2D SEISMIC REFLECTION DATA INTERPRETATION, INTEGRATED WITH FACIES MODELLING, SEISMIC ATTRIBUTE ANALYSIS & PETROPHYSICAL ANALYSIS OF MIANO AREA, SINDH

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CERTIFICATE

It is certified that **Mr. Salar Ali Khan (Registration No. 04111613070)** carried out the work contained in this dissertation under my supervision and accepted in its present form by Department of Earth Sciences as satisfying the requirements for the award of **BS Degree in Geophysics.**

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In the name of Allah the most beneficial and merciful. I dedicate this work to my parents, for their moral support, and those who assisted me in completing this work.

ACKNOWLEGMENT

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 humanity until the Day of Judgment. I thank Allah for giving me strength and ability to complete this study.

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I specially acknowledge the prayers and efforts of my whole family, specially my parents my brothers 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.

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ABSTRACT

The present study pertains to integrated seismic, petrophysics of Miano (Central Indus basin) area. This thesis work includes preparation of synthetic seismogram of Miano-07 well. Analysis of geophysical borehole logs provides one of the best approaches to characterize rocks within boreholes.

For the interpretation of the seismic lines, two 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 are confirmed by fault polygon of time and depth contour maps made from time and depth grids respectively.

Petrophysics is the one of the most reliable tools for the confirmation of the types of the hydrocarbon and for marking of the proper zone of the interest of the presence of the hydrocarbon by combination of the different logs results. In this dissertation, the petrophysics is performed on the Miano-07 well and zone of interest is marked, where there is chance of the presence of the hydrocarbon.

Facies Analysis is carried out and different cross-plots are produced using the existing data. It lead to further support of the interpretation results i.e. the reservoir environment, which seems to be a potential zone for hydrocarbon accumulation.

Seismic attributes are applied that also confirm the reservoir prospect zone.

Contents

CHAPTER NO. 01
INTRODUCTION

1 Introduction

The Miano Gas field is located in the Ghotki district of the Sindh province. Geologically it is located in the middle Indus basin of Pakistan. The present study is based on 2-D seismic survey carried out by OGDCL, PPL (Pakistan Petroleum Limited) and OMV Pakistan (formerly abbreviation for Österreichische Mineralölverwaltung (English: Austrian Mineral Oil Administration)) an Austrian integrated oil and gas company which is headquartered in Vienna, Austria.

The study mainly focuses on the interpretation of reflection data of seismic lines GP2094-211, GP2094-220 and GP2094-223, which are interpreted in this study with the aid of information from Miano, Well-07.

A summary of seismic lines and wells used in this study are provided in Table 1.1 and 1.2.

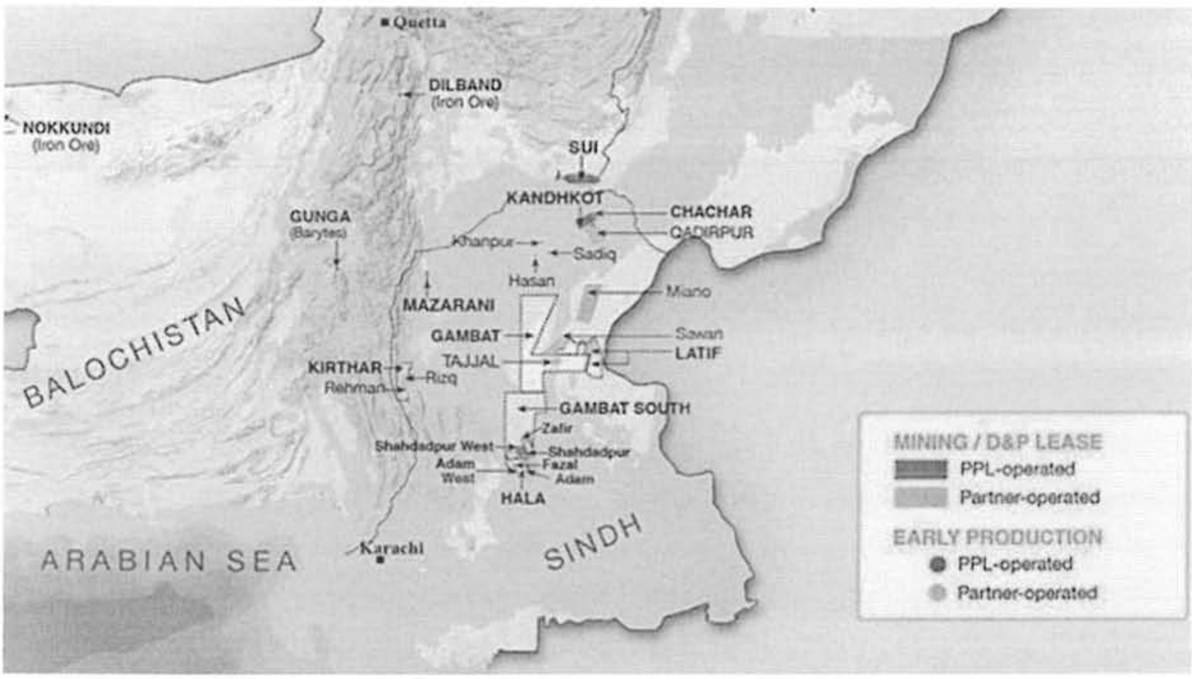

Figure 1.1: Location of the study area (https://www.ppl.com.pk/content/exploration-activity-map)

1.1 Miano Gas Field

A large part of known giant hydrocarbon accumulations (686.000 Bcf gas; 0.370 MMbbl NGL) is stratigraphically trapped (https://www.ppl.com.pk/content/miano-gas-field-overview). Many of these stratigraphically trapped fields are difficult to identify, being sub-seismic and subtle. In fact, many of these fields were discovered by accident while drilling for structural objectives. However, the stratigraphic trapping mechanism becomes apparent during the appraisal phase once sufficient well information has become available.

1.2 Geographical Location

The study area (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. Miano gas field is located in the Thar Desert (near Ghotki district). 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 satellite location of the study area are shown in the Figure below

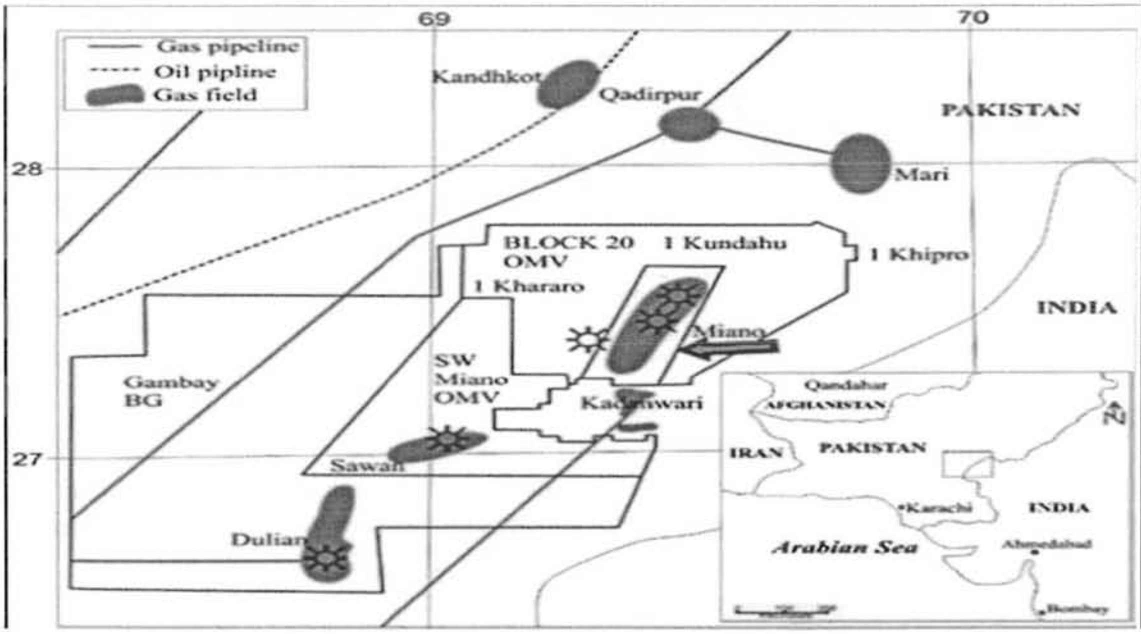

Figure 1.2: Location map of the study area (Zareef et al., 2016)

1.3 History

On January 21, 1991 the Petroleum Concession for Block 20 was awarded by the President of the Islamic Republic of Pakistan to a consortium comprising OMV (Pakistan) Exploration GmbH (operator), Hardy Exploration & Production Limited, Pakistan Petroleum Limited and Oil & Gas Development Corporation of Pakistan (P. Krois et al., 1998).

The first exploration well drilled in Block 20 resulted in the discovery of Miano gas field, which was subsequently appraised. A total of 22 wells have been drilled in the field, out of which 7 wells are currently on production. Raw Gas from the field is processed at Kadanwari gas plant before it is supplied to SSGCPL. The condensate is sold to National Refinery Limited (https://www.ppl.com.pk/content/miano-gas-field-overview).

1.4 Objective

Objective of this study is to understand structural and stratigraphic framework of the area using seismic lines and well data

- To delineate the potential reservoir of the area

- Preparing Time & Depth Contour map
- Petrophysical analysis of reservoir formation
- Seismic attribute analysis for the confirmation of the seismic interpretation

1.5 Methodology

The methodology involves the following steps:

- To study the tectonic settings and geology of the area.
- Preparation of base map for Miano seismic survey.
- Marking the reflectors on the seismic sections.
- Identifications of faults using the seismic sections.
- Preparation of Time and Depth contour maps for the marked reflectors.
- Interpretation of well logs of Miano-07.
- Generation of graphs using the well log data.
- Facies Modelling to confirm the reservoir environment.
- Seismic Attribute analysis
- To formulate most suitable recommendations and conclusions for the study area.

1.6 Seismic Reflection Data & Well Data

S.no	Line Name	Line Type	Line Orientation
1.	P2094-211	Dip Line	W-E
2.	P2094-220	Strike Line	N-S
3.	P2094-223	Dip Line	W-E

Table: 1.1. Seismic lines provided for interpretation.

S.no	Well Name	Well logs
1.	Miano-07	Gamma-ray
		Resistivity
		NPHI
		Caliper

Table: 1.2. Well logs provided for the petro-physical analysis.

1.7 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 the orientations of seismic lines 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 rent and allowance boundaries, wells, seismic survey points and other cultural data such as buildings and roads with geographic reference such as latitude and longitude. Geophysicist typically use shot points maps, which show the orientation of seismic lines and shot points at which seismic data were required , to display interpretation of seismic data.

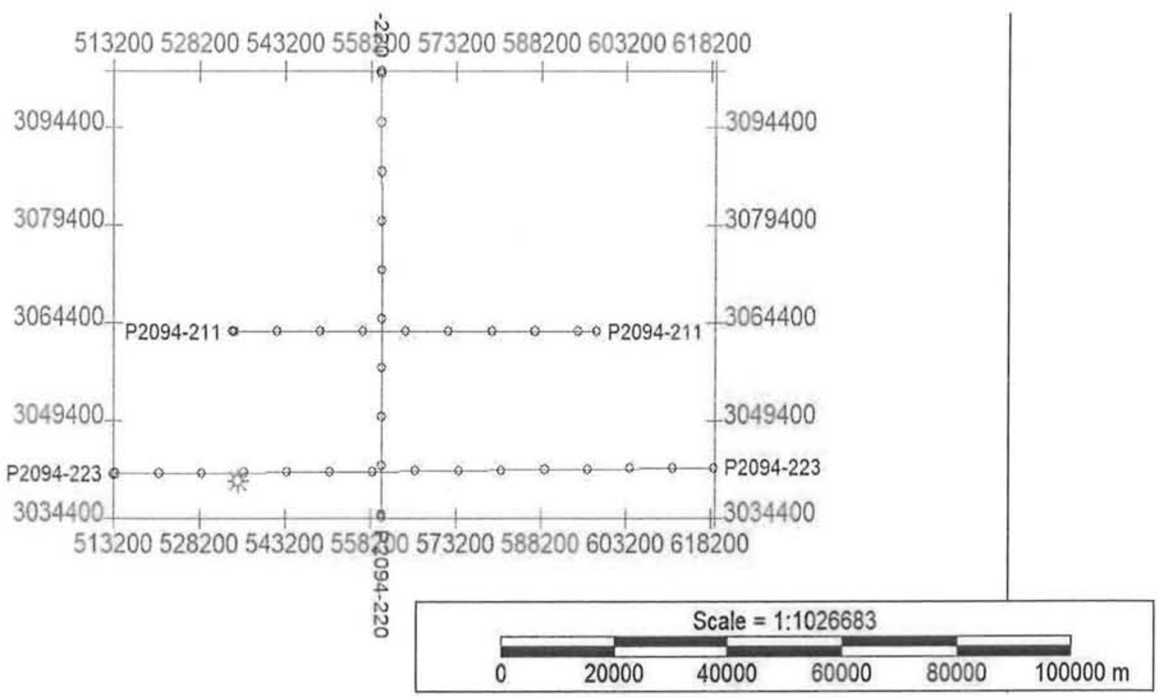

Figure 1.3 Base map of the study area

1.8 Software Tools Used

To complete project and completion of this dissertation course work I used following software tool:

- Kingdom Suite
- Wavelets
- GeoGraphix Discovery

CHAPTER NO. 2
GEOLOGY & STRATIGRAPHY OF STUDY AREA

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 Basins

Sedimentary basin is a low area in the earth's crust of tectonic regions, in which sediments accumulate. In terms of genesis and different geological histories, Pakistan comprises three main sedimentary basins.

