2D SEISMIC REFLECTION DATA INTERPRETATION, PETROPHYSICAL ANALYSIS AND MODEL BASED INVERSION OF MIANO AREA, LOWER INDUS BASIN, PAKISTAN

BY

UMER FAROOQ AWAN

BS Geophysics

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Department of Earth Sciences

Quaid-I-Azam University Islamabad

بسم الله الرحمن الرحيم

To start with the greatest name of Almighty Allah . Most gracious and merciful, with Him is the knowledge of the Hour, He sends down the rain, and knows that which is in the wombs. No person knows what he will earn tomorrow, and no person knows in what land he will die. The knower of the unseen is Allah these are the keys of the unseen, whose knowledge Allah alone has kept for himself and no one else knows them unless Allah tells him about them.

CERTIFICATE

This dissertation submitted by ***UMER FAROOQ AWAN*** S/O ***MUHAMMAD FAROOQ AWAN*** 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 M.Sc. degree in Geophysics.

RECOMMENDED BY

Dr. Aamir Ali ____________________

(Supervisor)

Dr. Mona Lisa _______________

(Chairperson Department of Earth Sciences)

EXTERNAL EXAMINER ____________________

Department of Earth Sciences Quaid-I-Azam University Islamabad, Pakistan

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

I am especially indebted to my honorable supervisor Sir DR. Aamir Ali for giving me an initiative to this study. His inspiring guidance, dynamic supervision and *constructive criticism*, helped me to complete this work in time .I express my sincerest appreciation to Altaf Fareed (Mphil) , Asif Chingwani (Mphil) and Bader Ali (Mphil for their guidance in the preparation of this thesis and their assistance in any way that I may have asked.

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

UMER FAROOQ AWAN

BS Geophysics (2014-2018)

ABSTRACT

Miano gas field is one of the prominent gas-producing fields of the Middle Indus Basin, SW Pakistan. In this dissertation, focus is placed on the structural interpretation of the Miano block-20 in order to demarcate the probable zone for the accumulation of hydrocarbons. This study attempts in preparation of synthetic seismogram of Miano-09 well. Analysis of geophysical borehole logs provides one of the best approaches to characterize rocks within boreholes. A model based post stacked inversion is applied with 2-D seismic data for quantitative interpretation of reservoir.

For the interpretation of the seismic lines, three reflectors are marked by correlating synthetic seismogram on seismic section. As the area of study lies in the Lower Indus Basin, horst and graben geometry in this region is common which is confirmed by fault polygon and time and depth contours maps.

Petrophysics is the one of the most reliable tools for the confirmation of the types of the hydrocarbon and for marking the proper zone of the interest for the presence of the hydro carbon by combination of the different logs results. In this dissertation the petrophysics is performed on the Miano-09 well and a zone of interest is marked where the average shale volume is 24%, effective porosity is 8% and potential of hydrocarbon is 62%.

The result from model based inversion show us the low acoustic impedance of (33509(m/s)*(g/cc)) and porosity map depict the high porosity of 6 to 7.5% throughout the layer of zone of interest.

DEDICATION TO

My Parents, Brothers and my beloved sister

And specially my most respectable supervisor

Dr. Aamir Ali

and to

Altaf Fareed , Asif Chingwani, Bader Ali, Sohail for their kind Guidness

Chapters

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1 INTRODUCTION

1.1 Introduction

Energy sector plays an important role in the development of any country. As the demand of energy increases in the world, the exploration increases in the energy sector of the countries. No doubt with exploration we mean the exploration of hydrocarbons over the unexplored areas to full fill the demand of energy. Developing countries like Pakistan is in the list of countries which have increased its explorations of hydrocarbons to increase its economy. Miano gas field is one of the prominent gas producing fields of the Middle Indus Basin, SW Pakistan. Daily average production of this field is 98 MMscf gas, and 52 barrel condensate. Present dissertation comprises of exploration results in this field.

One of the exploration concerns of Miano Field is its identification of the prospective structural design within the heterogeneous structural and stratigraphic reservoir system. These reservoir systems are composed of varied architectural elements such as the Horst and Graben geometries. The productive sand in the up thrown block i.e Horst is favorable for exploration of hydrocarbons and for the implication of reservoir characterization (Zareef et al., 2016).This dissertation comprises the attempt of the identification of structural features and the characterization of clastic sediments of Lower Goru reservoir using the preliminary seismic interpretation to the 2D seismic profiles of the Miano Gas Field, Middle Indus Basin, SW Pakistan. B- Sand is found to be the lead in seismic interpretation.

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 refraction method for deep hydrocarbon exploration in petroleum geology. Petroleum geology refers to the specific set of geological disciplines that are applied to the search for hydrocarbons. Oil and gas fields are geological features that result from the; source rocks, Migration, reservoir rocks, seals, and traps (Sroor, 2010). Hence geology and petroleum system of the area are important factor regarding exploration.

Investigation of earth through geophysical method involves taking measurement in order to check the variation in the physical properties of the earth both laterally and horizontally (Bust et al., 2010)

Petrophysics is one of the most important and reliable technique in the field of the earth sciences. Petrophysics provide the link between the rock physics properties i.e. lithology, water saturation, porosity, clay content, acoustic impedance, Primary and secondary wave velocity, and the elastic moduli. Similarly the rock physics is used for forecasting the seismic response with assumed reservoir and overburden properties (Avseth et al., 2010).

Seismic attributes derived from time, amplitude and frequency do not provide adequate information of reservoir properties on a layer by layer basis. Layer by layer information can be derived by means of stratigraphic inversion of post stack seismic data in terms of acoustic impedance. There are many inversion techniques, which are utilized in the industry for extraction of acoustic impedance from post stack seismic data. These techniques are band-limited, model based and neural network nonlinear inversions (Russell, 1988, Duboz et al.,1998,Keysand Foster,1998,Van Reil, 2000). In this study, model based inversion technique have been utilized for inverting a 2D seismic data set into acoustic impedance volumes from Miano gas field Middle Indus Basin, SW Pakistan

1.2 Objectives

The main objective of dissertation is to present a subsurface model of study area and to characterize the reservoir potential in the zone. In following all objectives, mentioned in points, to interpret surface structure exposed by satellite image and previous studies. Picking horizon at different intervals using synthetic from well data.

- Detailed seismic interpretation for identification of the structures favorable for hydrocarbon accumulation.
- Petrophysical analysis for the identification of the hydrocarbon bearing zones.
- Model based inversion to extract acoustic impedance and to generate porosity map of reservoir.

1.3 Data used

To achieve all the objectives, seismic and borehole data given in Table-1.1 and 1.2 is used provided by Directorate General of Petroleum Concessions (**Pakistan**) to complete the thesis project.There are total five seismic lines in which three are dip lines and there trend is from east to west and one strike line and its trend is from north to south.

Table 1.1 Seismic Data used in interpretation

No	Line Name	Orientation	Nature of line	SP Range
1	P2094-219	E-W	Dip	102 -1140
2	P2094-221	E-W	Dip	102 -1142
3	P2094-223	E-W	Dip	102 - 1153
4	P2094-214	N-S	Strike	102 - 1175

Well Data obtained from DGPC for completion of Thesies work		
Well Name	**TD(m)**	**Type of well**
Miano-02	**4030**	**Exploratory GAS**
Miano-05	**3400**	**Development GAS**
Miano-06	**3429**	**Development GAS**
Miano-09	**3385**	**Development GAS**
Miano-10	**3610**	**Development GAS**

1.4 Base Map

For a geophysicist base map is a special type of map which shows the orientation of the seismic lines and specify the shot points (Sroor, 2010). The base map of the study area is shown in the Figure 1.1 which contains 2 strike lines and 3 dip lines and 1 wells of Miano area. The 3D view of the base is also shown to understand the seismic lines orientation easily in Figure 1.2.

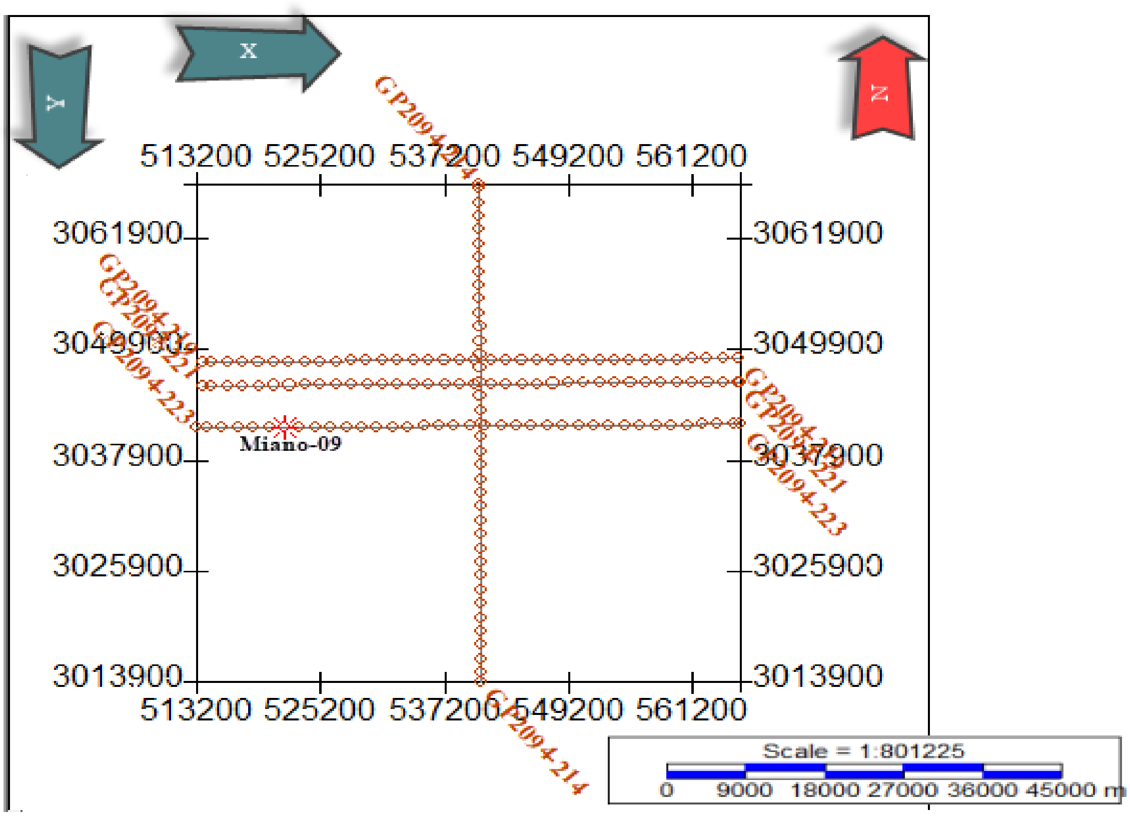

Figure.1.1 2D Base Map of the study area by IHS kingdom

1.5 Software Tools used

The tools used to carry out the research work are :

- SMT KINGDOM 8.6
- HRS
- Petrel
- Snagit 11 (Editor

1.6 Geographical Location

My study area the (Miano block 20) is located 62 km away in the southeast direction of the Sukkur city Sindh province. This field is about 42km long along the strike of the data.

Miano gas field is one of the prominent gas-producing fields of the Middle Indus Basin, SW Pakistan. Two of the largest gas field of the Pakistan Mari gas field and the Sawan gas fields are founded in the north of this area at 75km and 150km away from this are, Basically the Miano gas field is located in the Thar desert, Geologically it is located at the boundary of the Lower and Middle Indus basin, between Indian basement and Kirthar fold and thrust belt. The geographic coordinate of the area are below.

- **Latitude of the area:**
- Latitude of the area 27.15º to 27.45º N
- **Longitude of the area:**

  Longitude of the area is 69.00º to 69.45º E

The Location, satellite and Tectonic Location Map of the study area are shown below in Figure (1.2 and 1.3).

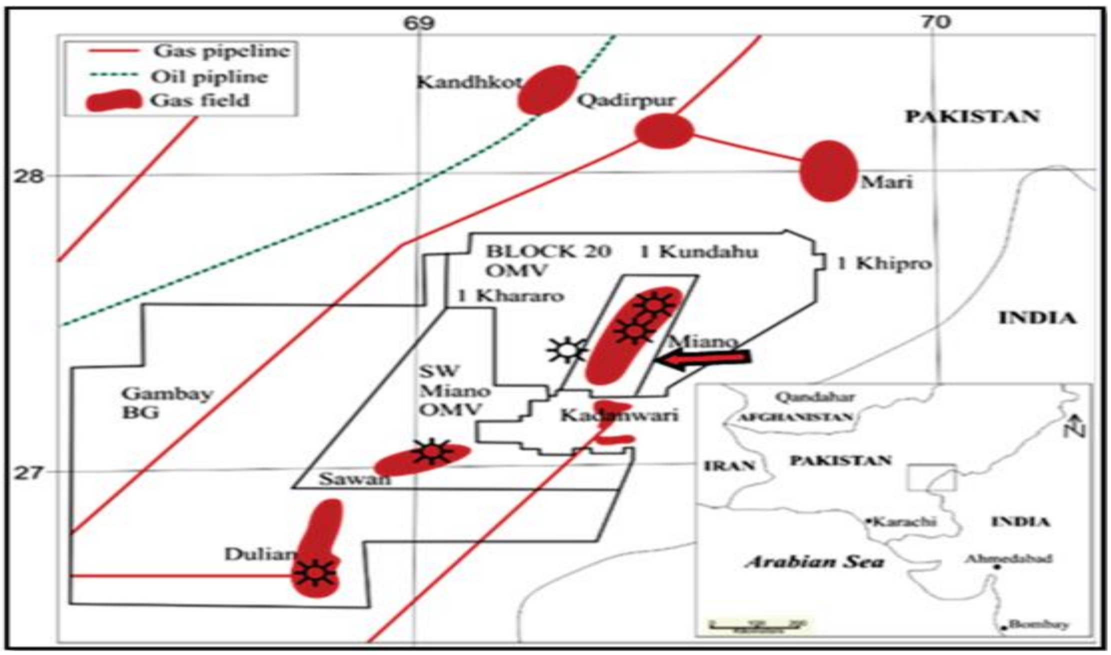

Figure 1.2 Location map of study Area (Zareef et al., 2016)

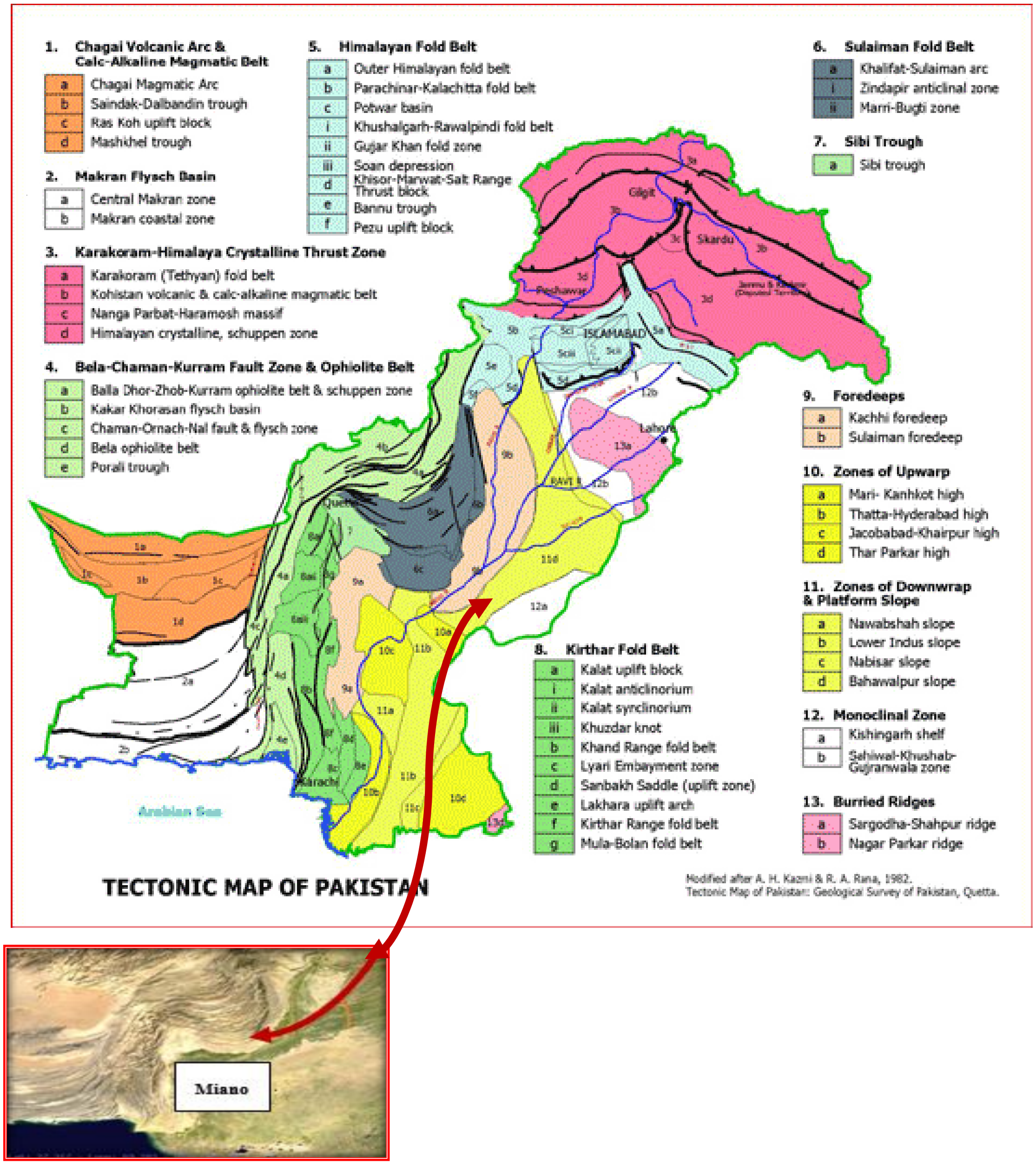

Figure 1.3 Geographical location of the Miano Area (Nadeem et al., 2004)

