section of GNA-10

Study area lies in compressional regime and structural interpretation occurred in upper Indus basin of Pakistan. There are difficulties in continuing the reflectors to the end of seismic section and confusions are arrived where reflectors are mixed that may be due to change in lithology, poor data quality seismic noise or presence of salt in subsurface at these locations.

On the basis of discontinuity reverse faults are seen in the upper part and normal faults in the basement. The interpreted seismic section of Dip line GNA-16 is shown in Fig 3.4. showing anticline pop-up structures. Its orientation extends from NW-SE.

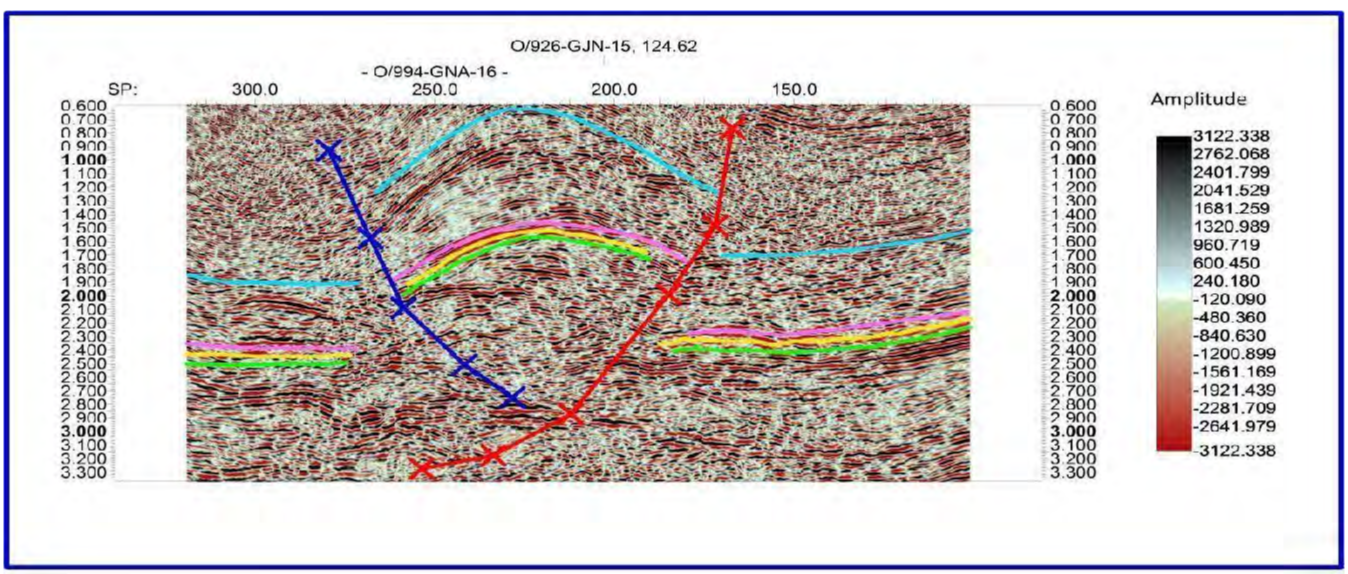


Fig 3.4 : Seismic section of GNA-16

The interpreted Seismic section of Strike line GJN-15 is shown in Fig 3.5.

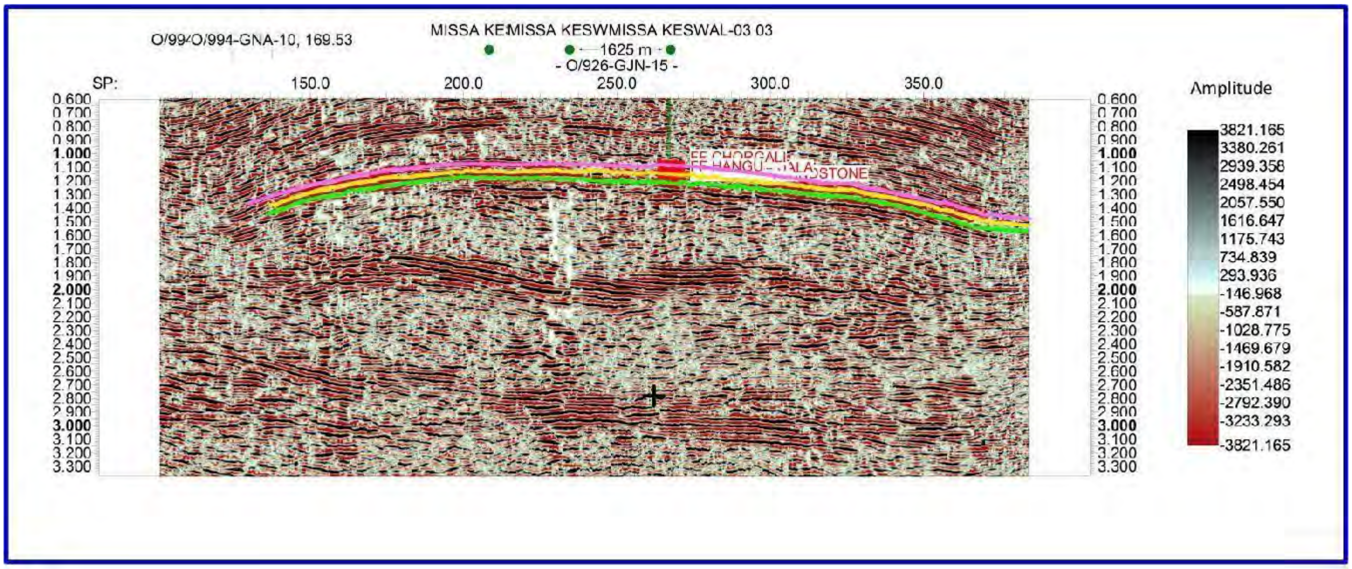


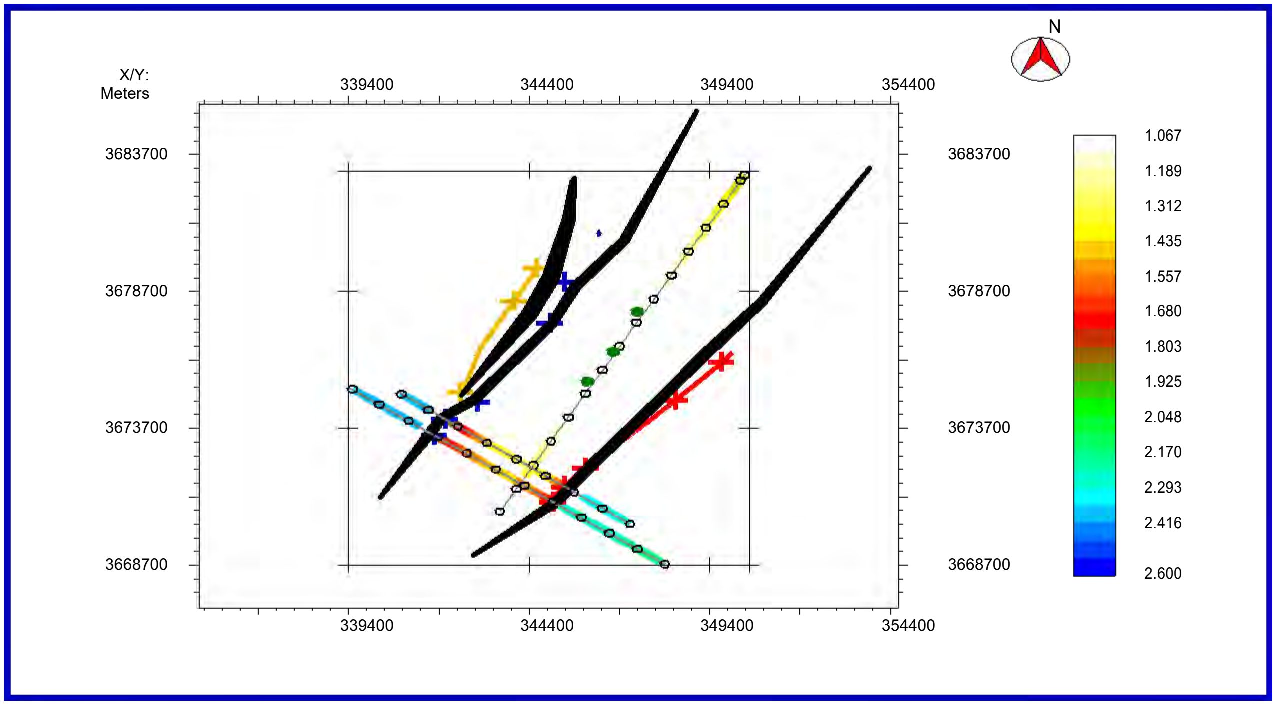
Fig 3.5: Seismic section of GJN-15

The marked section shows compressional regime characterized by thrust faulting and anticline structures. The line type is strike line and its orientation is from NE- SW. The given seismic line does not show any fault and the reason is that it is strike line and orientation is against basin configuration.

3.8 Faults Polygon Generation

A fault polygon represents the lateral extent of dip faults or strike faults having same trend. Fault polygons show the sub-surface discontinuities by displacing the contours. To generate fault polygons it is necessary to identify the faults and their lateral extent by looking at the available seismic data. If one finds that the same fault is present on all the dip lines, then all points on base map can be manually joined to make a polygon. Figs (3.6, 3.7 and 3.8), show that after construction of fault polygons, the high and low areas on a particular horizon become obvious. Moreover, the associated color bar helps in giving information about the dip directions on a fault polygon if dip symbols are not drawn. Fault polygons are constructed for all marked horizons and

. The reason is that if a fault is not converted into polygon, software doesn't recognize it as a barrier or discontinuity, thus making any possible closures against faults represents a false picture of subsurface structures and these are oriented in NE-SW direction



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3.6: Fault Polygon of Chorgali

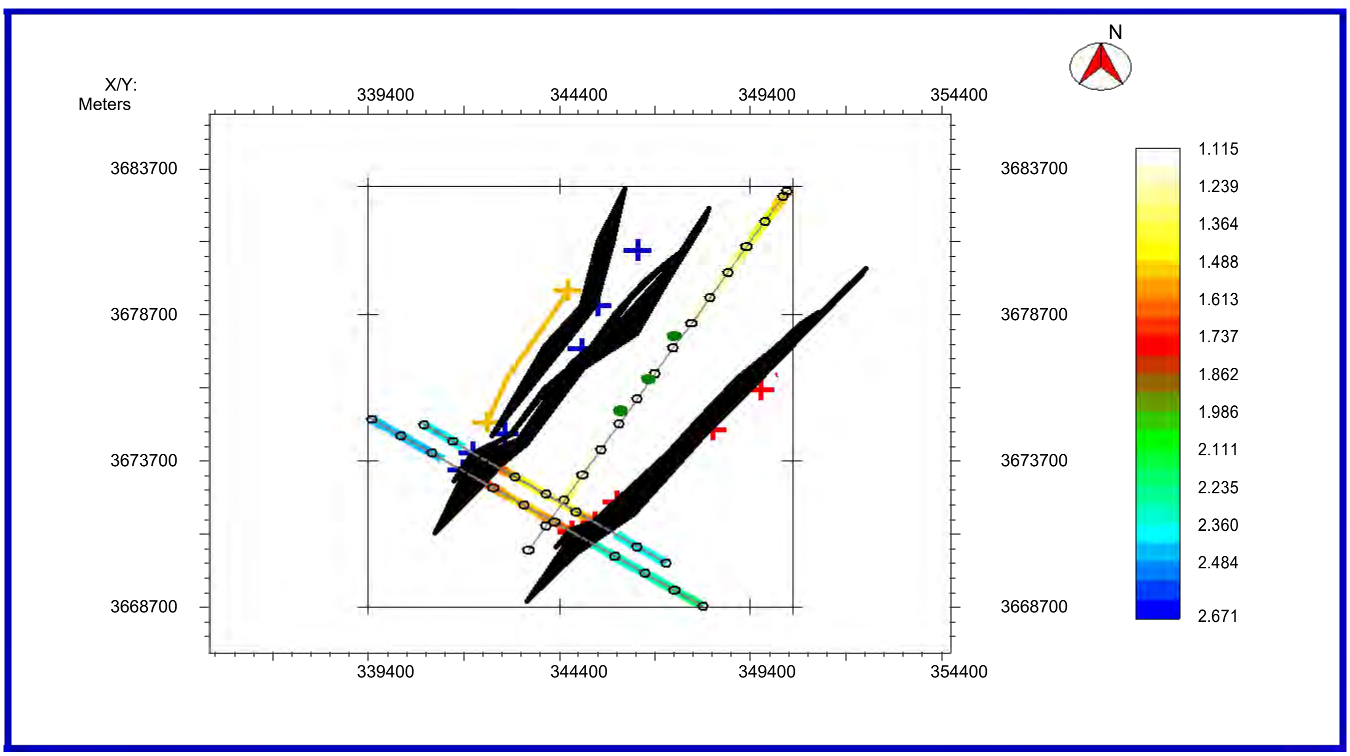

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Fig 3.7 Fault Polygon of Sakesar

