2-D SEISMIC INTERPRETATION OF REFLECTION DATA, SYNTHETIC SEISMOGRAM, PETROPHYSICAL ANALYSIS, ATTRIBUTE ANALYSIS OF MIANO AREA, LOWER INDUS BASIN, PAKISTAN

BY

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بسم الله الرحمن الرحيم

To start with the greatest name of Almighty Allah. Most gracious and merciful, with Him is the knowledge of 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 ***MUHAMMAD MUZAMIL BIN ZULFIQAR*** *S/O* ***ZULFIQAR AHMED*** is accepted in its present form by the Department of Earth Sciences, Quaid-I-Azam University Islamabad as satisfying the requirement for the award of BS degree in Geophysics.

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ACKNOWLEDGEMENT

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

I am especially indebted to my honorable supervisor **Dr. Mumtaz Muhammad Shah** for giving me an initiative to this study. His inspiring guidance and dynamic supervision helped me to complete this work in time.

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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M.Muzamil Bin Zulfiqar

BS Geophysics (2016-2020)

ABSTRACT

Miano gas field is one of the prominent gas-producing fields of the Middle Indus Basin, SW Pakistan. This thesis work includes preparation of synthetic seismogram of Miano-10 well. Analysis of geophysical borehole logs provides one of the best approaches to characterize rocks within boreholes.

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 of time and depth contour maps made from time and depth grid 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-10 well and B sand interval is marked, where there is chance of the presence of the hydrocarbon.

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

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Chapter 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.

The Miano Block is located in the Sukkur district, Sind Province, Pakistan covering total area of 814.02 Sq. km. The block extends between the 27º14´N to 27º32´N latitude and 69º12´E to 69º28´E longitude. The field was discovered in 1993. OMV Pakistan, Oil and Gas Development Company Limited (OGDCL), ENI Pakistan Limited and Pakistan Petroleum Limited (PPL) are the operators in Miano development and production with working interest of 17.68%, 52.0%, 15.16% and 15.0% respectively.

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.

- Detailed seismic interpretation for identification of the structures favorable for hydrocarbon accumulation.
- Petrophysical analysis for the identification of the reservoir types and various petro-physical and geo-mechanical properties of reservoir encountered in study area.
- Seismic attribute analysis for the confirmation of the seismic interpretation.

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 DGPC to complete the thesis project.

Table 1.1 Seismic Data used in interpretation

No	Line Name	Orientation	Nature of line	SP Range
1	P2094-213	W-E	Dip	102 -740
2	P2094-214	N-S	Strike	102 -1175
3	P2094-221	W-E	Dip	102 – 1142

Table 1.2 well data used in the interpretation

Well Data obtained from DGPC for completion of Thesis work		
Miano-10	**TD=3610(m)**	**GAS**

1.4 Base Map:

Base map shows the well locations, concession boundaries, orientations of seismic survey lines and seismic surveys shot points. The base map also contains cultural data such as buildings and roads with a geographic reference like latitude and longitude or Universal Transverse Mercator (UTM) grid information. Topographic maps are used as base maps for assembly of surface geologic information.

For a geophysicist base map is a special type of map which shows the location 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 1 strike lines and 2 dip lines and 1 wells of Miano area.

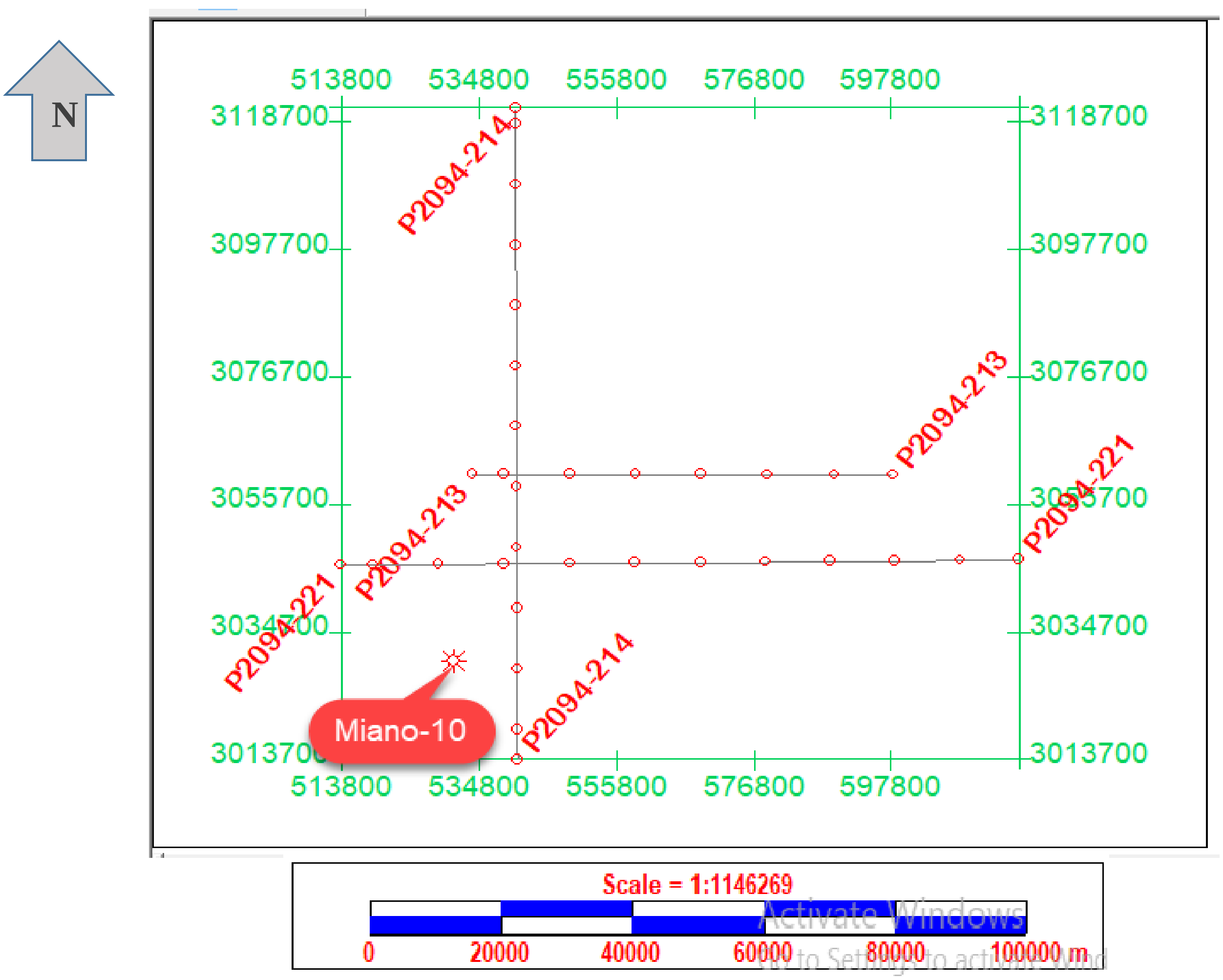

Figure.1.1 2D Base Map of the study area by IHS kingdom

1.5 Software Tools Used:

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

- SMT KINGDOM 8.7

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.

1.6.1 Latitude of the area:

Latitude of the area 27.15º to 27.45º N

1.6.2 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).

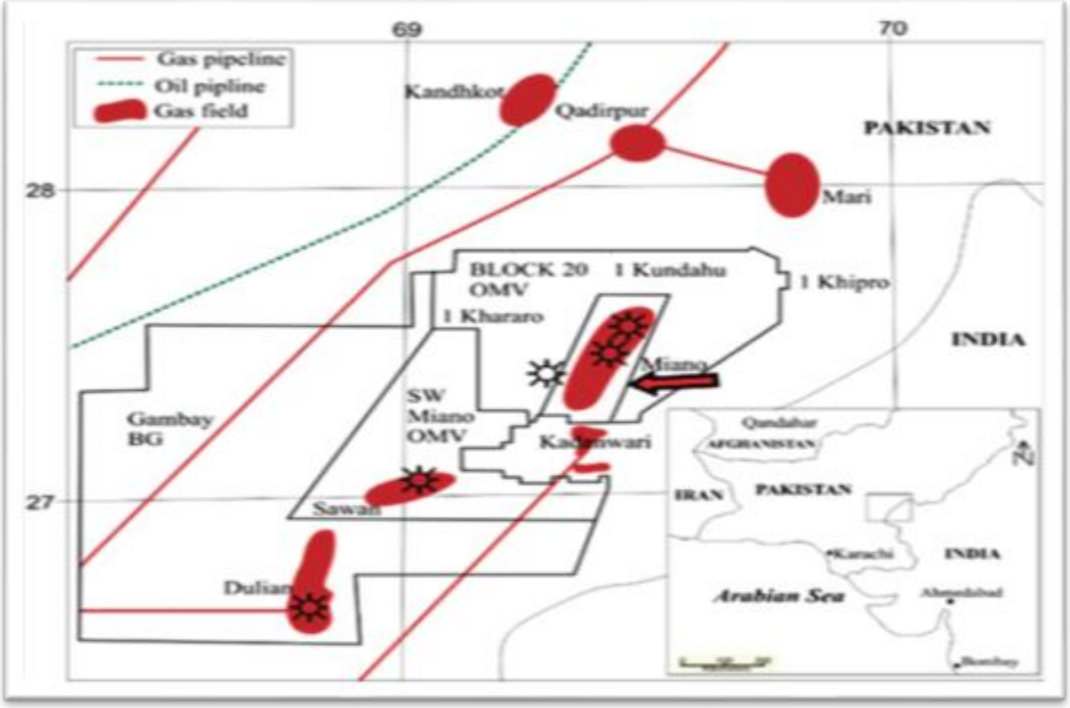

Figure 1.2 Location map of study Area (Zareef et al., 2016)