1.7 Thesis Organization

This Thesis is divided into five chapters with first chapter forming an introduction. The 2nd chapter covers the Geological setting and History of study area. In Chapter 2 central Indus Basin is discussed more thoroughly and Stratigraphic Chart with Source, Seal and reservoirs of study area are mentioned with various colors on the other hand, are mentioned as a whole too. Chapter 3 deals with the Basic goal of this dissertation i.e. Seismic interpretations of study area using

Seismic reflection methods. In Chapter 4, various Petro-physical properties of concerned reservoir in study are found by using well-logs. And chapter 5 covers the extraction of Acoustic Impedance and generation of porosity map of the reservoir by using Model based inversion Following were the methodologies adopted to complete this work.

- Collection of geological & Geophysical data
- Preparation of base map
- Identification of faults on seismic sections
- Marking of interested reflectors on seismic sections
- Determination of horizons by generating 1-D synthetic seismogram
- Finding velocity of horizon using well data
- TWT contour map generation
- Depth contouring
- Geo-mechanical properties with the help of log data.
- Finding Acoustic impedance and Porosity map of reservoir by Model Based Inversion.
- Conclusions

2 GEOLOGY

2.1 Importance of the Geology

In field of the oil and gas exploration study about the geological history of the area is most important. Basically the geological history of the area is related to the tectonic behavior of the area and deposited sedimentary sequences of that area (Kingston et al., 1993).

2.2 Sedimentary basin

Sedimentary rocks are deposited in the depressed area called the "Sedimentary basin". The sedimentary basins are depressed sites having the thick sediments in interior and thin sediments at sides (Shah et al., 2009). According to the depositional history and the tectonic behavior the Pakistan is comprises on the two main sedimentary basins which are below.

- Indus basin
- Baluchistan basin

Both these basins are evolved through different geological episodes and were finally combined together during the cretaceous age along Ornach Nal and the Chamman transform fault (Kazmi and Jan., 1997).The Indus basin is then further divided into three main parts ,and our study area lies in the central part of the Indus basin. The basin division of the Pakistan and then further subdivisions of the Indus basin are shown in the below Figure 2.1 (Kadri, 1995).Central indus basin have Punjab plateform sulainman depression and sulaiman fold belt.

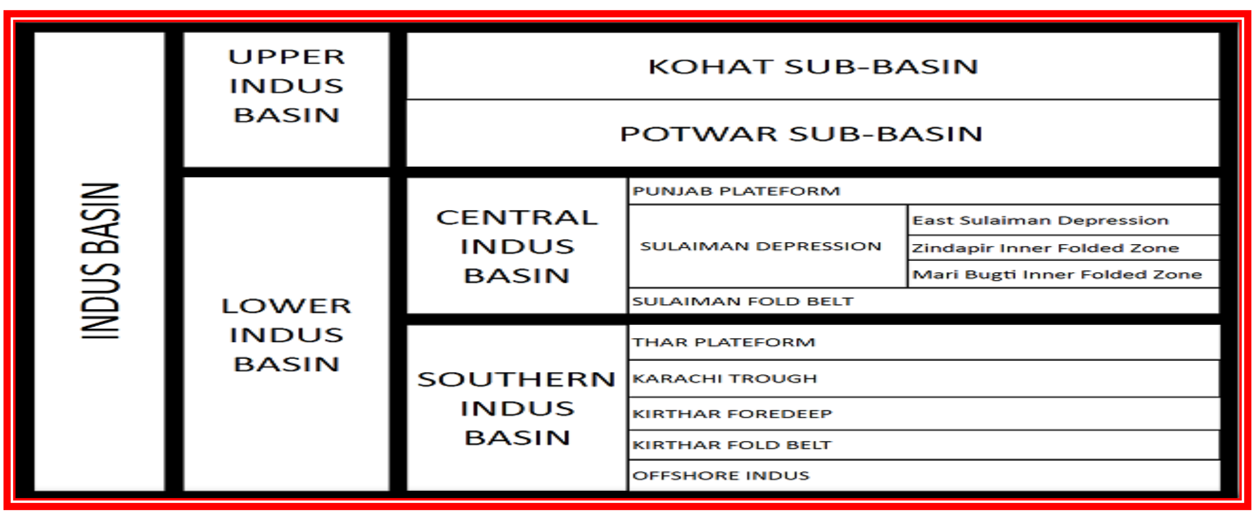

Figure 2.1 Division of the Indus Basin (Kadri, 1995)

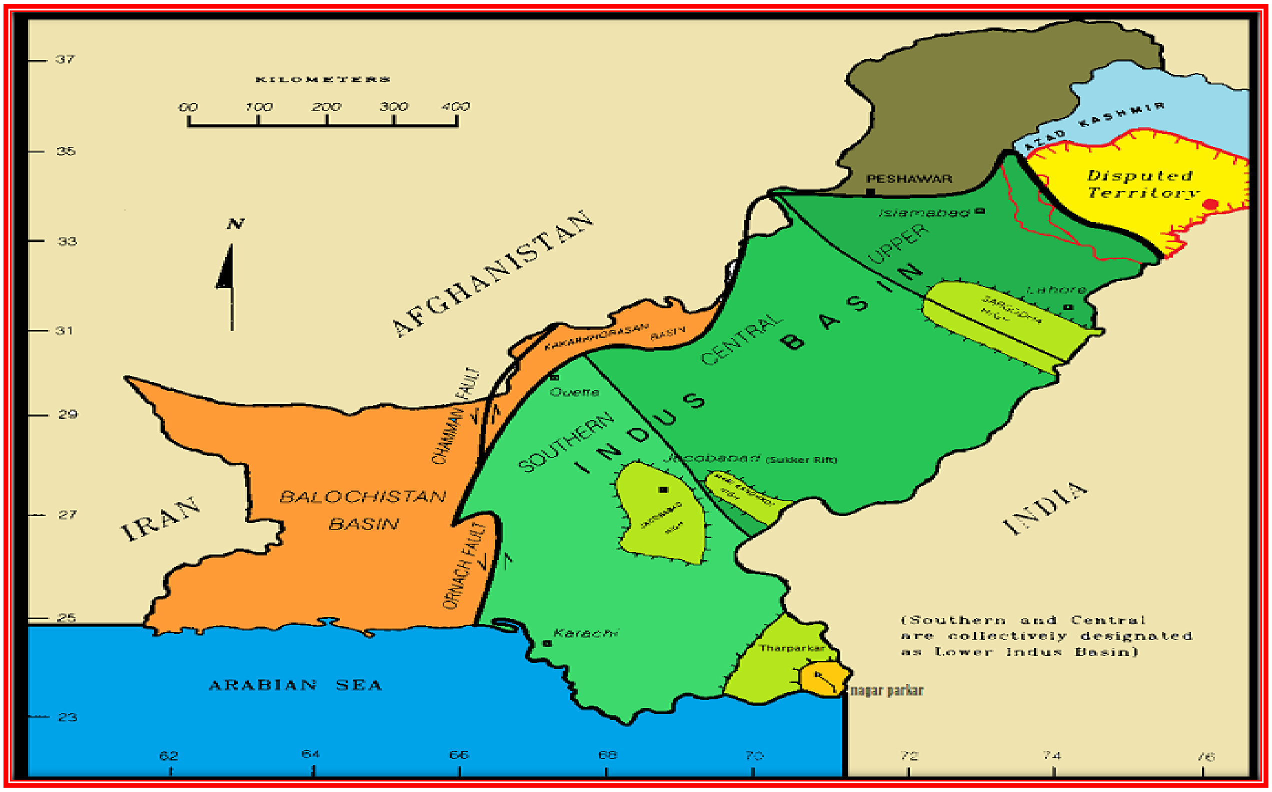

Figure 2.2 Sedimentary basin of Pakistan (Fateh et al., 1984)

2.3 <u>Structure and Tectonic Settings of the study Area</u>

The tectonic study of the Pakistan shows that Pakistan lies in the two main domain of large land masses i.e Gondwanaland domain and the Tethyan domain.The northern most part and the western part of the Pakistan lies in the Tethyan domain and its having most complex geology and structure, while the southern part lies in the Gondwanaland domain. The Indus basin is the largest basin in the Pakistan. The orientation of the Indus basin along SE-SW Direction is 2500 sq. km. The tectonic history of the Pakistan shows that it is most stable area as compared to the other tectonic zone of the Pakistan (Kazmi and Jan, 1995).

The study area for this project is (Miano block-20). This block is located in the eastern part of the Jacobabad-Khairpur high, which is of the most prominent feature identified in the seismic survey of the Indus basin. This study area lies at the boundary of the Middle and Central Indus basin. The Miano field shows the series of the fault which are mostly Normal and strike slip in the nature and having extension in the direction of N-NW to S-SE. These having some throw and they separate the reservoir of the sand in this area. These tertiary faults are produced in the result of the bending of the crustal plates due to the Indo-Eurasian collision and rebound relief (Nadeem et al., 2012). According to the seismic study of this area mostly features of this area are extensional and middle Indus basin is mostly characterized by the passive roof complex types structures (Kadri I.B., 1994). The tectonic setting of this area after (Mehmood et al., 2004) is shown in the below Figure 2.3.

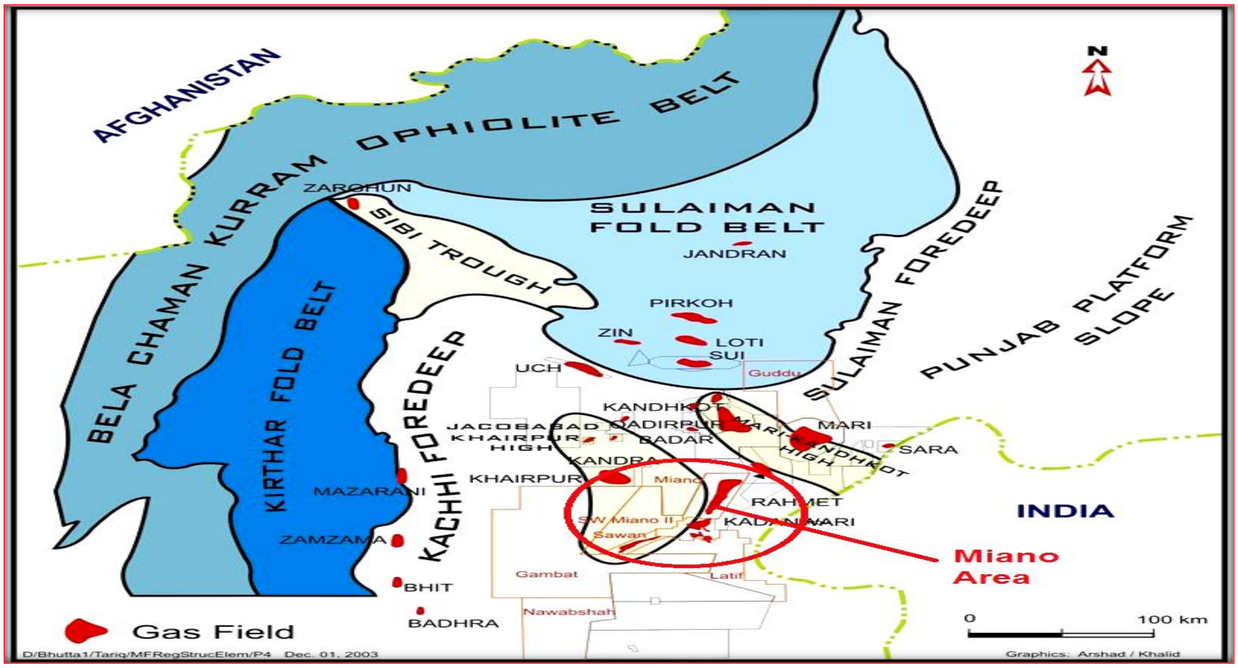

Figure 2.3 Regional tectonic map of Block-20 in the Middle Indus Basin (Mehmood et al., 2004)

2.4 Stratigraphy of the Area

To study the depositional history of that area the stratigraphic study of that area is most important .The study area Miano lies in the central Indus basin, which is located very close to the rift margin of the Indian plate and the African plate.

According to the stratigraphic history of this area this basin comprises mostly Permian to Mesozoic sediments which are overlying on the very clear angular unconformity of the late Paleozoic age whole of the study area is thickly covered by the alluvium and we cannot see any out crop on the surface, which is a direct indication of the stratigraphic succession. According to the stratigraphic study of this area lower Goru is acting as a reservoir in this area.The lower Goru is further divided into different four intervals, the lower Goru B-Interval is main productive reservoir in Miano area .According to the well log study the progradational sequences are founded in this area and Mesozoic progradational sequence is deposited on east ward inclined gentle slope. The sequence stratigraphic study shows that every prograding unit represent the latterly variation in the facies from shallow marine to continental side in the east and west.

In the Thar platform these Mesozoic sediments are regionally plunging towards west direction and are unconfirmabaly truncated by the (Khadro formation's basalts) volcanic rocks, also they shows the truncation towards sedimentary section of the Paleocene age (Nadeem et al., 2012).

The interbedded siltstone, Sand stone and shale's of the shallow marine and the continental origin are also present of Permian, Triassic and Jurassic age Mostly sedimentary rocks of this area belongs from the Permian and Mesozoic age and overlaid by the stronger angular unconformity of possibly Paleozoic age (Kadri I.B, 1994). The Chilton lime stone having the strongest and prominent seismic reflector in the middle Indus basin. This Chilton lime stone is down lapped and overlain by the cretaceous and late Jurassic regressive strata consists on the bottom sets, clinoform and the topsets which prograde towards the western part of the Indian Craton.

The source rock of the area is Sembar formation while the seal and Reservoir rocks are present within the lower Goru formation. The Sembar formation mostly consists on the argillaceous Foreset while initial topsets are called the Chichali formation. The younger topsets are "A-Sand" of the Lower Goru formation. Still no name has been associated with the submarine fan system associated with prograding system according to (Sturrock and Tait. 2004).

The Sembar formation is deposited in the marine environmental condition which consist on mostly black shales and subordinate siltstone and it is the main source of the hydrocarbon in the middle and the lower Indus basin. The TOC in Sembar formation ranges from the 0.5 TO 3.5 percent (William, 1995). The stratigraphic coloum of the area after Nadeem et al., 2012 is showen in the below Figure 2.4.