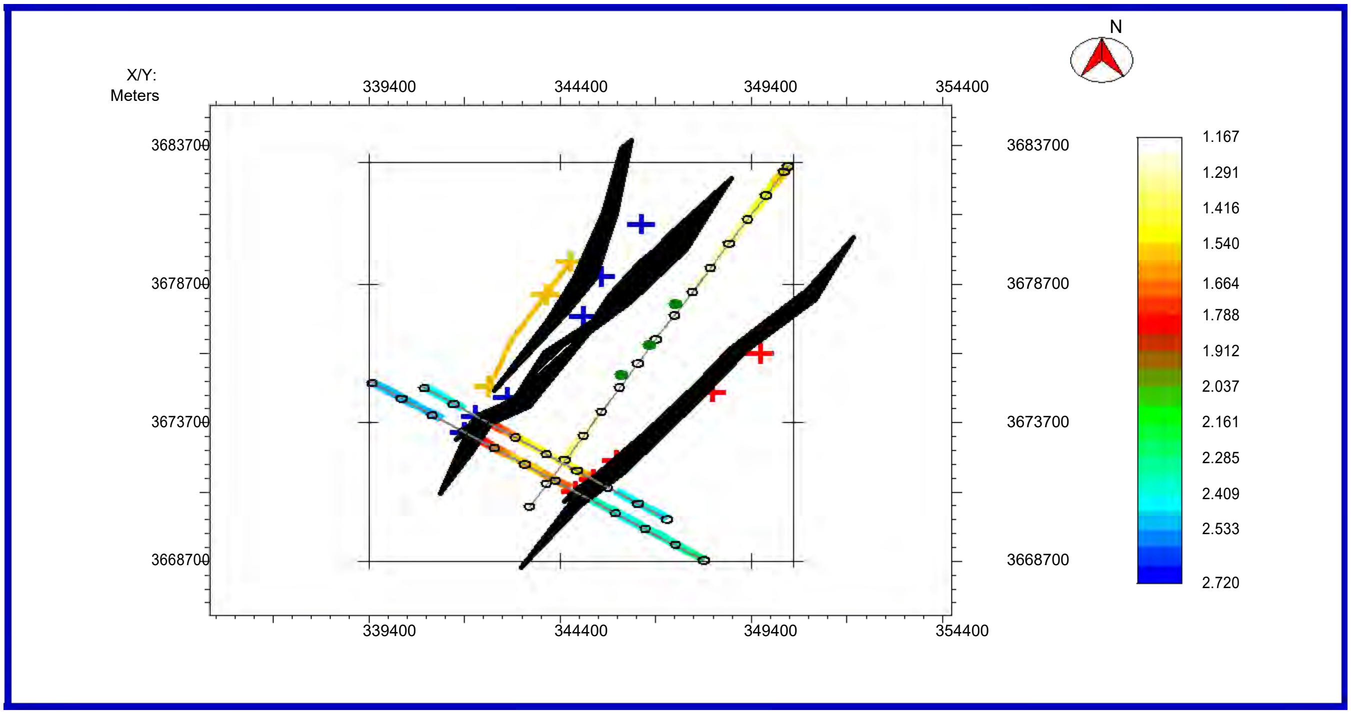

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Fig 3.8: Fault Polygon of Lockhart

3.9 Contour Map

The contours are the lines of equal elevation (time or depth). Mapping is usually final product of exploration, the one on which whole operations depends for its effectiveness (Coffeen, 1986). Contour maps show relief on horizons with contour lines that represent equal two way time (TWT) below a reference datum. These contour maps describe the slope of the formation, its dip, and any faulting or folding. In constructing a subsurface map from seismic data, a reference datum must first be selected. The datum may be sea level or any other depth above or below sea level.

3.9.1 Time Contour Maps

Time contour maps give a reliable picture of the subsurface if drawn properly**.** Seismic sections gives the time value along shot points and the times are read directly from the sections and are immediately available for mapping. After completing horizons and fault interpretation time contour map are constructed.

The pattern of time contour map confirms the shape of the subsurface structure. Time contour maps of these formations shows 2D- variations with respect to time and the Hydrocarbons probably accumulate at those places where time contour values are low hence low pressure zone. Contour Time interval of chorgali formation is 0.05.The minimum and maximum values are 1.1 and 2.65 respectively.

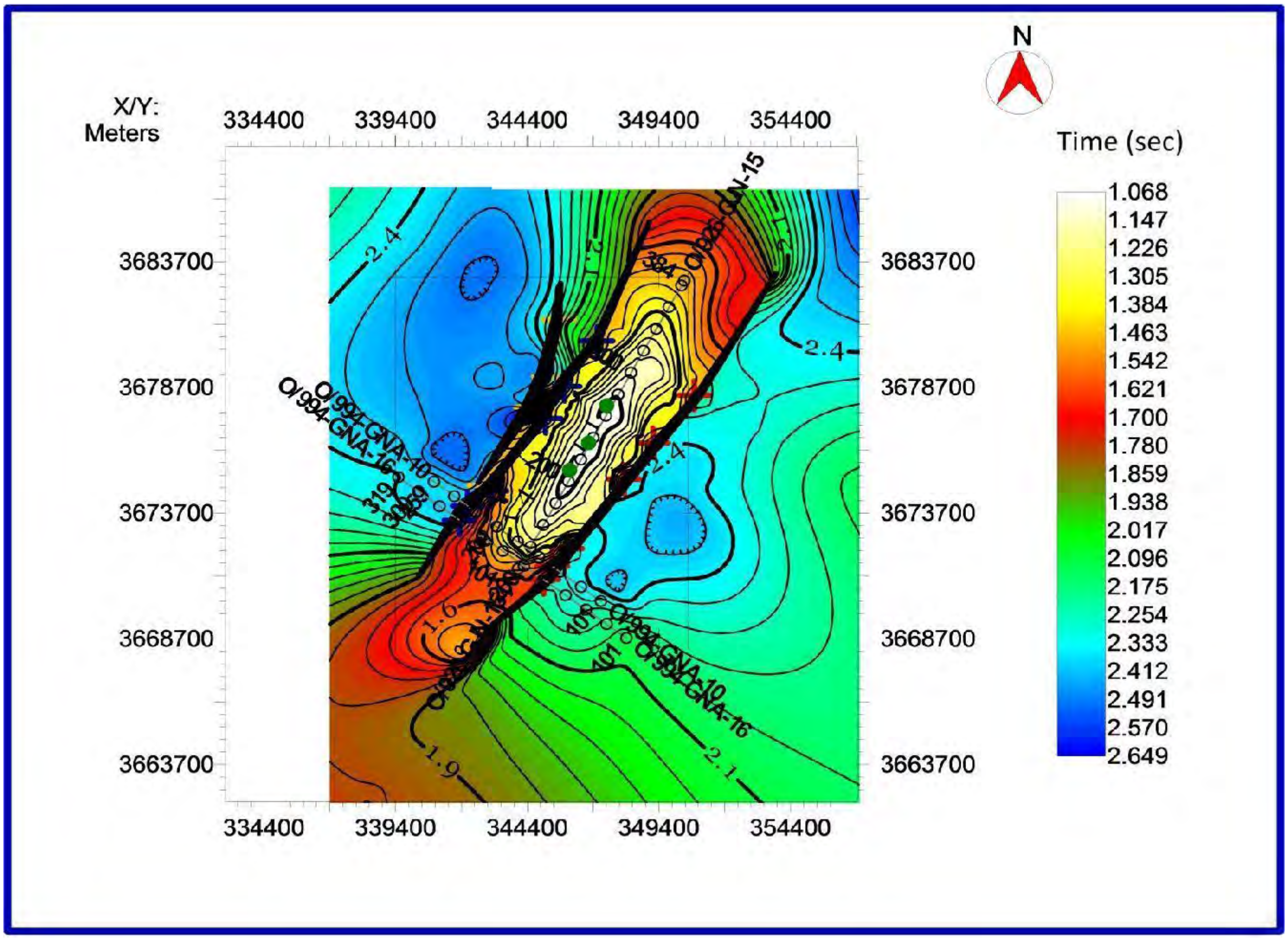

Fig 3.9: Time Contour map of Chorgali

Contour time interval of lockhart formation is 0.04.The min and max values are 1.2 and 2.72 respectively.