- Indus Basin
- Baluchistan Basin
- Pishin Basin

Indus and Baluchistan the basins evolved through different geological episodes and were finally welded together during Cretaceous/Paleocene along Ornach Nal/Chamman strike slip faults (Kazmi and Jan, 1997).The subdivision of the Indus basin is shown in figure 2.1.The main sedimentary basins of Pakistan are shown in figure 2.2. Our study area lies in the central part of Indus basin.

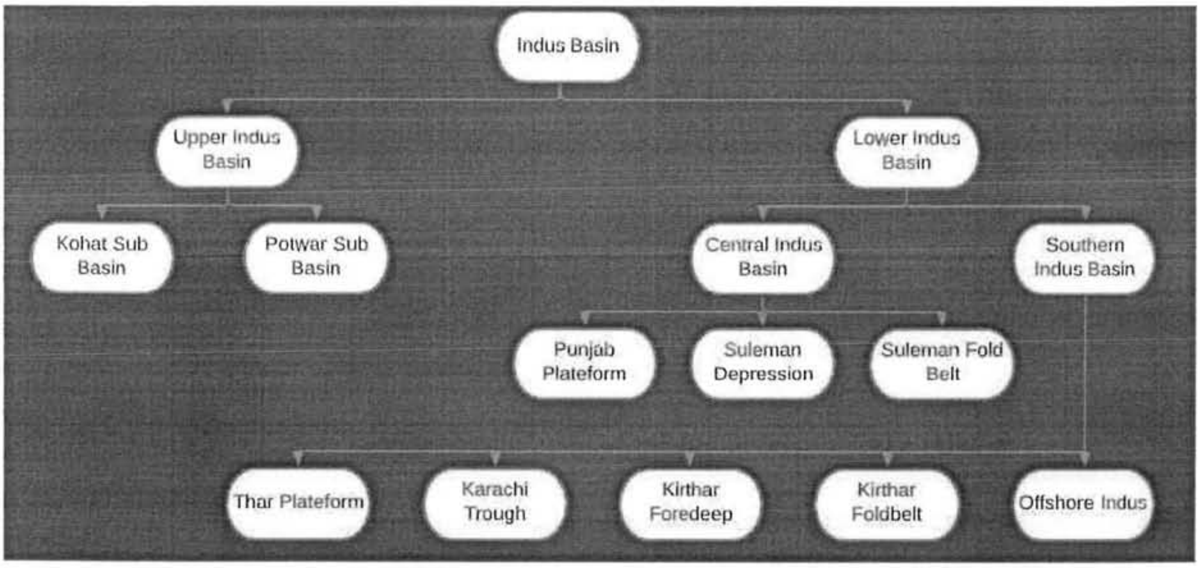

Figure 2.1: Division of Indus Basin, Pakistan

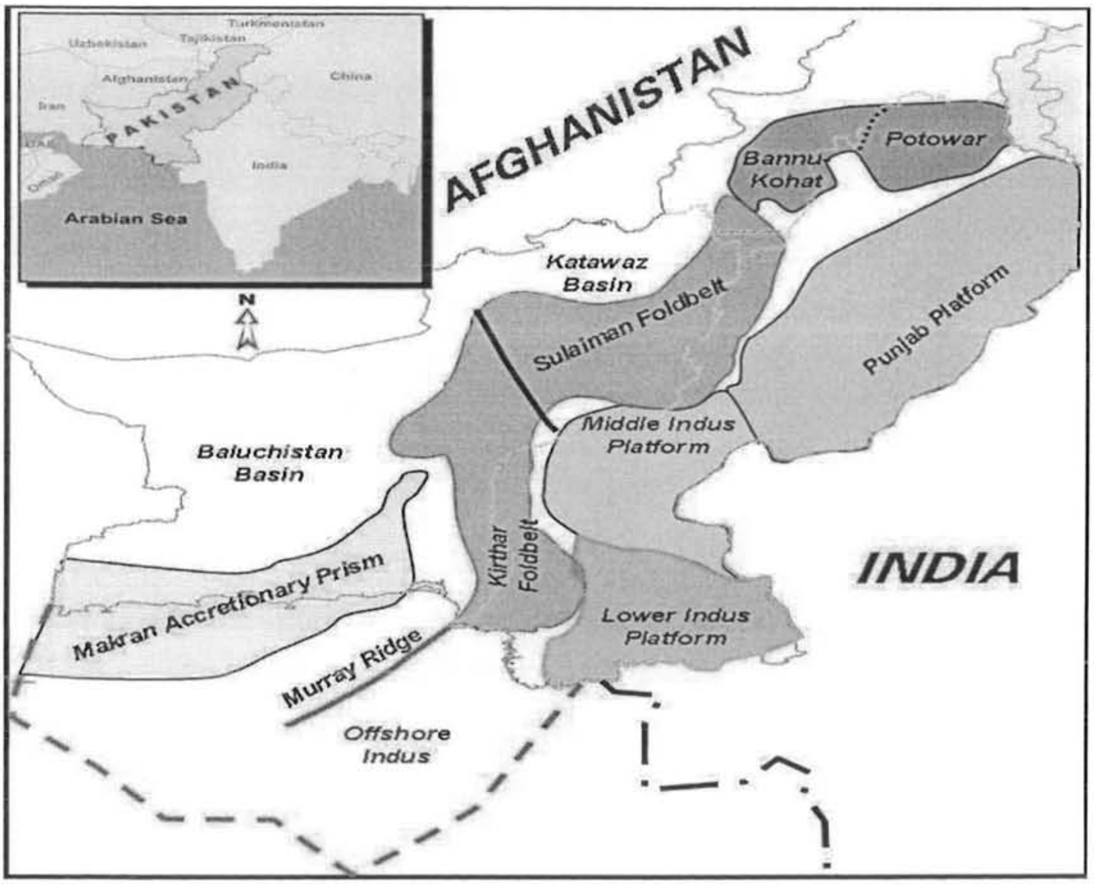

Figure 2.2 Sedimentary basins of Pakistan (Daud, Farrukh and NabiKhan, Gulzeb, Ibrahim and Muhammad, 2011: Remaining Hydrocarbon Potential in Pakistan-A statistical review)

2.3 Structure and Tectonic Settings of the Study Area

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 is shown in the below Figure 2.3.

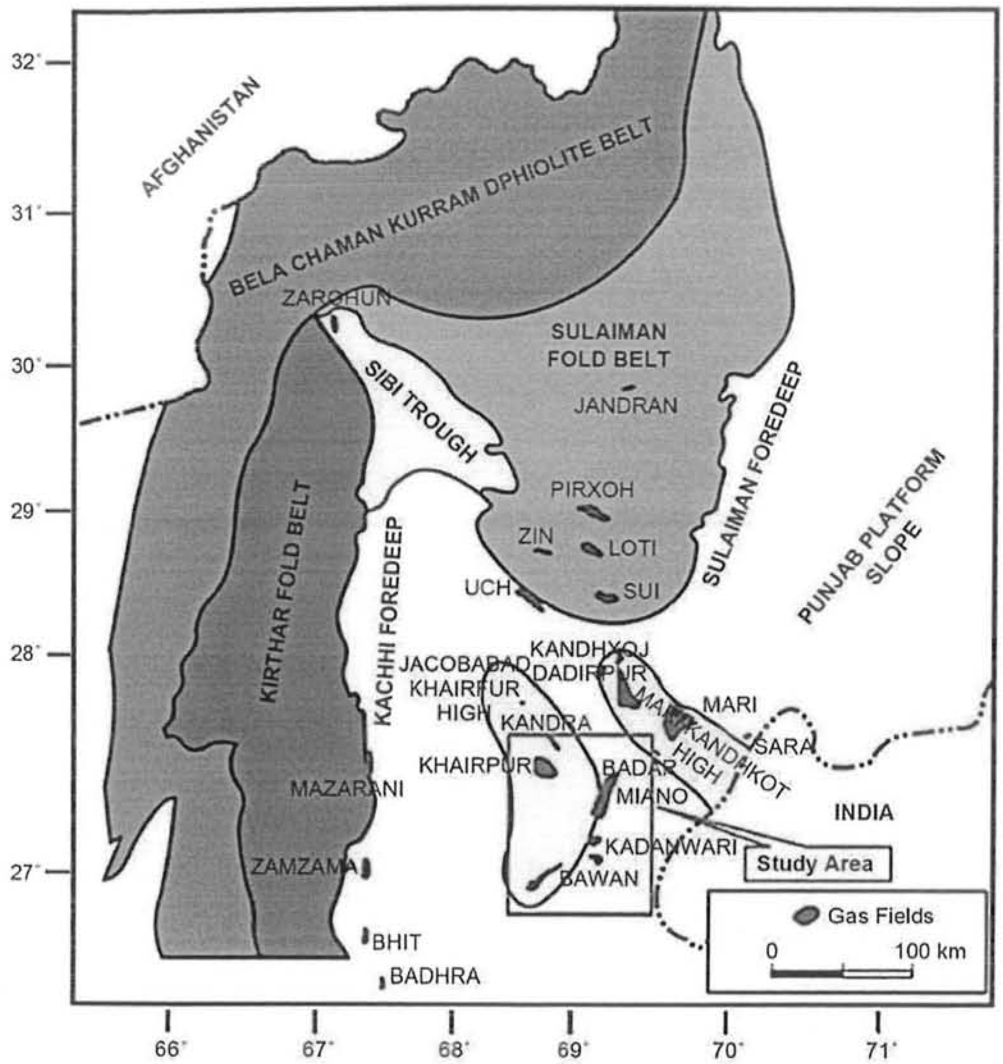

Figure 2.3: Regional Tectonic Map of Block-20 in the Middle Indus Basin (Mehmood et al., 2004)

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. Much of the study area is thickly covered by alluvium and the out crop is not clearly visible on the surface, which is an indication of 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 eastward 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 (Mehmood et al., 2004).

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 (Ahmed 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 limestone 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, 1959). The stratigraphic column of the area after Nadeem et al., 2012 is shown in the below Figure 2.4.

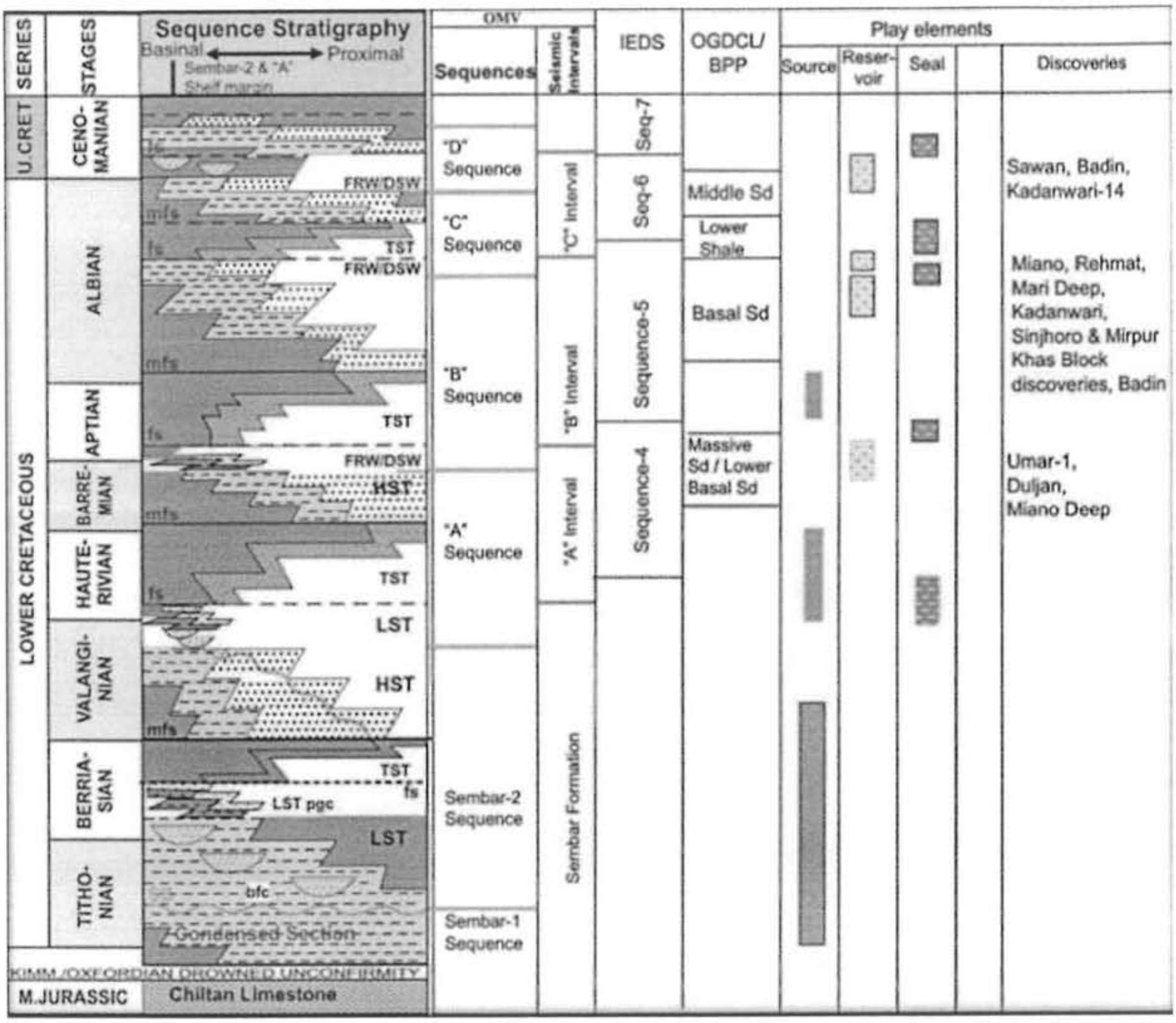

Figure 2.4: Stratigraphic Chart for Sembar & Lower Goru Formation (Ahmed et al., 2012)

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, (Krois et al., 1998).