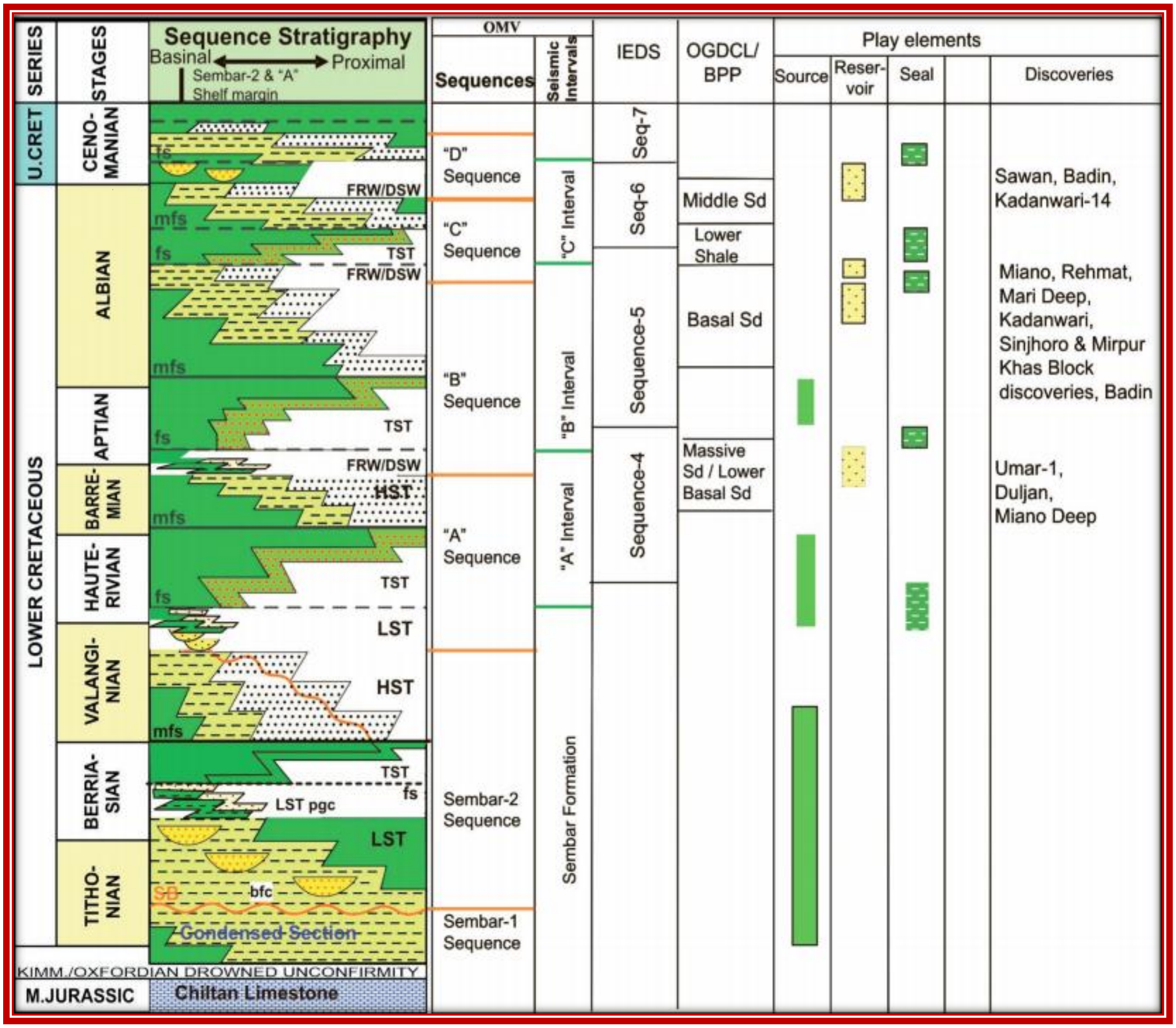

Figure 2.4 Stratigraphic chart for the Sembar and lower Goru formation (Nadeem et al., 2012).The Sembar formation consist on the type-III kerogen which having ability to generate the gas, also type-II kerogen is present in Sembar formation (Wandrey et al., 2004).

The Lower Goru formation which is reservoir in the study area is deposited during the Jurassic and the early Cretaceous regressive system. The lower Goru “A”, “B”, “C” and “D” interval are deposited during the long term third order gradual sea level rise, but the deposition is mostly punctuated by the high frequency 4th and 5th order relative sea level fluctuation. Hence they led the deposition of the prograding clastic sand packages on the vast and wide spread ramp. The balance between the sediment supply and the accommodation space from “E” to “SE” maintained slightly aggradation to overall progradational profile on the “A”,”B” and “C” interval of the lower Goru formation (Krois et al., 1998). The Progradation is occurred in the result of the relative sea level fall due to which the sediment supply becomes enhanced than the accommodation space (Nadeem et al., 2012).

2.5 Petroleum prospect

The petroleum prospect of the Area tells us about the source Reservoir and seal Mechanism .Different gas fields like Kadanwari, Sawan Miano and Tajjal are present in the area. The Stratigraphic column of the area shows different rocks act as Source, reservoir and Cap rock in the area. The general description is given below.

2.5.1 Source Rocks

Source rock is the productive rocks for hydrocarbons; these rocks also initiate the conversion of organic compound into oil and gas. The Formations which act as source rocks in the study area are as follow.

- **Sember Formation**

Sember Formation is believed to be the major source of hydrocarbons in central and southern Indus basins, also huge gas accumulation in Sulaiman province. Potential of a reservoir also occurs within the sand stone of formation.

- **Ranikot Formation**

Ranikot shales were used to be considering as the main source for all the gas present in that region, these are the source for overlying Lakhi Formation.

2.5.2 Reservoir Rocks

The main reservoir rocks in the study area are lower Goru and Parh formations. The depositional

Environment of the Lower Goru "B" sands in the Miano field is interpreted to be a tide dominated lithology of sandstone with interbedded shales. B-sands is the major producing reservoir in the study area. Sandstone is dirty white, and yellowish brown color, medium hard, friable medium grained, sub angular to sub-rounded, fairly sorted ancemented,argillaceous, visual inter-angular porosity ranged between 10-15%, fair oil shows with scattered and patchy yellowish to bluish white fluorescence and very weak, pale yellowish white residual cut. The low acoustic impedance of seismic waves together with strong seismic amplitudes indicates the presence of reservoir quality sands. This type of reservoir quality sands are only present in the depositionally up dip, i.e. the shallowest marine part of the lowstand wedge, as are found in the Sawan, Miano and Kadanwari Fields.

2.5.3 Trapping mechanism

The trapping Mechanism for the target reservoir in the study area is combination of structural and stratigraphic. An E-NE to S-SW trending isopach thick in the Lower Goru "C" Interval forms the structural trap, Supported by the horsts due to normal faulting. Towards the NE and SW trapping is caused by shaling out of the reservoir. The northwestern limit is defined by a facies controlled deterioration in reservoir quality, which creates an "effective zero reservoir" line.Transgressive shales of the Lower Goru "C" Interval directly, overlying the 'B' interval of reservoir sands, and thick shales and marls of the Lower Goru Formation form the regional top seal for the reservoir in the area. Shales and tight sands within the C-Interval of Lower Goru Formation act as lateral and bottom seals (Krois et al. 1998).

3 Seismic Data Interpretation

3.1 Introduction

Interpretation is a technique or tool by which we try to transform the whole seismic information into structural or Stratigraphical model of the earth. Since the seismic section is the representative of the geological model of the earth, by interpretation, we try to locate the zone of final anomaly. Not only a good interpretation be consistent with all the seismic data, it also important to know all about the area, including gravity and magnetic data, well information, surface geology as well as geologic and physical concept (Sheriff, 1999).

Seismic interpretation and subsurface mapping are key skills that are used commonly in the oil industry for exploration (Sroor, 2010). Seismic interpretation determines information about the subsurface of the earth from seismic data. It may determine general information about an area, locate prospects for drilling exploratory wells, or guide development of an already discovered field (Coffeen, 1986). Conventionally seismic reflection data which is result of seismic image of acoustic impedance interfaces having lateral continuity is used for picking and tracking laterally consistent seismic reflectors for the purpose of mapping geologic structures, stratigraphy and reservoir architecture. (Keary et al., 1986) have described two main approaches for analysis of seismic data structure analysis and stratigraphical analysis.

3.2 Types of the Interpretation

Qualitative interpretation and Quantitative interpretation are two main approaches for the interpretation of the seismic reflection data (Dobrin and Savit, 1988).

Qualitative interpretation is conventional or traditional seismic technique which is used primarily for mapping the sub-surface geology (Sheriff, 1999).

In this dissertation main emphasis is on the structural traps in which tectonic plays an important role. Whereas quantitative interpretations are more valuable than conventional techniques. By making some alterations in recorded data results in better prospect evaluation or mainly reservoir characterizations (Sheriff, 1999).The most important of these techniques include post-stack amplitude analysis (bright-spot and dim-spot analysis), offset-dependent amplitude analysis (AVO analysis), acoustic and elastic impedance inversion, and forward seismic modeling etc. These interpretations yield reservoir characterizations and quality. In this dissertation we have done 1-D forward seismic modeling, AVO analysis and facies modeling for determining characteristics and the sand class of the reservoir encountered in the study area. It is just due to lack of time and unavailability of well log data. We could not characterize each of formation in my study area, but in the same way each one can be characterized and results can be explained.

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 Figure 3.1, which provides the complete picture depicting how the dissertation has been carried out.

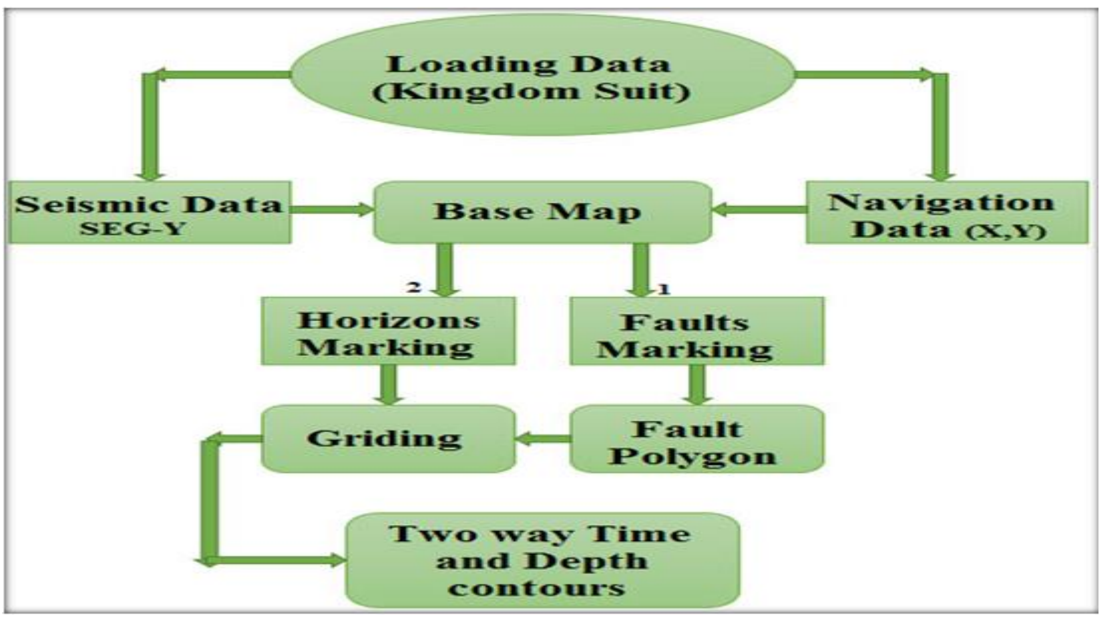

Figure 3.1 Work flow adopted for the seismic data interpretation

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.

3.4 Interpretation of the seismic lines

The Primary task of interpretation is the identification of various horizons as an interface among geological formation. For this purpose, good structural as well as stratigraphic knowledge of the area is required (McQuillin et al., 1984). Thus during interpretation process, we marked both, the horizons and faults on the seismic section by the information obtained from the synthetic seismogram generated from miano-09. We marked the four horizons. The horizons are named on basis of well tops of the well MIANO-09. Hence the first step before the Marking of the horizons is the generation of the synthetic seismogram. The steps used in the generation of the synthetic seismogram are explained below.

3.5 Synthetic Seismogram

Synthetic seismograms are artificial seismic traces use to establish correlations between local stratigraphy and seismic reflections. To produce a synthetic seismogram a sonic log and a density log is needed if the density log is not available then we can also use the constant density for that area. With the help of Miano-09 the synthetic seismogram was constructed shown in the (Figure 3.2) in order to mark the horizons.

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). Reflection profiles are sensitive to changes in sediment impedance, the product of compression wave velocity and density. Changes in these two physical parameters do not always correspond to observed changes in lithology. By creating a synthetic seismogram based on sediment petro-physics, it is possible to identify the origin of seismic reflectors and trace them laterally along the seismic line (Handwerger et al., 2004).

The following steps are adopted during the Generation of the synthetic seismogram using the IHS kingdom.

1. Load the Las file of the well in the software.

2. Open 1D forward modeling Project and select the well logs.
3. Integrate the sonic log to rescale from depth in meters to two-way travel time in seconds.
4. Compute velocity from sonic log for P and S waves.
5. Create a TD chart for the well from the velocity logs.
6. Compute Acoustic impedance log using velocity and density log.
7. Compute the reflection coefficients from the time-scaled velocity log.
8. Compute a first-order Ricker wavelet as a digital filter with two millisecond increments.
9. Two-way travel time; using a frequency in Hertz (35 Hz frequency is used in this study)
10. Convolve the reflection coefficient log with the Ricker wavelet to generate the amplitudes of the synthetic seismogram.

Now the generated seismogram is used to confirm the horizon. Basically we have the limited log data only miano-09 is the only well in our available data that having the DT and ROHB log to generate the synthetic seismogram .Hence due to the limitation of the well data the generated synthetic seismogram only confirm the B-interval but on the basis of the formation tops of the Miano-09 we marked the C-interval, top of the Lower Goru and the Ranikot formation. The display of the synthetic seismogram is shown in the Figure (3.2)

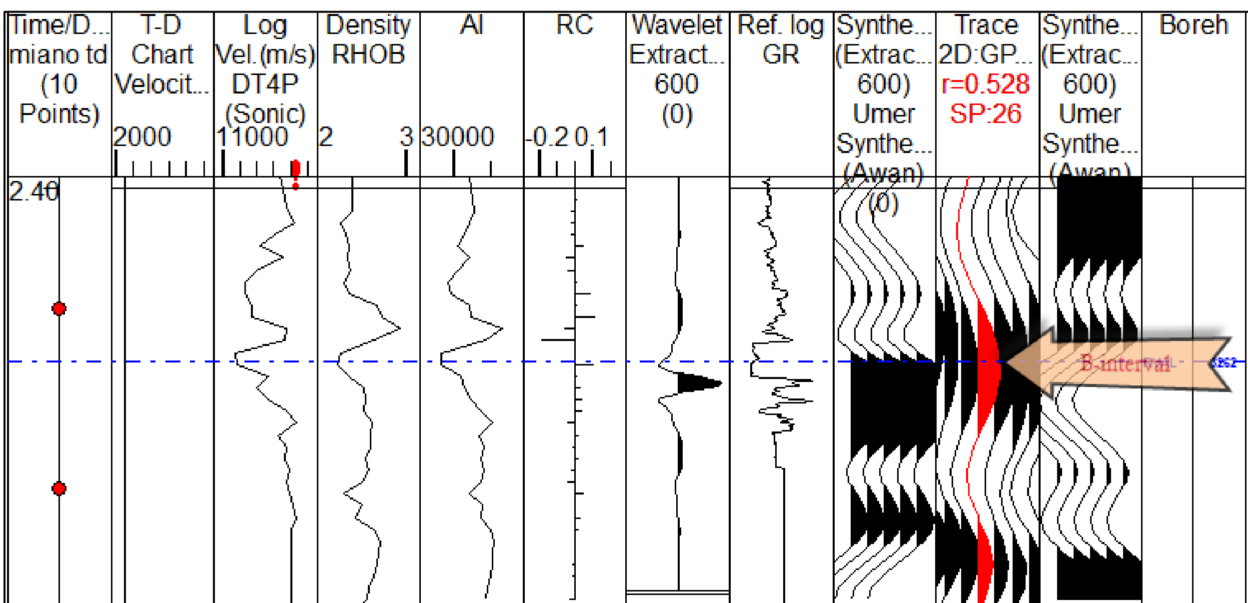

Figure 3.2 Synthetic Seismogram of the well Miano-09 on line GP2094-22

3.6 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. The Miano block 20 is lying in extensional regime hence we have conjugate normal faulting due to which the clear cut horst and Graben are formed.