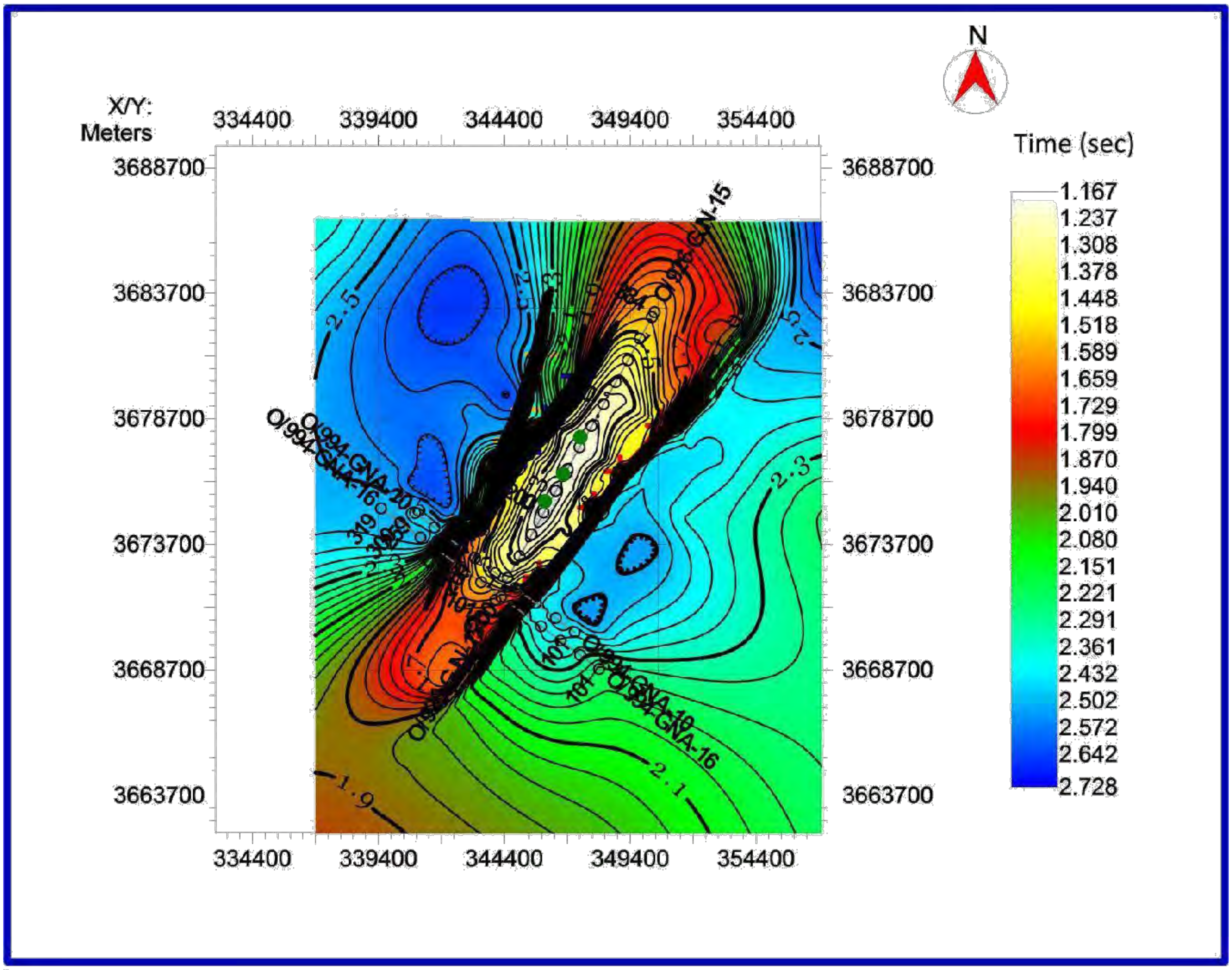

Fig 3.10: Time contour map of Lockhart

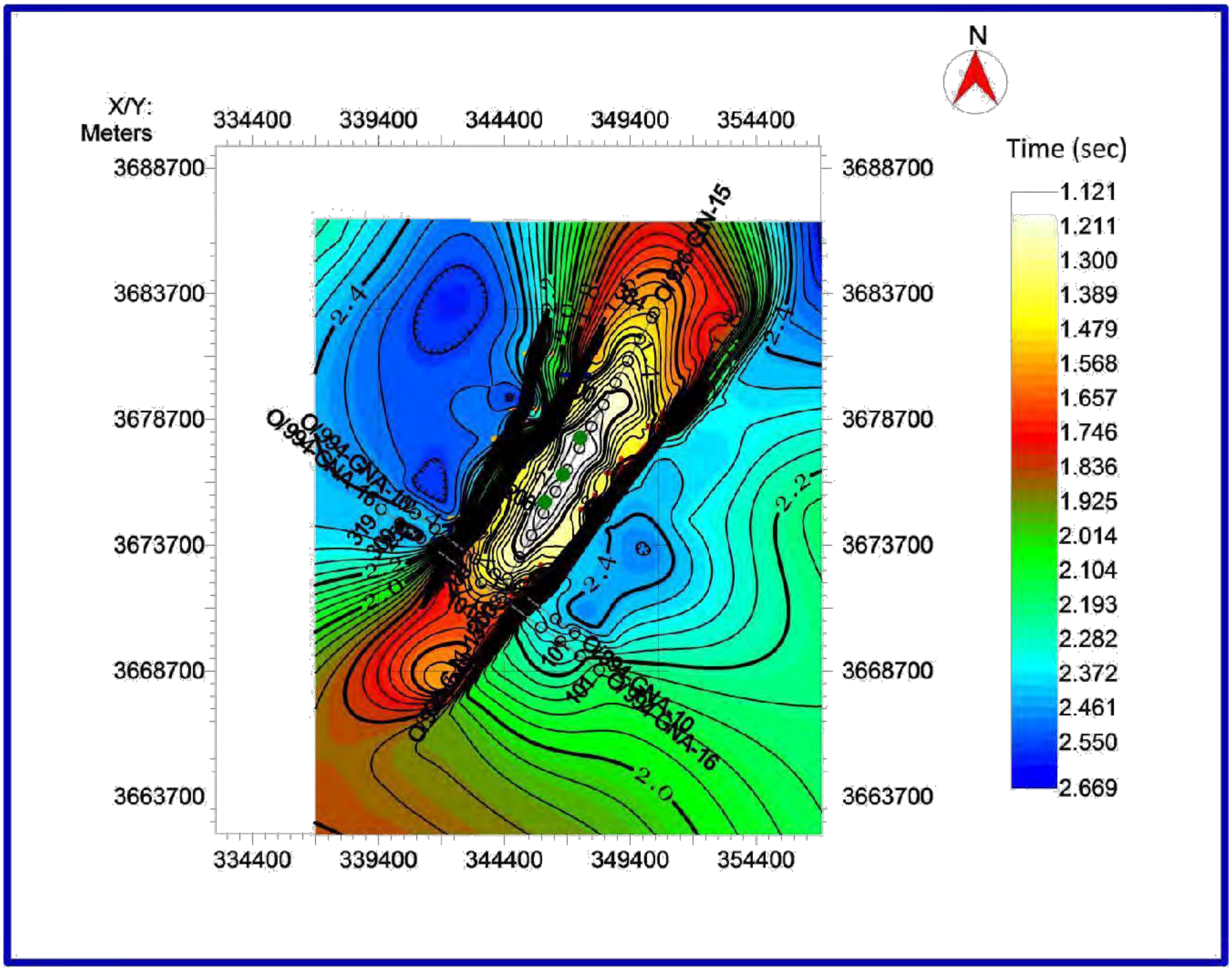

Fig 3.11: Time Contour map of Sakesar

Contour time interval of sakesar is 0.04.The min and max values are 1.16 and 2.64 respectively.Low pressure zones are the favorable site for hydrocarbons accumulation and we look for such zone to dig wells. Deciding the new well location for our study area we have to mark the low pressure zone and is mostly the zone present nearest to the surface.

3.9.2 Depth Contour Maps

Depth contour maps are not as common as time contour maps. Mostly,depth estimates are made with the help of time contour maps in a particular area. However, depth contour maps can give an extra edge when there's a good velocity control. Contouring can be a challenging job when done over areas of extensive faulting or mapping small features in stratigraphically complex regimes.

Depth conversion and depth contour maps are connected to see the horizons in the subsurface at their true positions. Depth must be calculated from time to make a map that is more truly related to the subsurface shapes, because structures is a matter of depth. The idea of converting the times into depths is very reasonable in case of showing the subsurface structures. Depth contour is showing same pattern to the time contour as constant velocity is multiplied with time.

Shapes of geological surfaces are complex and not readily approximated by simple mathematical functions because they result from a multitude of interacting processes that vary at different spatial scales.

In most cases, subsurface geological features are sparsely sampled relative to their complexity and the samples are highly biased to geophysical and/or geological anomalies. Therefore, values of a variable across an area of interest must be estimated by interpolating from a sparse, irregular control point set.The depth contour interval of chorgali is 80m.The depth contour interval of Sakesar and lockhart is also 80m.