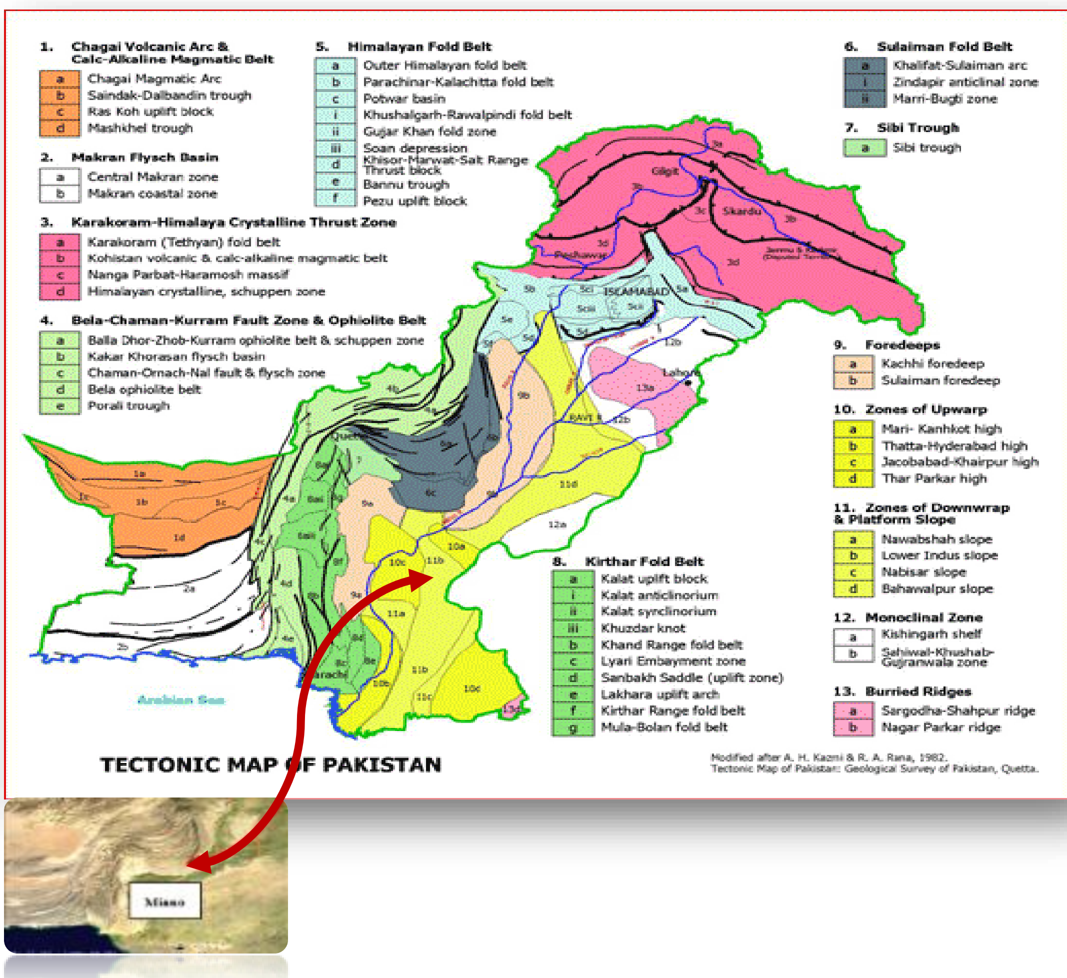

Figure 1.3 Geographical location of the Miano Area (Ahmed et al., 2004)

1.7 Exploration History of the Miano Field:

OMV (Pakistan) started exploration activities in the desert of Sindh in 1991 and its first major breakthrough in 1993 was the discovery of a natural gas reservoir called "Miano" in the Thar Desert, District Sukkur. In continuation of its efforts the Sawan gas field, in district Khairpur was discovered in 1998 which is presently the fourth largest gas producer. OMV (Pakistan) currently holds interests in five exploration blocks, of which three (South West Miano II, Gambat and Latif) are operated by OMV and two (Zamurdan and Sari South) as non-operating interest. The company's recent discoveries in early 2007 in its exploration licenses Latif and Gambat blocks in the northern Sindh Province have opened the potential for further discoveries in the vicinity. New acreage in Baluchistan has also been acquired. OMV has also promoted local companies to become partners in its international ventures. A total of 18 wells have been drilled in the field, out of which seven wells are currently on production.

1.8 Thesis Organization:

This thesis is divided into fourth chapters with this first chapter forming an introduction. Chapter 2 covers the Geological setting and history of study. 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. In Chapter 5, various Seismic attributes are applied for the study of concerned reservoir area.

Following are the methodologies adopted to complete this work.

- Collection of geological & Geophysical data
- Preparation of base map
- Identification of faults on seismic sections
- Determination of horizons by generating 1-D synthetic seismogram
- Finding velocity of horizon using well data
- TWT contour map generation

- Optimal time to depth conversion
- Depth contour map generation
- Geo-mechanical properties using Well-Logs
- Seismic attributes
- Conclusions

Chapter 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 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 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 indus basin.

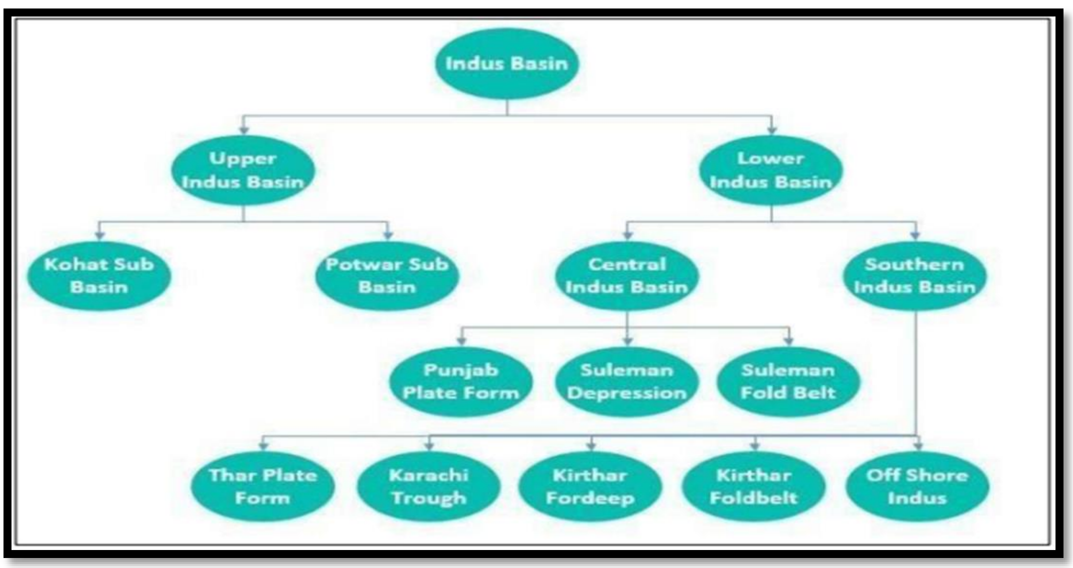

Figure 2.1 Division of the Indus Basin

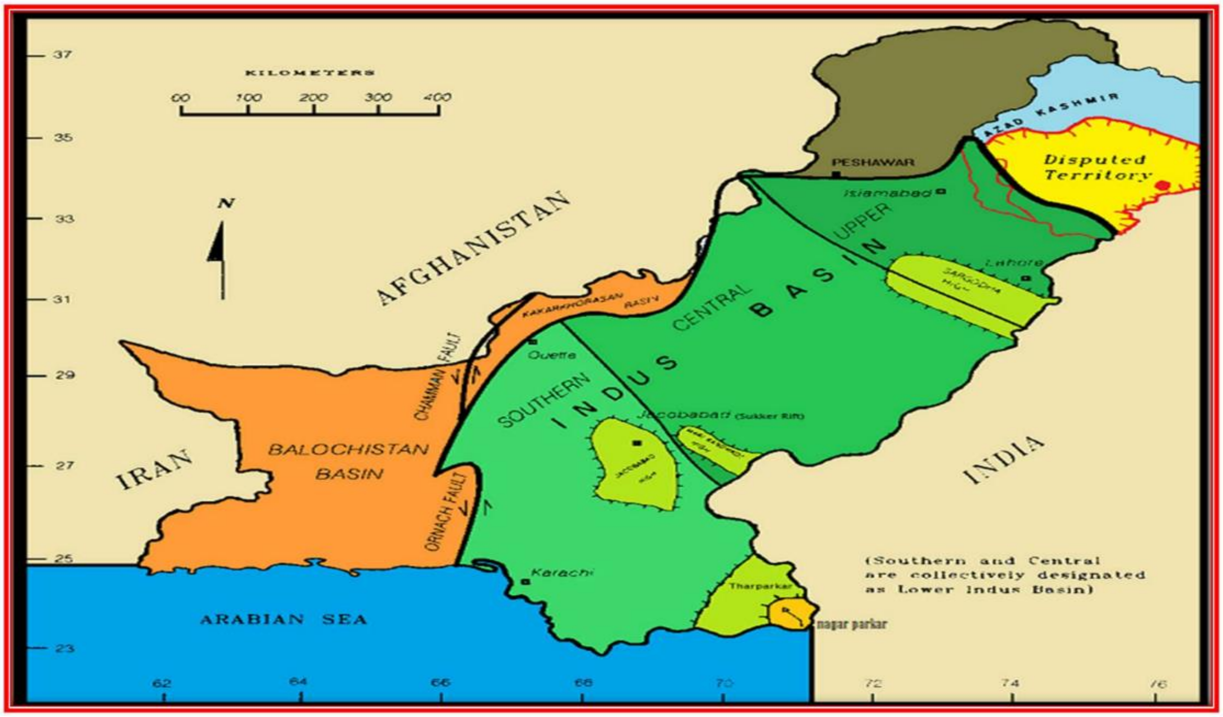

Figure 2.2 Sedimentary basins of Pakistan (Mehmood et al. 2004)

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, 1997).

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 bend in of the crustal plates due to the Indo-Eurasian collision and rebound relief 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.

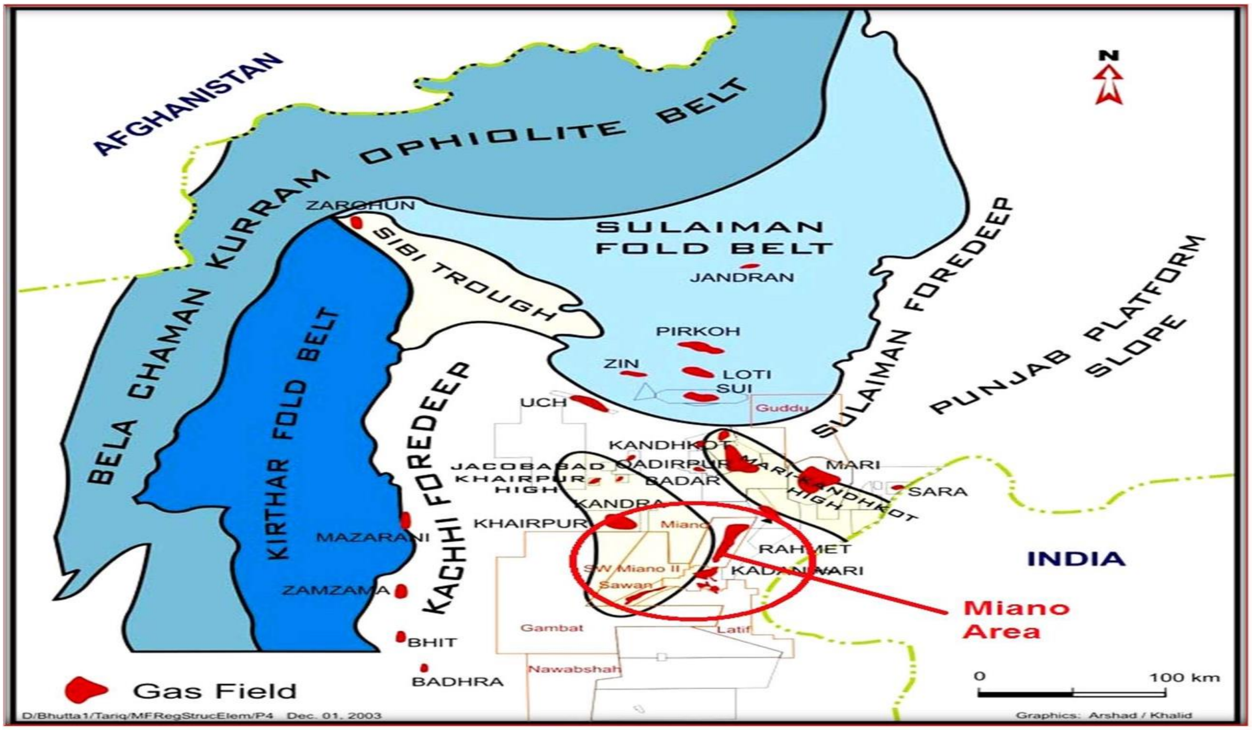

Figure 2.3 Regional tectonic map of Block-20 in the Middle Indus Basin (Mehmood et al, 2004)

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.