3.7 Horizon Marking

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. Following are interpreted seismic sections of all lines assigned to me for completion of this dissertation.

3.7.1 Interpretation of the of Dip line GP2094-223

Figure 3.2 shows well tie with real time domain section. We marked horizons of B-interval, C-interval. Top of the lower Goru and Ranikot formation on the basis of the change in the acoustic impedance also confirmed by the synthetic seismogram .The following color scheme is used to mark the horizon.The interpretation shows the alternatively horst and Graben are formed between conjugate normal faulting. The fault having almost trend of the N-S. The main purpose was to show the favourable structure for petroleum accumulation. The horst sand graben structures are considered good structural trapes for the petroleum accumulation.

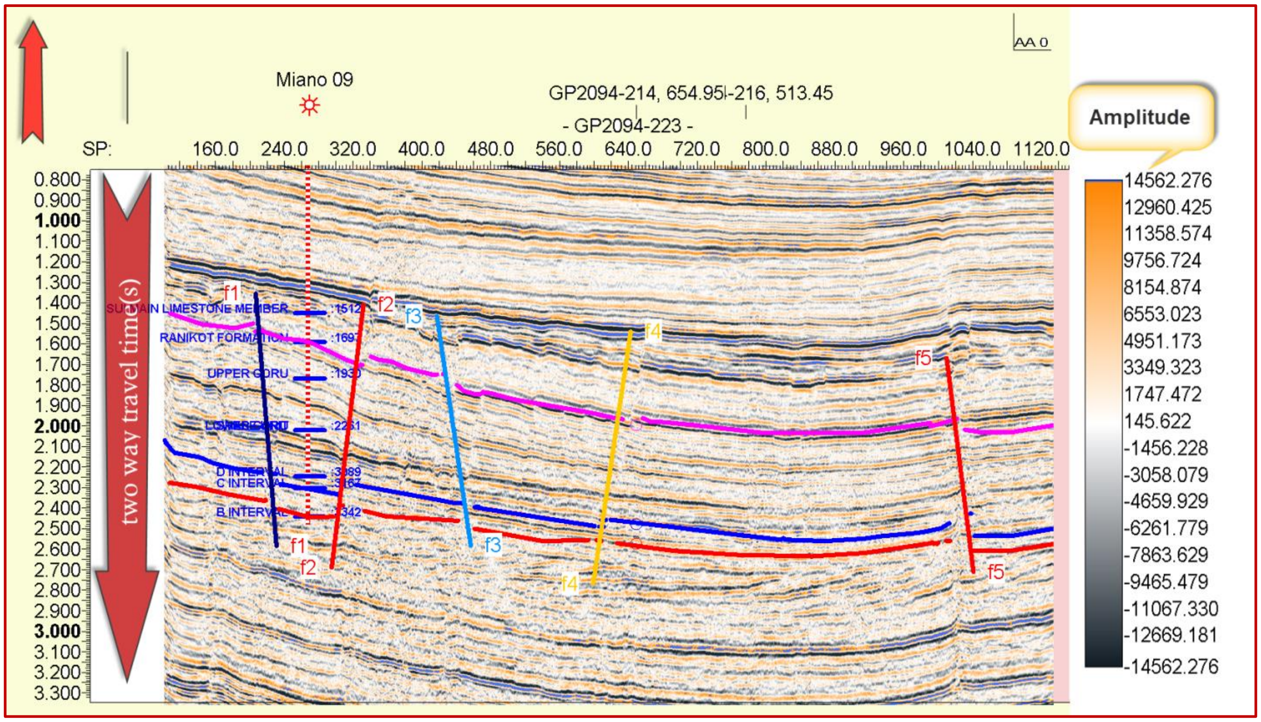

Figure 3.3 Well tie and interpretation of Dip line GP2094-223

In the interpretation of the line GP2094-223 the conjugate normal faulting can be seen. Due to this conjugate normal faulting the horst and graben structures are formed. These structures are considered favorable for the hydrocarbon accumulation in the extensional regime as in the Miano area. The marked horizon are named as given in below legend.

Table 3.1 TD chart for three marked Horizon

SN	***Formation Name***	***T(sec)***	***Depth(m)***
1	Ranikot	1.35	1697
2	C-interval	2.3	3167
3	B-interval	2.4	3342

3.7.2 Interpretation of the seismic Strike line GP2094-214

Using IHS kingdom we digitize the seismic line GP2094-223 with the strike line GP2094-214 .Then we removed the misstie however, in the given seismic section doesn't show any faults. The reason behind is that the given line is a strike line and the orientation of the line is against the basin configuration.

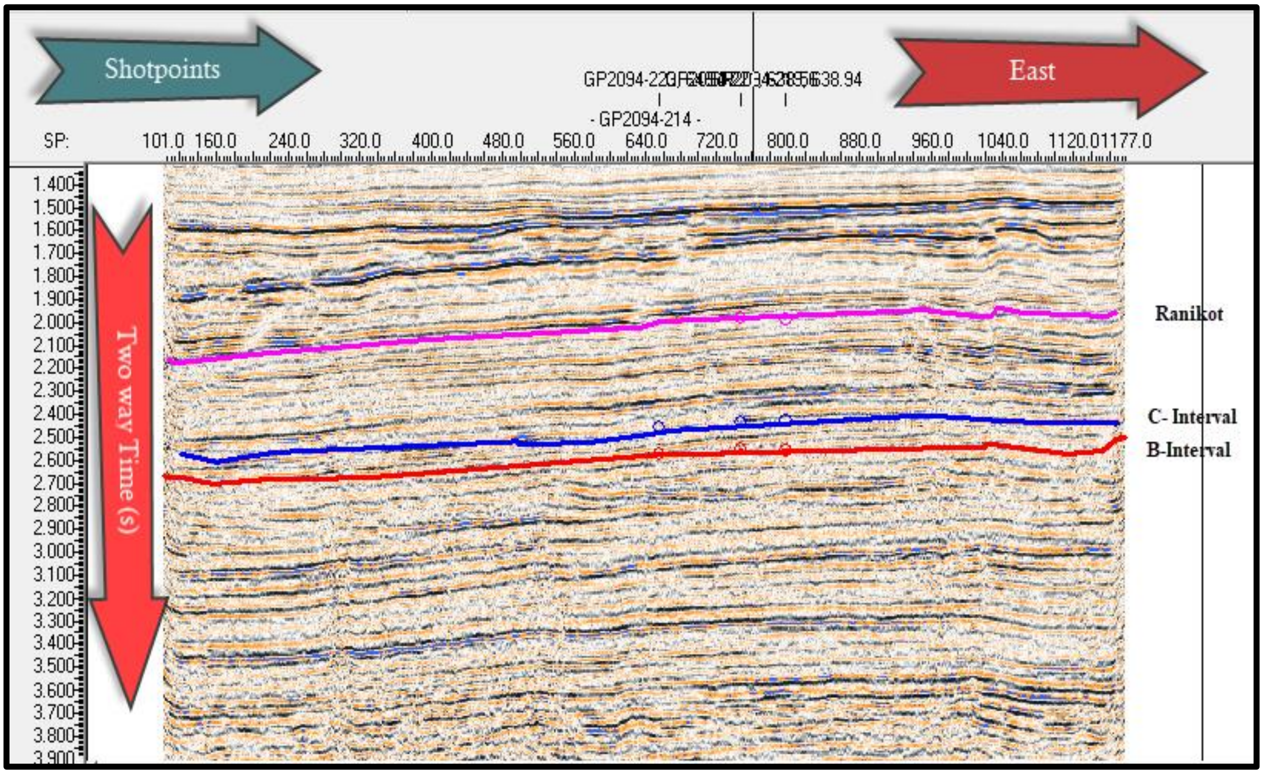

Figure 3.4 Interpretation of the seismic Strike line GP2094-214

3.8 Interpretation of the seismic Dip line GP2094-221

After marking the seismic strike line GP2094-214 we digitized this strike line with dip line GP2094-221 because this strike line was crossing all the dip lines which are showen in the base map in chapter-01. After digitizing the strike line with this dip line we marked the horizon and removed the miss tie. The faults were already marked on this seismic section. When faults and horizon were marked then the horst and Graben geometry is formed as showen in the below figure 3.6.The main purpose to interpret this line was to show the favourable structures for accumulation of the hydro carbon. The horst and graben structures are considered the good structures for petroleum system to accumulate the hydrocarbon after migration

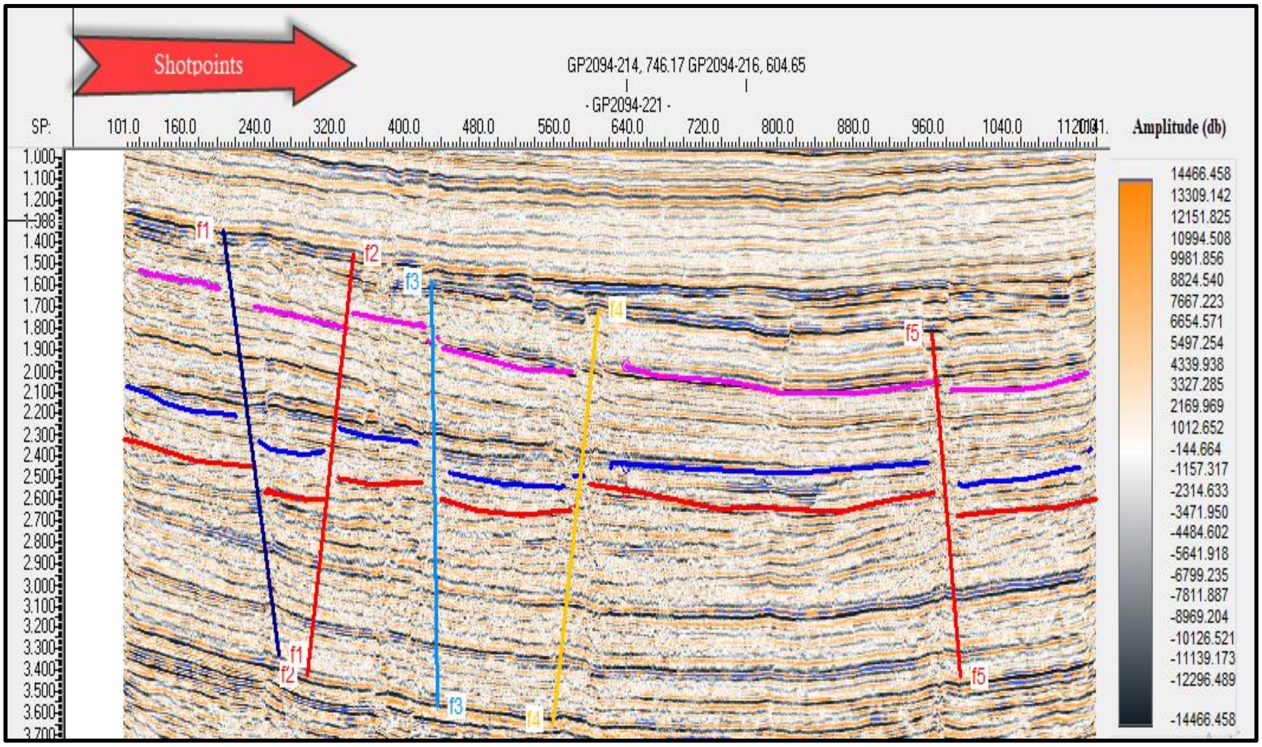

Figure 3.5 interpretation seismic Dip line GP2094-221

To see the clear geometry of the horst and Graben in Figure 3.7 the colors are filled in the displaced blocks of the formation .From the Figure it is clear that the elevated block between two faults is Horst and depressed Block is named as Graben.

3.9 Fault polygon construction

We pick the fault on seismic section & find it at the other seismic lines. The fault in seismic section is called Fault Segment and the fault on map view is called Fault Polygon (Sroor, 2010). In any software for mapping an area total fault should be converted into fault polygon before the contouring. The reason is that if we will not convert them into fault polygon then the software will not recognize it as a barrier due to which a wrong picture of the earth will be generated. I construct the fault polygon at B-interval level and at C-interval level. Because the B-interval is acting as reservoir in my study area and C-interval is acting as seal. The fault polygon on both these level are showen in the below figures (3.8, 3.9).

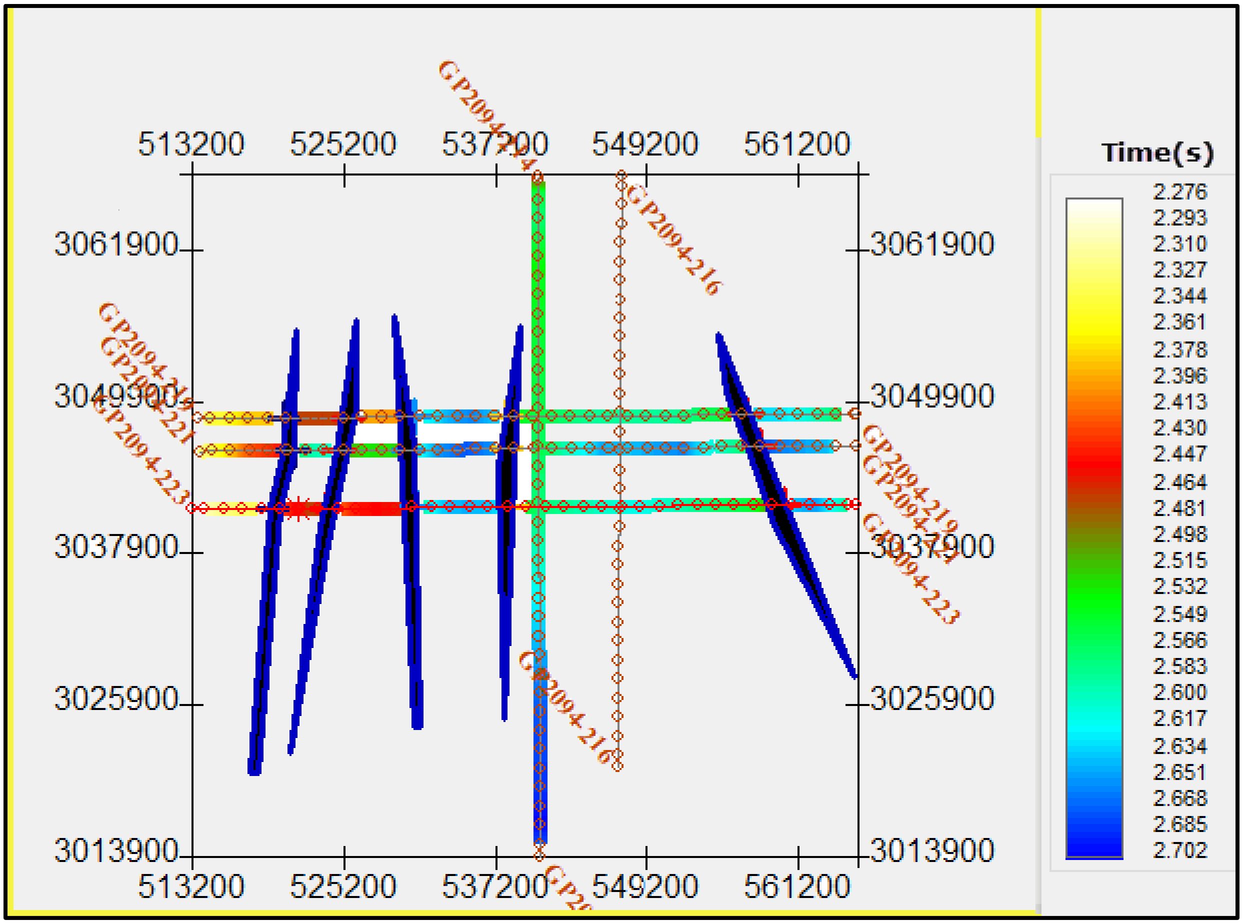

Figure 3.6 Fault polygon constructed at B-interval level

In the above fault polygon the small red rectangle shows the dip direction of the faults. It is clear that two conjugate normal faults are dipping towards each other hence Grabens are formed also when two conjugate normal faults are dipping away from each other horst is formed. The horst and graben geometry is clear from the faults polygon.