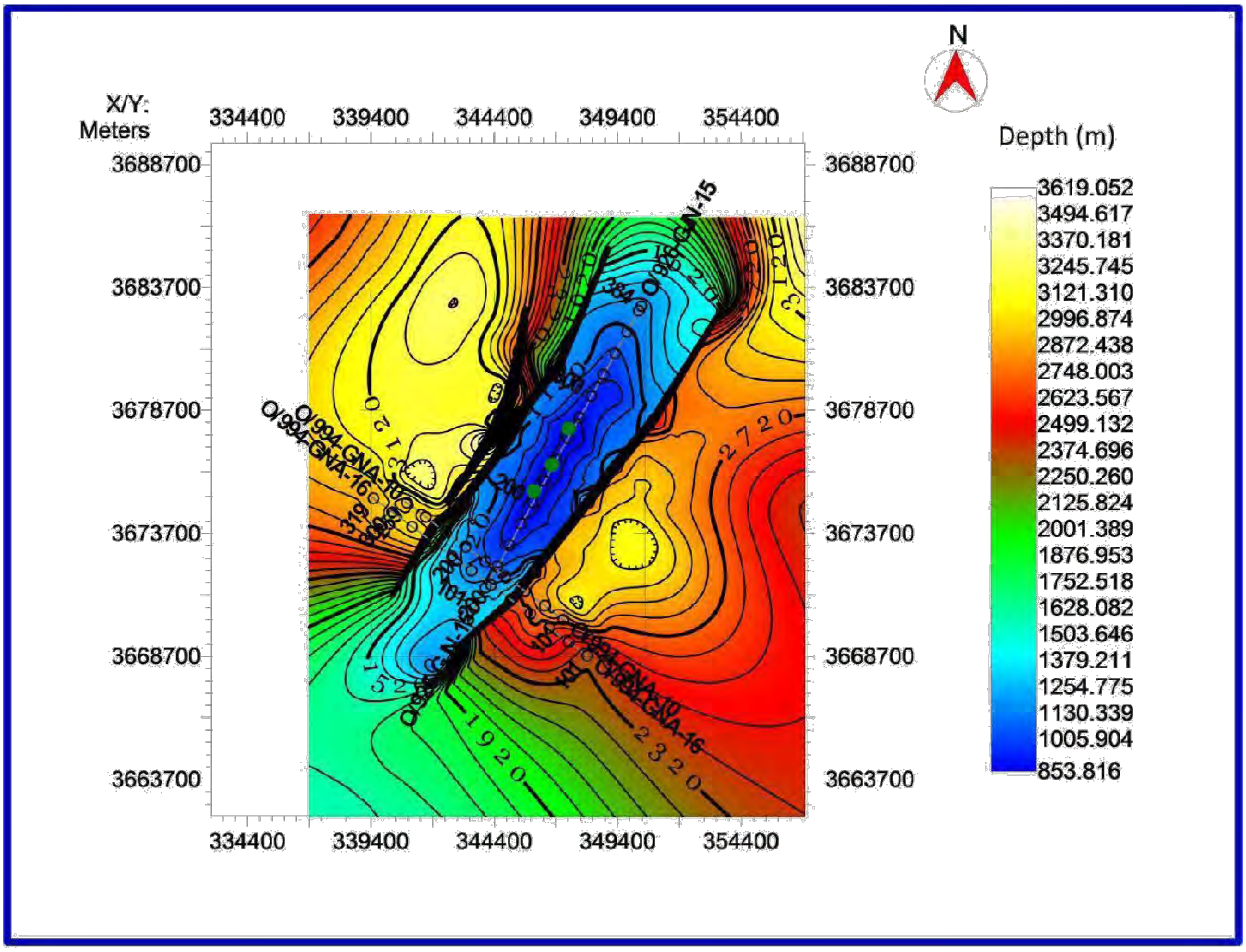

Fig 3.12: Depth Contour map of Chorgali

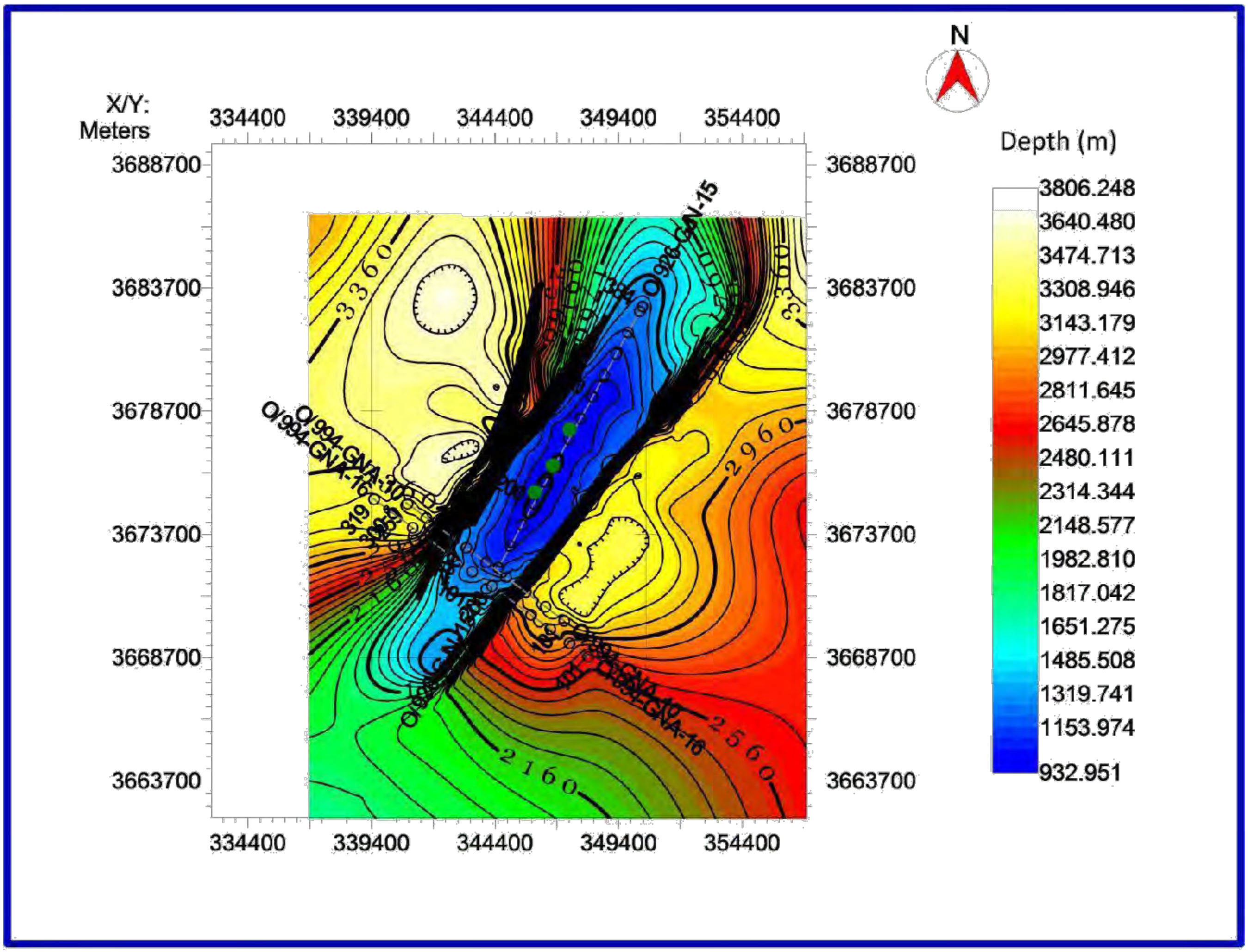

Fig 3.13: Depth Contour map of Lockhart

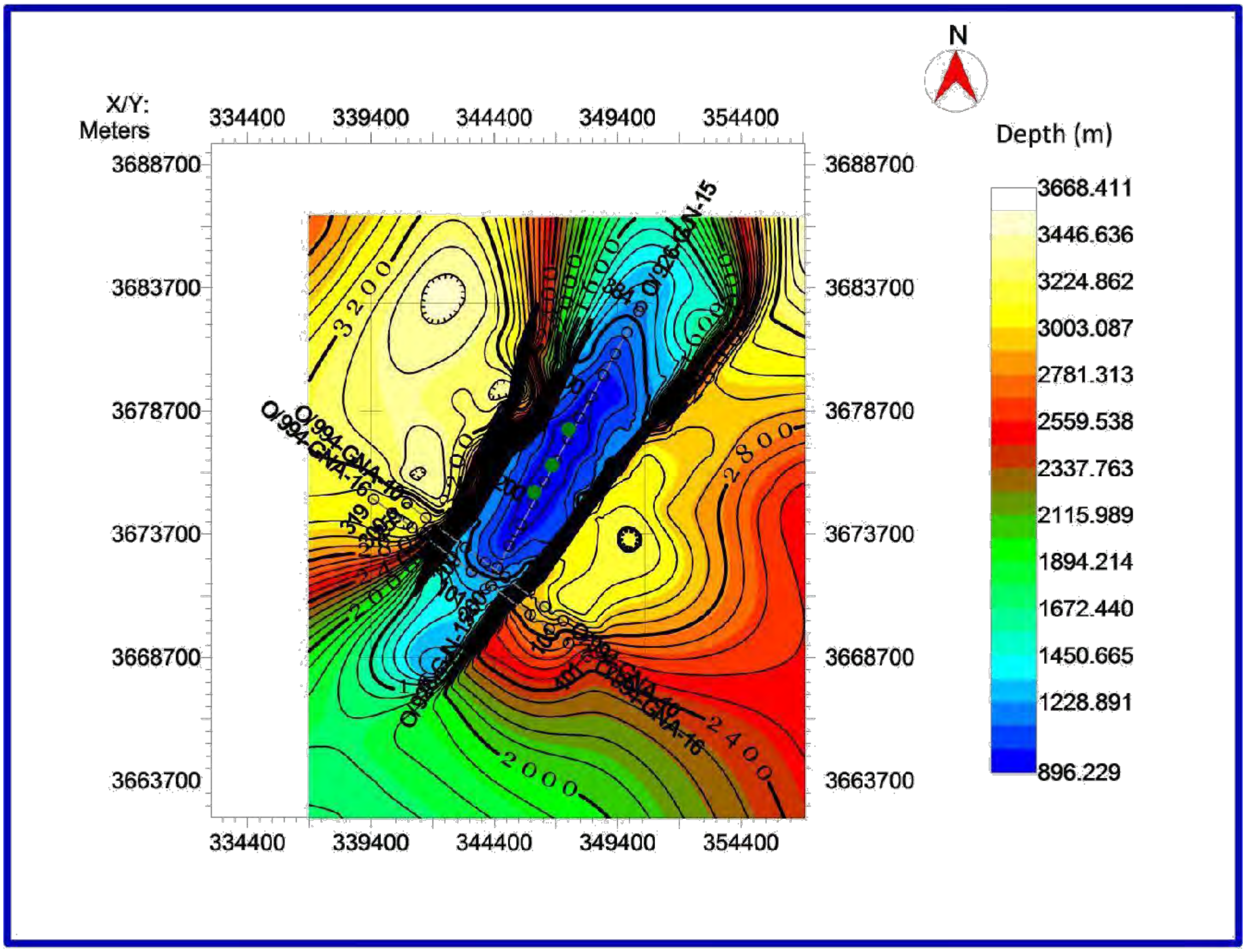

Fig 3.14: Depth Contour Map of Sakesar

Chapter 4

PETROPHYSICAL ANALYSIS

4.1 Introduction

Petrophysics is study of the physical properties relating the incidences, behavior of the rocks and fluids inside the rocks Reservoir characterization is the key step in oil and gas industry as it helps in defining the well and field potential so identify the zones within the reservoir which bears the hydrocarbons and can be recovered (Cosgrove et al., 1998). Petrophysics is one technique used for the reservoir characterization. This study facilitates in identification and quantification of fluid in a reservoir (Aamir 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 hydrocarbons. The integration of petrophysics along with the rock physics enables the geologists and geophysicists to understand the risks and opportunities in the area. Petrophysics is apprehensivewith using well measurements to subsidize reservoir depiction (Daniel, 2003).

Petrophysics uses different geophysical tools (GR, Caliper Log, SP, LLD, and LLS etc.), core data and production data and integrates the results extracted. These geophysical tools are designed to quantify some specific reservoir property such as porosity, shale volume, net pay, effective porosity, saturation of hydrocarbon etc.

Petrophysical analysis is often less related to seismic data but more concerned to well log data for reservoir description.

4.2 Data Set

The petrophysics analysis has been carried out in order to measure the reservoir characterization of the MissaKeswal area using the borehole data of Missa -03.

We used the log curves including Spectral Gamma ray (GR), Sonic log (DT), Latero log deep (LLD), Neutron log, density log. For petrophysics analysis the following parameters are acquired on the basis of the log curves.

- . Volume of shale
- Water saturation
- Hydrocarbon Saturation

The scales used for different logs track area explained in the below table.

Table 4.1: Scale used for the different logs.

N0	**Logs name**	**Abbreviation**	**Scale**	**Unit**
1	Gamma ray Log	GR	0------------ 200	API
3	Caliper Log	CALI	6------------- 16	INCHES
4	Sonic Log	DT	140---------- 40	µsec/ft
5	Density Log	ROHB	1.95--------- 2.95	Gm/cm3
6	Neutron Log	NPHI	0.45--------- (-0.15)	PU
7	Latero-log Deep	LLD	0.2------------ -2000	Ωm

4.3 Volume of Shale

Volume of shale can be calculated by using Gamma ray log. For finding the volume of shale computation of Gamma ray index is first step. It can be computed as

I_{GR}= Gamma Ray Index,

GR_{log} = Gamma Ray log reading of the formation,

GR_{max} = Maximum gamma Ray log reading,

GR_{min} = Minimum gamma Ray log reading

Then by using the following formula volume of shale is computed

$$V_{sh}=0.0883[2(3.7*I_{GR}) -1],$$

The average value of shale content (vsh) in reservoir zone having Limestone is 50 %.

4.4 Porosity

Porosity is defined as the ratio of the volume of void spaces to the total volume of the rock. Velocities have an inverse relation with the porosity, so that for small values of velocities the porosity value is high. The porosity is represented by (Φ).

Porosity is calculated by averaging the sonic and density porosity. Sonic and density porosity is computed by using sonic log and density log with the help of following formulae:

————,

Where

Φ_S = sonic porosity μs/ft

ΔT= Log response

ΔT_{mat}= Transit time in matrix

ΔT_f=Transit time in fluids

——— ,

Where

ρm = density if matrix (gm/cm^3)

ρf = density of fluid (gm/cm^3)

ρb = log Response in zone of interest

Fig (4.1) shows reservoir zone has a good amount of porosity. The average porosity of reservoir zone having Limestone is 9%.

4.5 Water and Hydrocarbon Saturation

Archie's Equation can be used to calculate the water saturation:

Sw= —X — ,

Where,

Sw = water saturation

Rw = is water resistivity (formation)

Φ= is porosity, m is (cementation factor) = 0.81, **a** (constant) = 1

Rt = LLD log response

Rw has been calculated with help of the following formula:

$$Rw = \Phi^2 \times R,$$

Where

Φ **=** porosity in clean zone

RT = Observed LLD curve in clean zone.

By using following relation hydrocarbon saturation (**S_{hc}**) can be found

$$S_{hc} = 1 - S_w,$$

The average value of water saturation of Limestone is 31 % whereas the average value of hydrocarbon saturation of Limestone is 69 %.

The Petrophysical analysis of Missa -03 is shown in Fig 4.1.

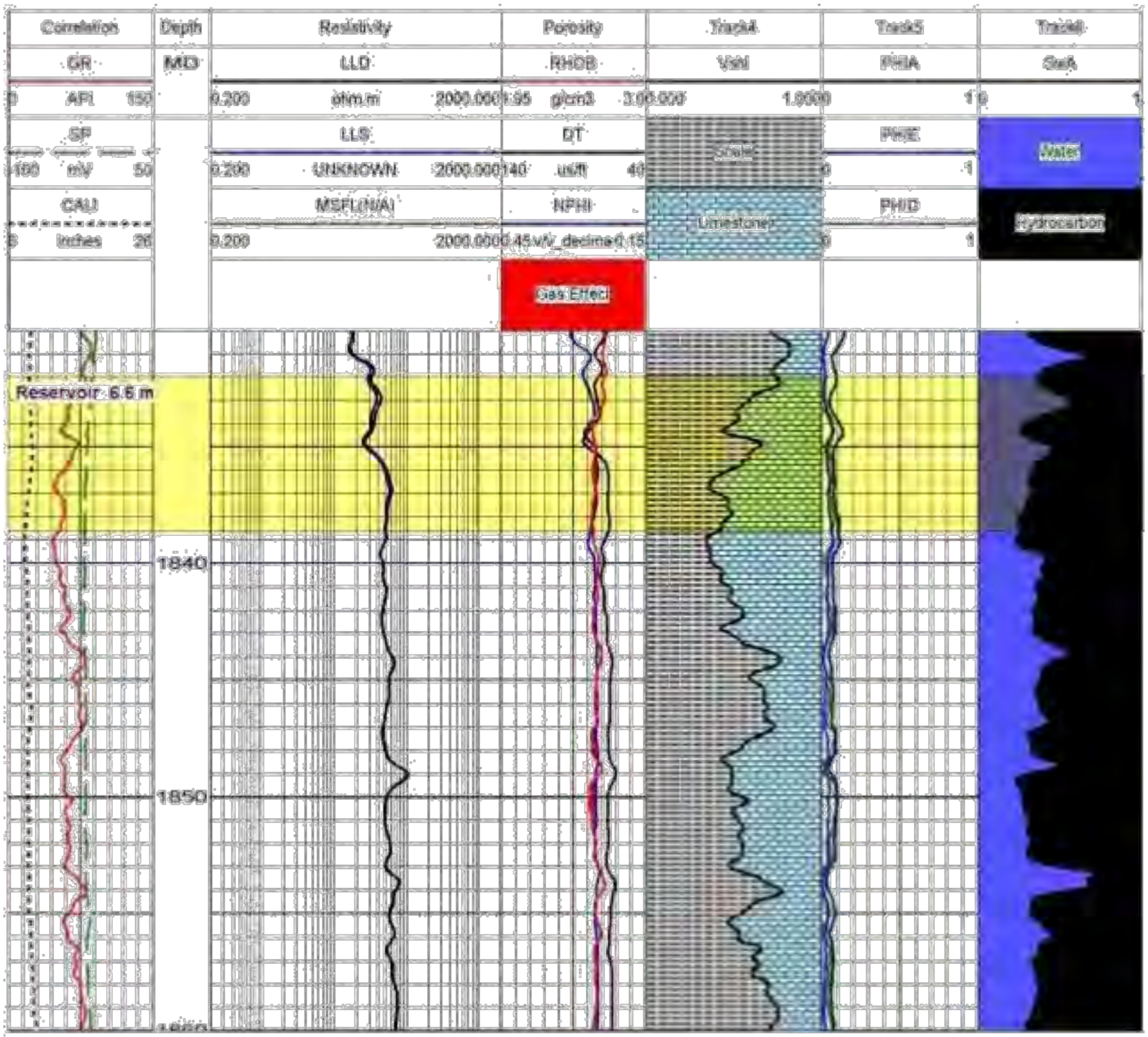

Fig 4.1: Petrophysical analysis of Missa -03

4.6 Defining Zone of Interest

The zone of interest is marked on the basis of appreciable effective porosity, hydrocarbon saturation, less volume of shale and water saturation. The depth of well starting from 1820 and ending on 1860m.