2.5 Petroleum System

The petroleum prospect of the Area tells about the source, Reservoir and seal mechanism. Different gas fields like Kadanwari, Sawan and Miano are present in the area. The Stratigraphic column of the area, figure 2.5 shows different rocks act as Source, reservoir and Cap rock in the area.

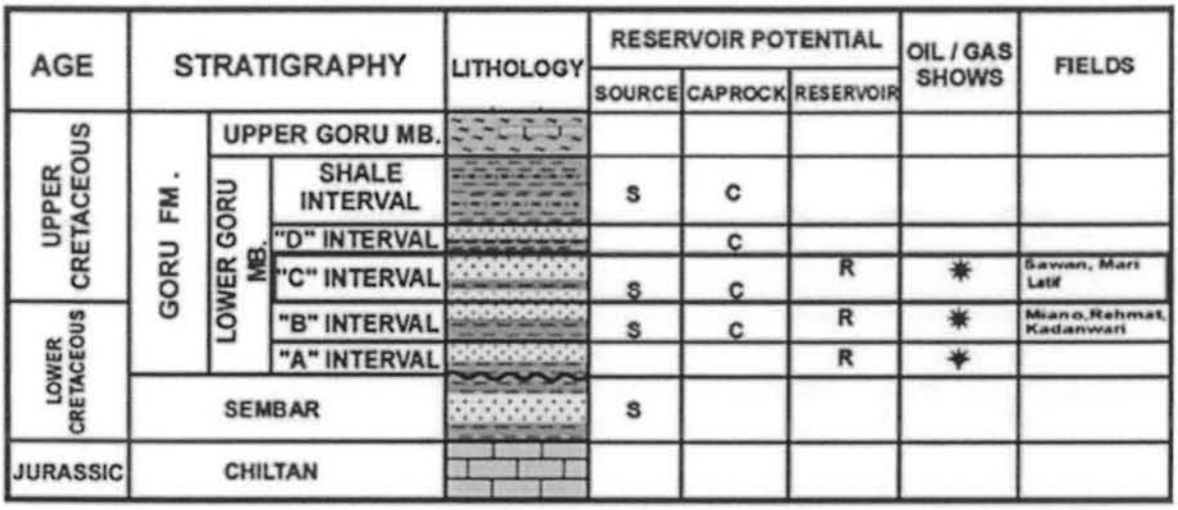

Figure 2.5 Stratigraphic charts for the Sembar and lower Goru formation (Anwer et al., 2017)

2.5.1 Source Rocks

Source rock is the productive rock 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.

- Sembar Formation

Sembar 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 (Krois et al. 1998).

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).

CHAPTER NO. 3
SEISMIC 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 & subsurface mapping are key skills that are used commonly in the oil industry for exploration (Sroor, 2010). Seismic interpretation determines information about the subsurface 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

- Structural analysis
- Stratigraphical analysis

3.2 Interpretation Types

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

- Qualitative Interpretation
- Quantitative Interpretation

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

3.3 Interpretation Workflow

The Interpretation was carried out using different techniques and steps. Each step involves different processes which were performed using the software tools. 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 by loading navigation data of seismic lines and SEG-Y in IHS 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 the study area.

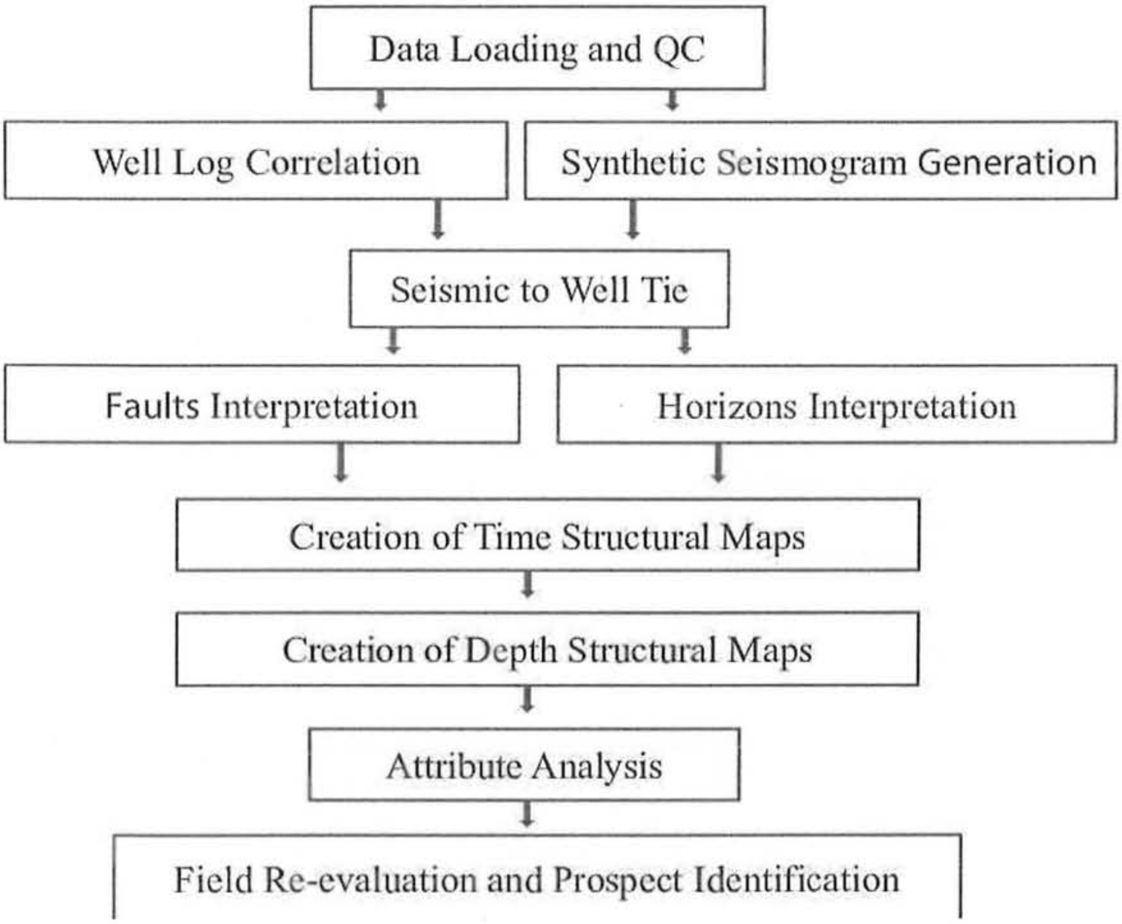

Figure 3.1: Generalized Workflow for 2D Seismic Interpretation

3.4 Interpretation of 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 the well, Miano-07.

For completion of this dissertation I have been assigned the following lines:

- GP2094-223..................... (Dip Line)
- GP2094-220......................(Strike Line)
- GP2094-211......................(Dip Line)

3.5 Synthetic Seismogram

Sroor (2010) defines synthetic seismogram as a direct one-dimensional forward model of acoustic energy traveling through the layers of the Earth. For the generation of synthetic seismogram Two Way time for each well top is required. Two Way time for each well top or reflector is calculated by using depth, sonic log data of well and replacement velocity of the area. By using two-way time against each well top time-depth chart is prepared and then finally synthetic seismogram Figure 3.3 is generated by convolving the well data as:

- Velocity – DT
- Reference log – GR
- Density – RHOB
- Wavelet—Extracted

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 and seismic reflection patterns (Handwerger et al., 2004).

The following steps are adopted during the Generation of the synthetic seismogram using the HIS 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 wave.
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. Two-way travel time; using a frequency in Hertz (frequency of extracted wavelet is used in this study)
9. Convolve the reflection coefficient log with the Extracted wavelet to generate the amplitudes of the synthetic seismogram.

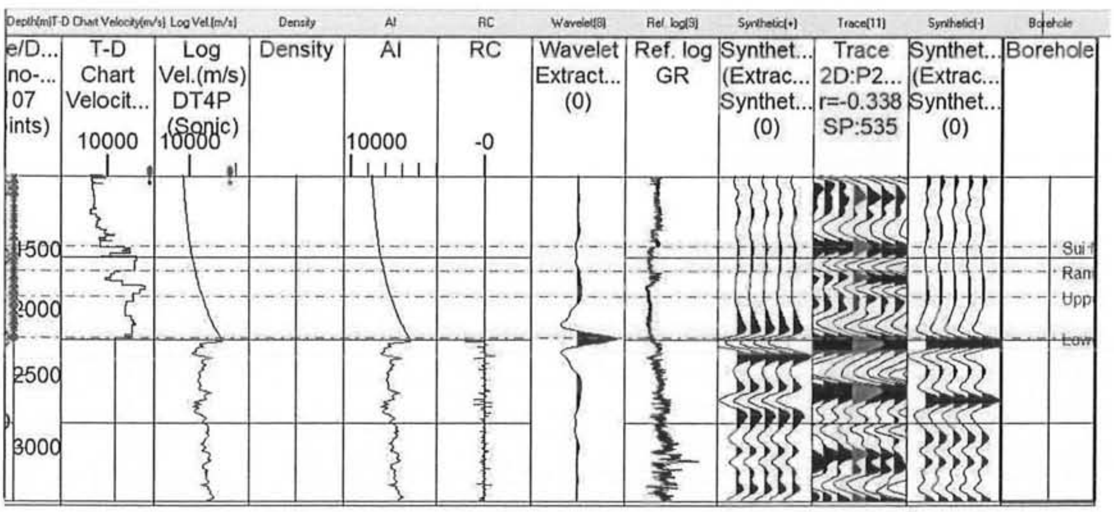

Figure 3.2: Synthetic Seismogram of the well Miano-07 on line GP2094-23

Now the generated seismogram is used to confirm the horizon. Miano-07 is the only well in available data that has the DT and ROHB log to generate the synthetic seismogram. The generated synthetic seismogram confirm the depths at which the well-tops are identified on seismic. The display of the synthetic seismogram is shown in the Figure 3.2

3.6 Fault Marking

Skills and thorough experience in Geology and Geophysics is required for Conventional seismic interpretations (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

According to the Schlumberger Oilfield Glossary, "horizon is an informal term used to denote surface in or of rock, or a distinctive layer of rock that might be represented by a reflection in seismic data. 22 In seismic data, horizons are observed as sets of reflectors consisting in lateral successions of points having approximately the same amplitude. Reflectors corresponding to one horizon may appear disconnected as a consequence of noise or of the interference with another geological object. One can visually recognize that several disconnected reflectors are attached to the same horizon, by comparing their thickness, their orientations, their colors (amplitude value) and their time relationships with other reflectors.

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 Seismic Dip Line GP2094-223

Figure 3.3 shows well tie with real time domain section. We marked horizons of Lower Goru interval. Top of the lower Goru and Upper Goru 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.

- Upper Goru Shales...............Blue
- Lower Goru Sands..............Yellow

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.

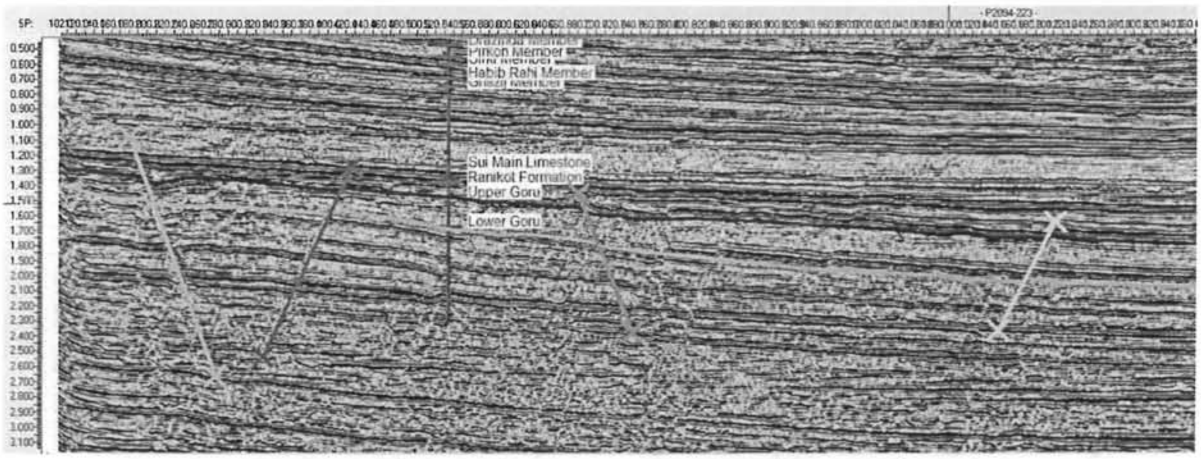

Figure 3.3: Well tie and interpretation of Dip line GP2094-223

3.7.2 Interpretation of the Seismic Strike Line GP2094-220

Using IHS Kingdom the seismic line GP2094-223 was digitized with the strike line of GP2094- 220. Then the miss-tie were removed however, in the given seismic section it 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.