3.10 <u>Contour Maps</u>

The final products of all the seismic exploration are the contour maps, time or depth. The mapping is one of the most important part of the data interpretation on which entire operations depends upon. The contours are generally the lines which join the point of the equal depth and time (Coffeen, 1986). Contours represent the three dimensional earth surface into the two dimensional earth surface. These contour maps represent the structural relief of the formation, any faulting and folding including dip of the strata. The following contours maps are generated in order to represent the two dimensional picture of the various layers with in the area which is intersected by the various shoot lines. These contours maps are generated with the help of the advanced micro seismic technology (IHS kingdom 8.6).

3.11 Time based models

Time contour maps have been generated using weighted average algorithm. Below are the only models for B-interval of the lower Goru (Figure 3.7) acting as reservoirs in study area.

3.12 Time based contour maps of B-interval of the Lowe Goru formation

From the time contour map it is clear that the red color represent the low time and the blue color represent the high time. The low time represent the horst and high time represent the Graben.In the time contour map of the B-interval all leads which were predicted by the interpretation are two, way dip closure i.e. they have one side bounded by the faults shown in the Figure (3.7).

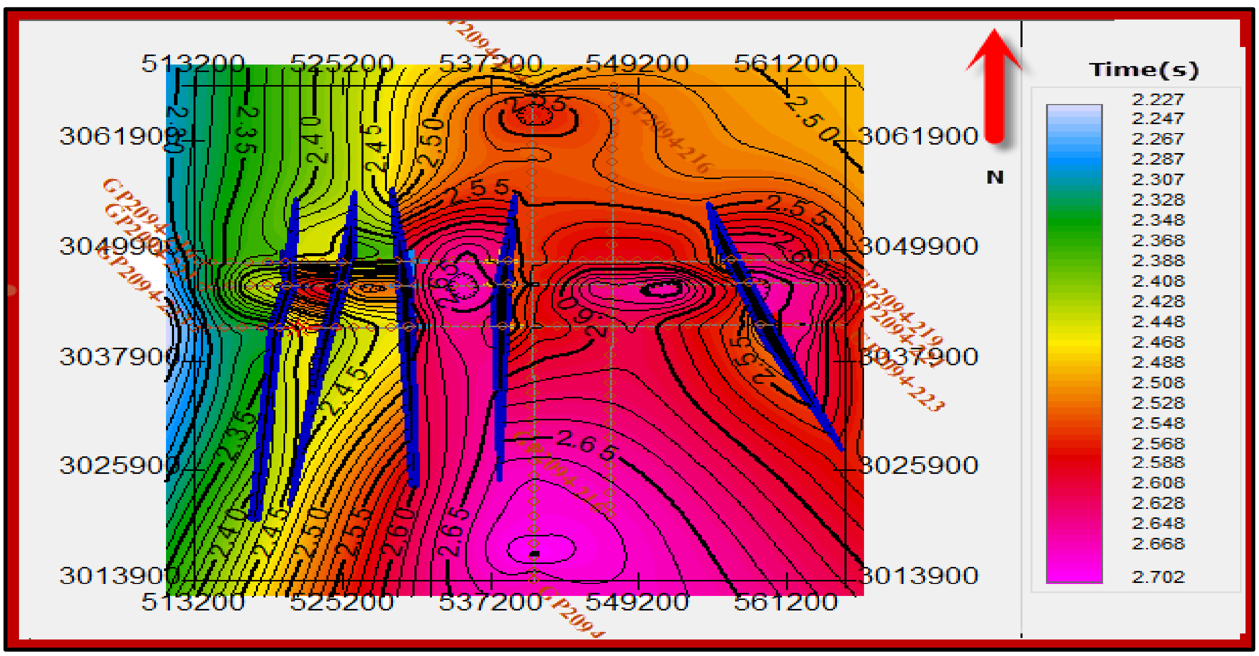

Figure 3.7 Time contour Map of the B-interval of the lower Goru

In the above time contour map of the reservoir B-interval are five major leads are predicted .They are given name of the leads on the basis of the closing contours, The leads having prospect of the presence of the hydro carbon. The well miano-09 is also present on the location of the lead L1 and the Miano-09 is the development well.Similerly if the other leads are studied in the detail there may be a chance of the presence of the hydro carbon.

3.12.1 Depth contour Map of the B-interval of the lower Goru formation

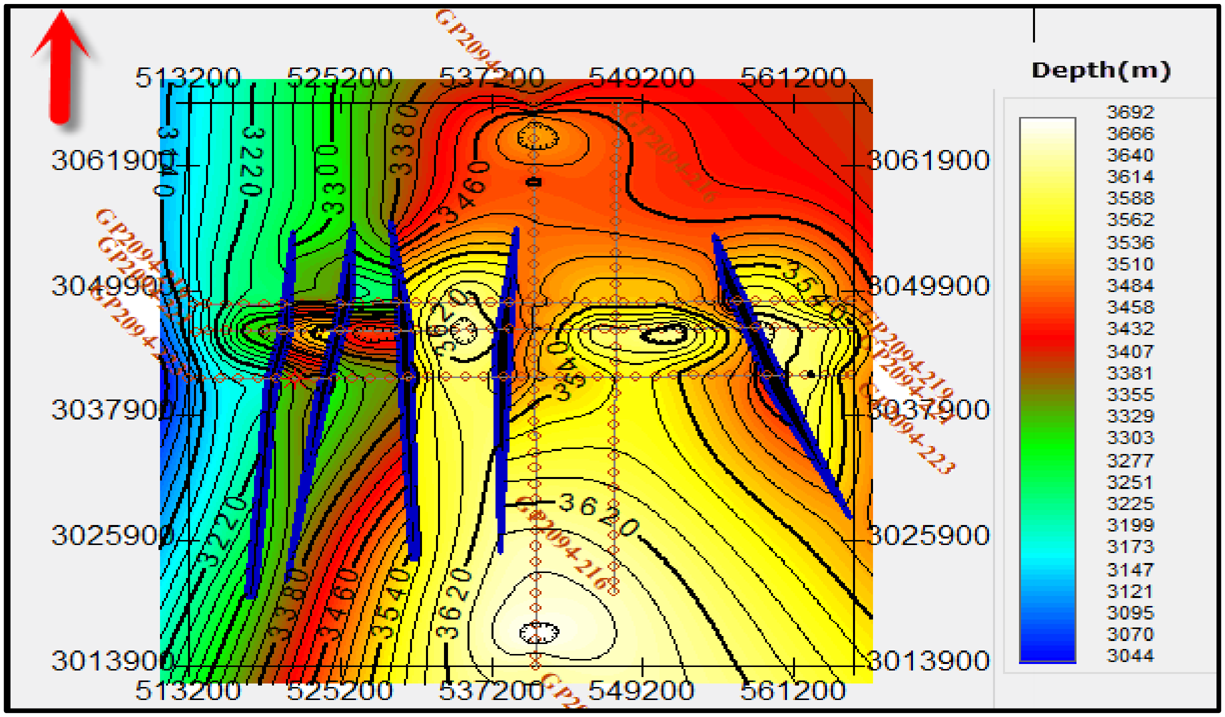

Figure 3.8 Depth contour map of the B-interval of the lower Goru formation.

After all interpretation it is concluded that in my study area there are horst and graben structures. The horst and Graben structures are formed in the results of the normal faulting which are also confirmed in the above interpretation. Hence we have favourable structures formed in the result of the normal faulting for accumulation of the hydrocarbon in the Miano area. This normal faulting is generated in the results of the Permo Triassic rifting, during the initial Gondwanaland breakup. Subsequent Triassic and Jurassic rifting initiated a marine incursion from the Southeast.

All models shown above either 2D showing clear horst and Graben structures which can act a very good structural trap in the petroleum play point of view. From stratigraphic column discussed in previous chapter and Petroleum Plays in study area B-interval of the lower Goru formations has potential for hydrocarbons and faults in the area are major migration pathways for hydrocarbon and in most places are acting as traps.

4 PETROPHYSICS

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 apprehensive with 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. Pertophysical 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 miano area using the borehole data of Miano-09 and Miano-10.We used the log curves including spontaneous potential log (SP), Gamma ray (GR), Sonic log (DT), Latero log deep (LLD), Latero log shallow (LLS), Neutron log, density log, Photo electric effect log (PEF).For petrophysics analysis the following parameters are acquired on the basis of the log curves.

- Volume of shale
- Water saturation
- Hydrocarbon Saturation

Before going to calculate these properties we must have to know about the different types of the logs and there characteristics which area explained below.

4.3 CLASSIFICATION OF GEOPHYSICAL WELL LOGS

Different classifications and some short explanation of geophysical well logs is as follow. The logs are explained according to the tracks in which they are run and this is clear from the flow chart given below.

4.4 LITHOLOGY TRACK

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

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

4.4.1 Gamma ray (GR)

With the help of this log we measure the natural radio activity of the formation. Basically the gamma ray log is the passive logging because we measure only the formation property without using any source. The gamma ray emits from the formation in the form of the formation in the form of the electromagnetic energy which are called the photon. When photon collide with the formation electron hence they transfer the energy to the formation electron so the phenomenon of the Compton scattering occurs. Now these emitted gramma ray reached to the detector of the gamma ray and counted and displayed as count per second which is termed as the Gamma ray.

Basic purpose of this log is to differentiate between the shale and non-shale (Acquith and Gibson, 2004).

4.4.2 Spontaneous Potential log (SP)

The SP log is also passive log which record the naturally occurring potential in the well bore. In this log we used the single moving electrode in the bore hole and reference electrode at the surface, located in the mud pit. Hence the SP log therefore record the potential difference between the reference electrode and the moving electrode in the borehole (Gibson, 2004).

This log is used for the following purposes according to the (Danial 2003).

- Identification of the permeable and non-permeable zone.

- Detection of the bed boundaries.
- Determination of the shale volume.
- Determination of the resistivity of the formation.
- Up to some extent the qualitative measure of the permeability.

4.4.3 Caliper Log (CALI)

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

4.5 Porosity Logs Track

Porosity logs measure the porosity in the volume of the rock. These logs are also helpful in order to distinguish between the oil, gas and water in combination with the resistivity log.

4.5.1 Porosity log include

- Sonic logging (DT)
- Density logging (ROHB).
- Neutron logging (NPHI).

4.5.2 Sonic Log

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

1-Porosity (using interval transit Time)

2-Lithology identification (with Neutron or Density).

3-Synthetic seismograms (with Density).

4-Mechanical properties of formation with (Density).

5-Porosity (using interval transit time).

6-Lithology identification (with Neutron and/or Density).

7-Synthetic seismograms (with Density).

8-Mechanical properties of formation (with Density)

9-Abnormal formation pressures detection.

4.5.3 Density Log

In the density logging gamma ray collide with the electron in the formation and scattered gamma ray (Compton scattering) received on the detector which indicate the density of the formation. Increase in the bulk density of the formation causing the decrease in the count rate and vice versa.

Bulk density which is obtained from the density log is considered the sum of the density of the fluid density and the matrix density of the formation. However density log used separately and also along with the other log to achieve the various goals (Tittman and Wahal, 1965).

4.5.4 Neutron log (NPHI)

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

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

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

4.6 Electrical Resistivity Logs Track

Basically there are different types of electrical Resistivity Logs. But in my work I have only two logs available in my data which are simply explained as follow.

This log measures the resistivity of the subsurface, but actually they measure the resistivity of the formation fluids. They are very helpful in order to differentiate between water filled formation and the hydrocarbon filled formations. Resistivity logs includes the following.

- Latero log Deep (LLD).
- Latero log shallow (LLS).
- Micro spherical focused log (MSFL), but MSFL was not present in my Data of Miano-09 and Miano-10.

4.6.1 Laterolog Deep (LLD)

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

4.6.2 Laterolog Shallow (LLS)

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

4.7 SCALE USED FR THE DIFFERENT LOGS TRACK

The scales used for different logs track area explained in the below table 4.2

Table 4.1 Scale used for the different logs track in SMT kingdom for petrophysical logs

N0	Logs name	Abbreviation	Scale	Unit
1	Gamma ray Log	GR	0------------300	API
2	SP Log	SP	-120--------40	Mvolt
3	Caliper Log	CALI	3-------------16	INCHES
4	Sonic Log	DT	120----------40	µsec/ft
5	Density Log	ROHB	1.95---------2.95	Gm/cm3
6	Neutron Log	NPHI	0.45---------(-0.15)	PU
7	Laterolog Deep	LLD	1--------------1000	Ωm
8	Laterolog Shallow	LLS	1--------------1000	Ωm

4.8 Workflow for Pertophysical Analysis

Petrophysical interpretation is carried out using the kingdom sotware.First of all the raw log curves are loaded step by step and different log properties are calculated. Different mathematical equations and the schlumberger charts are used in order for the calculation of the different log properties. Work flow is given in Figure 4.1.

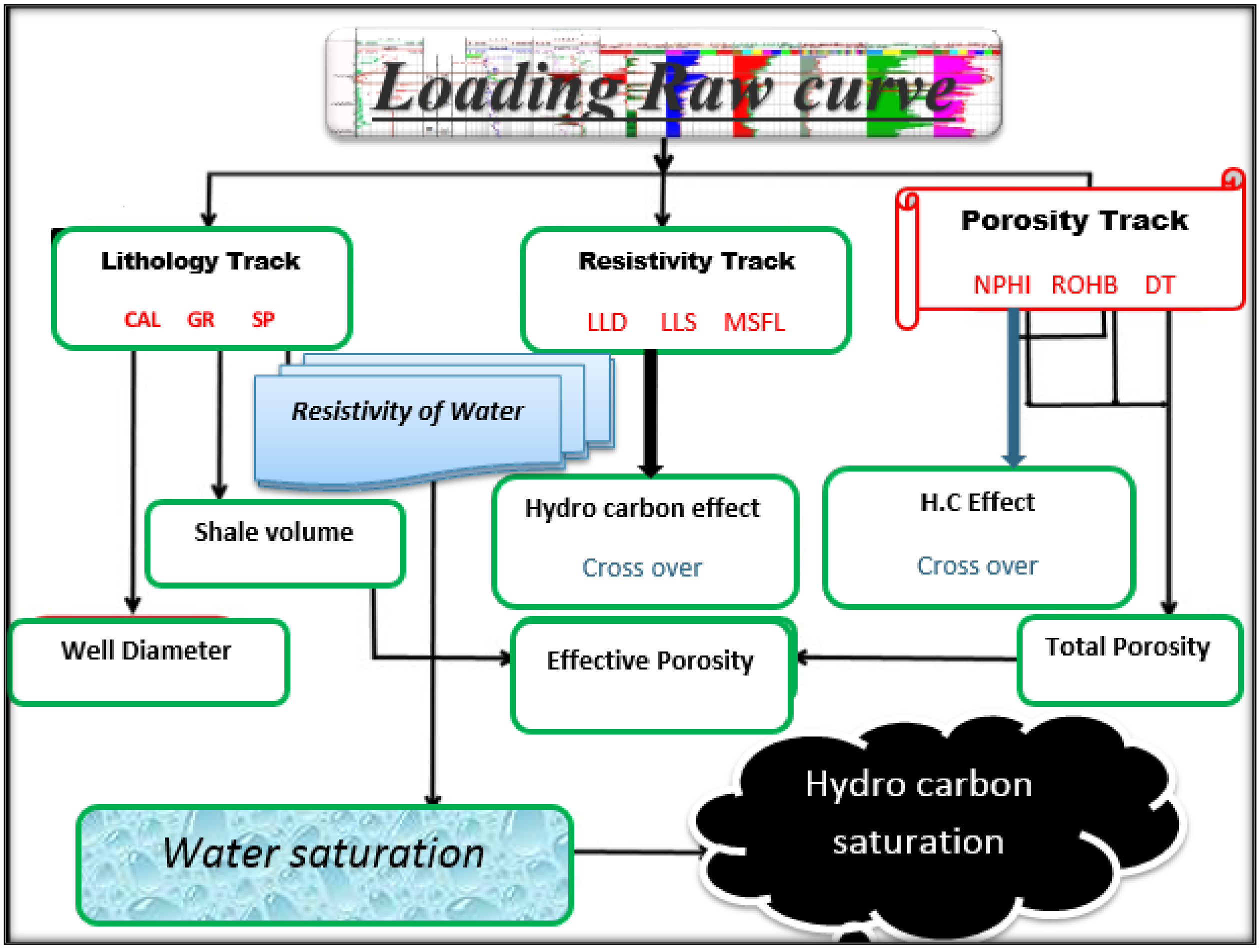

Figure 4.1 Petrophysical interpretation workflow

Raw log curves from the wells Miano -09 and Miano-10 are used for the petrophysical interpretation .The main reservoir in the area is Lower Goru formation of the cretaceous age. The lower Goru is divided into the 4 intervals (A, B, C, and D interval). In Miano area the B-Interval is acting as a reservoir.The top and the bottom of the is defined by the petrophysical analysis. The zones of interest are also identified on the basis of the petrophysical interpretation where there is chance of the presence of the hydrocarbon. The raw logs curves which are used are showen in the above interpretation workflow.

