2-D SEISMIC MODELLING AND RESERVOIR CHARACTERIZATION USING WELL DATA OF SINJHORO BLOCK, LOWER INDUS BASIN PAKISTAN

BY

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CERTIFICATE

This dissertation submitted by ***Javeed Iqbal*** son of ***Badshah Khan*** is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the requirement for the award of BS degree in Geophysics.

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Javeed Iqbal

BS Geophysics (2014-2018)

DEDICATED TO

My Parents, Brothers

(Ahmad Nawaz, Hamid Nawaz) and

My beloved Sister

And specially my most respectable

Supervisor

Dr. Muhammad Toqeer

Abstract

In this dissertation, focus is placed on the structural interpretation of the Chak 66-01 well in order to demarcate the probable zone for the accumulation of hydrocarbons. The work is carried out on 3 seismic lines along with petro physical logs of chak 66-01, using Kingdom 8.8 software. The integrated study involves; structural interpretation of seismic data, time to depth conversion, synthetic seismogram and colored inversion.

The area of study lies in the southern Indus basin, horizons of Massive sands, Basal Sands and Lower Goru are confirmed by synthetic seismogram. Horst and graben geometry bounded by normal faults is common in this region which is confirmed by fault polygon and time and depth contours made from time and depth grid respectively. Petro-physical interpretation of well Chak66-01 leads to probable zone for hydrocarbon extraction in Lower Goru Sands. Porosity of thick reservoir (Massive Sands of Cretaceous) is 13%.

For the interpretation of the seismic lines, four reflectors are marked by correlating synthetic seismogram on seismic section. The horizons were identified using formation tops from wells and their depth were confirmed through correlation with synthetic seismogram generated from sonic and bulk density logs. Time, depth and horizon contour maps of the horizons of interest have been generated to understand the spatial geometry of the structures.

Petro physics 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 hydro carbon by combination of the different logs results. In this dissertation the petro physics is performed on the Chak 66-01 well and different zone of interest are marked where there is chance of the presence of the hydro carbon.

At last the colored Inversion is performed in order to identify the Acoustic impedance and porosity in the study area.

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Chapter: 1

Introduction to study area

1.1 Introduction:

Hydrocarbons are one of the Earth's most important energy resources and economically very essential for any country. Hydrocarbons become popular in our modern-day vernacular. Using different geophysical methods geophysicists explore these hidden treasures of Earth. Exploration geophysicists used other geophysical techniques e.g. Gravity and Magnetic to image subsurface geological structures and identify structural or stratigraphic traps but with the passage of time, there became advancements in the geophysical methods (Yilmaz, 2001). In 1915, exploration geophysicists started working on seismic method because of its high resolution and improved accuracy. It became quiet useful for imaging subsurface geological features and for identifying structural or stratigraphic traps (Coffeen, 1986). In order to achieve target depth and better detection of anomalous zones, they had to adopt seismic reflection method (Badley, 1985). Hence in 1930s, seismic reflection became widely used principle for performing seismic surveys. Seismic method is one of the most widely used geophysical methods for exploration of hydrocarbons.

Seismic reflection response depends on different variations existing in a rock such as lithological composition and fluid saturation (Yilmaz, 2001). Seismic data is recorded by producing seismic waves by a source and these waves travelling through the earth are recorded at specific interval of time. This data is further processed for noise and becomes ready for interpretation. It provides help to map the reservoir and delineate oil/gas producing Zones (Bacon et al., 2007). Formation tops and faults are the main features to be marked. Seismic method gives results with 70 % accuracy for quantifying reservoir characteristics (Yilmaz, 2001) because of its indirect surveying technique. Therefore, well data is used in Petro physics to gain 100 % accuracy because of its direct surveying technique (Zerrouki et al., 2014). Next step involves reservoir characterization using well log data. Reservoir characteristics can be calculated using borehole data. This data is acquired by lowering a logging tool into the well. Sometimes natural radiations coming from a rock are recorded and sometimes radiations are sent into the rock which after travelling some distance is recorded by the logging device. These reservoir characteristics are lithology, porosities and fluid saturations (Zerrouki et al., 2014).

1.2 Location of study Area:

Pakistan has high potential of hydrocarbons in its Northern (Potwar, Kohat) and Southern (Badin, Mari etc.) parts. The Indus basin, including the Kohat-Potwar (study area) depression, belongs to the category of extra-continental downward basins which account for 48% of the world's known petroleum resources. (Hasany & Saleem, 2001).The Sinjhoro field is located in district Sanghar of Sindh Province. Sinjhoro covering an area of 179.31 Sq.km (approx.) and latitude/longitude of the area is 26.030N to 26.120N and 68.80E to 69.30E respectively. Geographically it is located in South Eastern part of province Sindh and basin wise it is located in Southern Indus Basin (Figure 1.1). Geologically it is in between Indianan basement and the kirther fold and thrust belt. Normal fault of the area explain that it is present in extensional due to cretaceous rifting.