The Reservoir zone of Chorgali formation and Limestone lithology have depth of 6.6 m having 50 % Vsh , 9 % porosity 31 % water saturation and 69 % hydrocarbon saturation.

Chapter 5

ROCK PHYSICS AND FACIES MODELLING

5.1 Introduction

Rock Physics is an integration science linking seismic data, its derived attributes, Petrophysical data, computed as well as lab measured elastic parameters and core data. It consists of a wide range of empirical relations that have been established through best-fit least square regression. Correlations can be established between any two or more rock properties that can be used to compute one rock parameter with another.

Rock physics templates have been developed to visualize lithological and mineralogical variations in terms of Petrophysical logs; derived rock physics derived seismic attributes, and can be applied for the quantitative interpretation of well log and seismic data. (Perez et al, 2011) constructed rock physics templates using a combination of Hertz–Mindlin contact theory and the lower modified Hashin–Shtrikman bounds to guide interpretations of estimated ultimate recovery in shales.Fig (5.1) shows petrophysical logs of Missa -03 for the depth range 1810m to 2200m.To compute the elastic logs we need sonic, shear sonic and density logs.

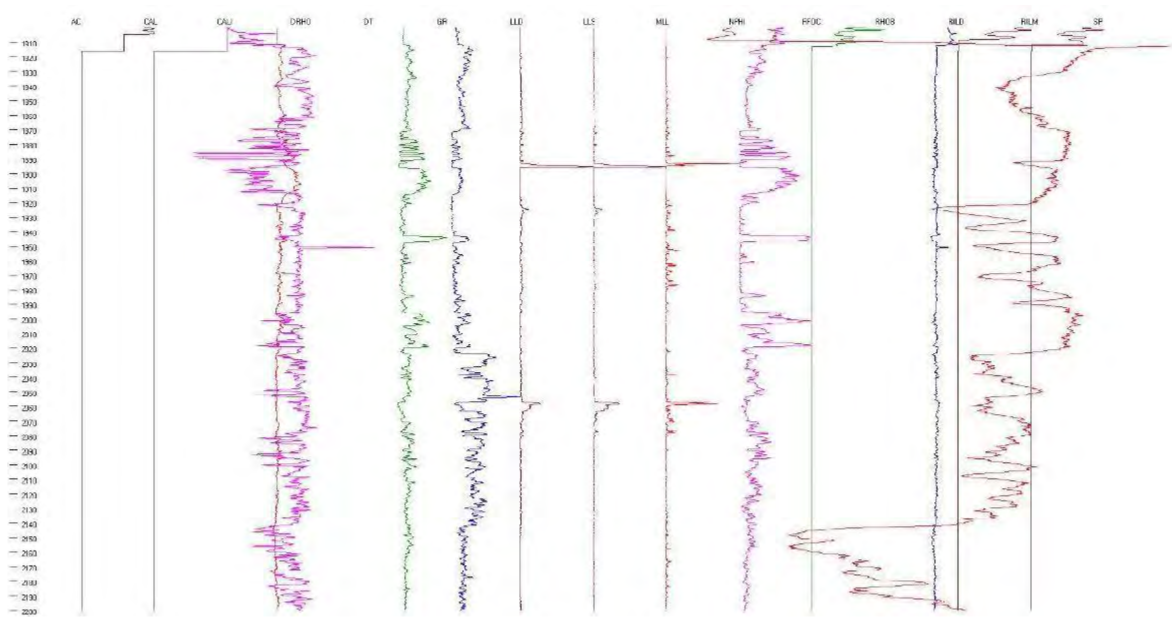

Fig 5.1: Petrophysical logs of Missa _03 well

5.2 Computation of Elastic Logs

The P-wave velocity (sonic) log, S-wave velocity (computed shear sonic) log and density log are used to compute the elastic logs of various moduli along with acoustic impedance and shear acoustic impedance logs as shown in Fig 5.2.

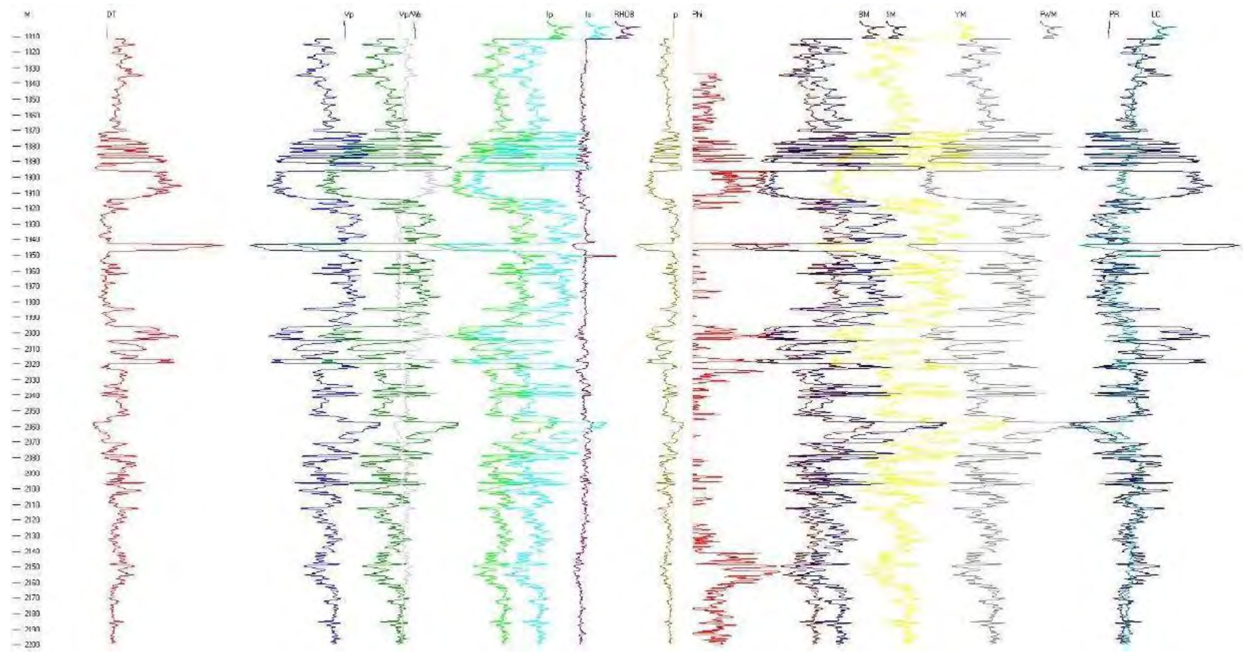

Fig 5.2: Acoustic impedance and Elastic logs computed from well log of MissaKeswal-03

The Petrophysical logs along with the computed Acoustic Impedance and Elastic Logs are used in various types of cross plot for classification or facies modeling. Before we go into the details of each facies modeling cross plot a brief description of each elastic parameter is given below.

5.2.1 Acoustic Impedance (AI)

Acoustic impedance is a layer property of a rock and is equal to the product of compressional velocity and density (Onajite et al., 2014). The density log and the compressional wave velocity log generated from the DT log are used to compute the acoustic impedance log by using equation:

Where, b is the density of the formation and Vp is he compressional wave velocity.

5.2.2 Shear Impedance (SI)

Shear impedance is a layer property of a rock and is equal to the product of shear velocity and density also known as elastic impedance (Connolly, 1998, 1999). Similarly, as acoustic impedance the density log and the shear wave velocity derived from the Castagna et al., (1993) empirical relation was used to generate the shear impedance log using equation:

Where, b is the density of the formation and Vs is the shear wave velocity.

5.2.3 Young's Modulus (E)

This modulus is obtained to measure the stiffness of the material. The relation between the density, compressional wave velocity, young's modulus, and shear wave velocity is given in equation (Mavko et al., 2009).

Where, is the density that is obtained from the density (RHOB) log, Vs and Vp are the shear wave and compressional wave velocity that is obtained from the sonic log (DT).

5.2.4 Poissons's Ratio ( )

The Poisson's ratio is used to indicate the maturity of the shale oil/gas zone. The low value of poisson's ratio will indicate the mature oil/gas shale zone. The relation between the poisson's ratio, compressional wave velocity, and shear wave velocity is given in equation (Mavko et al., 2009).

5.3 Facies Modeling

Cross plot based facies analysis is an important methodology accepted worldwide to properly characterize a hydrocarbon reservoir and exploit the remaining volumes in development phase. In this study, Shale, Limestone and Fractured limestone are characterized using various cross plots. Common methods for cross plot based facies modeling are polygon bounds and cluster analysis.

In this study the polygon method is used for facies modeling. With the help of Log data of Missa - 03, different cross plots which are compared with the standard cross plots to identify the lithologies, and the prospect zone to be marked.

5.3.1 Vp/Vs versus Acoustic Impedance

Vp/Vs versus Acoustic Impedance is considered as an import cross plot for classification of Limestone and Fractured Limestone. The Vp/Vs ratio can be expressed in terms of represents poisson's ratio ( ) by the following equation:

— √

In Fig 5.3 it can be observed that Limestone, Fractured Limestone can be easily differentiated and characterized.

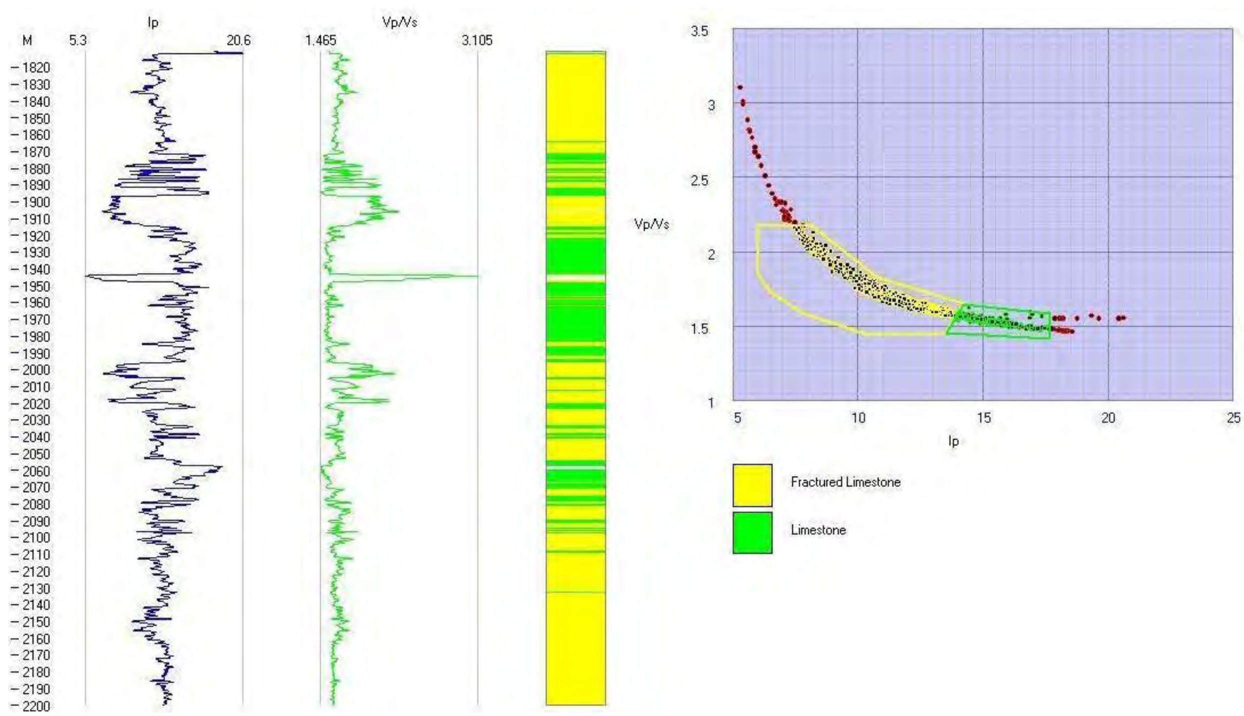

Fig 5.3: Cross-plot of Vp-Vs Ratio and Acoustic Impedance characterizing fractured limestone and limestone.