The interbedded siltstone, sandstone 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 have 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.

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. The stratigraphic coloum of the area is shown in the below Figure 2.4

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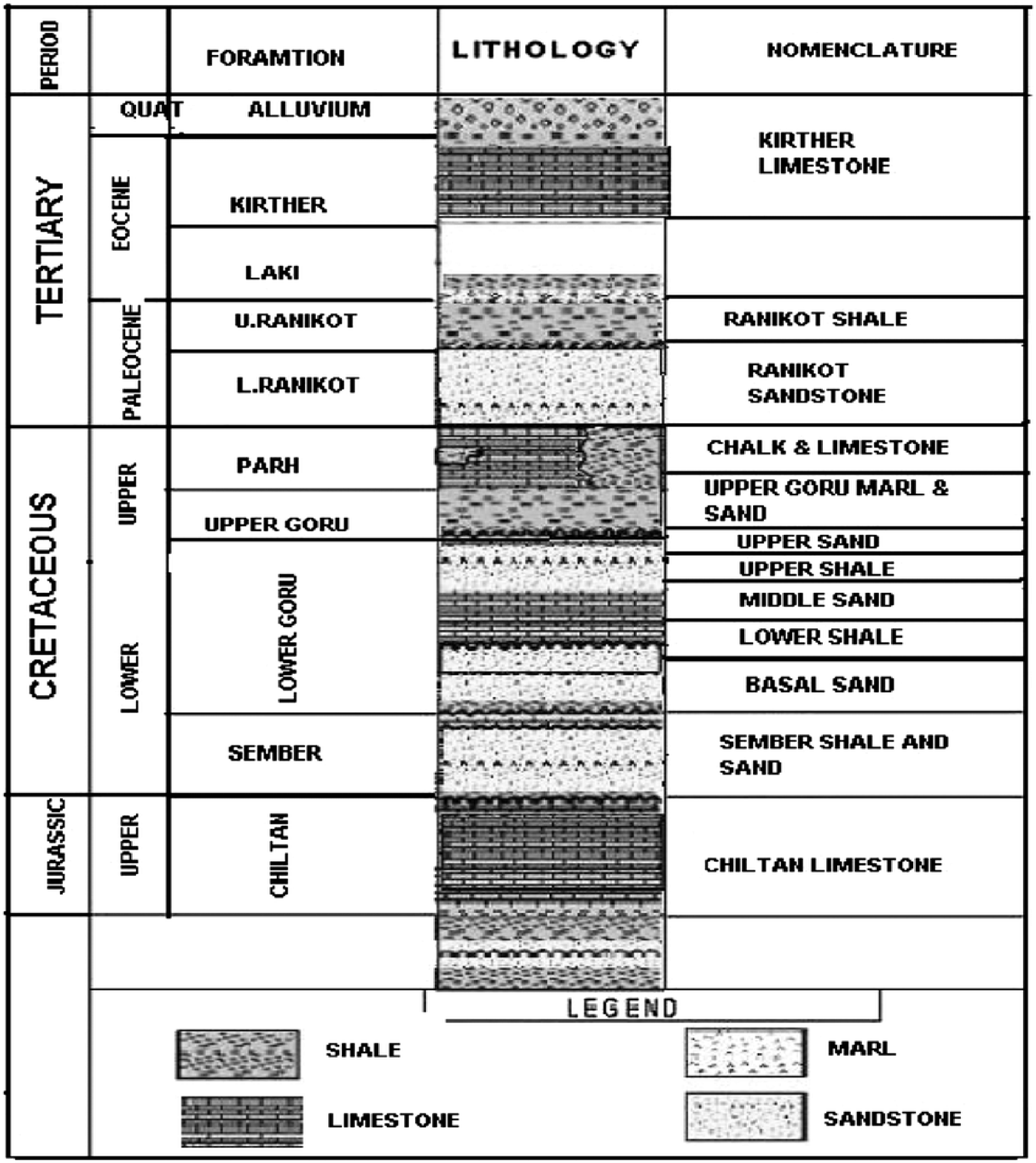

Figure 2.4 Generalized Stratigraphic Chart

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.

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. The general description is given below.

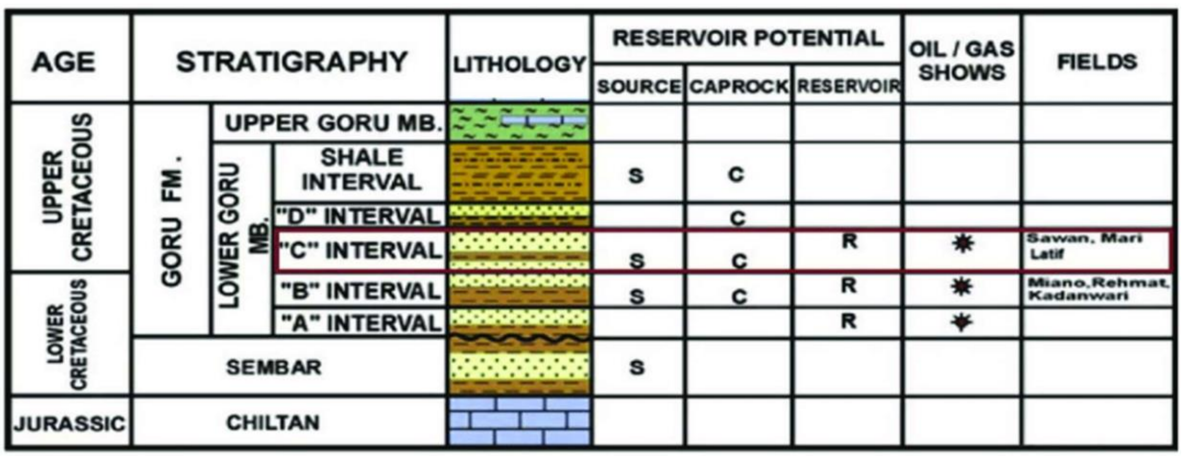

Figure 2.5 Stratigraphic charts for the Sembar and lower Goru formation (Ashraf & Zhu, 2017)

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 Suleiman province. Potential of a reservoir also occurs within the sandstone of 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. Reservoir quality in the Miano field is strongly controlled by the depositional environment. Strong amplitudes and low acoustic impedance seismic waves indicates the presence of reservoir qualities.The principal reservoirs are deltaic and shallow-marine sandstones in the lower part of the goru in the Lower indus basin and the lumshiwal formation in the middle indus basin and the limestones in the Eocene ghazij and equivalent straigraphic units.

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 (Krois et al. 1998).

Chapter 3

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 Types of the Interpretation:

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 study area.

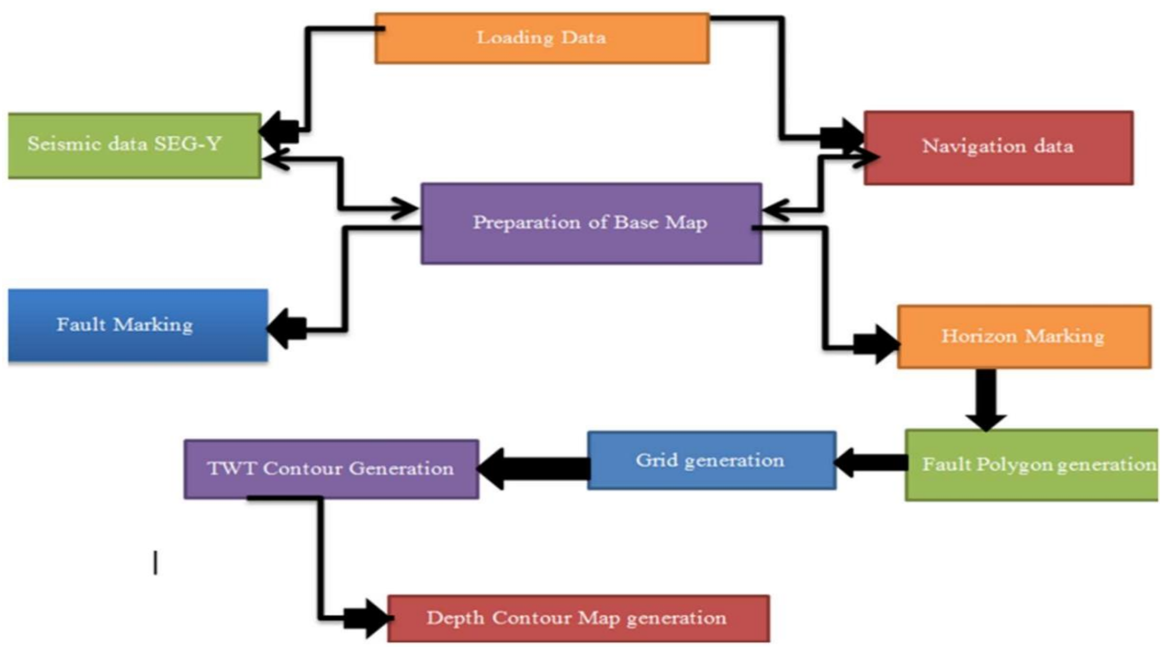

Figure 3.1 Work flow adopted for the seismic data interpretation

3.4 <u>Interpretation of the Seismic Lines:</u>

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-10. We marked the four horizons. The horizons are named on basis of well tops of the well Miano-10. 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.

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

- GP2094-213 ....(Dip Line)
- GP2094-214 ....(Strike Line)
- GP2094-221 ....(Dip Line)

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 is needed. Ideally, a density log should also be used, but these are not always available hence we can also use the constant density for that area. With the help of Miano-10 the synthetic seismogram was constructed shown in the (Figure 3.2) in order to mark the horizons.

- Velocity – DT
- Reference log – GR
- Density – RHOB
- Wavelet- Ricker

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).

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 Ricker wavelet as a digital filter with two millisecond increments of
9. Two-way travel time; using a frequency. Frequency varies from 10-40Hz.
10. Convolve the reflection coefficient log with the Ricker wavelet to generate the amplitudes of the synthetic seismogram.