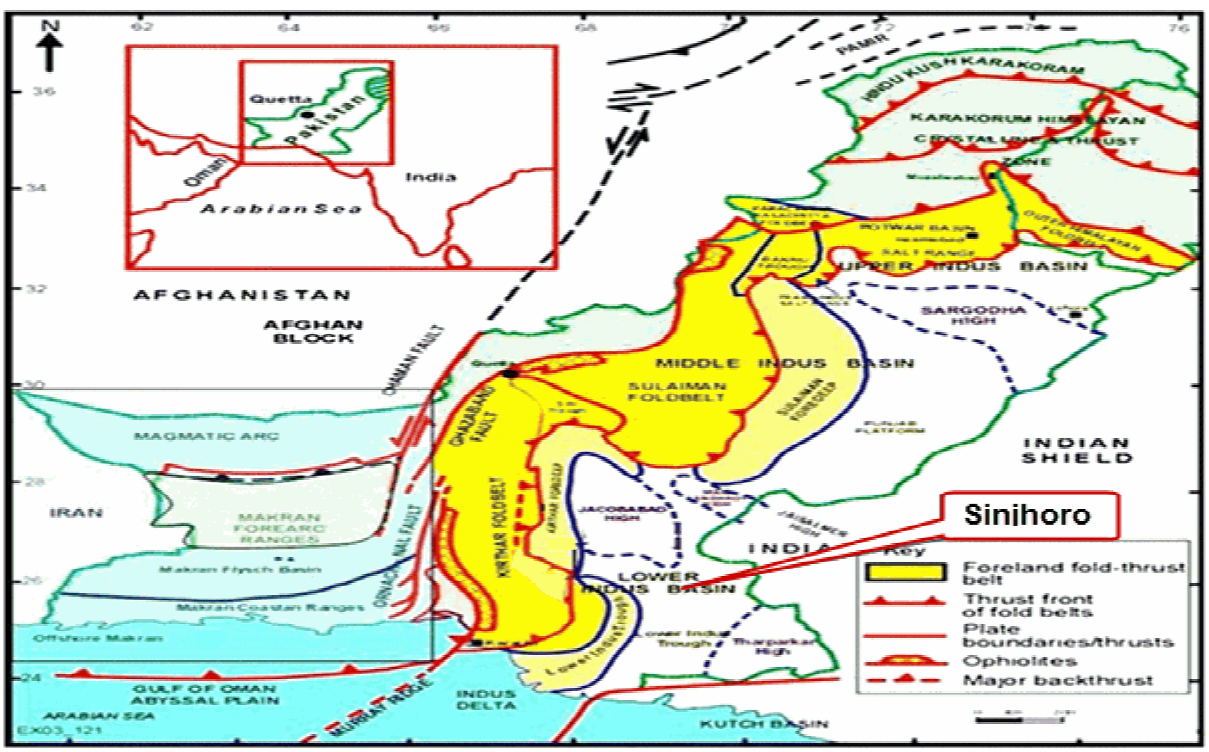

Figure 1.1 Location Map of the study area. (Fateh et al,. 1984)

1.4 Exploration and production history:

OGDCL has started production from Sinjhoro field located in District Sanghar Sindh, about 65 KM northeast of Hyderabad City. The Sinjhoro Gas Field of OGDCL has started production of 12 MMCFD gas to SSGCL and 1,100 BBLS of condensate. Sinjhoro field was awarded to joint venture of OGDCL (62.5%), OPL (15%) & GHPL (22.5%) with effect from Dec 29, 1999 for the initial term of ten years.

Sinjhoro development consists of a number of small fields discovered in proximity of each other with in the Sinjhoro Exploration License: Baloch, Chak-2, Chak-63, Chak-63SE, Chak-66, Chak-66NE, Chak-7, Hakeem Daho, Lala Jamali and Resham Figure 1.2. Sinjhoro Gas Field is currently producing with full potential having 3000 BPD oil, 30 MMCFD gas and 101 MTD of LPG. The tie-in of 14 wells of Sinjhoro has been completed while tie-in of 01 well is underway.

The field is producing 12 MMcfd of gas and 1,100 b/d of condensate, according to the Ministry of Petroleum and Natural Resources.

Figure 1.2 Explorations from Sinjhoro Block (Hanif et al.)

1.2 Data Used:

In this study data have been used to evaluate the study purpose that is 2D seismic interpretation. The data has been provided by the Department of Earth Science (QAU).

This data includes;

- 2D Seismic lines
- Well Data

Given data have been used to create time and depth contour maps Well correlation, stratigraphic horizons and structural interpretation.