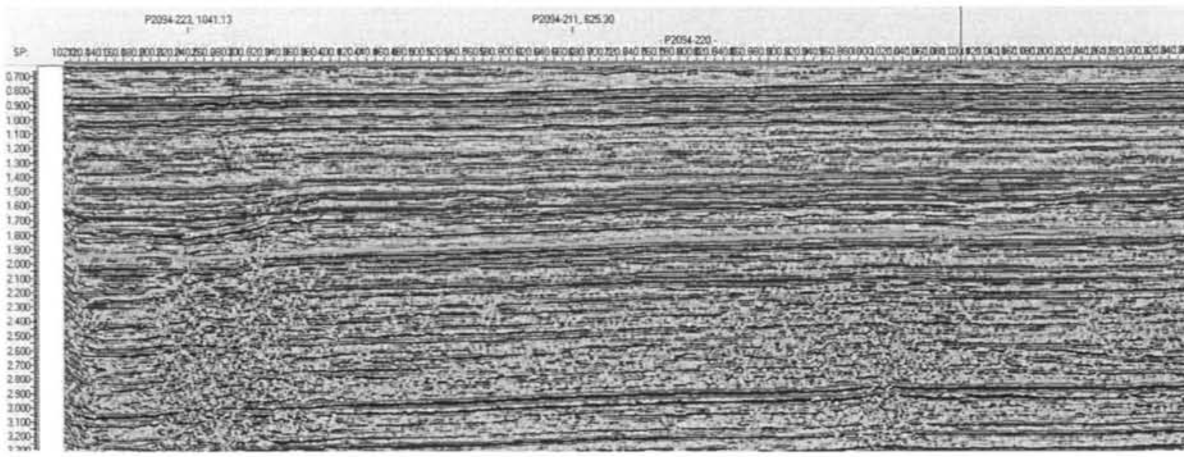
Figure 3.4: Interpretation of the seismic Strike line GP2094-220

3.7.3 Interpretation of the Seismic Dip Line GP2094-211

After marking the seismic strike line GP2094-220 we digitized this strike line with dip line GP2094-211 because this strike line was crossing all the dip lines which are shown 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 shown in the below figure 3.5.The main purpose to interpret this line was to show the favorable structures for accumulation of the hydrocarbon. The Horst and Graben structures are considered the good structures for petroleum system to accumulate the hydrocarbon after migration.

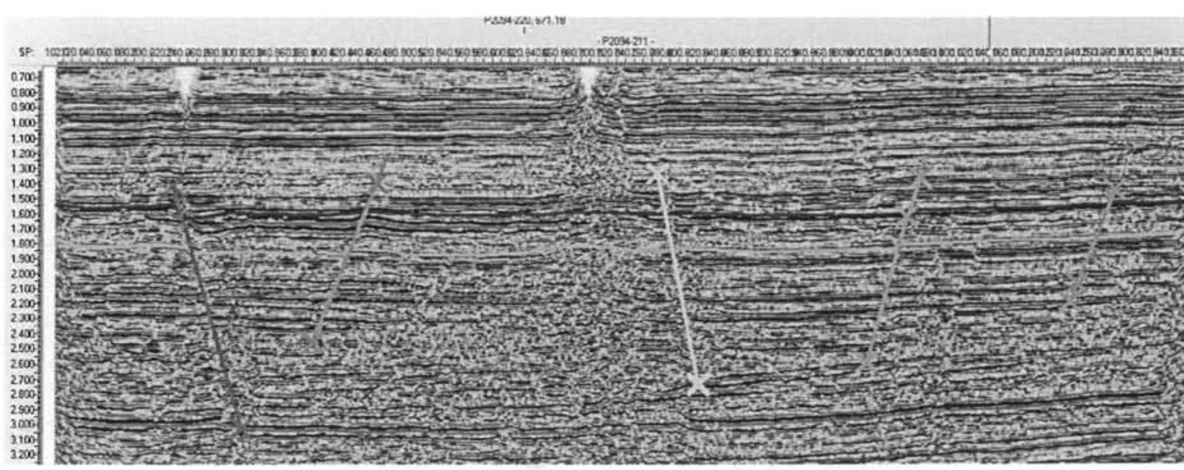
Figure 3.5: Interpretation seismic Dip line GP2094-211

3.8 Fault Polygon Construction

Construction of fault polygons are very important as far as time and depth contouring of a particular horizon is concerned. Any mapping software needs all faults to be converted into polygons prior to gridding and contouring. The reason is that if a fault is not converted into a polygon, the software doesn't recognize it as a barrier, thus making any possible closures against faults represent a false picture of the subsurface.

For generation of 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 (represented by a "+" or an "x" sign by Kingdom software) can be manually joined to make a polygon.

I construct the fault polygon at Lower Goru. As the Lower Goru is acting as a reservoir in this study, the fault polygon on this level are shown in the figure 3.7. Minor faults or the faults that has different lateral extent are ignored.

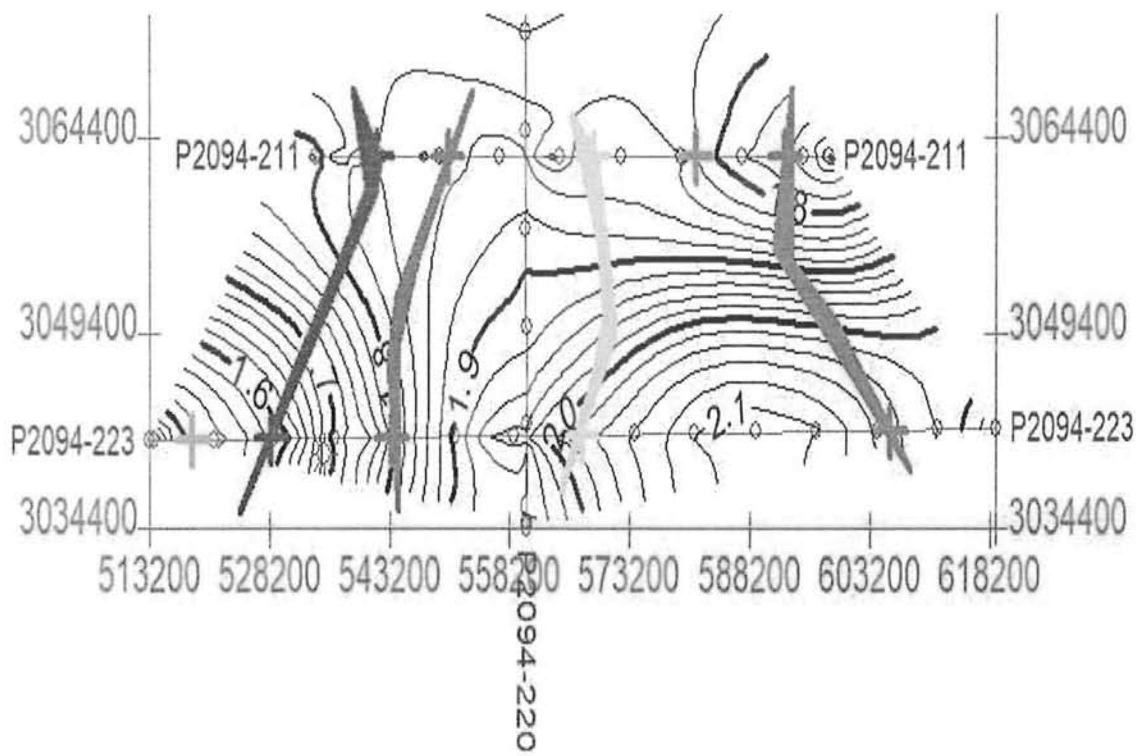

Figure 3.6: Fault Polygon constructed at Top of Lower Goru

3.9 Contour Maps

The results of seismic interpretation are usually displayed in maps. Mapping is part of the interpretation of the data. The seismic map is usually the final product of seismic exploration, the one on which the entire operation depends for its usefulness. The contours are the lines of equal potential wandering around the map as dictated by the data (Coffeen, 1986).

It is essential to construct a datum plane for a subsurface map generated from the seismic data, which may be at sea level or other plane above or below it. Frequently, another datum above sea level is selected in order to image a shallow marker on the seismic cross-section, which may have a great impact on the interpretation of the zone of interest. Contouring represents the three dimensional earth on a two dimensional surface. The spacing of the contour lines is a measure of the steepness of the slope, the closer the spacing, the steeper the slope. A subsurface structural map shows relief on a subsurface horizon with contour lines that represent equal depth below a reference datum or two way time from the surface. These contour maps reveal the slope of the formation, structural relief of the formation, its dip, and any faulting and folding. The interpreted seismic data is contoured for producing seismic maps which provide a three-dimensional picture of the various layers within an area which is circumscribed by intersecting shooting lines. The Kingdom software is used to generate all contour maps (Gadallah & Fisher, 2009)

3.10 Time Contour Maps

A map prepared by seismic time of horizons at every seismic line is intended to show the structure in the subsurface. Obviously it doesn't show structure directly but it gives us the idea of subsurface structure as well as the distribution of horizon in subsurface. The time and depth contour maps are limited to the specific area so basically it is a local study of the area. In this study time contour maps are generated with the help of the SMT Kingdom software. Two-way travel time of the seismic waves is plotted against the Northings and Eastings (X and Y's) and the contours of time are calculated.

The time contour maps for the reservoir formations of the area Lower Goru with respect to time. The details of these time contour maps is given below.

3.11 Time Contour Maps of the Lower Goru Formation

From the time contour map it is clear that the blue color represent the high time and the yellow to red color represent the low time. The low time represent the Horst and high time represent the Graben. The contour map is shown in the figure 3.7. The contour maps clearly show that the formation is shallow towards west and vice versa which clearly indicates that this formation was deposited on a slope from west to east. Miano-07 is located in the Horst structure between 1.6-1.7 (seconds).

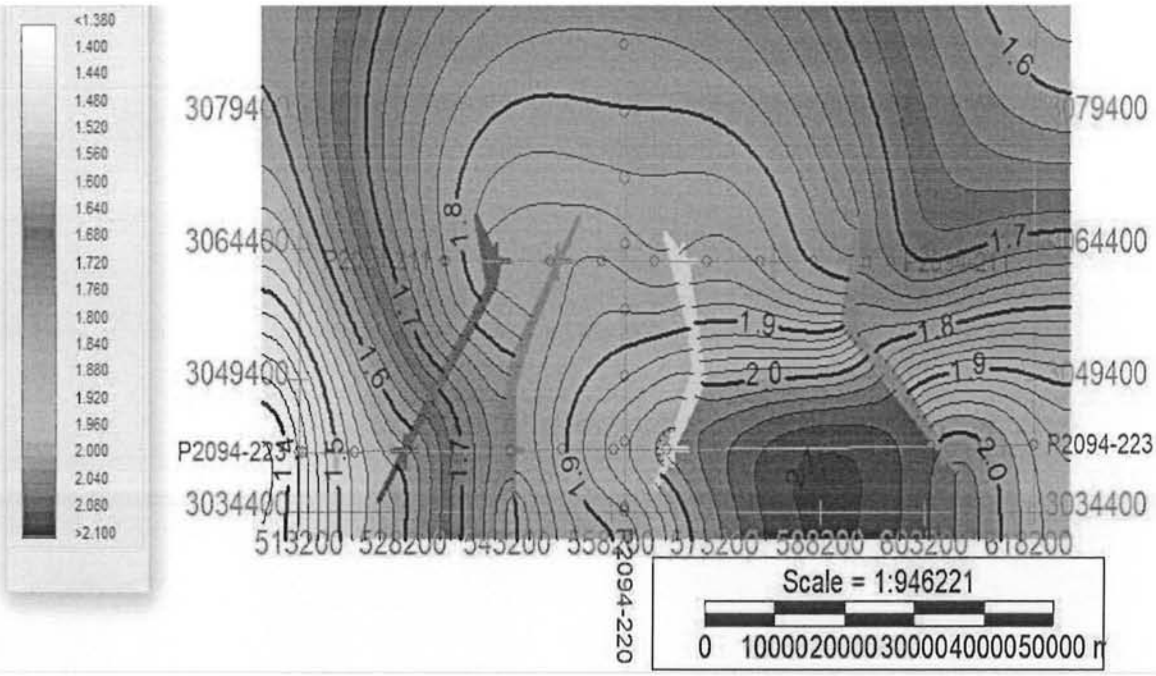

Figure 3.7: Time contour Map of the lower Goru

3.12 Depth Contour Map of the Lower Goru Formation

As structures are related to the depth, and the data is in two way travel time of seismic waves. To prepare a map that is more truly related to the subsurface shapes and structures, depths must be calculated from these time maps using the velocity of the horizons from the sonic log or velocity functions of seismic data. For this purpose time and depth contour maps of reservoir formations, of the horizon i.e. lower Goru Formation, are created. These maps are generated with the help of the Kingdom software. Depth of the horizons is plotted against the Northings and Easting of the survey. Four major faults were plotted on the maps. The depth of Lower Goru Formation Ranges from 2000 to 2400 meters. Depth contours maps show that the depth of horizons increases from West to East direction. Depth contour maps of the horizons are shown in the figure 3.8.