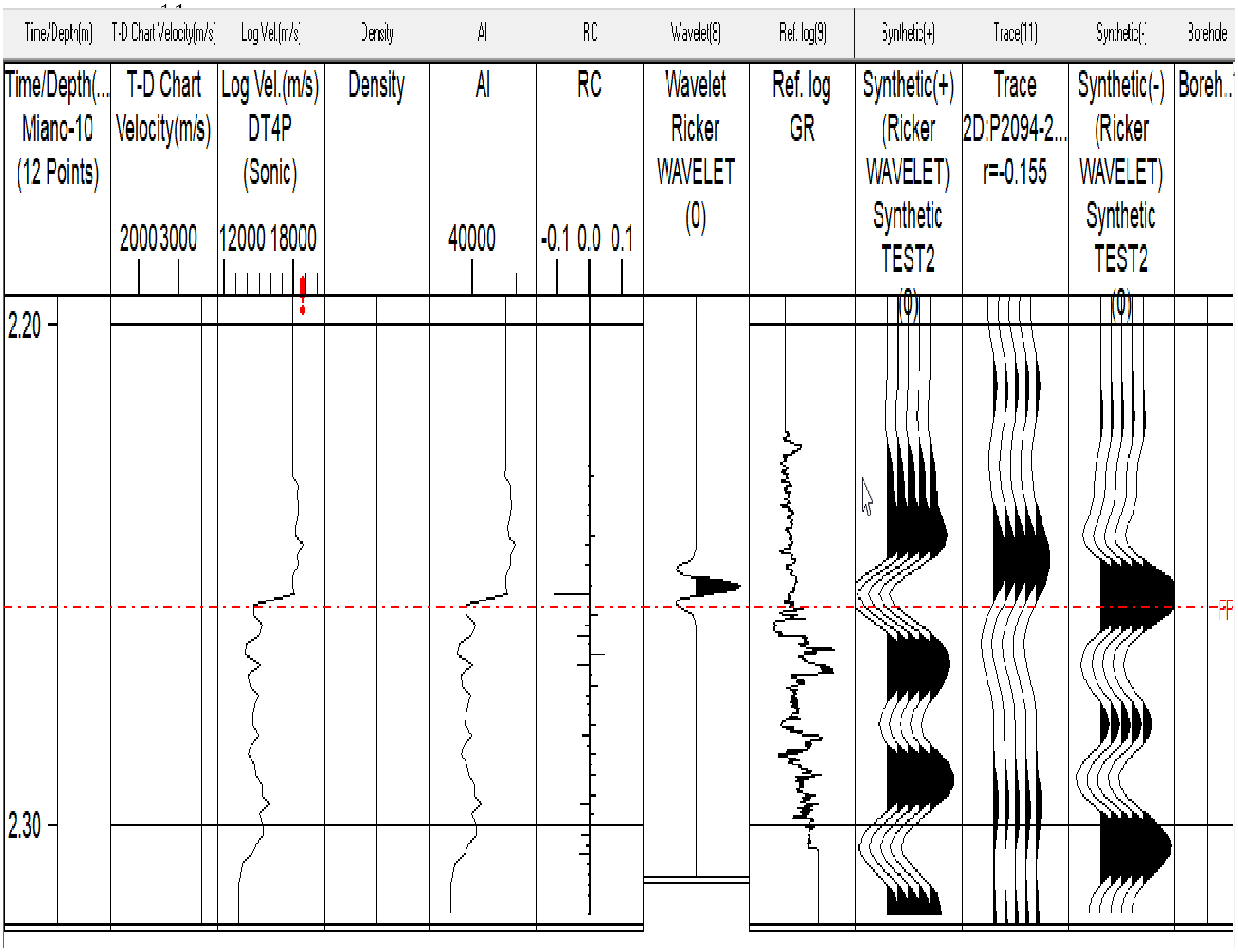

Figure 3.2 Synthetic Seismogram of the well Miano-10

Now the generated seismogram is used to confirm the horizon. Miano-10 is the only well in available data that has 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-10 the C-interval is marked, top of the Lower Goru and the Ranikot formation. 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. 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 the Seismic Strike 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 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 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.

- Ranikot.. Cadet blue
- C-Interval.. Green
- B-Interval.. Yellow

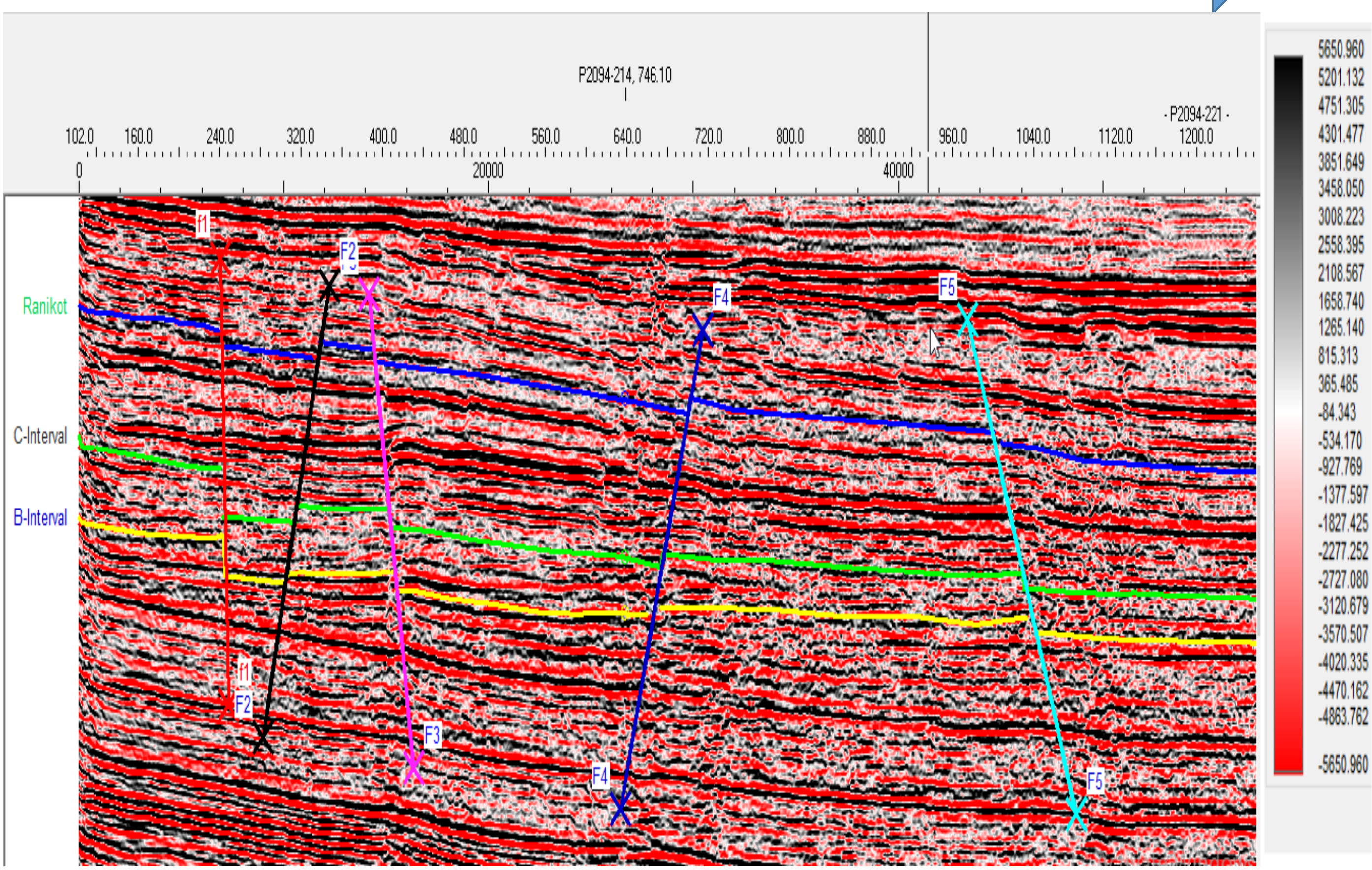

Figure 3.3 Interpretation of seismic Dip line GP2094-221

Location the formations are picked at the following intervals of the time and depth shown in table 3.1.

Table 3.1 TD chart for three marked Horizon

SN	***Formation Name***	***T(sec)***	***Depth(m)***
1	Ranikot	1.6	1694
2	C-interval	2.05	3152
3	B-interval	2.33	3327

3.7.2 Interpretation of the Seismic Strike Line GP2094-214:

Using IHS kingdom digitize the seismic line GP2094-221 with the strike line GP2094- 214.Then remove 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.

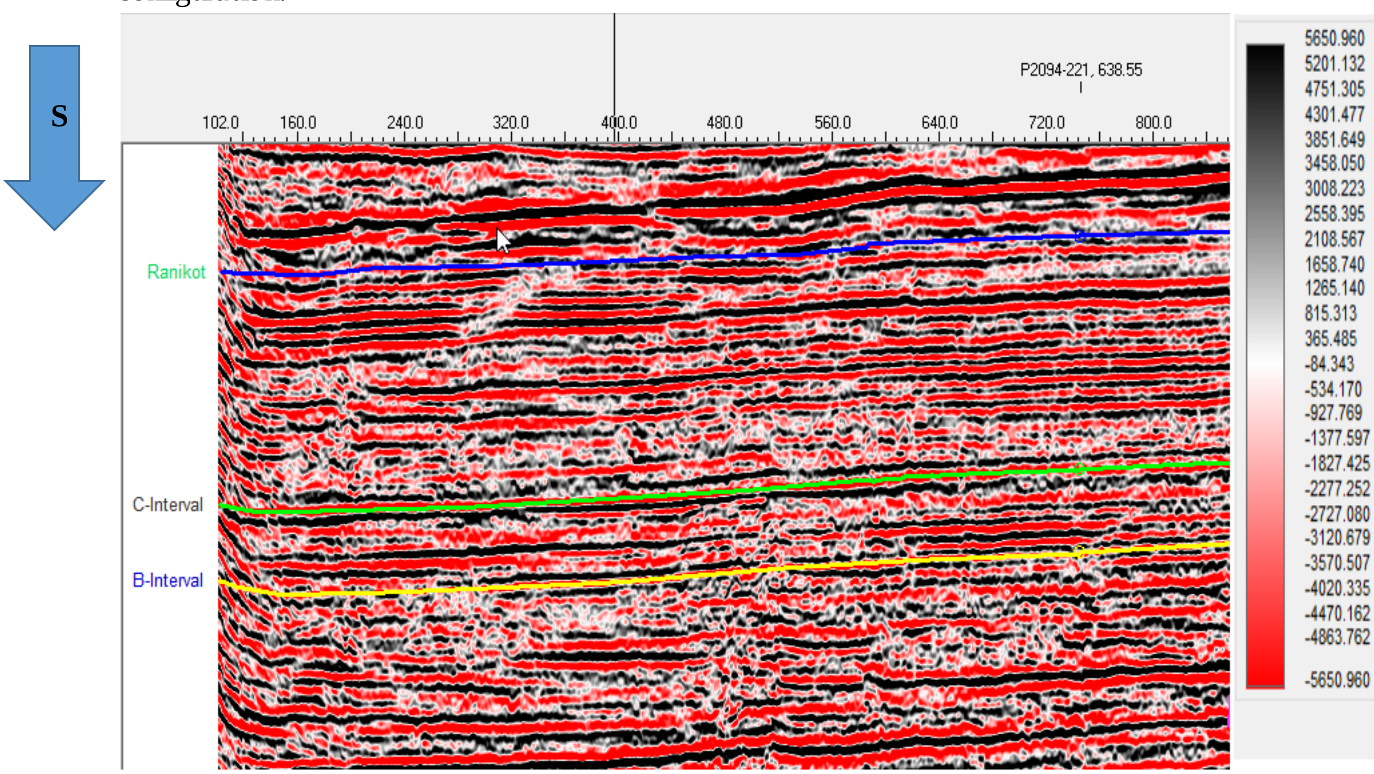

Figure 3.4 Interpretation of the seismic Strike line GP2094-214

3.7.3 Interpretation of the Seismic Dip Line GP2094-213:

Figure 3.4 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 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 favorable structure for petroleum accumulation. The horst sand graben structures are considered good structural traps for the petroleum accumulation.