5.3.2 versus λ

Fig 5.4 shows the λ - crossplot, also referred as LMR, by Goodway et al., (2007) for improved fluid detection and lithology discrimination. The parameters of λ and are measures of the incompressibility and rigidity of rocks, respectively, of which and λ were calculated from the petrophysical logs. We can see that decreases as clay content increases for increase in the porosity, but λ may represent opposite trends. This proves λ to be a good indicator for lithology.

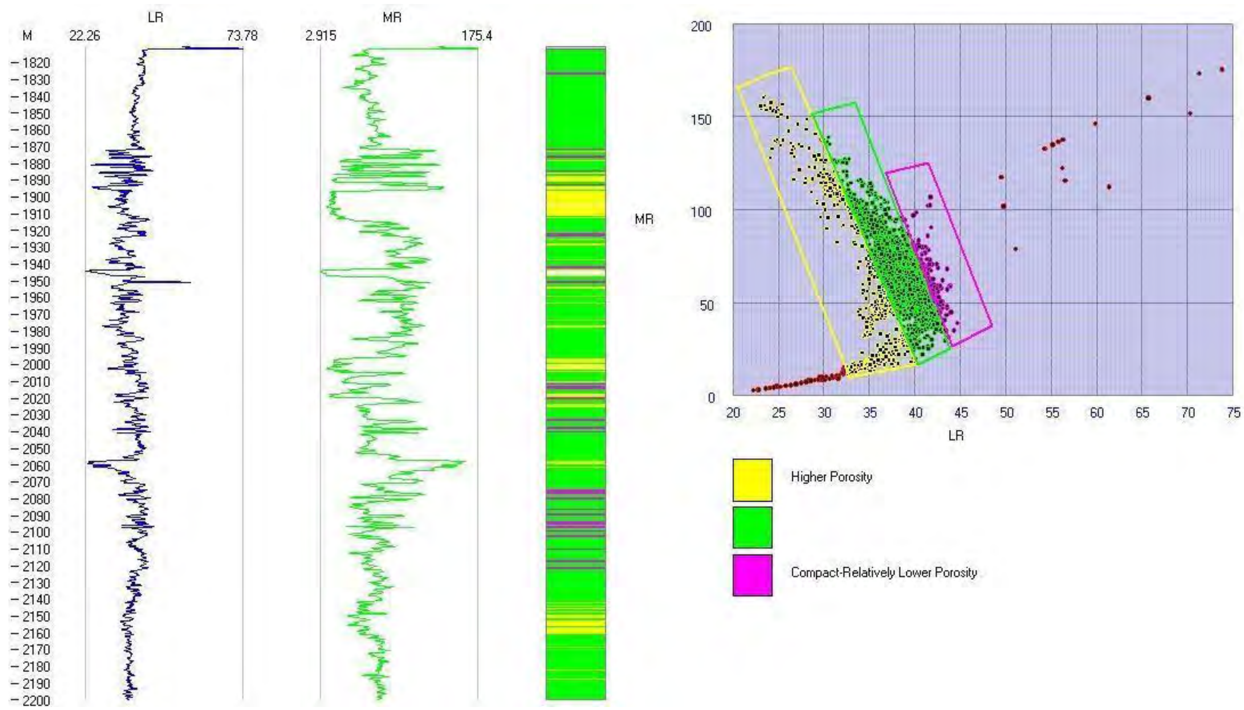

Fig 5.4: Lambda -Meu-Rho Cross-plot used for characterizing higher porosity and compact relatively lower porosity

5.3.3 P-Wave Velocity versus Density

Finally P-wave velocity versus density cross plot is shown in Fig 5.5. It also shows almost same interpretation as the previous cross plots. This confirms that using different cross plots we are getting the same classification of facies.

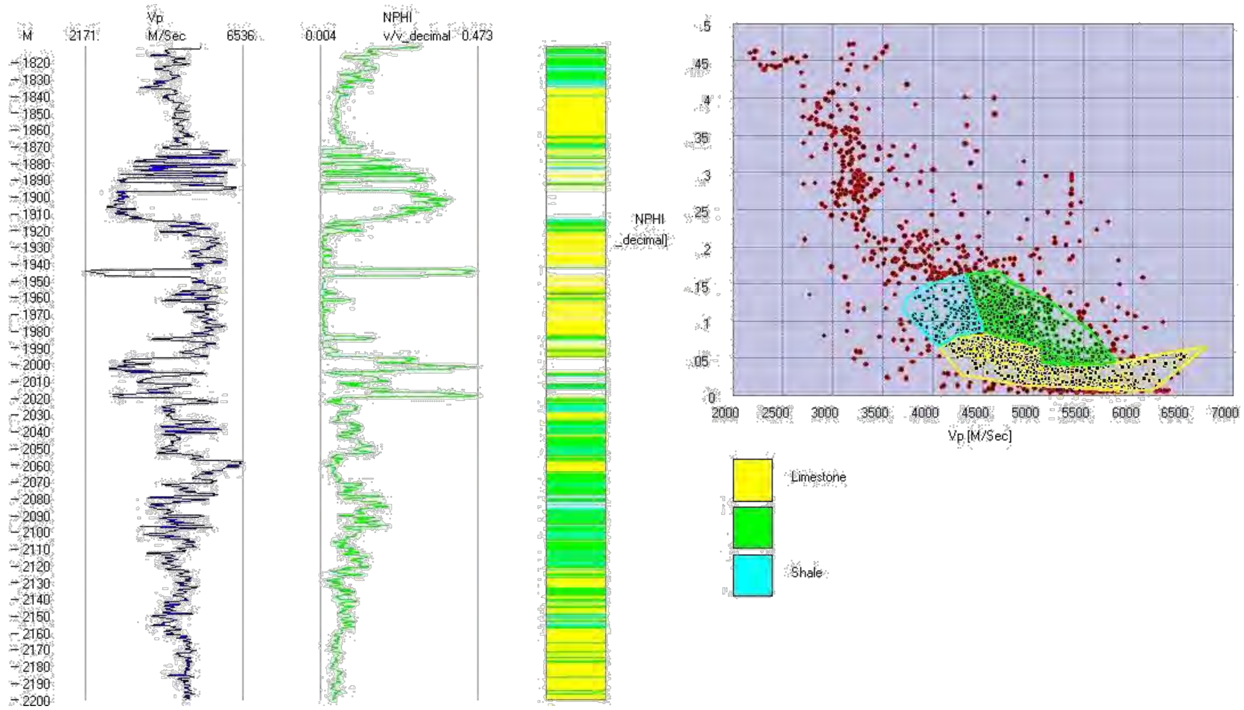

Fig 5.5: P-Wave Velocity-Density Cross-plot based characterization

5.3.4 SP versus VP

SP versus Vp cross-plot is shown in Fig (5.6) .This cross-plot characterize Limestone and Shale.

Using different cross-plots we are getting same Classification of facies.

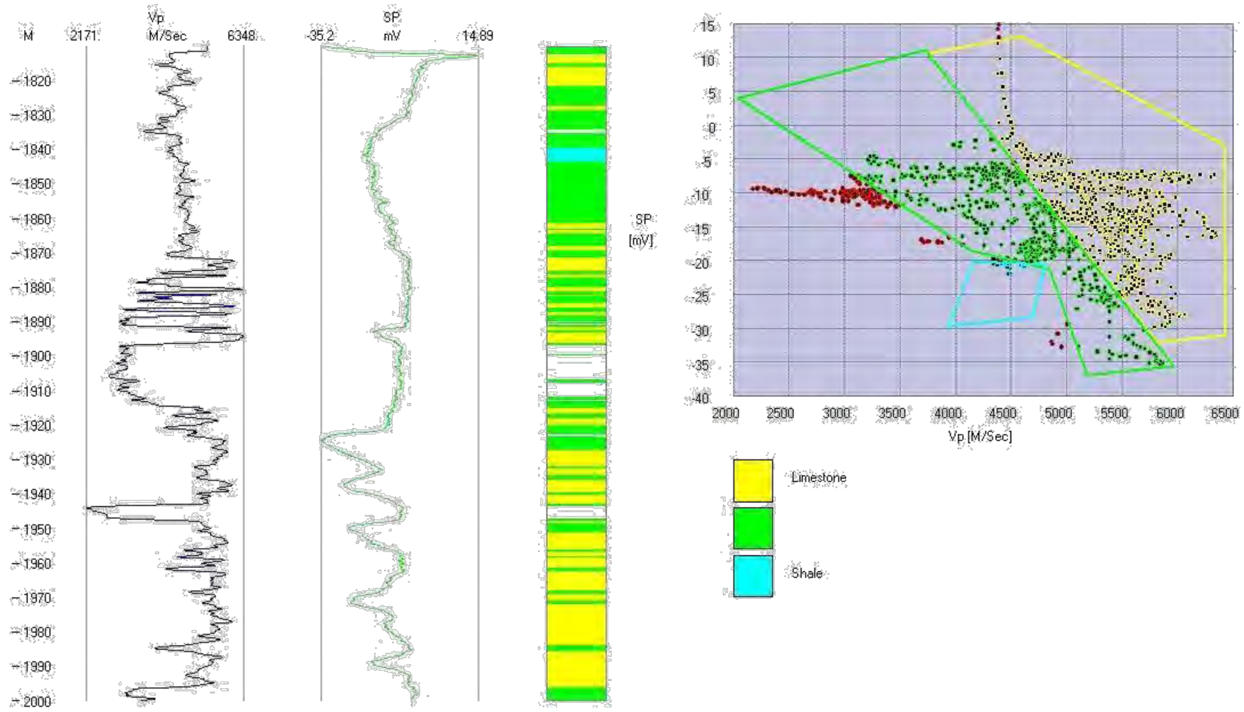

Fig 5.6: Showing cross-plots of SP and Vp.

Chapter 6

Seismic Velocity Analysis

6.1 Introduction

Velocity is a single most important parameter in seismic analysis (Khan et al., 2010). Seismic velocities varies vertically as well as laterally due to the physical-geologic variations of rocks.. It is necessary to compute velocity functions at various locations along the seismic profile. Seismic velocities can be derived by indirect methods such as velocity analysis in seismic data processing and direct methods such as check shot, vertical seismic profiling and sonic log. Direct methods can only be carried out at boreholes thus they can be used to calibrate the velocities derived from velocity analysis. The velocity data is usually available in the form of functions (velocity as a function of time or depth) consisting of velocity time (VT) pairs. X-Works reads velocity data in IGS format.