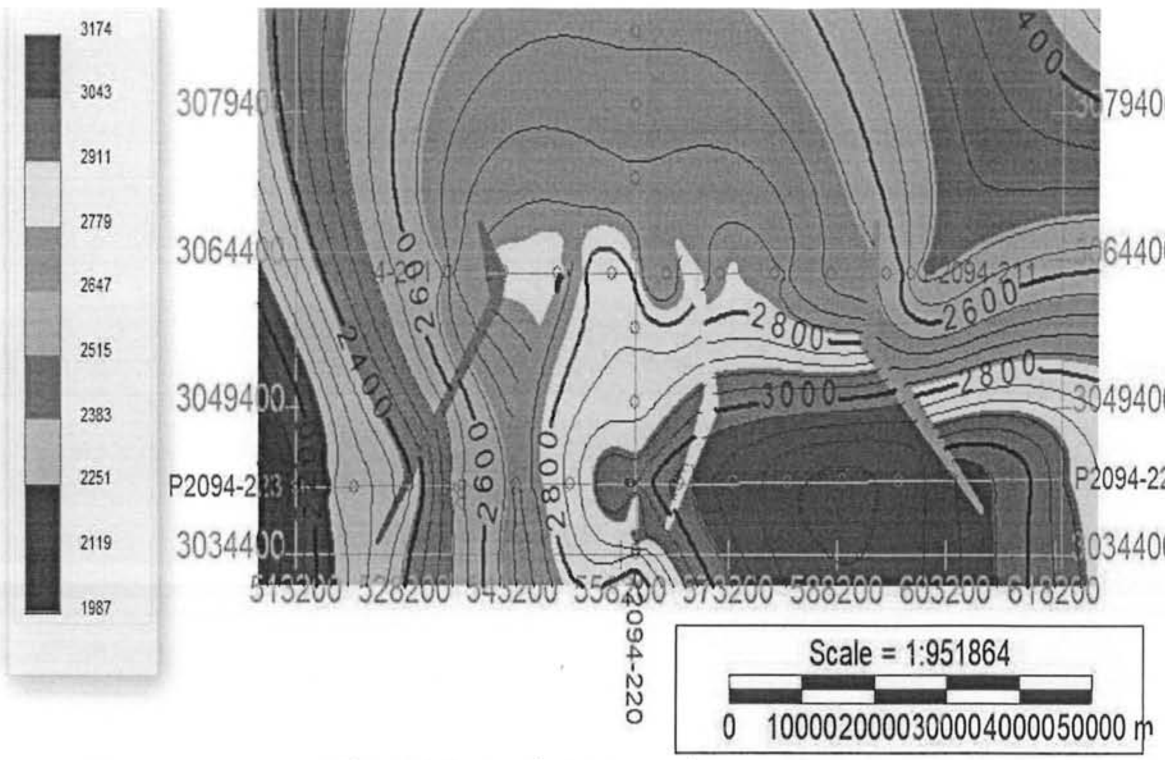

Figure 3.8: Depth Contour of Lower Goru

3.13 Conclusion

After the seismic interpretation it is concluded that there are Horst and Graben structures are present in the study area. In the result of normal faulting Horst and Graben structures are formed which are also confirmed in the above interpretation. Hence we have favorable structures formed in the result of normal faulting for hydrocarbon accumulation 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 the study area of interval of the lower Goru formations has potential for hydrocarbons. Faults in the area are major migration pathways for hydrocarbon and in most places are acting as traps.

CHAPTER NO 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. 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).

The continuous recording of a geophysical parameters along a borehole produces a geophysical well log. It involves measuring the physical properties of s rock surrounding rock layers with a sensor located in a borehole. The record of the measurements as a function of depth is called a well log. (Telford, 1990)

Geophysical well 'Logging has become a standard operation in petroleum exploration, identification of geological formations, formation fluids, correlation between wells and evolution of the productive capabilities of reservoir formations are usually the principle objectives. (Telford, 1990)

The instrumentation necessary for borehole 'Logging is located in a cylindrical metal tube known as Snode. There are many types of well logs, depending upon characteristics of the rock properties being measured.

4.2 log Interpretation Objectives

Quantitative analysis of well logs provides the analyst with values for a variety of primary parameters such as:

- Its storage capacity (Porosity)
- Water saturation , fluid type (oil, gas, water)
- Type of reservoir (Lithology)
- Its productivity (Permeability)

The main objectives of Logging are:

- To provide data for evaluating petroleum reservoir
- To aid in testing, completion and repairing of the well

To calculate the oil reserves in an oil pool we must have the knowledge of following:

- Thickness of the oil bearing formation
- Porosity of formation
- Oil saturation
- Lateral extent of the oil bearing strata

4.3 Data Set

The Petrophysical analysis has been carried out for reservoir characterization of Miano area. For this purpose the data of the drilled borehole, well Miano-07 is used. The log curves of the borehole are used i.e. Spontaneous potential (SP) log, Gamma ray (GR), Sonic log (DT), Lateral log deep (LLD), Lateral log shallow (LLS), Neutron log, Density log (RHOB), and Photoelectric effect (PEF) etc. For Petrophysical analysis, the following parameters are determined on the basis of these log curves:

- Volume of shale
- Water saturation
- Hydrocarbon Saturation

In order to calculate these properties, we should be familiar with the different types of the logs and their characteristics.

4.4 CLASSIFICATION OF GEOPHYSICAL WELL LOGS

The different logs are explained below. Shown in fig 4.1

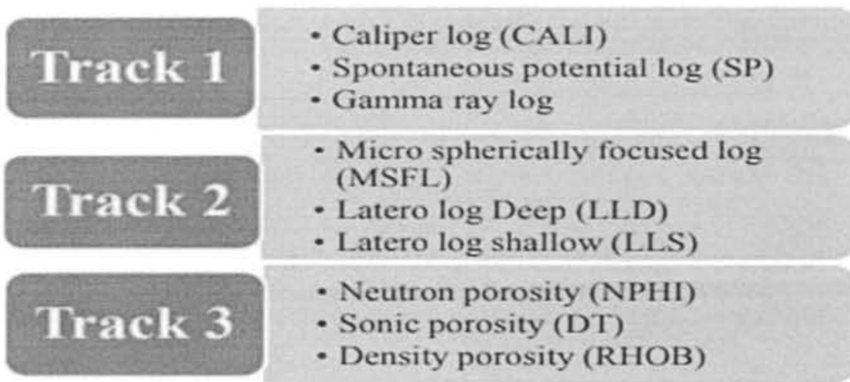

Figure 4.1: Basic three log tracks (George, 2012)

4.5 Lithology Track

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

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

4.5.1 Gamma Ray (GR)

This log is actually a measurement of the natural radioactivity of the formation. Gamma radiations are emitted in the form of electromagnetic energy called photon. When photon collides with electrons, some energy is transferred to electron called Compton scattering. These scattered radiations reached the detector and are counted after absorption of gamma rays from natural radioactive source present within the layer. These emissions are counted and displayed as count per second which is termed as gamma ray log. This log is very important and used for various purposes however, its basic purpose is to differentiate between sand and shale (Asquith and Gibson, 2004).

4.5.2 Spontaneous Potential log (SP)

The "SP" log is a record of the naturally occurring potential in the well bore. This log utilizes a single moving electrode in the bore hole and a reference electrode at the surface, located in the mud pit. The "SP" curve therefore is a record of the potential difference, which exists between the surface electrode and the moving electrode in the bore hole (Asquith and Gibson, 2004). This log can be used for the following purposes (Daniel, 2003).

- To identify the permeable and impermeable zone.
- To detect the boundaries of bed.
- To determine the volume of shale.
- To determine the resistivity of formation water.
- Qualitative measure of permeability.

4.5.3 Caliper log

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

4.6 Porosity Logs Track

Porosity logs measure the percentage of pore volume in a bulk volume of rock. These logs are also helpful to provide data to distinguish between oil and gas and, in combination with resistivity measurements and calculate water saturation. Porosity log include:

- Sonic log (DT)
- Density log (RHOB)
- Neutron Porosity log(NPHI)

4.6.1 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).

4.6.2 Density log

Gamma rays collide with electrons in formation and scattered gamma rays (Compton scattering) received at detector and counted as indicator of formation density. An increase in counting rate causes a decrease in bulk density of formation and vice versa.

Bulk density from the density log is considered to be sum of density of fluid times its relative volume plus density of matrix time its relative volume. However, density log separately and also along with other logs used to achieve various goals (Titman and Wahal, 1965).

4.6.3 Neutron log (NPHI)

This is the porosity log which measure concentration of hydrogen ions in the formation. Neutron is continuously emitted from a chemical source in neutron logging tool. 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 neutron collide with hydrogen atom. Hydrogen is usually indication of presence of fluids in pores, so energy loss is related to the formation porosity.

In shale free formation (clean formation), this log measures the liquid filled porosity where the porosity is filled by water or oil. Neutron porosity will be very low when pores in the formation are filled with gas instead of oil or water. This occurs because there is less concentration of ions (hydrogen) in the gas as compared to water and oil. This decreasing of neutron porosity due to presences of gas called as gas effect (Asquith and Gibson, 2004).

4.7 Electrical Resistivity logs Track

Basically there are different types of electrical Resistivity logs, which measures the subsurface electrical resistivity. This helps to differentiate between formations filled with salty waters and those filled with hydrocarbons. Resistivity and porosity measurements are used to calculate water saturation. Resistivity logs includes:

- Laterolog Deep (LLD)
- Laterolog Shallow (LLS)
- Micro- Spherically Focused log (MSFL).

4.7.1 Laterolog Deep (LLD)

Laterolog is used for deep investigation of the undisturbed zone (Uninvaded zone) and it is called Lateral log 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. LLD having deep penetration as compared to the (LLS).

4.7.2 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 LLD.

4.8 Workflow for Petrophysical Analysis

Petrophysical interpretation is carried out using the kingdom software. 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 4.2.

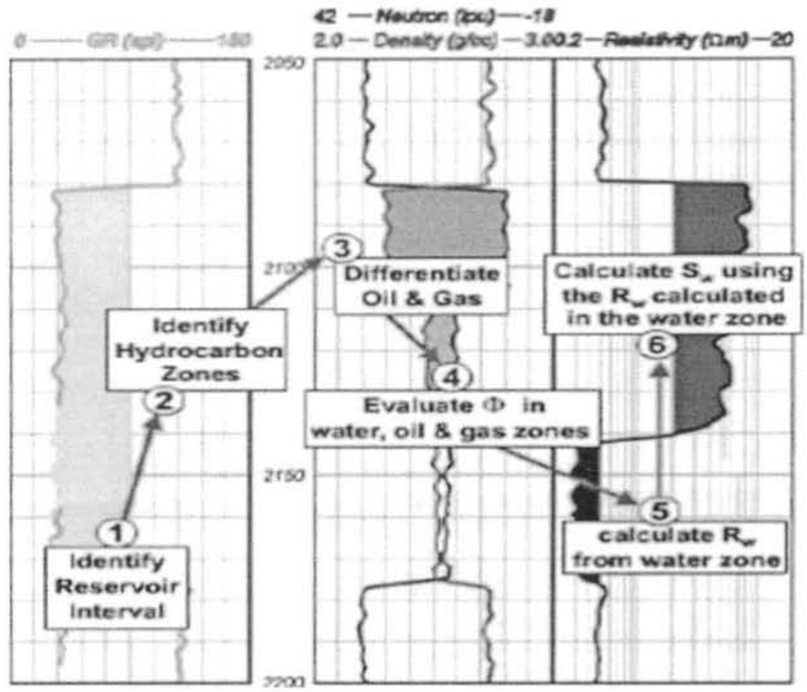

Figure 4.2: Petrophysical Workflow (Ishwar, N.B and Bhardwaj, A)

Raw log curves have been used for the petrophysical analysis of Miano-07. Main reservoir in Lower Indus Basin is Lower Goru of Cretaceous age. In study area, the interval of Lower Goru is the most productive. Top and bottom depth of Lower Goru interval is defined for petrophysical analysis. Also the zones of importance are defined within the reservoir for more specific interpretation of reservoir. These raw log curves include Gamma Ray (API), Caliper (Inches), LLD (ohm-meter), LLS (ohm-meter), RHOB (g/cm3), PEF and NPHI (v/v decimal).

4.9 Calculation of Rock Properties

Many of the rock properties are derived using geophysical well logs. We have calculated the following properties using the different equations which are given below in Table 4.1

Rock Property	Mathematical Equation
Volume of Shale	Vshl[] = min(1, max(0, (GR-GRcln) / (GRshl-GRcln)))
Density Porosity	PHID[] = (RhoM - RHOB[]) / (RhoM - RhoF)
Average Neutron Density Porosity Effective Porosity	PHIA = (PHID + PHIN) / 2 PHIE = PHIA * (1-Vshl)
Archie Water Saturation	SwA = sqrt(Rw / (LLD * PHIA^2))
Hydrocarbon Saturation	Hc = 1-Sw

Table 4.1: Different equations for calculating rock properties (Asquith et al., 2004)

4.9.1 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).

4.9.2 Calculation of Porosity

The most important property in order to understand the petroleum system is porosity. 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.

4.9.3 Average Porosity

Average porosity is the sum of all porosities logs divided by number of logs used for calculating porosity. Its mathematical equation (Schlumberger, 1989) is given in Table 4.1.

4.9.4 Effective Porosity

Effective porosity is the ratio of linked pore volume to the total volume, calculated after removing the effect of shale.

Effective porosity is used for the estimation of water saturation. It can be calculated using the mathematical relation (Schlumberger, 1989) given in the Table 4.1.

4.9.5 Resistivity of Formation Water (Rw)

After the calculation of volume of shale, effective, total and Neutron/Density porosities, the next step is the calculation of resistivity of water. Computing water resistivity is the vital step in finding the saturation of water. Pickett Plot Method is used to calculate the water resistivity. A Pickett plot lets us compare water saturations of different parts of a reservoir in one or many wells. The Pickett plot is a visual representation of Archie equation and therefore is a powerful graphic technique for estimating S_w ranges within a reservoir.

Archie's Equations

Archie's Equations describe the empirical relationship between the formation factor *F*, porosity ϕ, water saturation S_w, and resistivities *R*, in granular rocks.

$$F = \frac{R_o}{R_w} = \frac{a}{\phi^m} \quad \text{eq. (1)}$$

$$S_w^n = \frac{R_o}{R_t} \quad \text{eq. (2)}$$

Where:

a = proportionality constant varying from 0.6 to 1.5

m = cementation factor that varies between 1.3 and 3

n = saturation exponent, often assumed to be 2

R_o = resistivity of the formation when 100% saturated with formation water

R_w = resistivity of the formation water

R_t = true resistivity of the formation

Manipulation of Archie's Equations

Solving for R_o in equation *(2)* and plugging into equation *(1)* yields

$$\frac{R_t S_w^n}{R_w} = \frac{a}{\phi^m}$$

Isolate ϕ^m on the left hand side and take logarithms of both sides of the equation to obtain

$$m\log(\phi) = \log(aR_w) - \log(R_t) - n\log(S_w) \quad \text{eq. (3)}$$

Equation *(3)* describes a set of parallel lines on the Pickett plot that indicate water saturation, S_w.