4.8.1 CALCULATION OF ROCK PROPERTIES

Many of the rock properties can be derived using geophysical well logs. We have calculated the following properties using the different equations which are given in below Table 4.3.

Table 4.2 Different equations for calculating rock properties (Asquith et al., 2004)

	PROPERTIES	*MATHMATICAL FORMULAS*
1.	VOLEUME OF SHALE (Vsh)	VSH=(GR-GRCLN)/(GRSHL-GRCLN)
2.	DENSITY POROSITY (PHID)	PHID=(RHOMA-RHOB)/(RHOMA-RHOF)
3.	SONIC POROSITY(PORS)	PORS=(DLT-DLTM)/(DLTF-DLTM)
4.	TOTAL POROSITY (PHIT)	PHIT=(DPHI+NPHI)/2.0
5.	EFFECTIVE POROSITY (PHIE)	PHIE=((DPHI+NPHI)/2.0)*(1-VSH)
6.	STATIC SPOTANIOUS POTENTIAL (SSP)	SSP=SP(CLEAN)-SP(SHALE)
7.	RESISTIVITY OF MUD FILTRATE(Rmf2)	$R_{mf2} = \frac{(ST + 6.77) \times R_{mf1}}{(FT + 6.77)}$,
8.	FORMATION TEMPRATURE (FT)	$FT = \frac{(BHT - ST)}{TD} \times FD$
9.	SATURATION OF WATER (Sw)	$S_w = \sqrt[n]{\frac{F \times R_w}{R_t}}$,
10.	HYDRO CARBON SATURATION (HS)	HS= 1-S_W

4.9 Volume of Shale

The volume of shale is calculated using the Gamma ray (GR) log. This log is used to measure the natural radio activity of the formation. Hence it provides the concentration of the radioactive material present in the formation, hence it is very useful in order to identify the lithology. The value of the gamma ray is low in the carbonate and in sandstone while it having higher value in the shale. The reason is that the concentration of the radioactive material is larger in the shale as compared to sand and the carbonates.

This will lead us to distinguish between reservoir and the non-reservoir rocks (Acquith and Gibson, 2004).The volume of the shale is estimated by using the following equations given in table 4.3 by (Rider, 1996).

4.10 Calculation of Porosity

Porosity is one of the most important property in order to understand the petroleum system. The porosity is estimated by using the Neutron, Density, and the Sonic log. Sonic log is acoustic measurement and the Neutron and Density log are nuclear measurement. The combination of these three logs gives the accurate estimation of the porosity. We have different types of the porosities which are given below.

4.10.1 Average Porosity

Average porosity is the sum of the all porosities logs divided by the number of the logs. The mathematical equation (Schlumberger, 1998) is given in the table 4.3.

4.10.2 Effective Porosity

The effective porosity is the ratio between the pores volume of the rock and the total volume of the rock calculated after removing the effect of the shale. The effective porosity is used to estimate the water saturation. The effective porosity is calculated using the mathematical equation of the (Schlumberger, 1989) given in the table 4

Now to calculate the Water saturation we have required the Resistivity of the water of formation. This is a Lengthy procedure which is explained as follow.

4.11 Resistivity of formation water (Rw)

When the volume of the shale, effective total and sonic porosity has been calculated the next step is the calculation formation of the water. Computing the resistivity of the water is the initial step in finding the saturation of the water. The following steps has been carried out in order to calculate the resistivity of the water.

Step 1: The values of the surface temperature (ST), maximum recorded temperature (BHT), and the resistivity of the mud filtrate (RMF1) from the well headers, the very first step is to find the

(SSP) static spontaneous potential from the relation given in the table 4.3 from (Rider, 1996).

Step 2: Formation temperature is calculated using the using the relation which is given in the table 4.3 by (Rider,1996).

Step 3: In this step the resistivity of the mud filtrate is calculated using the relation given in the table4.3.

Step 4: In step 4 the resistivity of the mud equivalent (Rmf_{eq}) is calculated by the equation given in the table 4.3.

Step 5: Rweq (Water equivalent resistivity) is determined from the Essp (Static spontaneous potential)

After calculating the all the above explained properties and the resistivity of the water equivalent the next step is to find the value of the resistivity of the water (Rw) against (Rmfeq) at SSP value BHT from the graph (Figure 4.3).

Step 6: This is the last step in this step the value of the resistivity of the water (Rw) is obtained against the value of the Rweq (Resistivity of the water equivalent) and formation temperature. Now when the resistivity of the water is determined the next step is to compute the saturation of the water by using the famous Archie equation as showen in the (Table 4.3)

4.12 Petrophysical Interpretation of Miao-09

Petrophysical analysis of the well Miano-09 is carried out on the basics of the different logs curves. The first indicator is Gamma ray which is very useful to differentiate between shaly and sandy portion in Miano area. So on the basics of the gamma ray the clean and shaly zones are marked to make the further interpretation easily.

Where there is low value of the shale we can say that this is the zone in the reservoir where the hydrocarbon can be present, but not confirm. Basically to confirm the types and amount of hydrocarbon we go towards the integrative results of other logs that give a comprehensive report about the hydrocarbon and water present in that zone.

The principal use of the resistivity log is to detect the hydrocarbon zone. With the help of the resistivity log volume of the oil and gas can be founded in the particular zone of the reservoir. In petrophysical term the hydrocarbon saturation can be defined as, that when in the porous formation the water saturation is not 100% then the hydrocarbon will be present there. The higher value of the resistivity usually indicates the presence of the hydrocarbon or the fresh water. If the separation between the LLS and LLD is reported then it is quite possible that hydrocarbon will be present there. In the case of the presence of the oil and gas the value of the LLD is much higher than the LLS,becaue the LLD reads the resistivity of the formation .If the formation the hydrocarbon will present then there resistivity will quietly higher.

Density in the study area mainly varies between 2 to 2.9 gm/cm^{3,} because] in the study area there is variation of the shale and sand. The other main result which is observed that very high density corresponding to low resistivity is noted, it may be due to presence of the some heavy minerals Gluconate, Chlorite,Chamosite,Siderite etc. (Fareed et al.,2003).

The other main important result is obtained when Neutron and density logs are combined, because there crossover possibly gives the best clue of the presence of the hydrocarbon (Rider, 1996).After considering all the above explained results and logs response the reservoir B-interval is interpreted and some important petrophysical properties are quantified which are given in the below table 4.4.

4.12.1 Interpretation of Entire B interval (3331-3385m)

Depth range of the B-Interval which is acting as reservoir varies from the (3331-3385m) in the Miano-09.It consist on the alternate layers of shale and sand. The ranges of the GR are given below.

- GR Minimum ………… 12.52 API
- GR Maximum………….286.43 API

Shale volume for the total depth range in the lower Goru formation is 44% and water saturation is the 51.7%. A prominent zone is marked through the well section in Figure 4.5 where high net pay is expected .In this zone also the clear separation of the LLD and LLS is observerd.This zone bears relatively low value of the GR and the high resistivity and high porosity.

The detail of this zone is explained below. The zone B which is generally called the bassel sand is main productive zone in Miano field. We calculated the petrophysical properties of this entire zone and then zone of interest which lies in the zone B of bassel sand as showen in the figure 4.5.

4.12.2 Interpretation of Zone of interest

Only one main zone of interest is marked. Depth range of Zone of interest varies from 3338-3346m in well Miano-09. Shale volume of the whole depth range is 24 %. Effective porosity is about 8% and potential of the hydrocarbon is 62%. This is only one pay zone in which high net pay is expected. This zones bear low value of the GR, high porosity and the greater value of the resistivity. Petrophysical properties of this zone is given in the Table 4.4.

4.13 Zone Marking Criteria

On the basis of the single log we cannot give the information about the productive zone we correlate the different logs and get the results. We marked the zone of interest from 3338-3346m. Because there was low value of Gr which is clear cut condition that it is reservoir zone. Now in 2nd track we run the LLD, LLS, these are resistivity log now there cross over is also the clear cut indication of the formation contain some high resistivity fluid i.e. hydrocarbon.similerly in the track three the crossover of density and neutron logs is also showing that this is hydro carbon bearing zone. Also calculated effective and average porosity are greater than other zone and hydrocarbon saturation is greater than water saturation. Hence combination of all these calculated properties makes us assure that this zone is productive zone and hence we marked this zone which is showen in Figure 4.2..

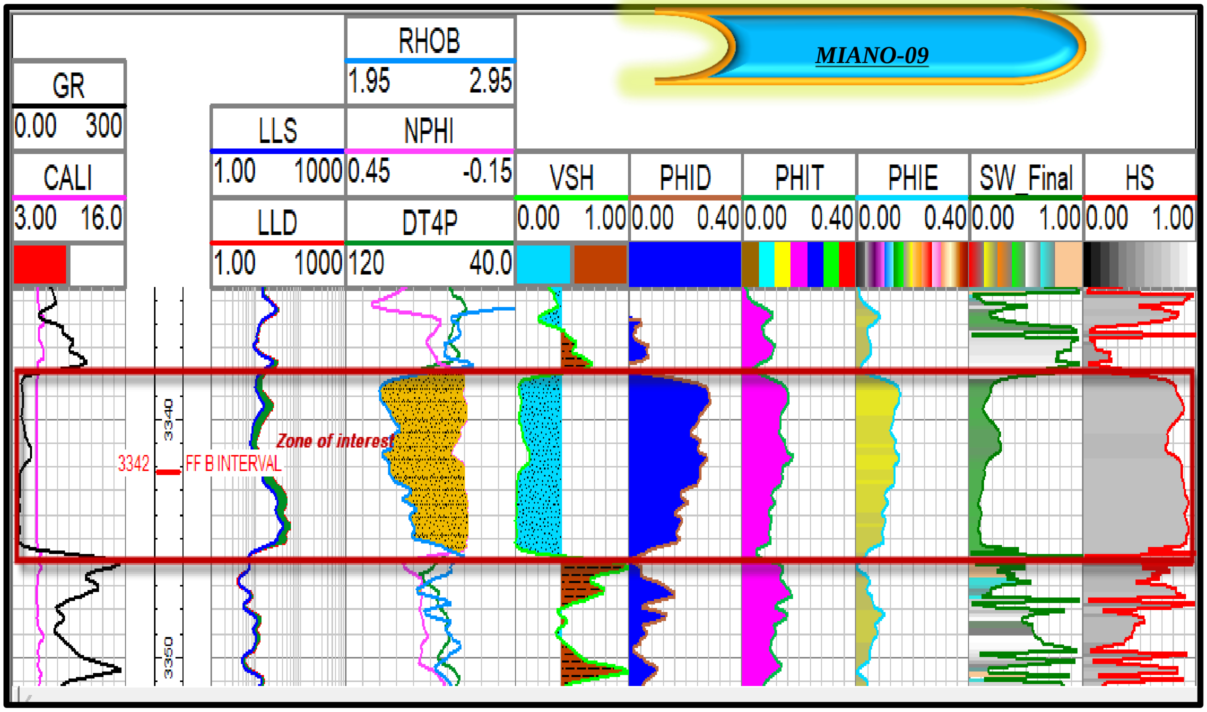

Figure 4.2 Well log interpretation of Miano-09 by IHS kingdom

Table 4.3 Rock properties of the zone-A and zone-B Miano-09

Zone/Rock Property		Entire B interval 3331-3385	Zone of interest(zone-A) 3338-3346m
1	Surface temperature (ST)	**80^0fh**	
2	Bore hole temperature (BHT)	**314^0fh**	
3	Resistivity of the mud filtrate (Rmfi)	**0.151 Ωm**	
4	Average volume of the shale (VOS)	44%	24%
5	Average sonic porosity (PROS)S	11.3%	18%
6	Average Porosity (PHIT)	11.8%	12%
7	Average, Effective Porosity (PHIE)	6.4%	8%
8	Average,Saturation of Water (Sw)	51.7%	38%
9	Average,Saturation of Hydrocarbon (Sh)	47.2%	62%

4.14 Well Log Correlation

Well log correlations show the trend and well tops of subsurface horizons at their specific depth (Badley, 1995). The well tops can also be used for the correlation with the corresponding reflectors. For this purpose five different Miano wells, MIANO-02, MIANO-05, MIANO-06, MIANO-09 and MIANO-10 have been correlated together in order to evaluate the variation in thickness of the lithology at different depths of reflectors across the area.The zone below the reservoir Lower Goru top shows the minimum and maximum value of GR which indicates different sand and shale intervals and packages in which include B-Sand interval. The well log correlation is shown in Figure 4.3.

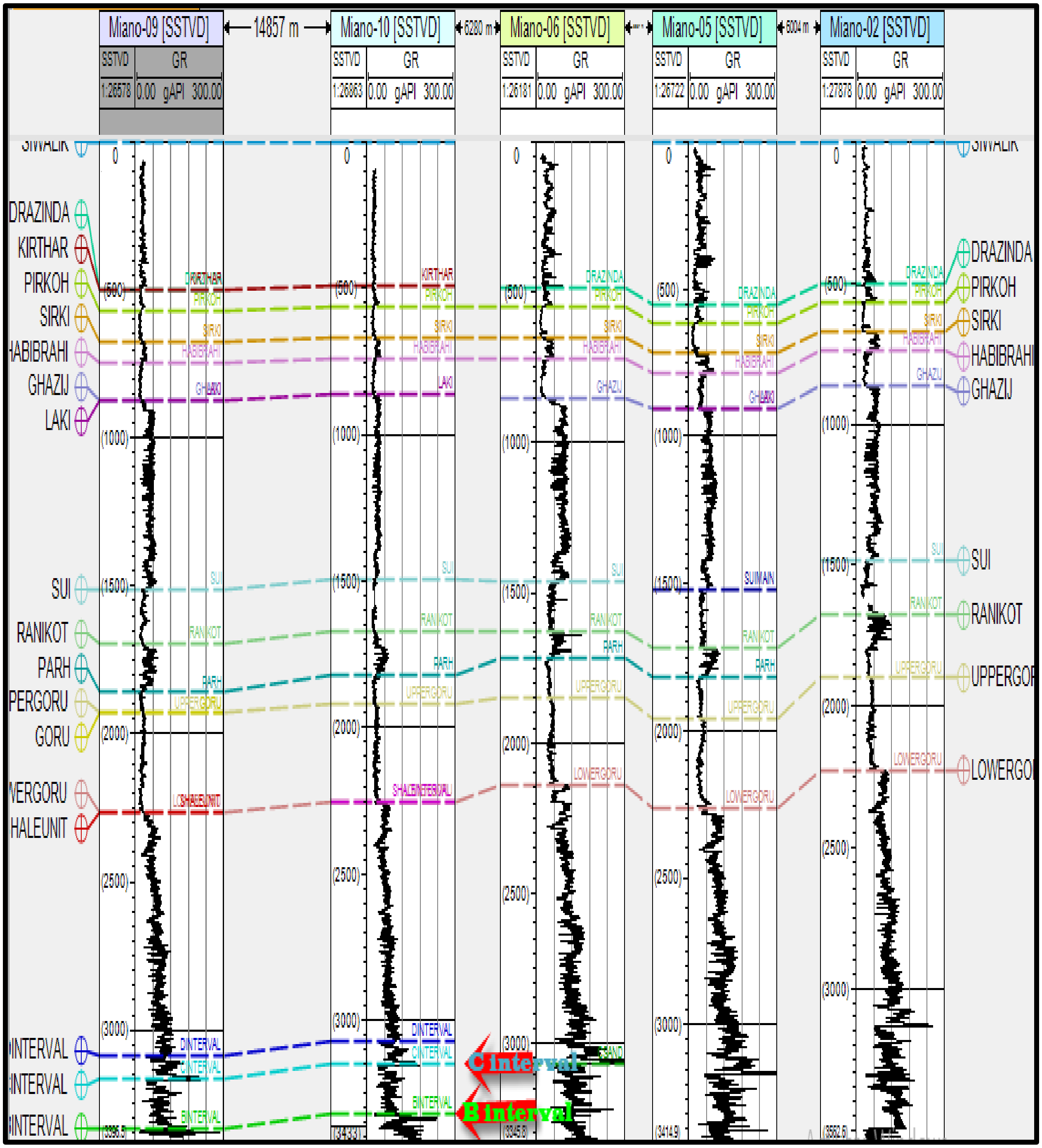

Figure 4.3 **Wells Correlation of various wells with panels (left to right) –Miano-09, Miano-10, Miano-06,Miano-05 and Miano-02.**

5 Model Based Inversion

5.1 Introduction

Seismic attributes derived from time, amplitude and frequency do not provide adequate information of reservoir properties on a layer by layer basis. Layer by layer information can be derived by means of stratigraphic inversion of post stack seismic data in terms of acoustic impedance. There are many inversion techniques, which are utilized in the industry for extraction of acoustic impedance from post stack seismic data. These techniques are band-limited, model based, and neural network nonlinear inversions (Russell, 1988, Duboz et al., 1998,Keys and Foster, 1998, Van Reil, 2000). In this study, model based inversion technique have been utilized for inverting a 2D seismic data set into acoustic impedance volumes of Miano gas field of the Middle Indus Basin, SW Pakistan. Inverted results of study area show that the generated acoustic impedance enhances vertical resolution, which simplifies lithologic and stratigraphic definitions. We can generate the porosity map of reservoir from extracted Acoustic Impedance. Model based inversion provide strong impedance contrast, probably identifying the presence of gas bearing formation associated with gas hydrates.