6.2 Raw Function Velocity Model

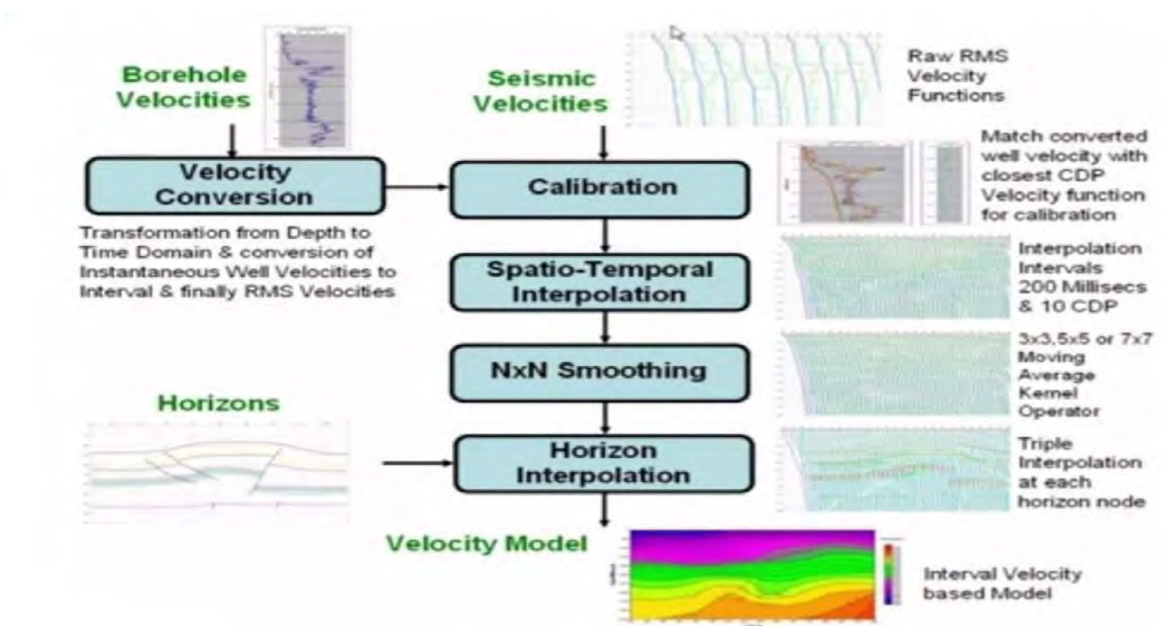

Fig6.1: Complete Workflow of Velocity Model building using Seismic velocities (Khan & Akhter, 2011).

6.3 Velocity Conversion

As the seismic sections are in time domain, but the real subsurface structures are in depth domain so we have to convert time sections into depth sections using velocities (Vrms). Velocity analysis is carried out in X-Works in which RMS velocities are converted into interval and average velocities. Dix equation is used to convert RMS velocity into interval velocity.

————————(Dix, 1955)

= Interval velocity (m/s)

= Root mean square velocity (m/s)

= Zero Offset travel time (s)

X-Works uses a velocity processing engine which automatically converts the input RMS velocities into interval velocity and average velocity for time to depth conversion.

The Interpreted geologic section GNA -16 containing faults and horizon used to construct the velocity model contain the additional horizons above and below the section to compute the interval velocity layer by layer as shown in Fig 6.2.

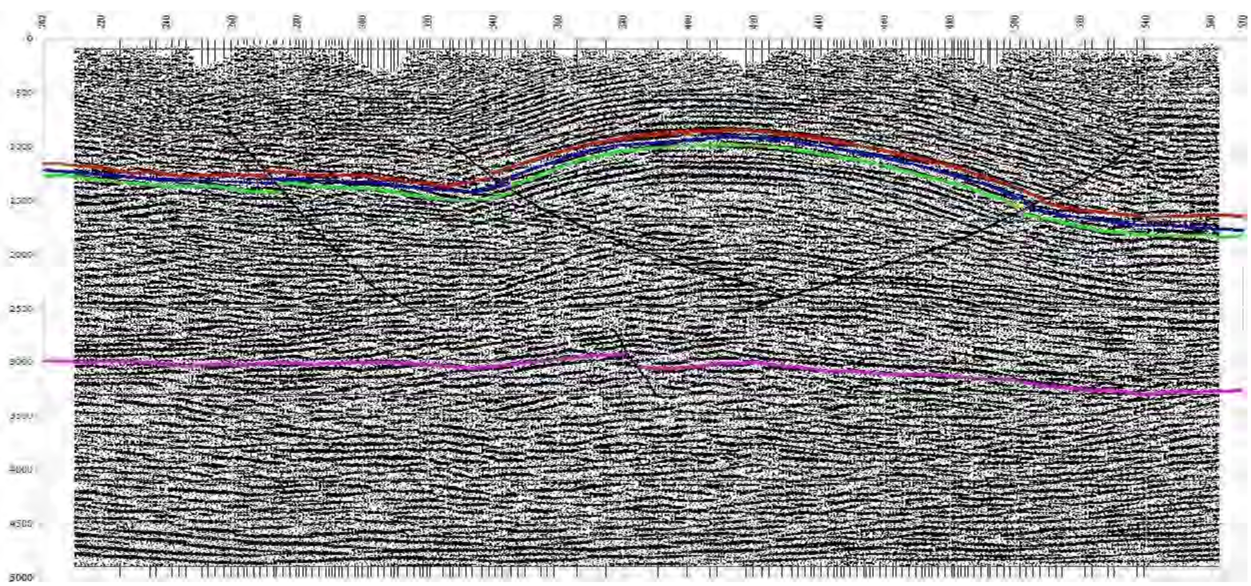

Fig 6.2: The interpreted section of line GNA-16

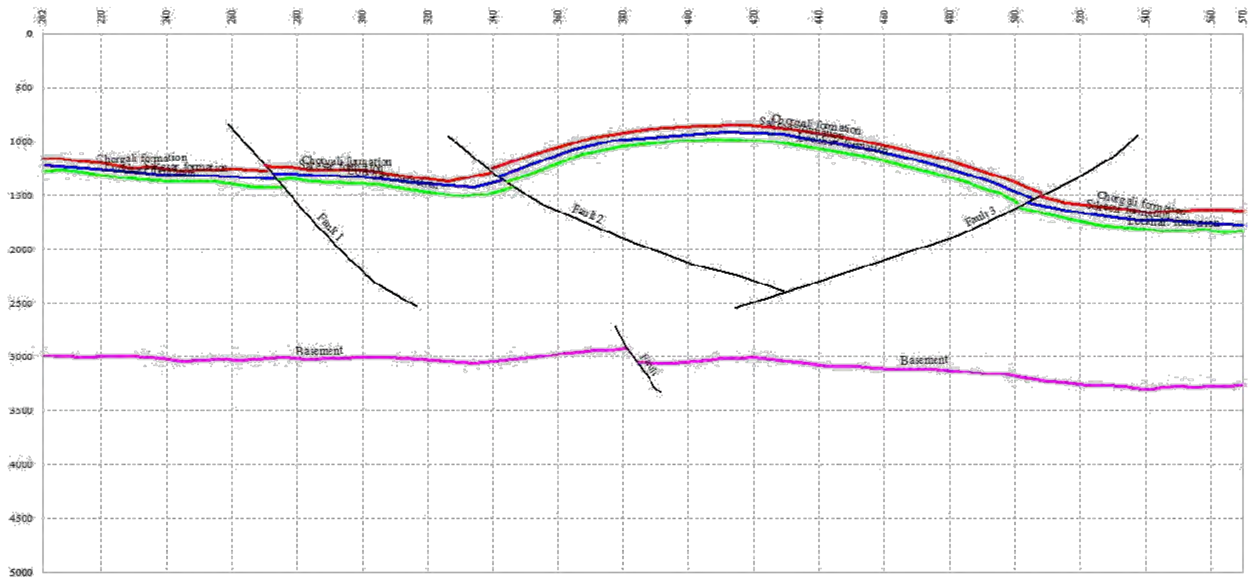

Fig 6.3 shows the same line GNA-16 without seismic section.

When the velocity data is loaded the velocity function for all three types are displayed at their corresponding CDP locations i.e. RMS Velocity (Light Blue), Interval Velocity (Green) and Average velocity (Dark Blue) with red nodes. Fig 6.4.

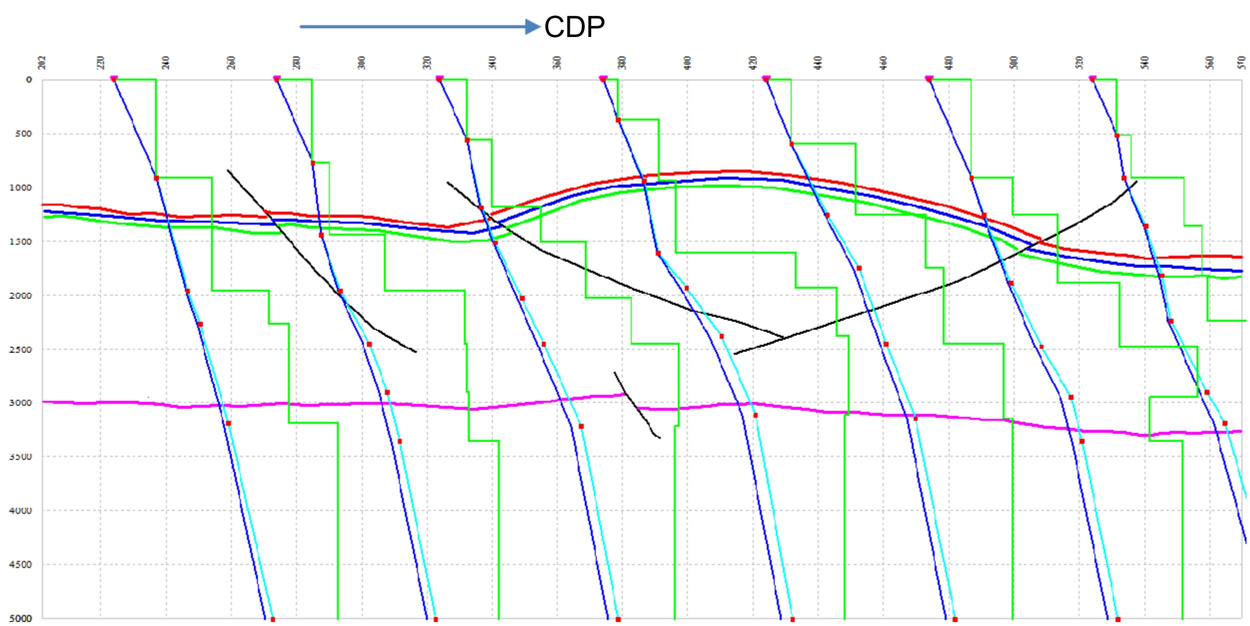

Fig 6.4: Seismic section along with average,interval and RMS velocity

6.4 Spatio Temporal Interpolation

The seismic velocities highly fluctuated and are acceptable regarding seismic modelling and horizon based interpolation. Therefore these lines are first interpolated and after that 3*3 Spatio-Temporal smoothing has been applied along the seismic line to get more precise velocities for time to depth conversion.

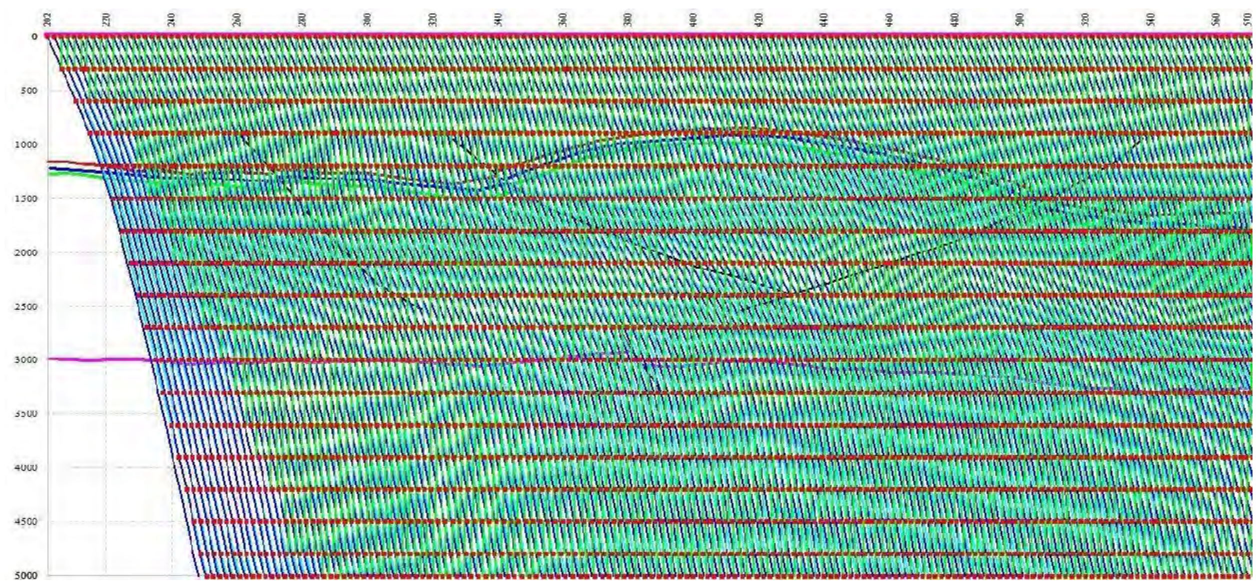

Fig 6.5: Velocity based Spatio Temporal Interpolation

6.5 Horizon based Interpolation

The velocity model generated by horizon interpolation technique closely matches the subsurface structures as shown in Fig 6.6. Horizon velocity analysis provides velocities at ever CDP location along the profile (Yilmaz,2001).