Construction

The following steps lead to the calculation of resistivity of water.

Step 1 (Plot Points): Plot points of matching porosity and true resistivity (R_t) values obtained from well logs on 2×4 cycle log-log paper. Use the x-axis for the resistivity (R_t) scale and the y-axis for the porosity (Φ) scale.

Step 2 (Plot rw points): Plot the R_w value (resistivity of formation water) by plotting the R_w point along the R_t scale on the x-axis at the top of the graph grid where porosity is 100%. R_w values are published by logging companies, or we can calculate them from the SP log.

Step 3 (Determine m): Estimate *m* (cementation factor) using the table below. Laboratory analysis is necessary for a precise determination of *m*. However, by knowing what the expected porosity type is, we can estimate the value. If you are unsure of the porosity type, use an *m* of 2.

Step 4 (Plot the 100% Sw line): On a Pickett plot, the value of *m* determines the slope of the S_w lines. The first S_w line plotted on a Pickett plot is the 100% S_w line. To plot this line, draw a line with a negative slope equal to *m* that begins at the R_w point. Use a linear scale to measure the slope; for example, go down 1 in. and over 2 in.

Step 5 (Plot Sw lines): After plotting the 100% S_w line, plot the lines representing lower percentages of S_w using this procedure:

1. Find the intercept of R_t = 1 and the 100% S_w line (made in the last procedure).
2. From this intercept, draw a line parallel to the x-axis across the plot. Any point on this line has the same porosity.
3. For example Fig 4.3
    a) Where this line passes through R_t of 2, 4, 6, 8, 14, and 20, draw a series of lines parallel to the 100% S_w line.
    b) Points on these lines correspond to S_w of 71, 50, 41, 35, 27, and 22%. These percentages are calculated from the Archie equation using m = 2 and n = 2 at R_t of 2, 4, 6, 8, 14, and 20.

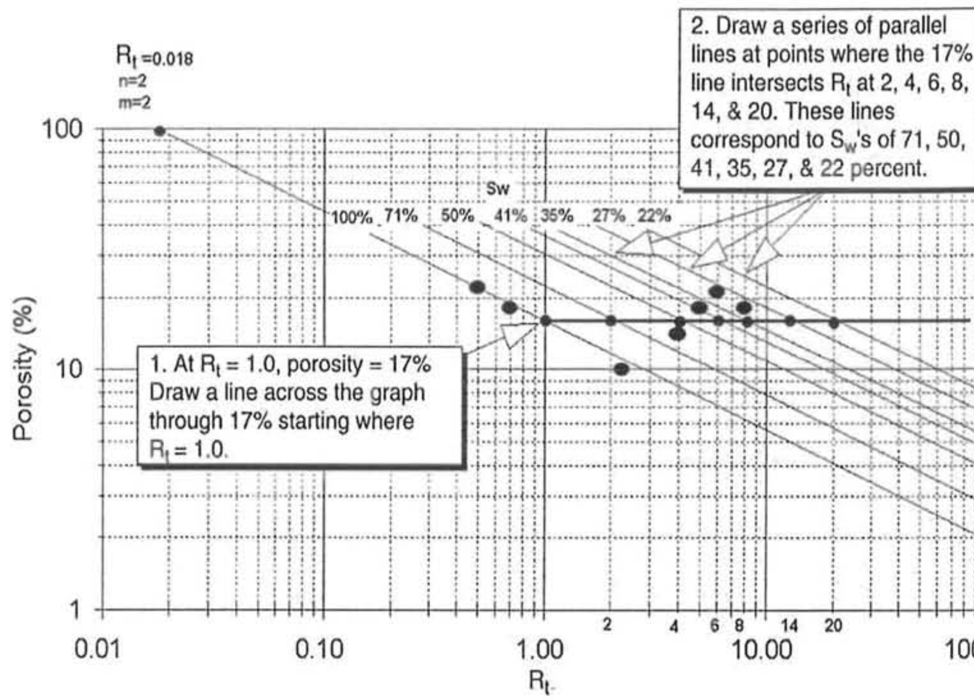

Fig 4.3: This figure is an example of the above-mentioned procedure.

Application in this Project

The Pickett plot is based on a pattern recognition approach to solving Archie's equation without the need for many of the constants that are often unknown. One benefit to this pattern recognition approach is that the water saturation can be derived without having any calibration data for the porosity-measuring device, including grain density, etc. as well as not having to know the resistivity of the formation water. The important aspect of the pattern recognition approach is that there must be a statistically significant number of zones plotted in order to provide accurate calculations. Additionally the unknown constants in Archie's equations must be relatively constant for the reservoirs. Nevertheless, the Pickett plot has become a powerful tool to characterize reservoirs with a simple, quick plot.

The software on which the Pickett plot method is applied is 'GeoGraphix Discovery'. The Results are displayed in fig 4.4 below.

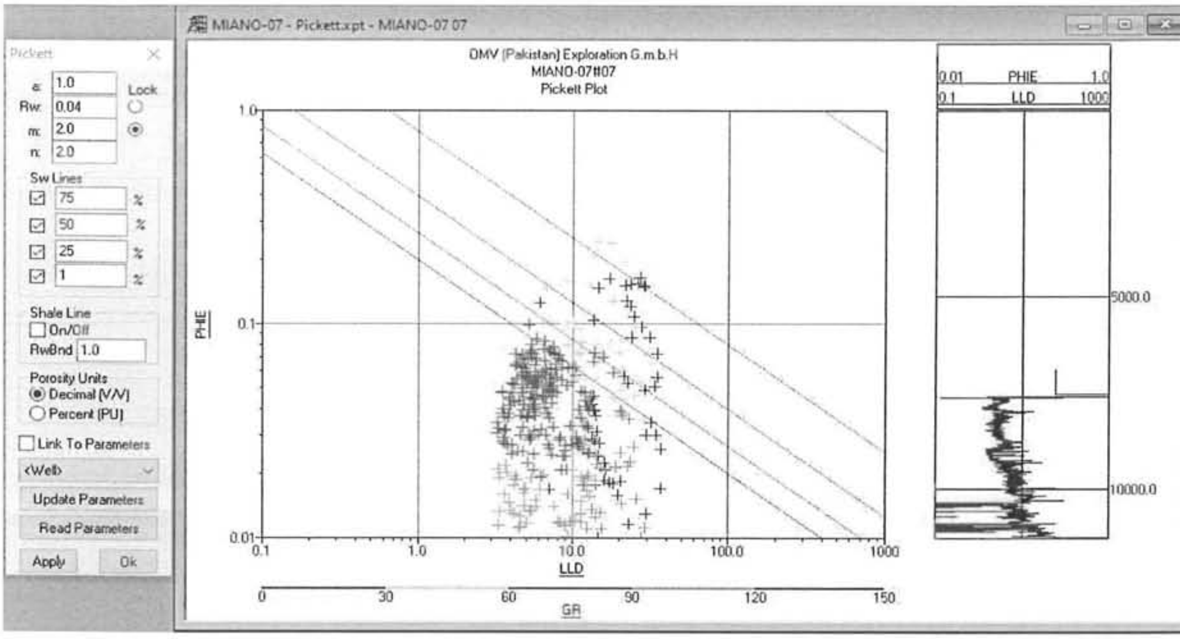

Fig 4.4: Pickett Plot results displaying Sw lines and the points of LLD (x-axis), PHIE (y-axis) with reference to GR values.

4.9.6 Saturation of Hydrocarbon

To calculate hydrocarbon saturation, just subtract the saturation of water from the pore spaces, the rest will be hydrocarbons saturated pore spaces.

Shc = 1-Sw

Sw = Saturation of water

Shc = Saturation of hydrocarbon

4.10 Petrophysical Interpretation

Petrophysical analysis 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. 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.

Resistivity log is used for the detection of hydrocarbon. The principle of resistivity log is detection of hydrocarbon. Volume of oil and gas in the particular zone of reservoir is found with the help of resistivity log. When Sw is not 100%, then hydrocarbons are present there. Higher values of resistivity usually indicate the presence of hydrocarbons or fresh water.

The separation between LLD and LLS is indication of a hydrocarbon zone as value of LLD is much higher in case of oil or gas. Density in the study field mainly vary from 2 to 2.8 g/cm3. Higher density is observed as corresponding to very low resistivity. It may be due to the Presence of some heavy minerals like gluconate, Chlorite, Chamosite Siderite etc. (Fareed et al 2003)

The other best indication of the presence of hydrocarbon is the crossover that formed by the combination of neutron and density log (Ridder, 1996). B-interval is interpreted as reservoir zone after considering all the above explained results and logs. Some important petrophysical properties are quantified which are given in the below table 4.2.

4.10.1 Interpretation of Entire B interval (3325-3330m)

Depth range of B interval varies from (3325-3330m) in well Miano-07. It consist of alternate layers of shale and sand.

Prominent zone for hydrocarbon is marked through the well in Figure 4.4 where high net pay is expected. The zone of interest is marked on the basis of following criteria

- Separation between MSFL and LLS
- Low value of GR
- NPHI & RHOB Cross-Over
- Presence of High Sand Content

These parameters are confirmed by log curves shown in fig 4.3.

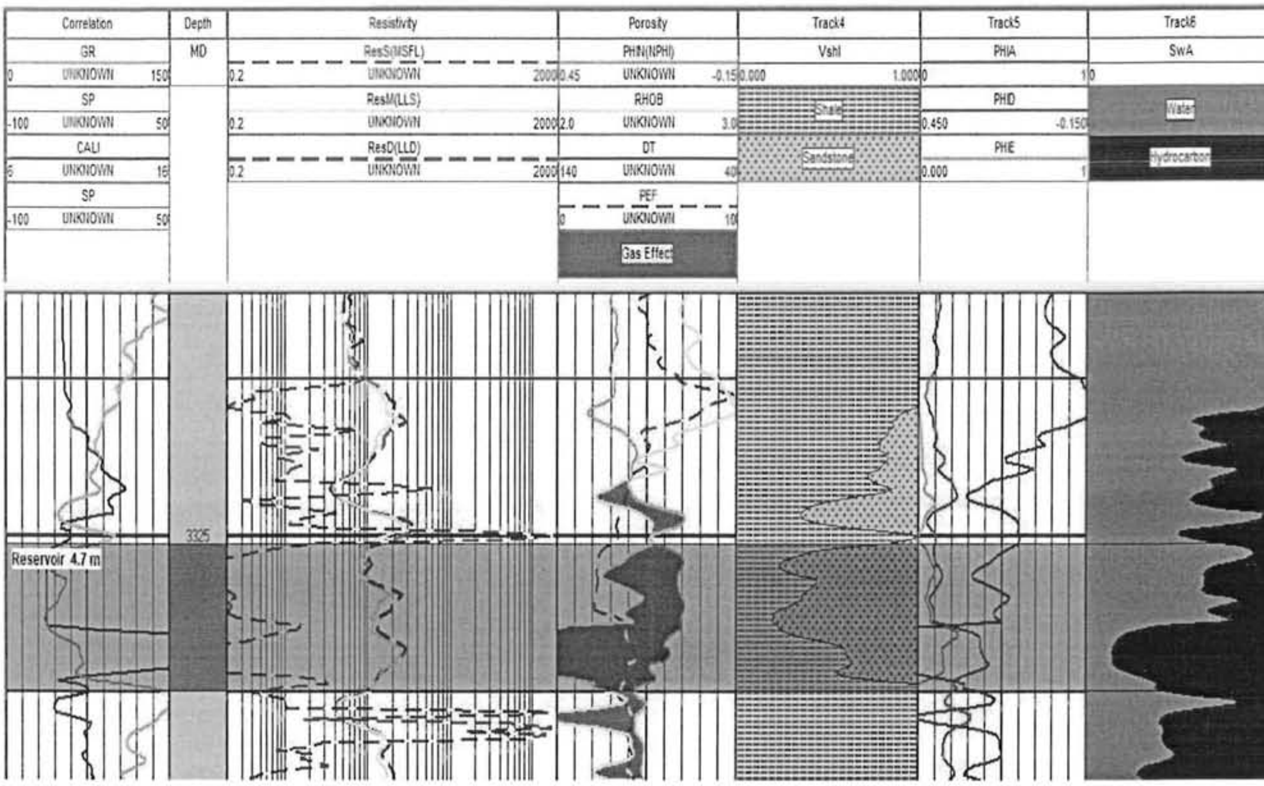

Fig 4.5: Well log interpretation of Miano-07 by GeoGraphix Discovery

4.10.2 Interpretation of Zone of Interest

Only one main zone of interest is marked. Depth range Zone of interest or reservoir varies from 3325- 3330 m in well Miano-07. Shale volume for whole depth range is 40 %. Effective porosity is about 9% and hydrocarbon potential of 60%. This is only one pay zone in where high net pay is expected. This zone bear relatively low values of GR, high resistivity and high porosity. Petrophysical properties of these zones are given in the Table 4.2.

4.10.3 Zone Marking Criteria

Based on a single log we cannot evaluate the productive zone. It requires correlating different logs and their results. The marked zone of interest from 3325-3330 m was concluded by correlations. There was low value of GR, which is a clear condition that it is a sand-bearing zone that can be potential reservoir zone. The 2nd track consisting LLD, LLS (resistivity logs) appeared to cross over which is an indication that the formation contain some high resistivity fluid i.e. hydrocarbon.