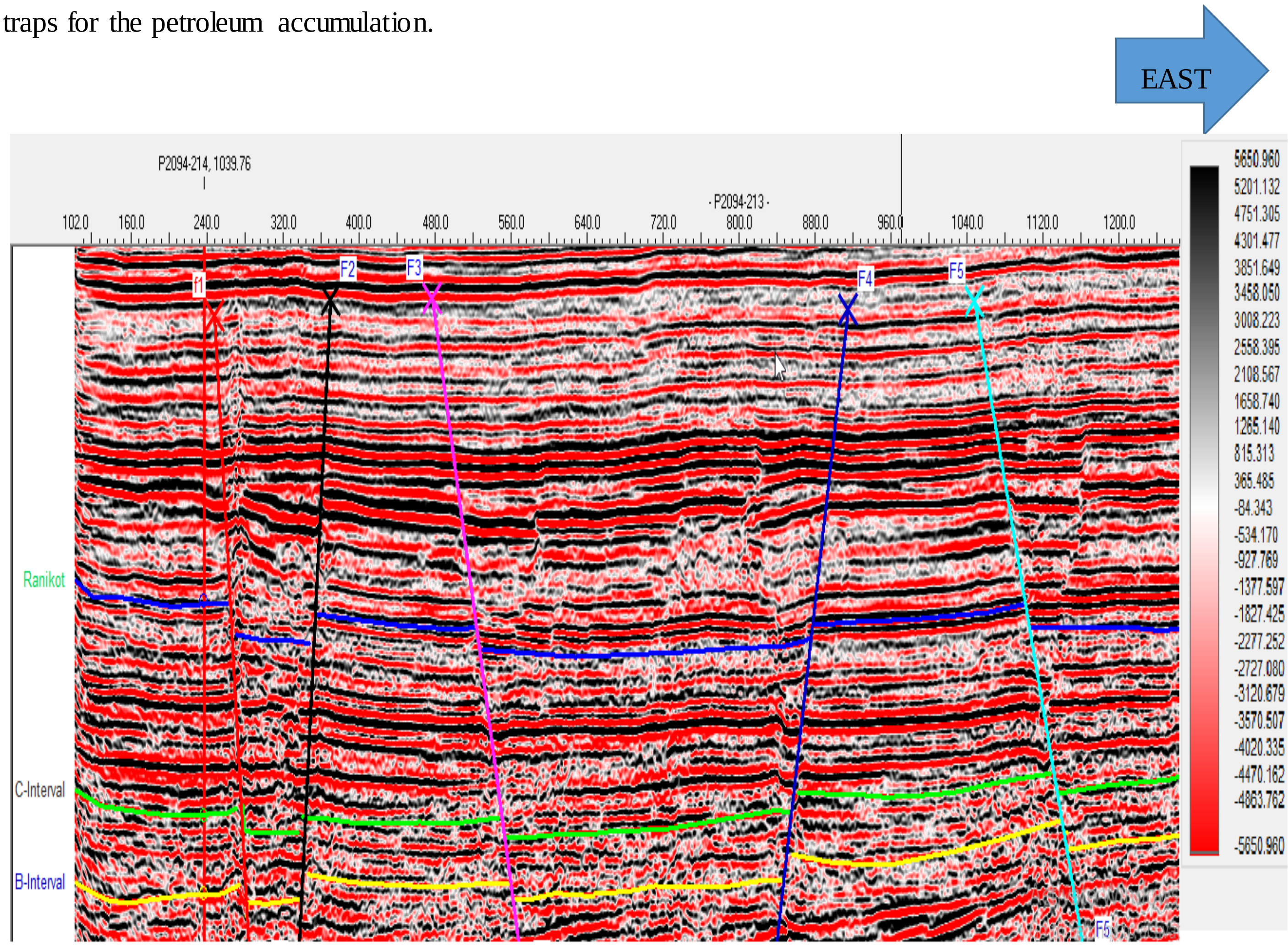

Figure 3.5 Interpretation of the Seismic Dip line GP2094-213

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 in to 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 B-interval level. Because the B-interval is acting as reservoir in this study. The fault polygon on both these level are shown in the figure 3.6.

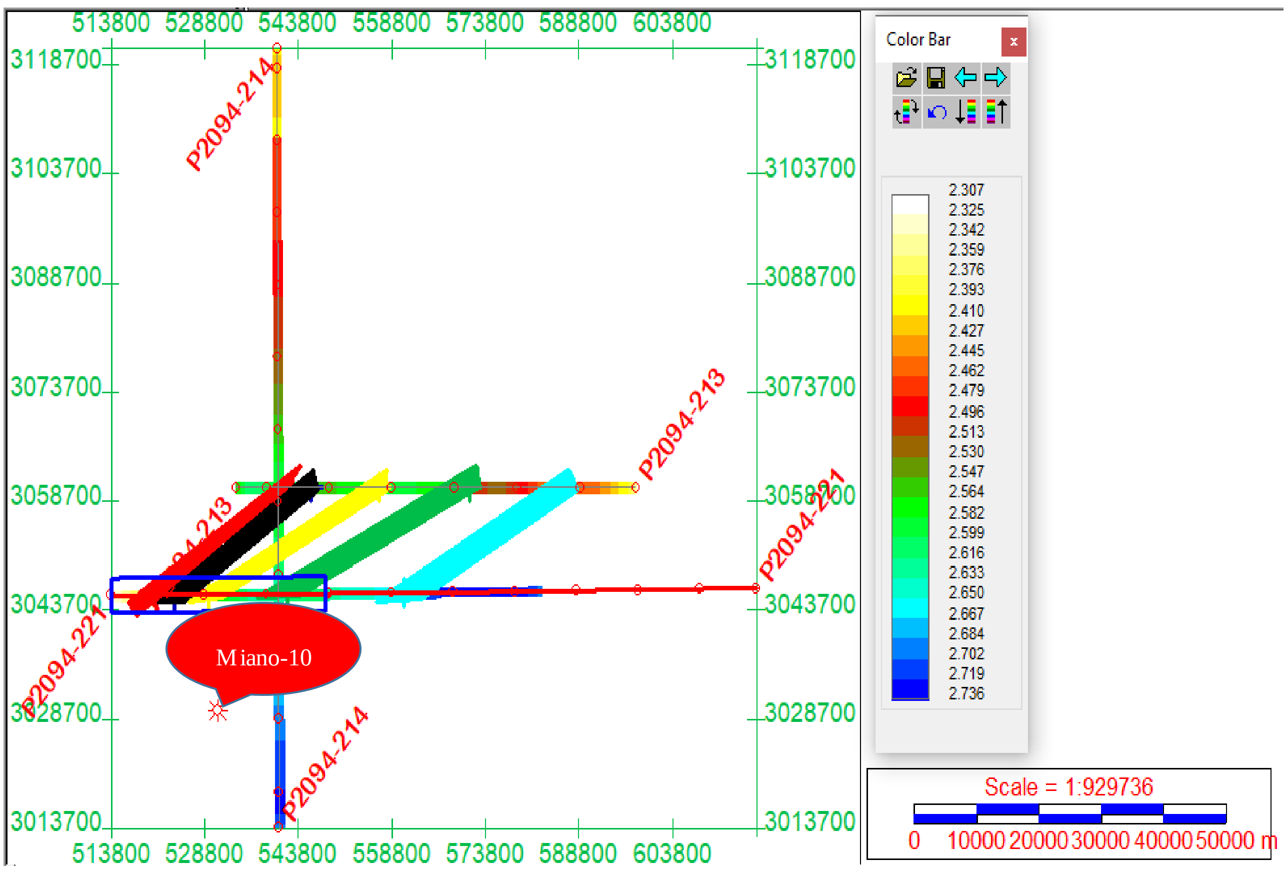

Figure 3.6 Fault polygon constructed at B-interval

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 as under.

3.11 Time Contour Maps of B-interval of the Lower Goru Formation:

From the time contour map it is clear that the red color represent the high time and the blue 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