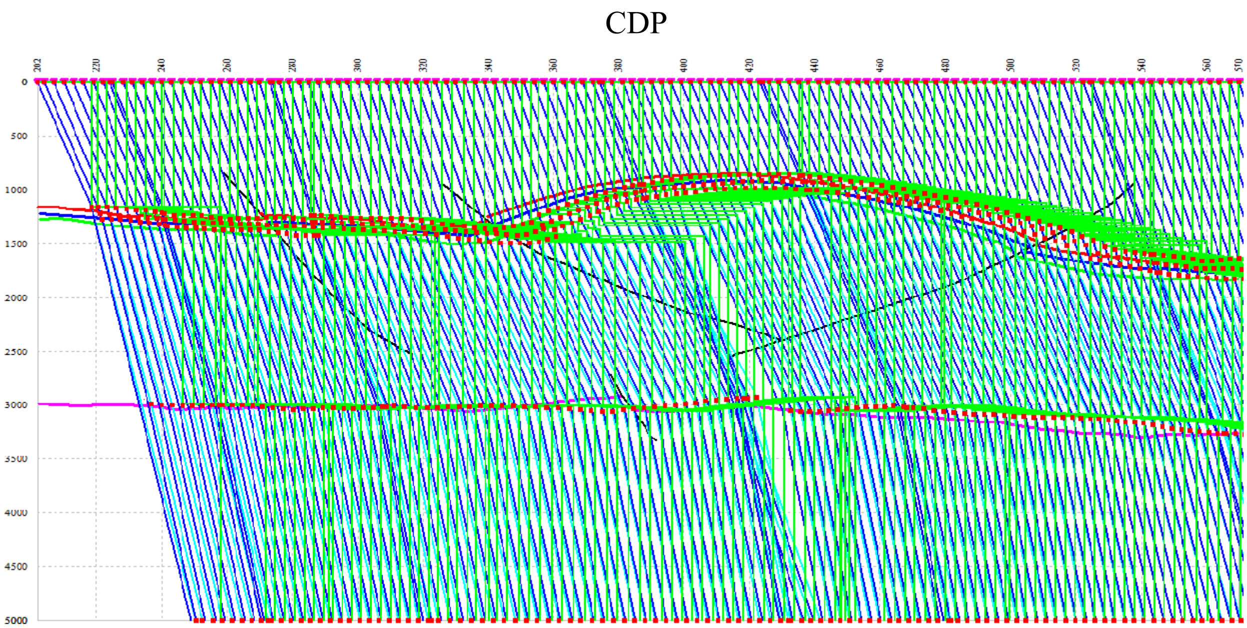

Fig 6.6: Horizon based Interpolation

6.6 2-D Seismic Modeling

2D seismic models are generated for GNA-16. It is generated from the horizon interpolated velocity model discussed in the previous section. In this method a Ricker Wavelet of 35Hz sweep frequency is used as a source. The wavelet is convolved with velocity models or interpreted depth section at every 10 CDP to generate a seismic section Fig 6.7. As the modeling is applied at zero offset, the resulting synthetic seismic model is a migrated section.

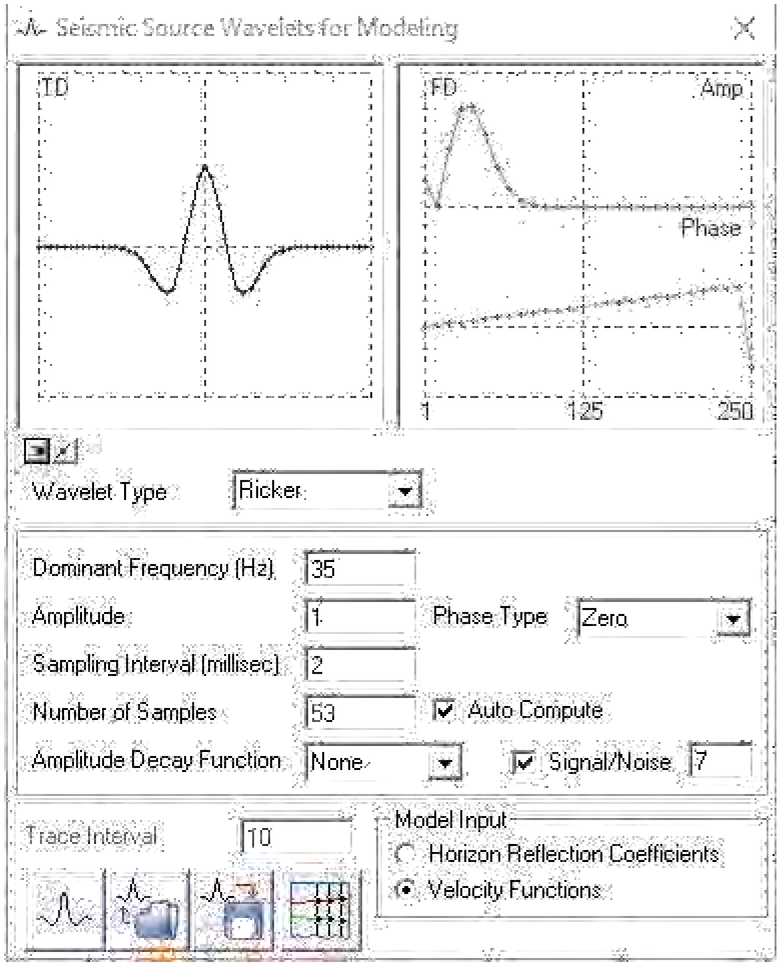

Fig 6.7: Ricker wavelet of sweep frequency 35 Hz used as a source

In this case section clearly shows the interpreted layers. It can be seen from the Fig (6.8 and 6.9) that this seismic model clearly shows affordable sub-surface image demonstrating some structure so it confirms the interpretation.The line direction of GNA-16 is (NW-SE)

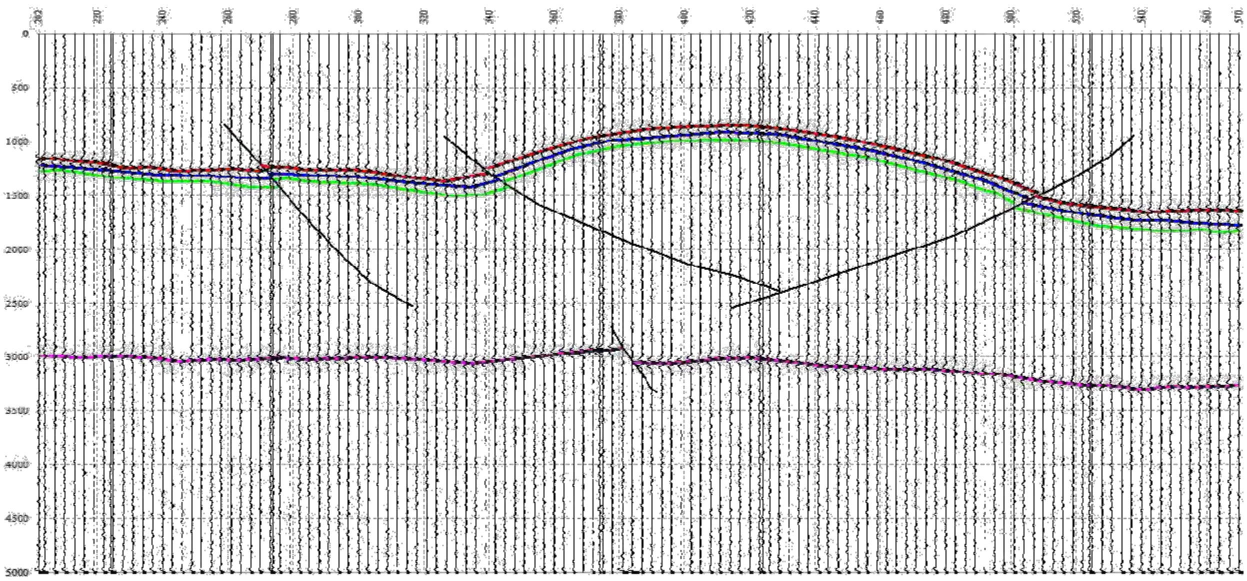

Fig 6.8: 2D seismic model along with Geologic interpreted cross section of line GNA-16

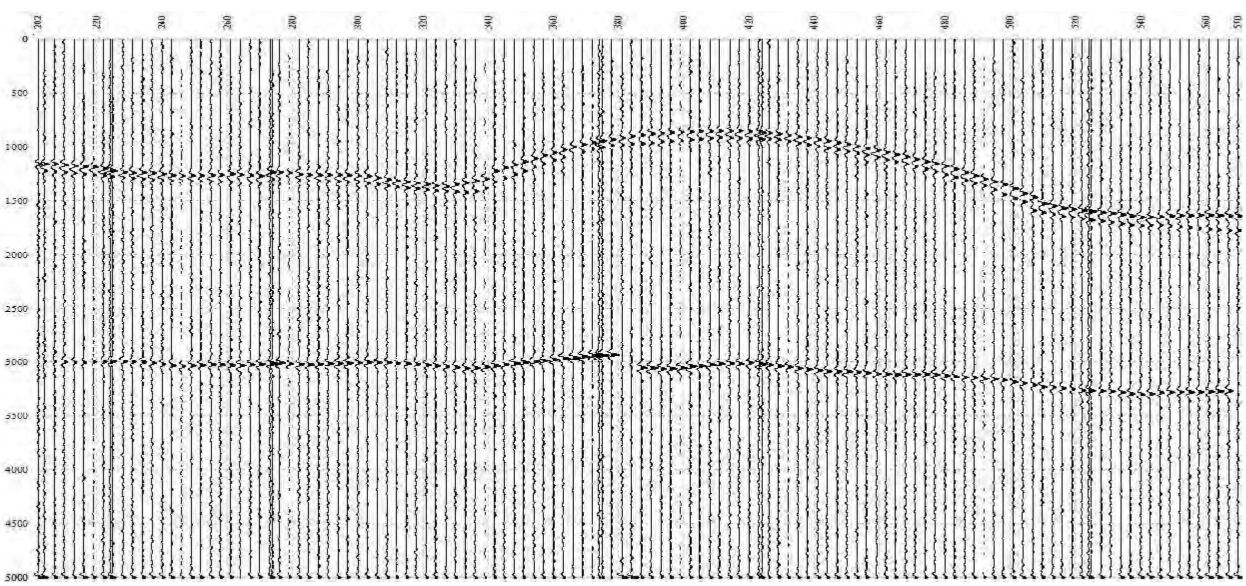

Fig 6.9: 2D seismic model without Interpreted geologic section of line GNA-16

Conclusions

- On the basis of general stratigraphic column present in the area and the formation tops of the MissaKeswal-03 well, three reflectors marked on seismic section.
- The marked sections are named as Chorgali, Lockhart and Sakesar . . Horizons are marked with the help of synthetic seismogram of well Missa -03 which is generated from well log data by using density log and sonic log.
- Major faults along with few minor faults were marked on seismic section depend on the geology and tectonics of the study area. Thrust faulting shows anticlinal pop-up structures which shows area of dissertation lies in compressional tectonic regime.
- In petrophysical analysis the volume of shale, porosity, water saturation and hydrocarbon saturation are calculated in reservoir zones to identify the zone of accumulation of hydrocarbons within the reservoir zone (Limestone). Quantitative results shows 8-9% porosity which is fair for the reservoir rock Which is Chorgali formation having 50 % volume of shale, 31 % water saturation and 69 % hydrocarbons saturation. These results show that the reservoir zone would be effective for the accumulation of the hydrocarbons.
- Petrophysical logs have been used to compute Elastic logs and petro-elastic cross plots have been generated for facies modeling which can effectively discriminate between Limestone ,Fractured Limestone and shale. The facies modeling interpretation is confirmed through four cross plots, which provide the same interpretation.
- Velocity Analysis on interpreted geologic section GNA-16 has been performed to generate a geologically realistic velocity model. 2D Modelling has been carried out on the velocity model to generate a 2D synthetic seismic section which further validates the velocity model..

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