Similarly, in 'Track 3' the crossover of density (RHOB) and neutron logs (NPHI) also supports the argument of presence of hydrocarbons. The calculated effective and average porosity are greater than any other zone and hydrocarbon saturation is greater than water saturation. Analysis of all the observations results in favor of the presence of hydrocarbons in the marked zone of Lower Goru B-interval.

Rock Properties	Zone of Interest-Lower Goru B-Interval (3325-3330) m
Average Volume of Shale (Vsh)	40%
Average Volume of Sand	60%
Effective Porosity	9%
Apparent Porosity	19%
Water Saturation	44%
Hydrocarbon Saturation	56%

Table 4.2: Rock Properties of the Zone of Interest, Miano-07

CHAPTER NO. 5
FACIES MODELLING

5.1 Introduction

The term 'Facies' was introduced by the Swiss geologist Amanz Gressly in 1838 and was part of his significant contribution to the foundations of modern stratigraphy. Geologically, Facies is a rock body having some specific characteristics which distinguish it from the other (Ravia et al., 2010).

The Facies is distinctive rock unit that form under certain condition of the sedimentation that reveals the environmental process. The differentiation between the shale and sand has been constantly challenged for the geoscientist. In this process the key challenge is identifying the Facies, from logging and core data, and degree to which the shale content effect the reservoir properties. This gives the main indication about the productive zone in the reservoir

These Facies are related to the certain depositional environment. Basically the depositional environment is specific type of place where the facies are deposited. Such as the Glaciers. Lakes, Abyssal plain, Sea bottom. Stream, Delta etc. The different types of the sedimentary environment.

5.2 Walter's Law of Facies

The Walther's Law of Facies was introduced by the German geologist Johannes Walther (18601937) as an important geological principle, after the establishment of the concept of "Facies", one of the foundations of modern stratigraphy. Walther's Law states that any vertical progression of facies is the result of a succession of depositional environments that are laterally juxtaposed to each other.

Sedimentary environments that started out side-by-side will end up overlapping one another over time due to sea level change (transgressions and regressions). The result is a vertical sequence of beds. The vertical sequence of Facies mirrors the original lateral distribution of sedimentary environments. Walther's Law is an important principle upon which the origin of vertical rock successions is explained. Sediments are deposited in environments that change over time as a result of relative sea-level fluctuations. As the environments change, so does the nature of the sediments deposited at any one location. The vertical succession thus records the lateral changes in environments over time.

A) TRANSGRESSION

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

B) REGRESSION

A marine regression is a geologic event during which sea level falls relative to the land and the shoreline moves toward lower ground so it exposes former sea bottom and produce coarsening upward.

5.3 Facies Analysis

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

5.4 Facies Analysis on Lower Goru Sand-Shale

The Facies modeling is performed by plotting different logs depending on objectives of Facies modeling. Following cross-plots of logs provide the facies change in Miano well with respective lithologies.

5.4.1 Cross-Plot of LLS & RHOB

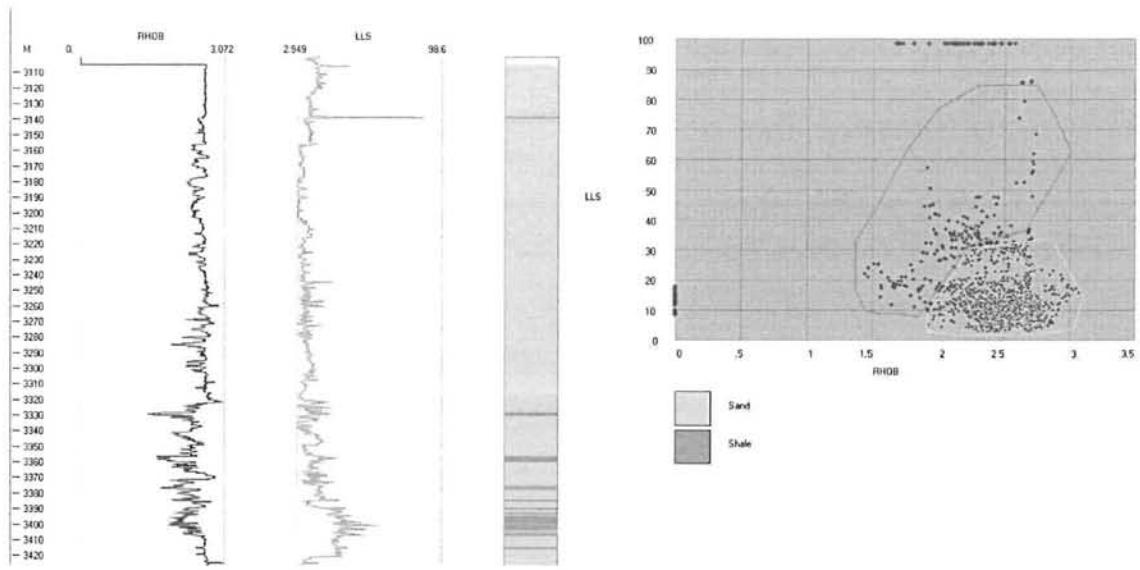

Figure 5.1: Cross-plot of LLS & RHOB

LLS log gives an insight to the extent of resistivity in the Shallow region around borehole while density log provides valuable information about lithology densities. The cross-plot pf both logs result in a conclusion about the environment. Figure 5.1 indicated the presence of Sand content around the reservoir zone which is indicative of a possibility that it also may be accumulating hydrocarbons.

5.4.2 Cross-plot of Vp & RHOB

Density and Velocity has an inverse relation which supports the interpretation of facies correctly by modelling the cross-plots of Vp-RHOB. Density of Sands is, by some margin, greater than shale. On the contrary, sonic velocity of Shale is greater than Sands. In the following cross-plot density (RHOB) is plotted on y-axis while sonic velocity (Vp) is drawn on x-axis.

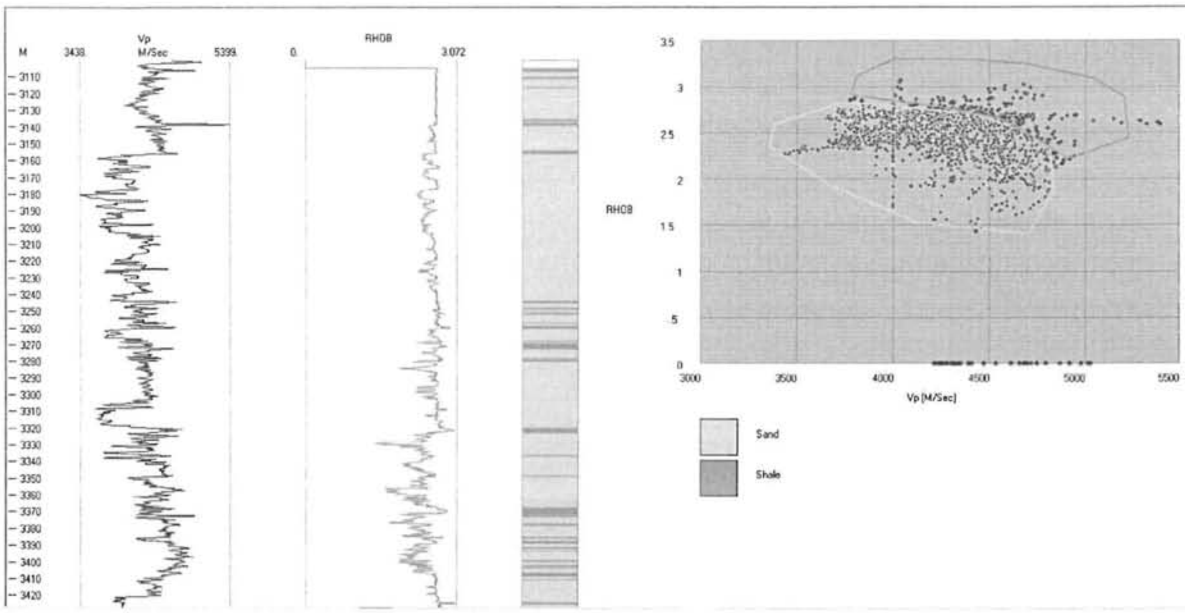

Figure 5.2: Cross-plot of Vp & RHOB

Figure 5.2 delineates sands and shales on the basis of their resistivities and sonic velocities. This is aided by a reference log of GR which justifies the separation and concludes the presence of greater sand content in the reservoir.

5.4.3 Cross-plot of Vp & NPHI

Shales show a high gamma-ray reading, a high neutron reading, and a moderate density reading. While, Sandstones have a low gamma-ray value, a relatively high-density porosity (because the grain density of quartz is small), and a relatively low neutron reading.

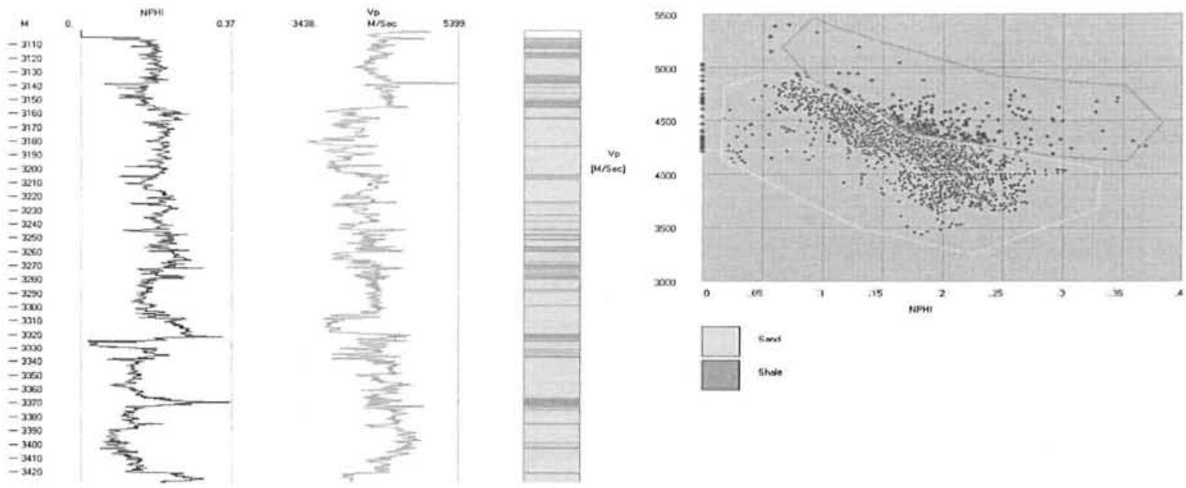

Figure 5.3: Cross-plot of Vp & NPHI

Figure 5.3 is the result of cross-plot between Vp and NPHI (Neutron-Porosity). It can be said that Sands have relatively low Neutron readings and low velocities, which is natural. Furthermore, aside from justification of correct modelling of these properties, it can be concluded that sand content, here too, seems to be greater in content which is needed to support the hypothesis of presence of hydrocarbons. The environment is capable of hydrocarbon accumulation.

5.4.4 Regression Analysis

Regression techniques are commonly used in rock physics to establish empirical relationships between to physical quantities. Several samples are collected which have values for both the parameters and then an appropriate order regression curve is fitted into the data to get an empirical relationship between the two quantities. One common example is the Castagna equation, which establishes a relationship between compressional (Vp) and shear (Vs) wave velocities. Similarly Gardner's equation relates the densities with compressional wave velocities.

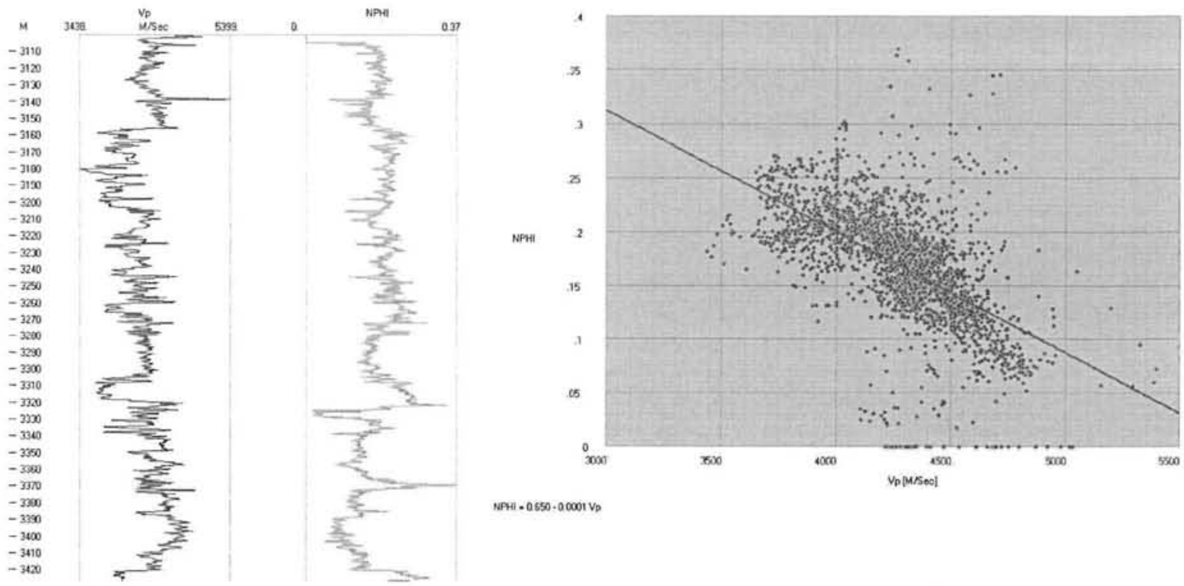

Figure 5.4: Regression Analysis (Curve fitting) between Vp & NPHI

The above results are the product of Gardner's equation, which relates the neutron densities (NPHI) with compressional wave (Vp) velocities. Correlation coefficient is 0.650 which is considered a good number and thus supports the interpretation.