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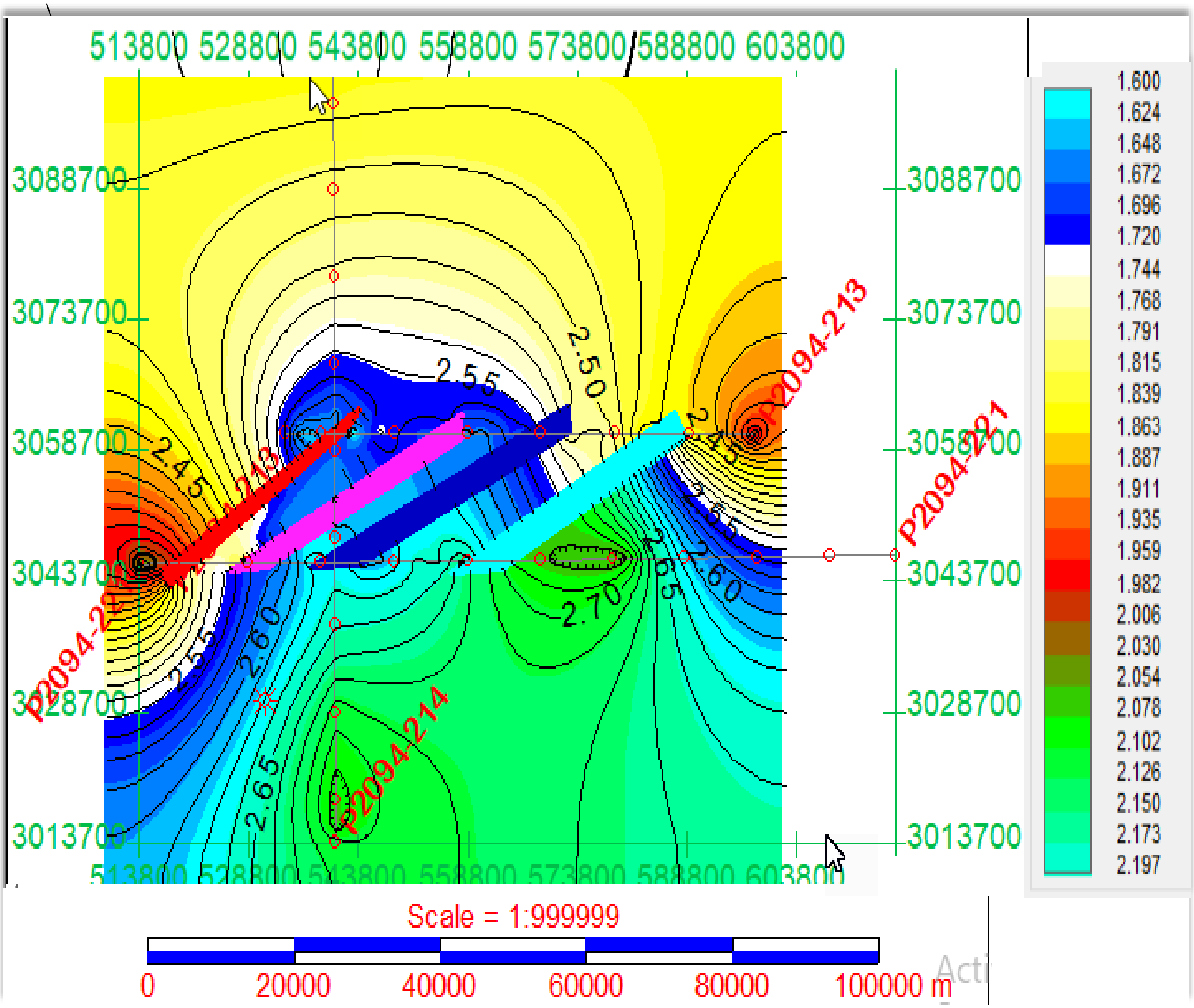

Figure 3.7 Time contour Map of the B-interval of the lower Goru

3.12 Depth Contour Map of the B-interval of the Lower Goru Formation:

As the data is in the two way travel time, gives information about the subsurface structure. The depth contour map is prepared that truly related to the subsurface structure. We have five faults having same directions as in the time contour maps. Formations are shallower in the West and deeper in the East. Depth of the horizons is plotted against the Northings and Easting of the survey. Depth contour maps of the horizons are shown in the Fig 3.8

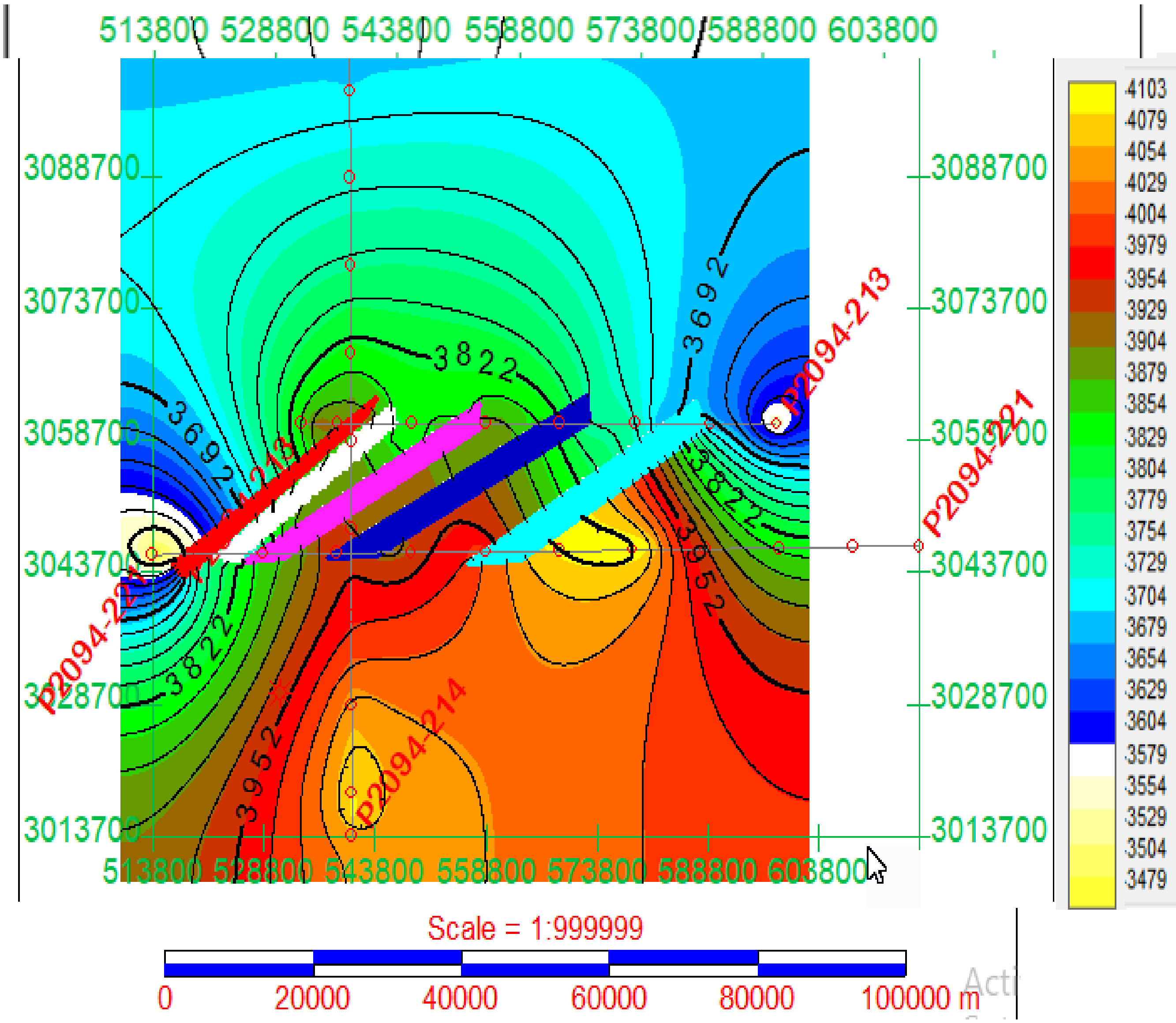

Figure 3.8 Depth contour Map of the B-interval of the lower Goru

3.12 Conclusion:

After the seismic interpretation it is concluded that there are horst and graben structures are present in my 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 structure 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 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 because the area is so disturbed we have a lot of faults which help in migration of hydrocarbon.

Chapter 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.

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,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.

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/gas bearing formation.
- Porosity of formation.
- Oil/gas saturation.
- Lateral extent of the oil/gas 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-09 used. The log curves of the borehole is 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.

4.3.1 Volume of shale

4.3.2 Water saturation

4.3.3 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 logs are explained according to the tracks in which they displayed. Shown in fig 4.1

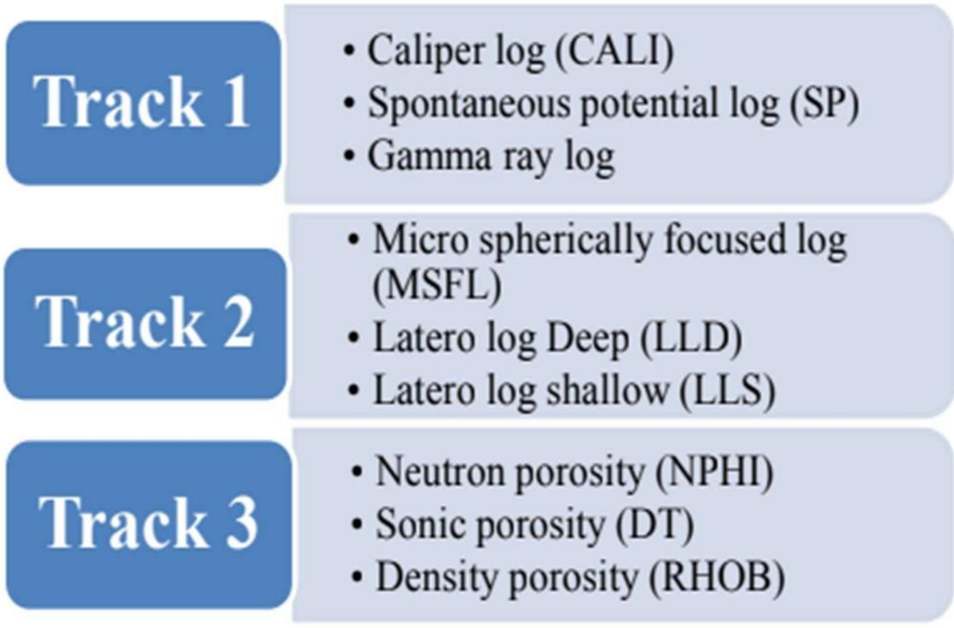

Figure 4.1 Basic three log tracks

4.5 Lithology Track:

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

4.5.1 Gamma ray (GR)

4.5.2 Spontaneous Potential log (SP)

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.

- 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.

4.6.1 Sonic log (DT)

4.6.2 Density log (RHOB)

4.6.3 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 (Tittman 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

- Lateral log Deep (LLD)
- Lateral log Shallow (LLS)
- Micro- Spherically Focused Log (MSFL), But MSFL was not present in my data of Miano-10

4.7.1 Laterolog Deep (LLD):

Lateral log 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):

Lateral log 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.

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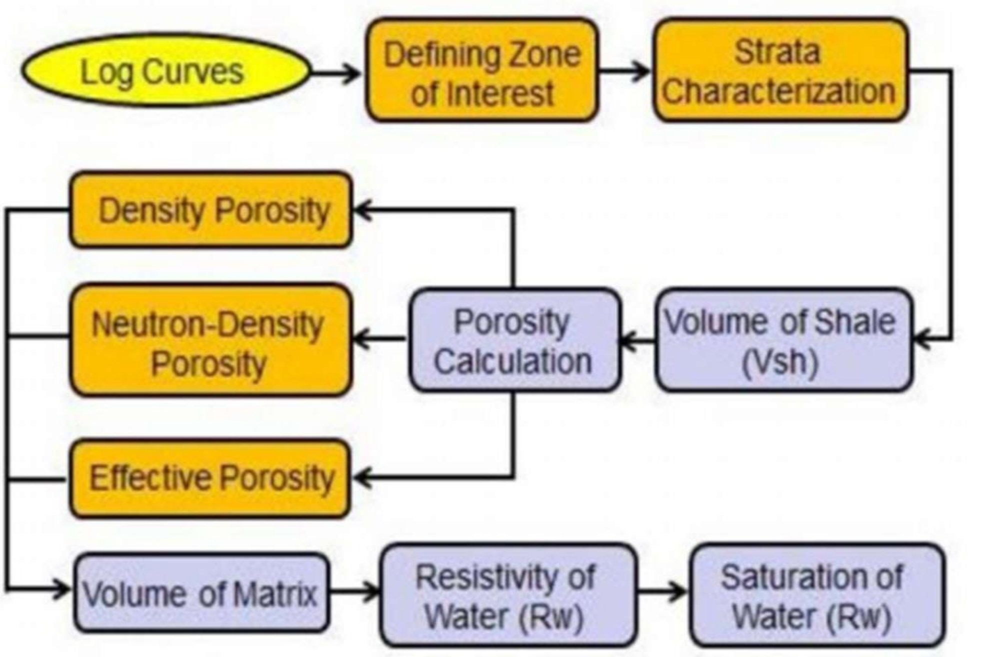

Figure 4.2 Petrophysical interpretation workflow

Raw log curves have been used for the petrophysical analysis of Miano-10. Main reservoir in Lower Indus Basin is Lower Goru of Cretaceous age. Sand intervals (A, B, C and D) of Lower Goru are acting as reservoir in different areas of Lower Indus Basin. In study area, B interval is most productive. Top and bottom depth of B 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), SP (mv), Caliper(Inches), LLD (ohm-meter), LLS (ohm-meter), RHOB (g/cm3), DT (us/ft) and NPHI (v/v decimal).