5.2 Methodology

Following are the steps discussed which are performed in performing seismic inversion.

5.2.1 Wavelet extraction

Seismic inversion is based on convolution model and states the the synthetic trace,S(t), can be generated from the convolution of Earth's reflectivity series with a desired wavelet(Mallick, 1995; Cooke and Cant, 2010; Barclay et al., 2008), such as:

$$S(t) = W(t) * R + N , \qquad (1)$$

where, W (t) is extracted statistical wavelet, R is reflection coefficient (RC) series and N is the random noise. Constant phase wavelet is shown in Figure 4.7, was extracted to perform a correlation between extracted reflectivity and inverted reflectivity from seismic data at well Miano-09. The reflectivity, in turn, is related to the acoustic impedance of the earth by

$$R_t = \frac{Zi+1+Zi}{Zi+1-Zi} , \qquad (2)$$

Where r_t is the zero-offset P -wave reflection coefficient and $z_t = \rho v_t$ is the ρ -impedance of layer, where ρ is density, v_t is P-wave velocity. Lindseth (1979) showed that if we assume that the recorded seismic signal is as given in Equation (2), we can invert this equation to recover the P-impedance using the recursive equation given by

$$Z_{i+1} = Z_i[\frac{1+r_i}{1-r_i}] , \quad (3)$$

applying of Equation (3) to a seismic trace can effectively transform the seismic reflection data to P- impedance. The Acoustic Impedance for the first layer needs to be estimated from a continuous layer above the target area. In this method, the impedance for the n- the layer can be calculated as follows

$$Z_n = Z_i \quad * \prod \left(\frac{1+r_i}{1-r_i}\right), \quad (4)$$

however, as also recognized by Lindseth, there are a number of problems with this procedure. The most severe problem is that the recorded seismic trace is not the reflectivity given in Equation (2) but rather the convolutional model given in Equation (1). The effect of the band limited wavelet is to remove the low frequency component of the reflectivity. This means that it cannot be recovered by the recursive inversion procedure of Equation (3). After proper processing and scaling of the seismic data, an intuitive approach to recovering the low frequency component is to simply extract this component from well log data and add it back to the seismic. An update approach to inversion is a Model based inversion in which an intial low frequency model is modified iteratively to give the best fit to seismic data. The main steps are data preparation and , and data input into the software , calibration by tying well logs to to the seismic data, estimation of wavelet, generation of low resolution initial model, inversion analysis and inversion. The software used in performing Model based inversion of stacked seismic data is H-R (Hampson-Russel).

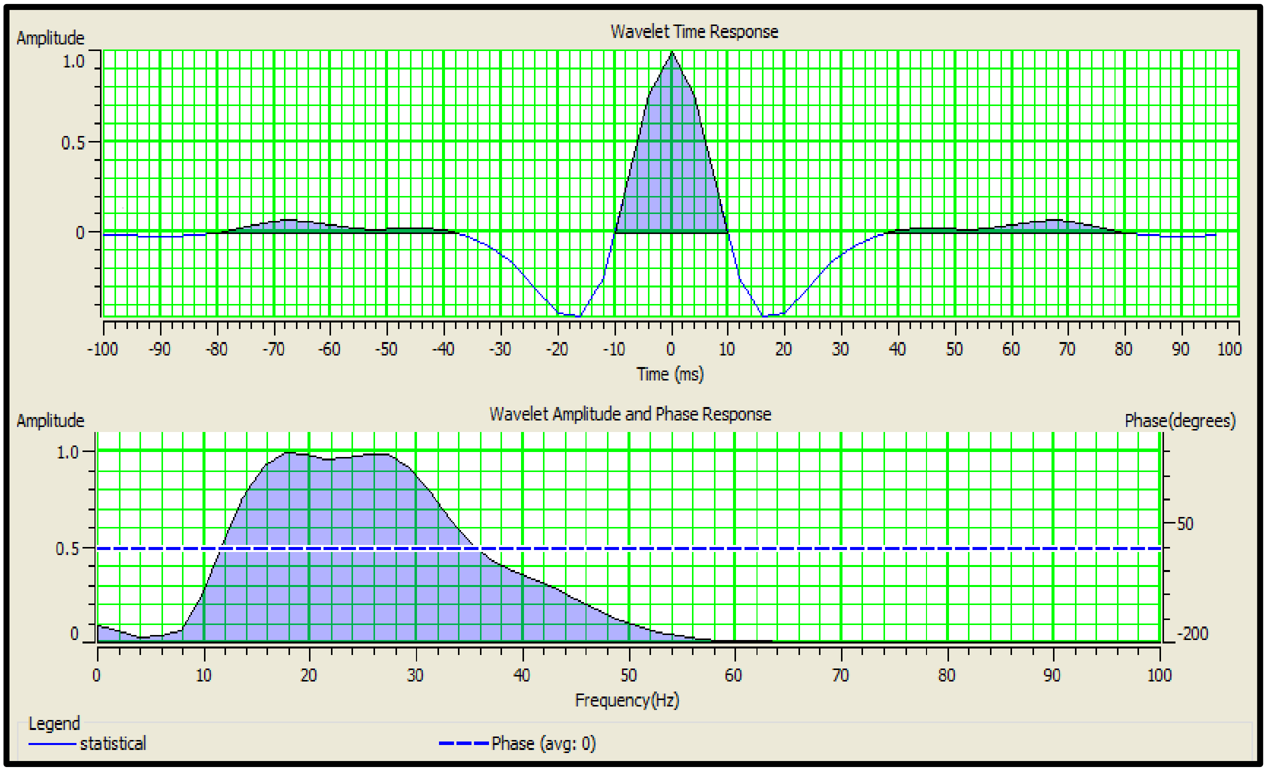

Figure 5.1 Extracted statistical wavelet from seismic data along with its amplitude and phase spectra. The dotted line display the average phase of the wavelet.

5.2.2 <u>Initial/Low frequency model</u>

Initial model provides the low and high –frequency components missing from the seismic data, which were used to reduce the non-uniqueness of the solution. Low frequency cut-off point, several band-pass filters were applied to the seismic data to the best estimate of the missing frequency range. In Model based inversion , low frequencies are added as a part of the inversion algorithm to obtain an absolute acoustic impedance a proper low-frequency component (approximately 0-15 Hz) is in corporated in inversion algorithms (Cooke and Cant, 2010).A low frequency model generated for the application of a model based inversion is shown fig. 4.8.In order to obtain absolute acoustic impedance from model-based inversion technique a low frequency model must be added from the well data to assure more realistic results(Lindseth, 1979).The spatial interpolation method used in the H-R software utilizes inverse- distance weighting and work.

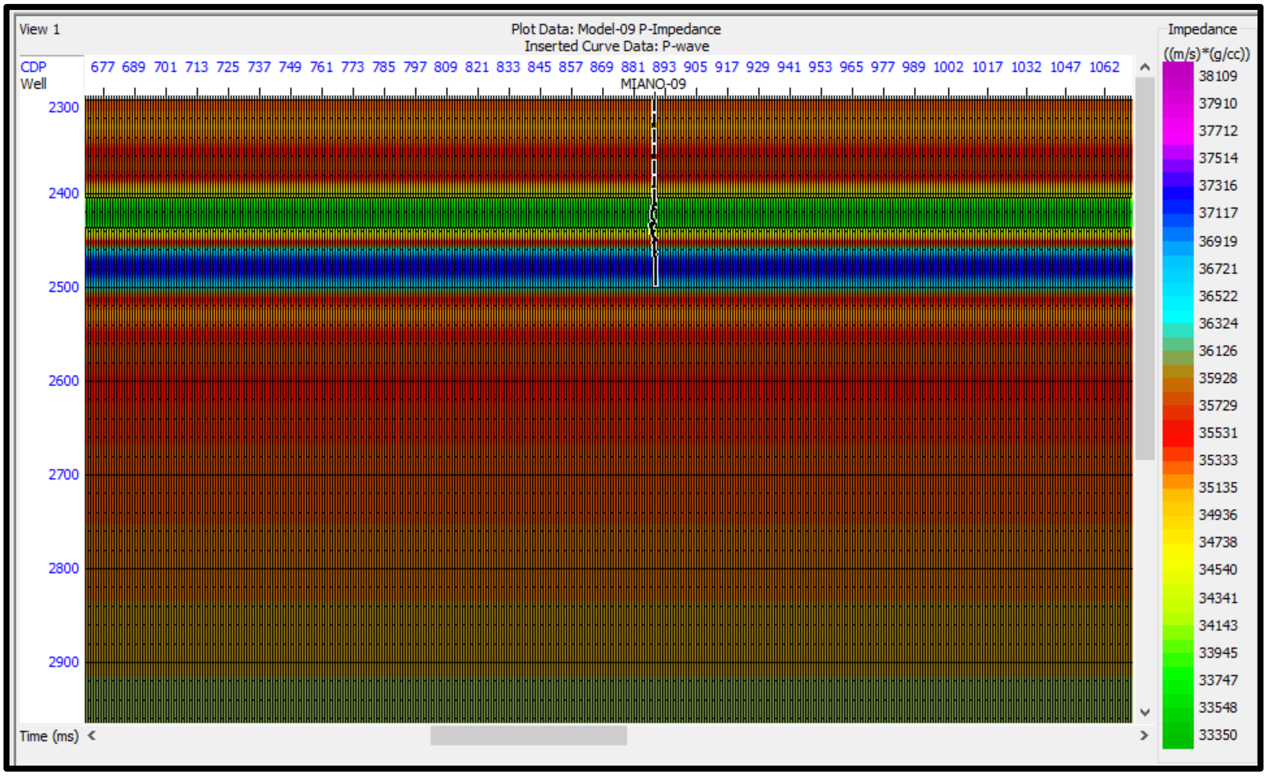

Figure 5.2 An Initial/ Low frequency model used for the application of the Model Based Inversion

5.2.3 <u>Model Based Inversion</u>

Model based inversion is an approach to inversion that avoids the problems of recursive inversion by iteratively changing a model to give a least-squares fit to the seismic data. The basis of all inversion analysis is the input data .In the post stacked inversion, stacked seismic volume and the well logs are including velocity and density log is required .It is recent approach to inversion, which is based on convolution model Equation (2). If the noises are uncorrelated with the seismic signal, we can solve the reflectivity satisfying the Equation (2). This is a non-linear and band-limited equation iteratively. That solution is gradually improving the fit between synthetic traces and the observed seismic data. The solution attempts to simultaneously solve the best-fit reflectivity and minimize the differences between the observed and predicted seismic traces(Karim et al.,2015).In H-R software model based inversion product is computed as shown in the Flow chart Fig.(4.9)

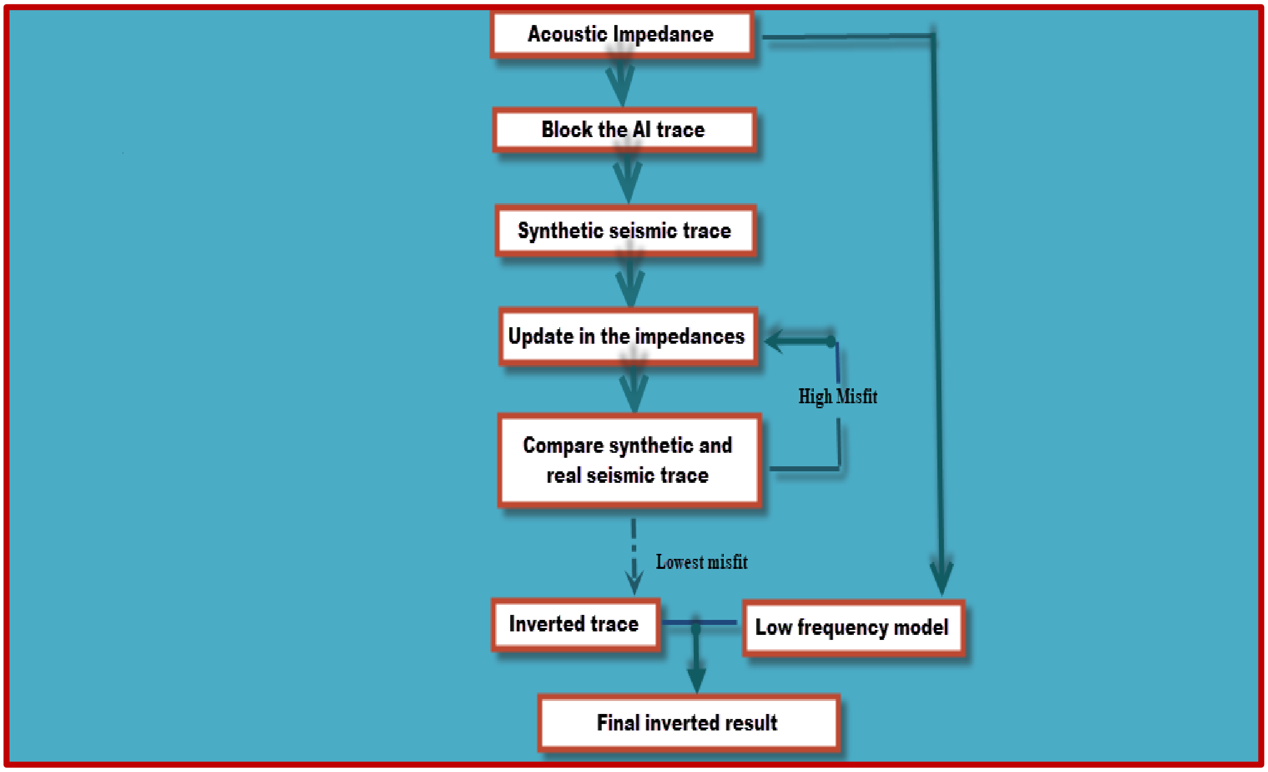

Figure 5.3 Flow Chart for Hampson- Russell (H-R) Software for Model Based Inversion.

5.3 Inversion

A statistical wavelet was extracted in a time window spanning with in a context of a model-based seismic inversion. The extracted zero phase wavelet (Figure 4.7) has sharp peak amplitude with higher dominant frequency and phase spectra is also shown in Figure 4.7. The tie between well log and seismic derived acoustic impedances at the Miano-09 well. Within the B-sand interval log derived acoustic impedance. The comparison between synthetic seismic trace synthetic seismic traces, obtained after convolving the final extracted wavelet, and the seismic trace at Miano-09 also result in excellent correlation (correlation coefficient = 0.99) with the least significant Root Mean Square (RMS) error (0.99 m/s)in term of impedance show in Figure 4.10.