CHAPTER NO. 6
SEISMIC ATTRIBUTES

6.1 Introduction

Seismic attributes can be conveniently defined as "the quantities that are measured, computed or implied from the seismic data".

From the time of their introduction in early 1970's seismic attributes gone a long way and they became aid for geoscientists for reservoir characterization and also as a tool for quality control. Different authors introduced different kinds of attributes and their uses. With the introduction of 3D seismic techniques and associated technologies and introduction of seismic sequence attributes, coherence technology in mid 1990's, and spectral decomposition in late 1990's has changed the seismic interpretation techniques and provided essential tools that were not available for geoscientists earlier. With the introduction of 3D visualization techniques, use of seismic attributes has attained a new dimension. Development of a wide variety of seismic attributes warrants a systematic classification. Also a systematic approach is needed to understand the use of each of these attributes and also their limitations under different circumstances.

6.2 Applications of Seismic Attributes

Uses of Seismic attributes include:

- To check seismic data quality identifying artifacts
- Performing seismic facies mapping to predict depositional environments
- Hydrocarbon play evaluation
- Reservoir characterization

6.3 Classification of Seismic Attributes

Though the purpose of this paper is to understand the purpose of different attributes that can be used as tools in interpretation, it is useful to understand the classification of different attributes at this stage. The following classification is taken from the paper "Seismic Trace Attributes and their Projected Use In Prediction of Rock Properties And Seismic Facies" by Rock Solid Images.

The Seismic Attributes are classified basically into 2 categories (Taner et al, 1994).

- Physical Attributes
- Geometric Attributes

6.3.1 Physical Attributes

Physical attributes are defined as those attributes which are directly related to the wave propagation, lithology and other parameters. These physical attributes can be further classified as pre-stack and post-stack attributes. Each of these has sub-classes as instantaneous and wavelet attributes. Instantaneous attributes are computed sample by sample and indicate continuous change of attributes along the time and space axis. The Wavelet attributes, on the other hand represent characteristics of wavelet and their amplitude spectrum.

6.3.2 Geometric Attributes

The Geometrical attributes are dip, azimuth and discontinuity. The Dip attribute or amplitude of the data corresponds to the dip of the seismic events. Dip is useful in that it makes faults more discernible. The amplitude of the data on the Azimuth attribute corresponds to the azimuth of the maximum dip direction of the seismic feature.

6.4 Seismic Attributes

In this dissertation, following attributes are applied:

- Envelope of Trace
- Instantaneous Phase
- Instantaneous Frequency

6.4.1 Envelope of Trace

The envelope is the envelope of the seismic signal. It has a low frequency appearance and only positive amplitudes. It often highlights main seismic features. The envelope represents the instantaneous energy of the signal and is proportional in its magnitude to the reflection coefficient. The envelope is useful in highlighting discontinuities, changes in lithology, faults and changes in deposition, tuning effect, and sequence boundaries. It also is proportional to reflectivity and therefore useful for analyzing AVO anomalies. This attribute is good for looking at packages of amplitudes. This attribute represent mainly the acoustic impedance contrast, hence reflectivity. It always remains positive whether the reflection coefficient is positive or negative and it highlights the petroleum play as a bright spot.

This attribute is mainly useful in identifying:

- Bright spots.
- Gas accumulation.
- Sequence boundaries, major changes or depositional environments.
- Unconformities.
- Major changes of lithology.
- Local changes indicating faulting.

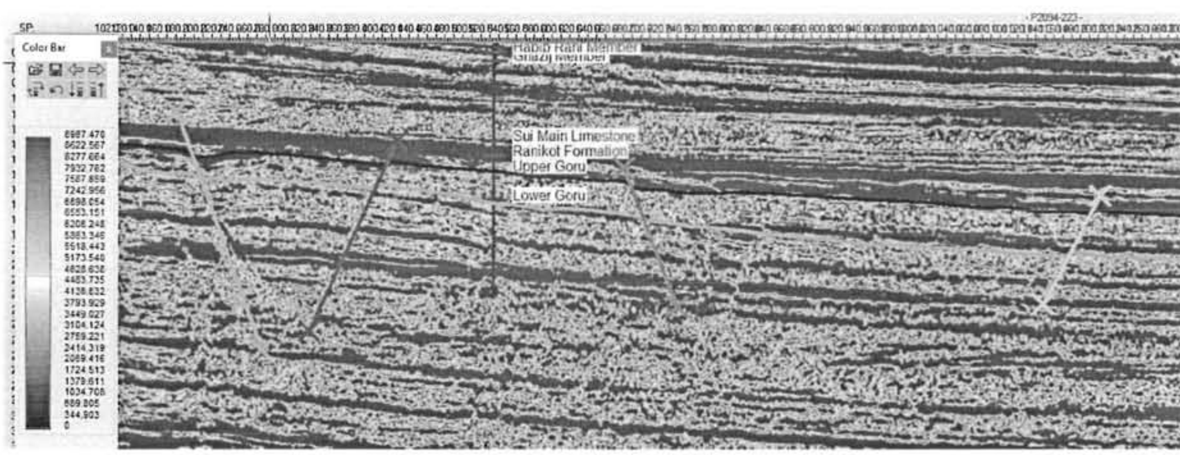

Figure 6.1: An Envelop attribute map of seismic line GP2094-223

Envelope of a trace shows mainly the acoustic impedance contrast, It always remains positive whether the reflection coefficient is positive or negative. Figure 6.1 clearly shows reflection strength of the reservoir zone.

6.4.2 Instantaneous Phase

Instantaneous phase attribute is given by

Φ (t)=arc tan |H(t)/T(t)|

The seismic trace T(t) and its Hilbert transform H(t) are related to the envelope E(t) and the phase Φ (t) by the following relation:

$T(t)=E(t)\cos(\Phi(t))$ $H(t)=E(t)\sin(\Phi(t))$

Instantaneous phase is measured in degrees ($-\pi$, π). It is independent of amplitude and shows continuity and discontinuity of events. It shows bedding very well. Phase along horizon should not change in principle, changes can arise if there is a picking problem, or if the layer changes laterally due to "sink-holes" or other phenomena.

This attribute is useful as

- Best indicator of lateral continuity.
- Relates to the phase component of the wave propagation.
- Can be used to compute the phase velocity.
- Has no amplitude information, hence all events are represented.
- Shows discontinuities, but may not be the best. It is better to show continuities Sequence boundaries.
- Detailed visualization of bedding configurations.
- Used in computation of instantaneous frequency and acceleration.

This attribute is marking clear cut continuity of the reflector as shown in the below figure.

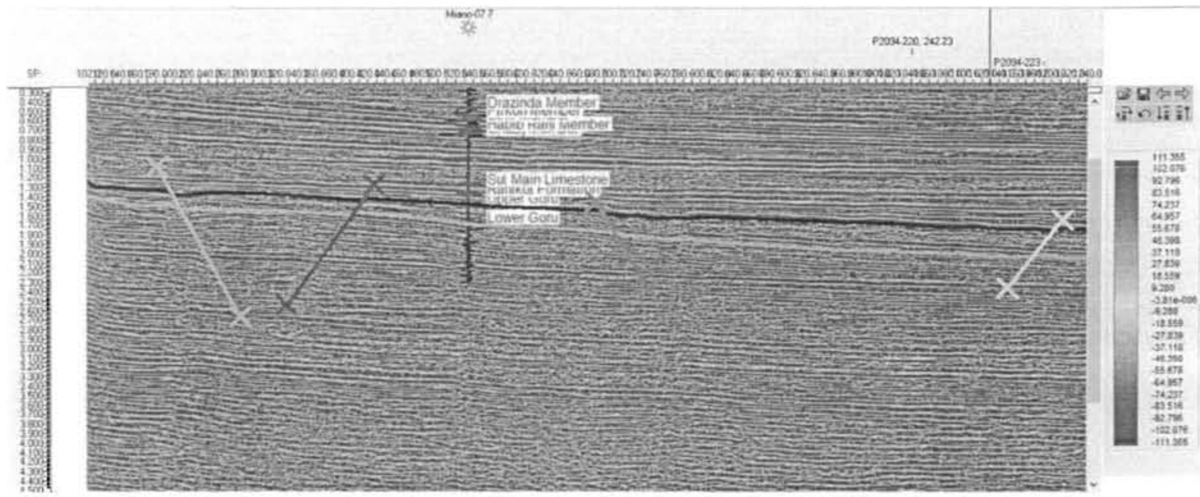

Figure 6.2: Phase attribute map of seismic line GP2094-223

6.4.3 Instantaneous Frequency

Instantaneous frequency is the time derivative of the phase, i.e., the rate of change of the phase.

$F(t) = d(\Phi(t))/dt$

Instantaneous frequency represents the mean amplitude of the wavelet. This attribute is useful in identifying abnormal attenuation and thin-bed tuning (Chopra et al, 2005). These attributes are mainly direct Hydrocarbon indicator by low frequency anomaly in high resolution 3D data because this effect is sometimes accentuated by unconsolidated sands due to the oil content of the pores. Fracture zone indicator, since fractures may appear as lower frequency zones best thickness indicator. Higher frequencies indicate sharp interfaces such as exhibited by thinly laminated shale, lower frequencies are indicative of more massive bedding geometries, e.g. sand-prone lithologies (Taner, 2001).

From figure 6.3 at marked horizons are low frequencies indicating presence of hydrocarbon in the zone whilst as move downward, and time increases instantaneous frequency increases i.e. at greater depth.

This attribute is useful because;

- Instantaneous frequency can indicate bed thickness and also lithology parameters

- Corresponds to the average frequency (centroid) of the amplitude spectrum of the seismic wavelet
- Seismic character correlator
- Indicates the edges of low impedance thin beds
- Hydrocarbon indicator by low frequency anomaly
- Unconsolidated sands due to the oil content of the pores
- Fracture zone indicator, appear as lower frequency zones
- Chaotic reflection zone indicator
- Bed thickness indicator. Higher frequencies indicate sharp interfaces or thin shale bedding, lower frequencies indicate sand rich bedding
- Sand/Shale ratio indicator

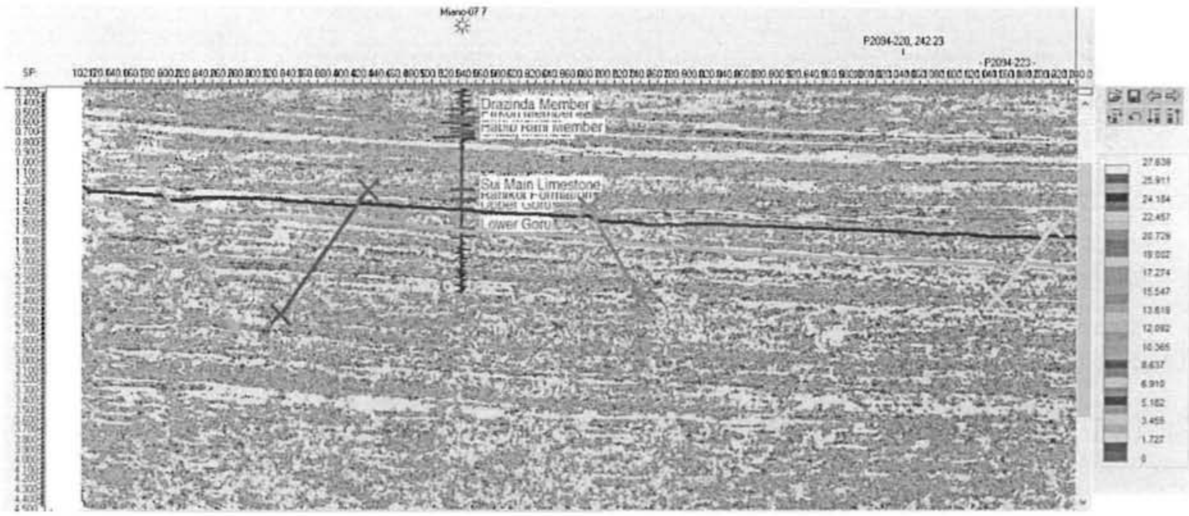

Figure 6.3: Frequency attribute map of seismic line GP2094-223

6.5 Conclusion

Complex seismic trace attributes have become important qualitative and quantitative measures for geophysical exploration. Attributes have made it possible to define seismic data in a multidimensional form and neural network technology enables us to unravel the complex nonlinear relationships between seismic data and rock and fluid properties. Recently published case histories clearly show that multiple attributes overcome the failures associated with single attribute usage. Combined attributes translated by neural networks are becoming principal tools for lithology prediction and reservoir characterization. It is not too unreasonable to expect considerable improvement in the accuracy of predictions in the near future.

CONCLUSIONS

- ✓ Two horizons are marked on the basis of available well log data.
- ✓ Structural interpretation indicates the Horst and Grabben structures associated with Normal Faulting which indicates that it is an Extensional Regime.
- ✓ Time contour maps are generated that confirms the Horst and Grabben structures by indicating high values in Grabben and low values in Horst.
- ✓ Depth contour maps shows the same result as time contour maps because we use average velocity value for the computation of depth.
- ✓ Petrophysical analysis is carried out on Miano-07 well which shows the highest porosity and hydrocarbon prospect zone in the zone B (3325- 3330 m) of lower Goru.
- ✓ Facies Modelling is carried out on the survey area well, Miano, which justifies the role of depositional environment in the reservoir zone for the accumulation of Hydrocarbons.
- ✓ Seismic attributes also applied on seismic data which confirm the hydrocarbon prospect zone.

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