4.9 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 4.1.

	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-SW

4.10 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 (Asquith and Gibson, 2004).The volume of the shale is estimated by using the following equations given in table 4.3.

4.11 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.

4.11.1 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.

4.11.2 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.

Now to calculate the Water saturation required the Resistivity of the water of formation.

4.12 Resistivity of Formation Water (Rw):

After the calculation of volume of shale, effective, total and sonic porosities, the next step is the calculation of resistivity of water. Computing water resistivity is the vital step in finding the saturation of water. The following steps lead to the calculation of resistivity of water.

Step 1: After noting the values of surface temperature (ST), maximum recorded temperature (BHT) and resistivity of the mud filtrate (Rmf1) from well headers, very first step is to find the static spontaneous potential (SSP) from the relation in Table 4.1

Step 2: Formation temperature is calculated by using the relation same Table 4.1.
Step 3: Finding the resistivity of mud filtrate by using the relation given in Table 4.1.

Step 4: Now for finding the resistivity of mud equivalent (Rmfeq), the relation is given in Table 4.1.

Step 5: Rweq (Resistivity of the water equivalent) determination from Essp (Static spontaneous potential)

After calculating the value of Rmfeq, the next step is to derive the value of resistivity of water equivalent against the value of Rmfeq at SSP value and BHT.

Step 6: Rw versus Rweq and formation temperature. The value of resistivity of water (Rw) is derived against the values of Rweq and formation temperature. After using all the relations of finding the resistivity of water by SP chart method, the next step is the computation of saturation of water by using Archie Generalized Water Saturation equation (Archie, 1942) Table 4.1.

$$S_w = \left(\frac{a \times R_w}{R_t \times \emptyset^m}\right)^{\frac{1}{n}}$$

4.13 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.

$S_{hc} = 1 - S_w$

Sw = Saturation of water

Shc= Saturation of hydrocarbon

4.14 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. 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

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. 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, 2013)

The other best indication of the presence of hydrocarbon is the crossover that formed by the combination of neutron and density log. 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.

4.14.1 Interpretation of Entire B interval (3318-3327m):

Depth range of B interval varies from (3318-3327m) in well Miano-10. It consist of alternate layers of shale and sand. Values of GR ranges are given below.

- GR Minimum.............................. 15.37 API
- GR Maximum...............................236.34 API

Prominent zone for hydrocarbon is marked through the well in Figure 4.3 where high net pay is expected. The zone of interest is marked on the basis of following criteria.

- Separation between LLS and LLD
- Low value of GR
- High resistivity
- High porosity

These parameters are confirmed by log curves shown in fig 4.3

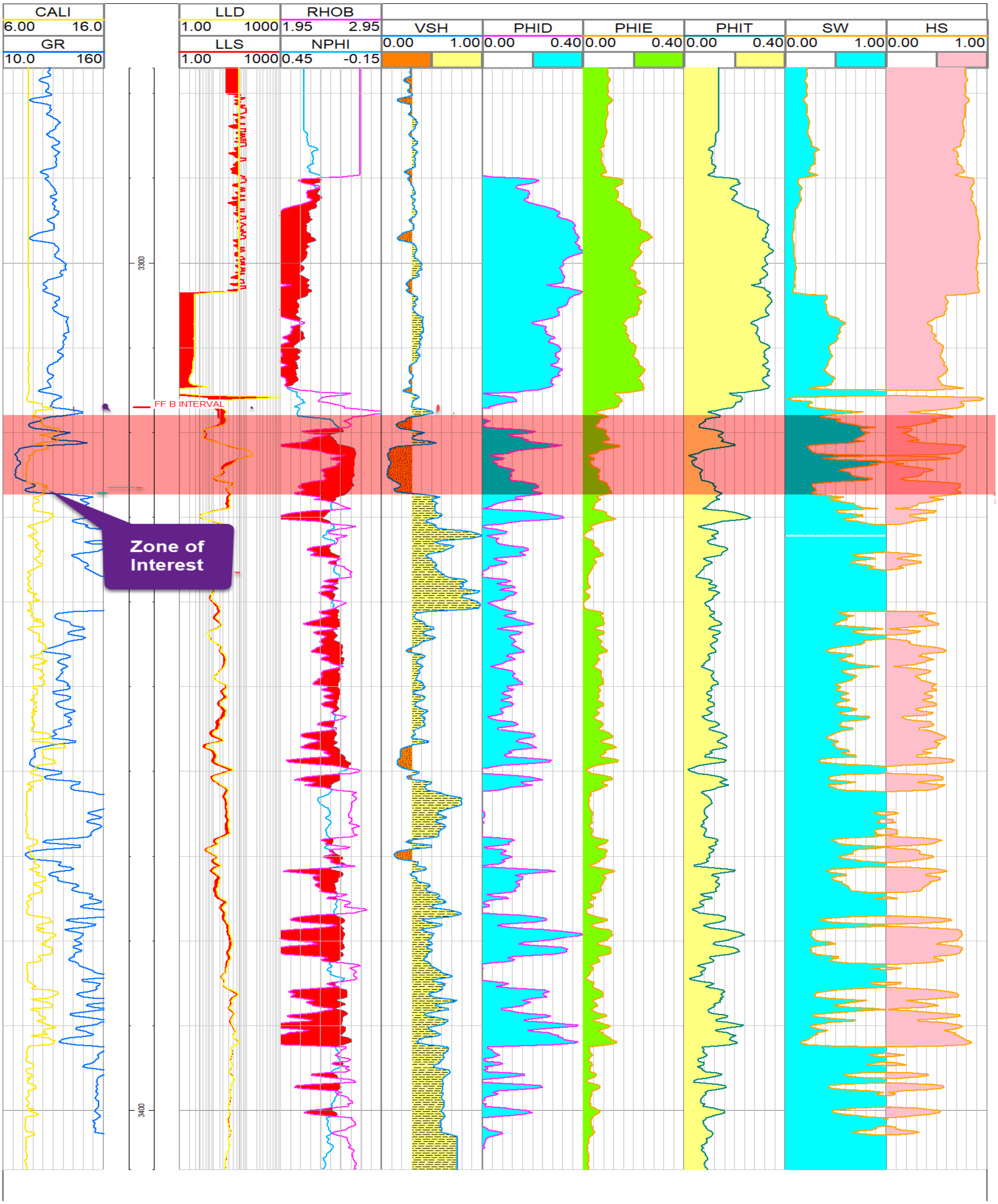

Figure 4.3 Well log interpretation of Miano-10 by IHS Kingdom

4.14.2 Interpretation of Zone of Interest:

Only one main zone of interest is marked. Depth range Zone of interest or reservoir varies from 3318-3327m in well Miano-10. Shale volume for whole depth range is 20.59%. Effective porosity is about 7.3% and hydrocarbon potential of 45%. 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.

4.15 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 3318-3327m. Because there was low value of Gr which is clear cut condition that it is reservoir zone. Now in 2^{nd} 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.

Similarly 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 shown in Figure 4. .

Table 4.2 Rock Properties of the Zone-A Miano-10

Sr No	Zone/Rock Properties	Zone of interest(3318-3327m)
1	Average Volume Of Shale	20.5%
2	Average Porosity	9.8%
3	Average Density Porosity	12.5%
4	Average, Effective Porosity	7.3%
5	Average, Saturation Of Water	55%
6	Average, Saturation Of HC	45%

Chapter 5
Seismic Attributes

5.1 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.

5.2 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

5.3 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

5.3.1 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.

5.3.2 Geometrical 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.

5.4 Seismic Attributes:

In my work, I applied following attributes to confirm seismic interpretation.