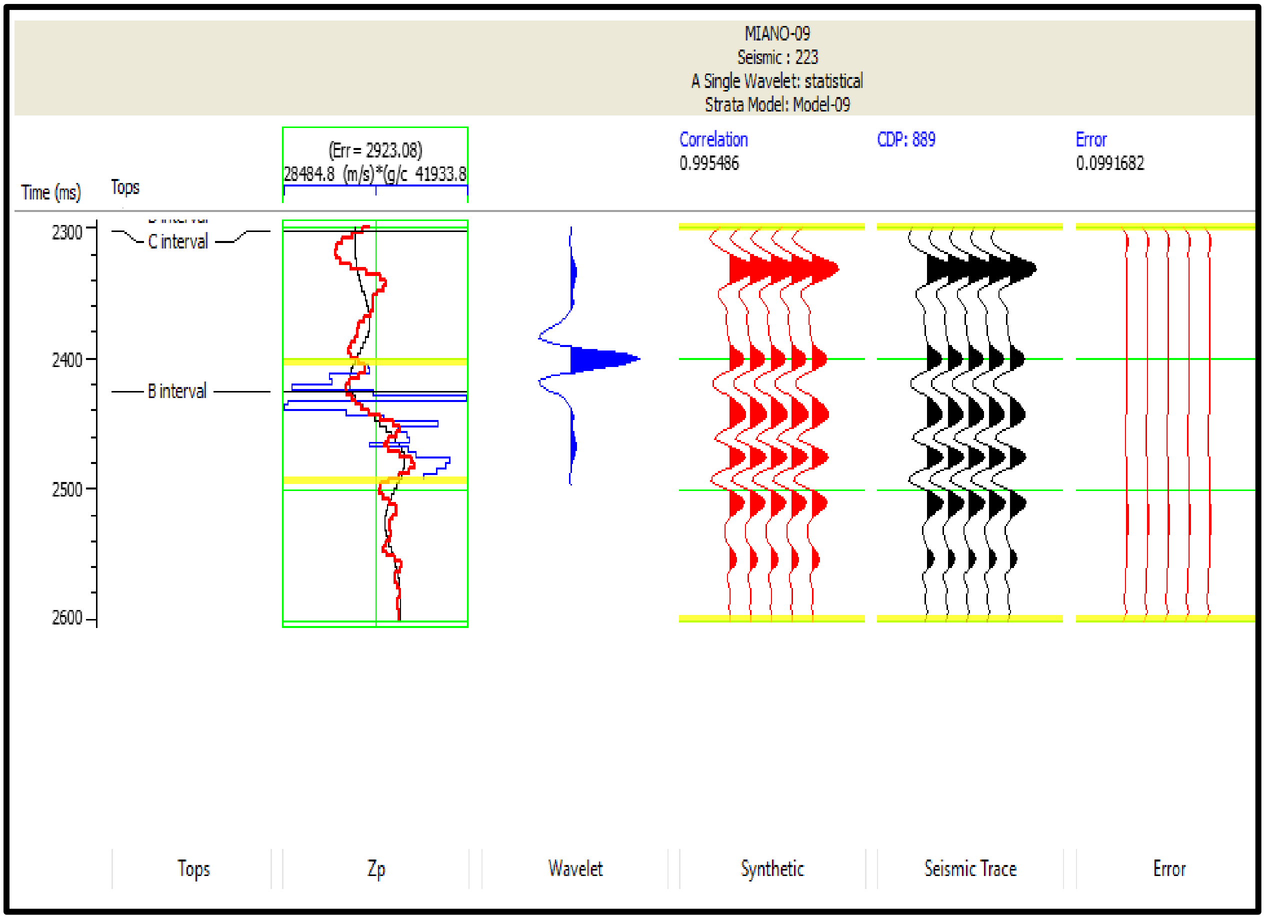

Figure 5.4 Generation of synthetic seismogram using data of well Miano-09. Synthetic and extracted traces, at the well location, are respectively shown.

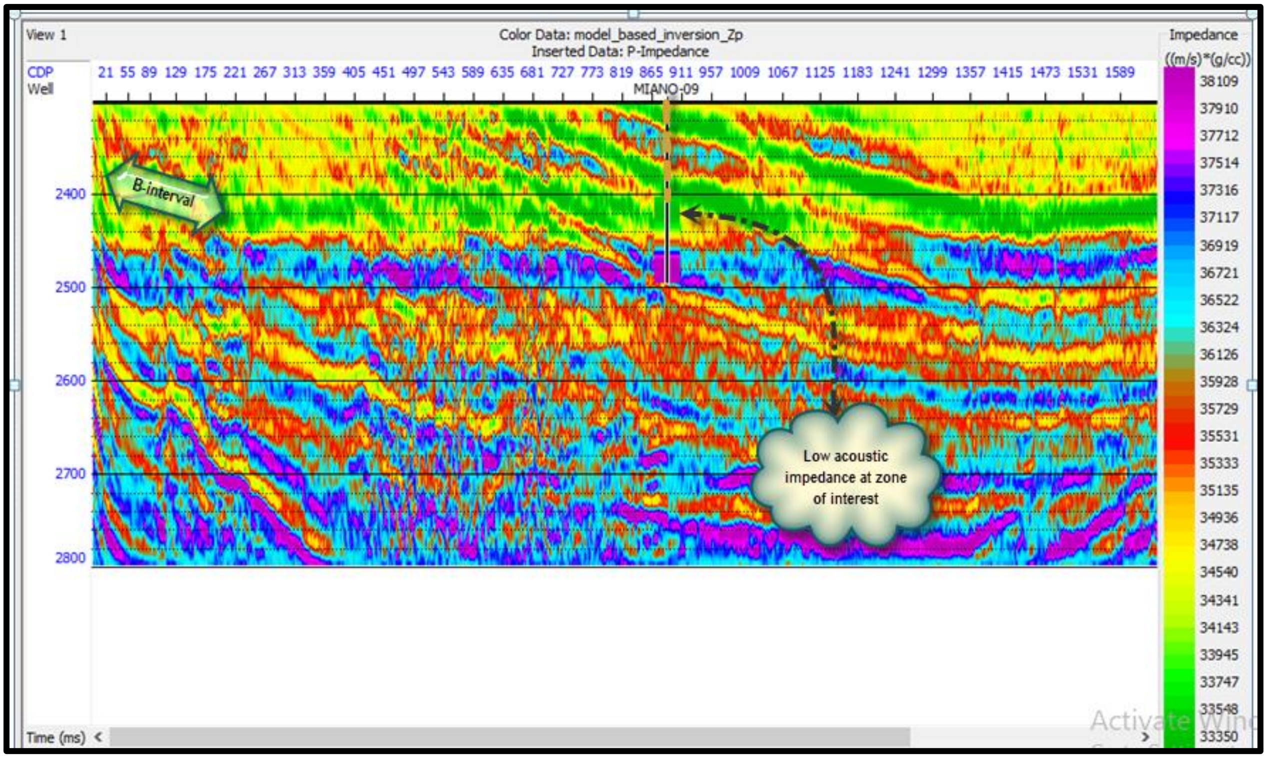

Figure 5.5 Model-based inverted acoustic impedance .The impedance log of well Miano-09 is also shown between 865-911 .the inversion algorithm is able to capture detailed lateral variations in lithology.

In Figure 4.15 at time 2380ms shows very low acoustic impedance of (33509(m/s)*(g/cc)) which is the time of B-interval of Lower Goru and at time 2320ms is the time of C-interval which has high impedance of(35531-36522(m/s)*(g/cc)) which is acting as seal in Miano field. This low acoustic impedance depicting the porous zone in B-interval

5.4 Reserviour character (porosity) estimation

Figure 5.6 shows the cross-plot of acoustic impedance against porosity. The correlation coefficient is reasonably good. Alinear regression technique is used to find the correlation coefficient. Since the relation between acoustic impedance and estimated porosity is linear in nature, we therefore used a linear regression technique.

As impedance decrease with increasing porosity, we have a linear relationship between porosity, and acoustic impedance with a negative slope. The cross-plot between acoustic impedance and porosity in Figure 5.6 was made by using average values at the well locations (Miano-09 and

Miano-10). The Linear relationship developed between acoustic impedance and porosity by a best fit line is given as follows:

$$\varphi = -0.003 * A + 48.63 \tag{5}$$

Where, φ is the effective porosity and A is the inverted impedance from model based inversion.

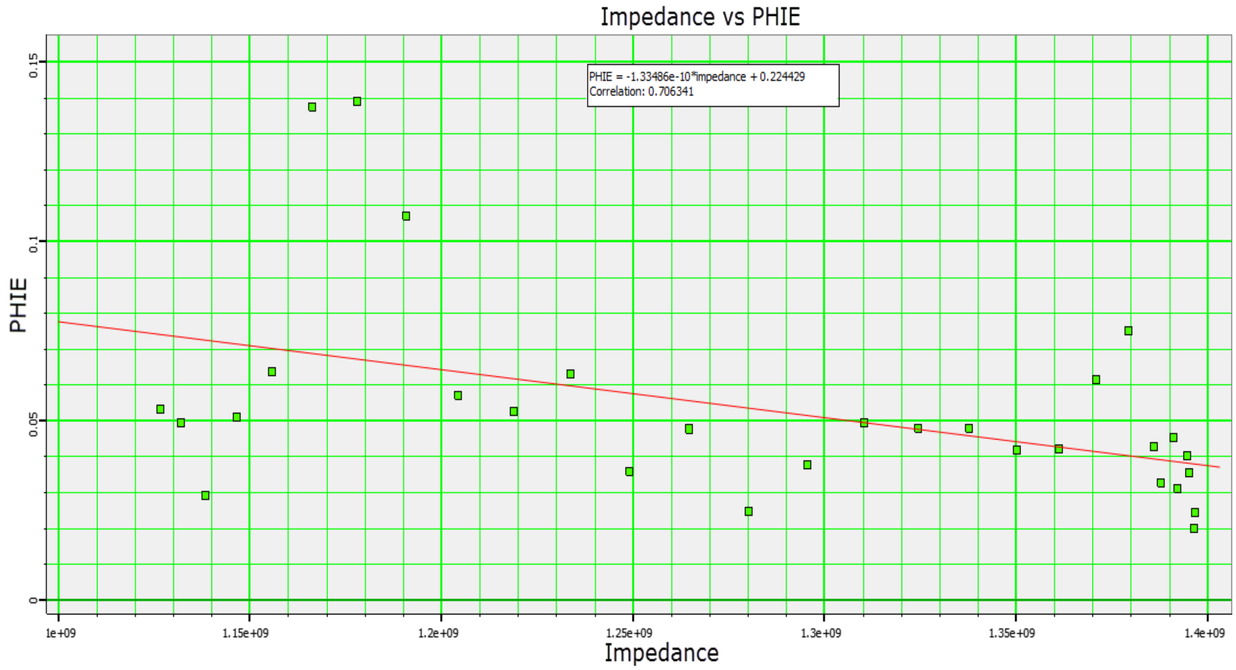

Figure.5.6. Cross-plot of acoustic impedance(AI) and effective porosity with acceptable value of correlation coefficient. Porosity andacoustic impedance are always linearly related, showing a negative slope.

5.4.1 <u>Porosity estimation</u>

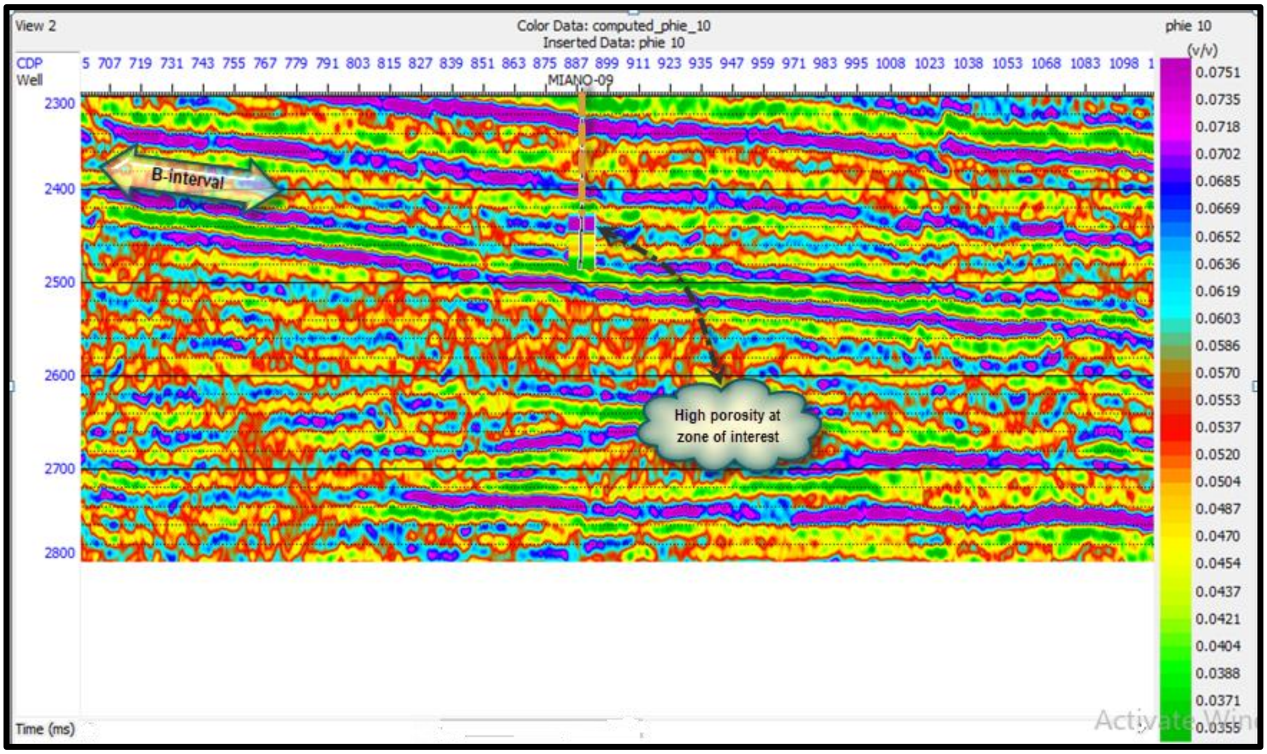

Figure.5.7 Computed Porosity map

Porosity and permeability are the most important parameters in reservoir characterization and are difficult to estimate. The problem which is faced during the estimation of porosity and permeability comes from the fact that these parameters vary considerably at reservoir scale and only be effective measured at specific well location. The solution to this caveat requires the integration of rock physics, petro physics, seismic inversion and surface seismic in order to get more reliable results (Leite and Vidal, 2011).

The goal of model based inversion is not only to estimate the acoustic impedance but also other reservoir properties such as porosity, volume of shale, water saturation etc. Porosity is quantitative estimation. In the Figure.5.7 it is shown that at 2380(ms) B-interval is marked and the purple color from the legend show us that we get a high porosity of 6 to 7.5 % around the well and the porosity is high throughout the layer. This porosity of B-interval is nearly equal to average effective porosity derived in petrophysics table 4.3.

5.5 Disscussion and Conclusion

In this study 2D seismic data has been interpreted in which 5 faults been marked than three horizons are marked Ranikot, C-interval, B-interval on the basis of synthetic seismogram. Fault polygon show us that Miano area have major normal faulting and the structure interpreted are Horst and Graben.Petrophysics is done on the logs of Miano well-09 of the area which shows that B-interval is our zone of interest from 3338-3346m in well. The value of average shale volume is 24 %. Effective porosity is about 8% and potential of the hydrocarbon is 62%. This is only one pay zone in which high net pay is expected. This zone bears low value of the GR, high porosity and the greater value of the resistivity. Petrophysical properties of this zone is given in the Table 4.4.The result from model based inversion show us the low acoustic impedance of (33509(m/s)*(g/cc)) at our zone of interest and the porosity map depict the high porosity of 6 to 7.5 % throughout the layer of zone of interest which is B-interval.

The gain from this study is we have major Horst and Graben structures, from petrophysics single point properties are calculated in the well and on the basis of that values we marked the zone of interest (B-interval).Model based inversion shows the low acoustic impedance and high prosity throughout the layer of B-interval. These result shows that B-interval is potential reservoir and hydrocarbon can be found this layer.

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