- Envelop of Trace
- Instantaneous Phase
- Instantaneous Frequency

5.4.1 Envelop 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.

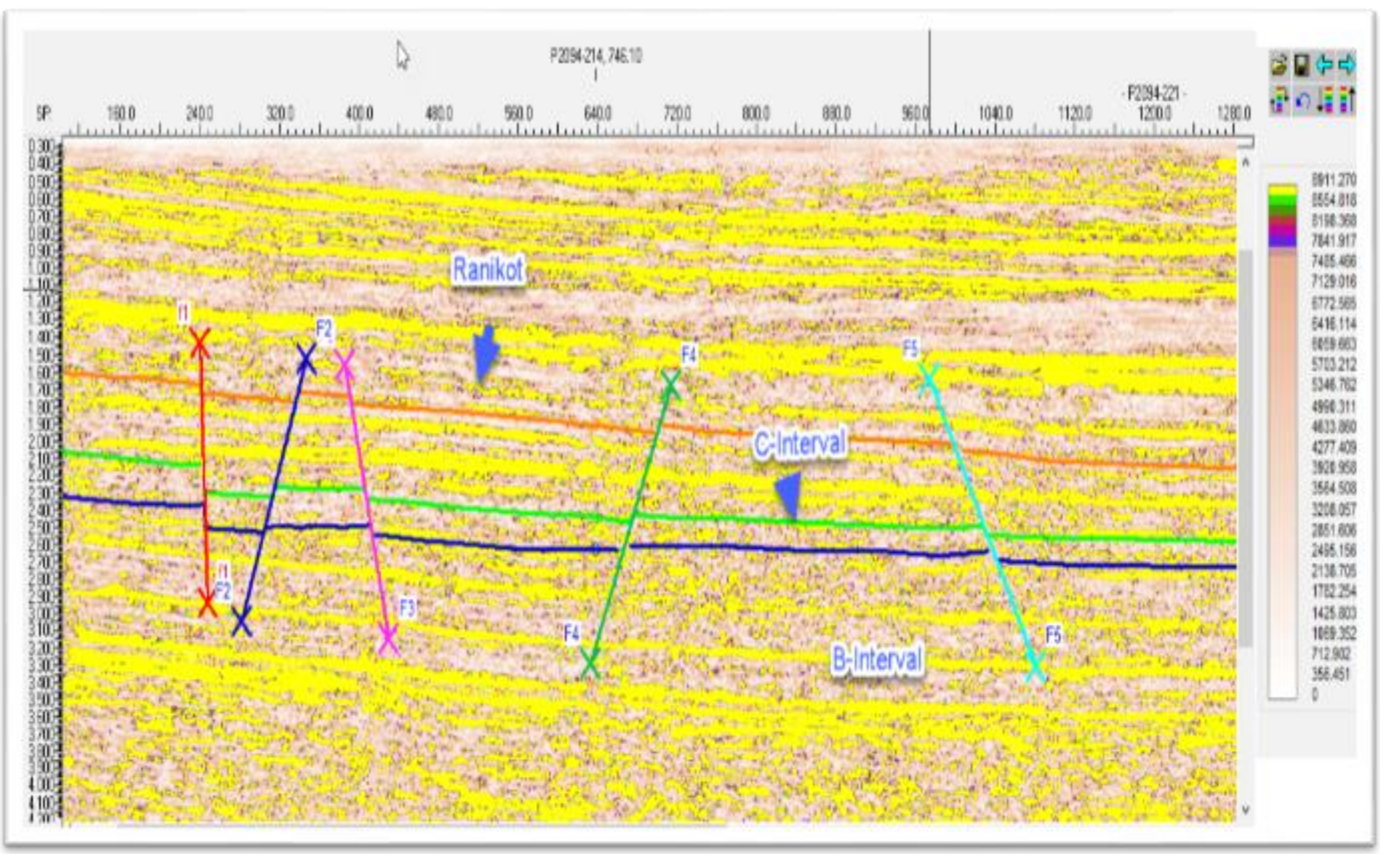

Figure 5.1 An Envelop attribute map of seismic line GP2094-221

Envelope of a trace shows mainly the acoustic impedance contrast, It always remains positive whether the reflection coefficient is positive or negative. Figure 5.1 clearly shows reflection strength of the reservoir zone.

5.4.2 Instantaneous Phase:

Instantaneous phase attribute is given by

$\phi(t) = \arctan|H(t)/T(t)|$

The seismic trace T(t) and its Hilbert transform H(t) are related to the envelope E(t) and the phase

$\phi(t)$ by the following relation:

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

Instantaneous phase is measured in degrees (-180, 180). 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

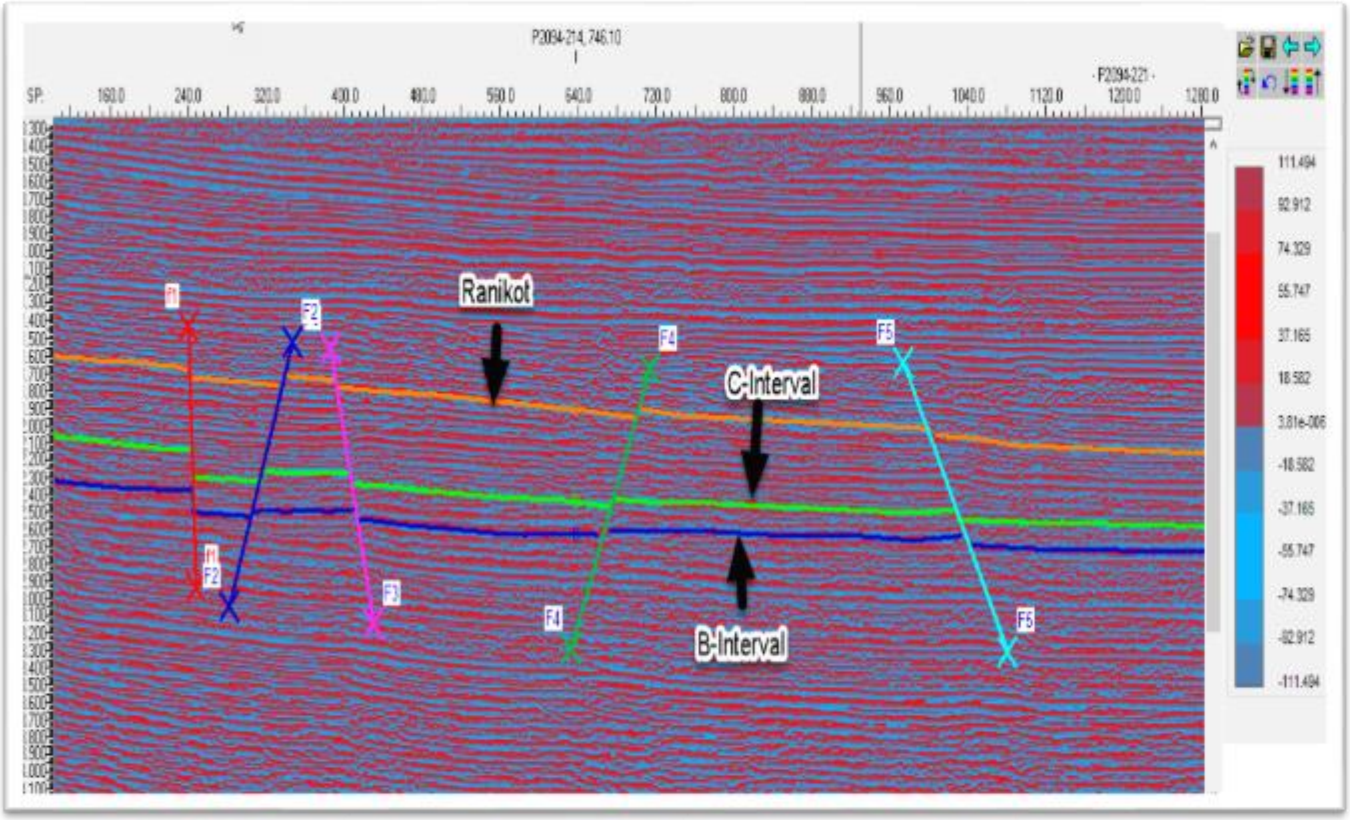

Figure 5.2 Phase attribute map of seismic line GP2094-221

5.4.1 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. 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 5.3 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.

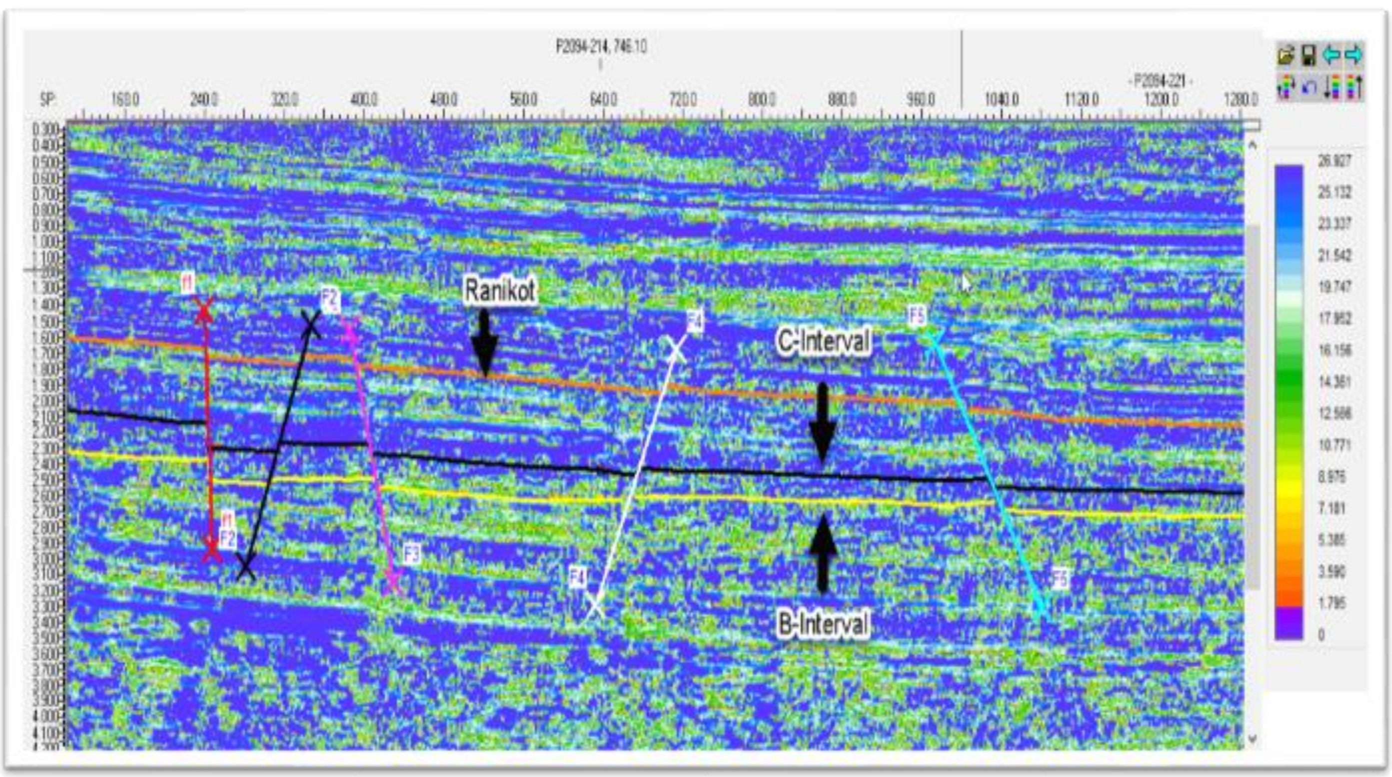

Figure 5.3 Frequency attribute map of seismic line GP2094-221

5.5 Conclusion:

The attribute analysis was specifically able to delineate the fault network in the horizons. Maximum curvature and coherence attributes were able to delineate several small-throw faults within the formations of the study area. Instantaneous phase attribute showed the lateral continuity of the fault networks within the horizons and shows detailed visualization of bedding. Instantaneous frequency showed low value of frequency in the horizon and also indicates bed thickness and lithology parameters. Envelop trace attribute shows bright spots and unconformities.

Seismic trace attributes became important qualitative and quantitative measures for geophysical exploration. Attributes have made it possible to define seismic data during 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 related to single attribute usage. Combined attributes translated by neural networks are getting principal tools for lithology prediction and reservoir characterization.

Conclusions:

- Three horizons are marked on the basis of available well log data i.e Ranikot, C-interval And B-interval on the basis of synthetic seismogram.
- Structural interpretation indicates the Horst and Grabben structures associated with Normal Faulting which indicates that there is Extensional Regime in this area.
- 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-10 well which shows the highest porosity and hydrocarbon prospect zone in the zone B (3318- 3327 m) of lower Goru. The value of average shale volume is 20.5 %. Effective porosity is about 7.3% and potential of the hydrocarbon is 45%. 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.
- Seismic attributes also applied on seismic data which confirm the hydrocarbon prospect zone.

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