The data used for current research includes 12 seismic lines and four wells, including 9 dip and 3 strike lines. The orientation of seismic lines with the location of wells is shown in the base map Figure 1.3; all lines are taken at mean sea level with a sample rate of 4ms in seg-y format other the detail of assigned seismic lines is given below in Table 1.1.

Table 1.1 Showing details of seismic lines of study area

Line name	Line Nature	SP Range	CDP Range	Traces
20017-SNJ-01	Strike	102-1059	1-1915	1915
20017-SNJ-03	Dip	102-1259	1-2315	2315
20017-SNJ-04	Dip	101-739	1-1277	1277
20017-SNJ-05	Dip	102-740	1-1277	1277
20017-SNJ-06	Strike	102-1099	1-1995	1995
20017-SNJ-07	Dip	102-420	1-637	637
20017-SNJ-08	Dip	102-420	1-637	637
20017-SNJ-09	Strike	102-1099	1-1995	1995
20017-SNJ-10	Dip	102-560	1-917	917
20017-SNJ-11	Dip	103-540	1-875	875
20017-SNJ-12	Dip	102-978	1-1753	1753
20017-SNJ-13	Dip	102-960	1-1717	1717

Lines and well assigned to complete study work is given below in Table 1.2 and Table 1.3

Table 1.2 showing detail of seismic lines

Serial No	Line Number	Type
1.	200-17-SNJ-03	Dip
2.	200-17-SNJ-22	Dip
3.	200-17-SNJ-08	Strike

Table 1.3 Information for well Data

Well Name	Latitude	Longitude	Elevation	Depth	Total Depth
CHAK-66-01	27º9’ 54”N	70º52’34”E	31.93	KB	2999

1.9 Base Map:

A base map is a map with geological information on it that more specialized information can be added to. A base map may have latitude and longitude, X and Y coordinates, townships and ranges, whatever basic grid system may be used to fix other position on. It may also have coastlines, rivers, towns, etc. When seismic surveying is done, and the shot point locations obtained from surveying can be plotted on the base map in their relationship to the grid system already on it. This map then becomes a base map for further addition of specialized information, seismic data. It is also called as a shot point’s location map, the base map of Sinjhoro Block is given in Figure 1.3.

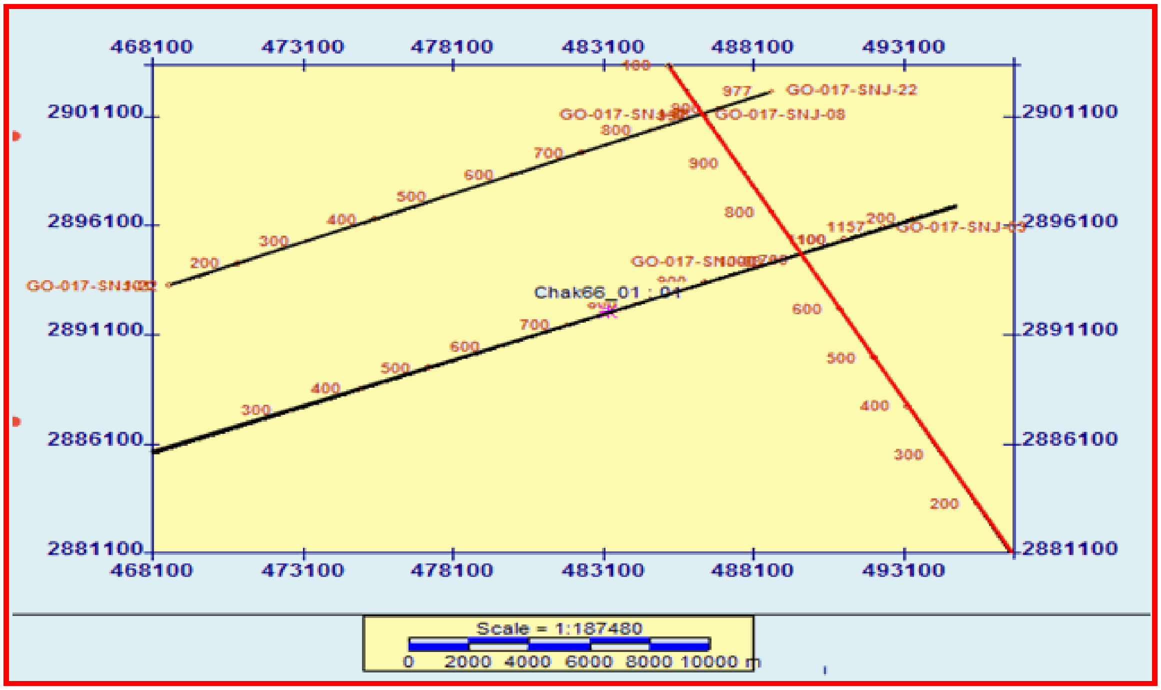

Figure 1.3 Base map of Study area (Sinjhoro).

1.3 Objective of Research Work:

The main objectives of this dissertation, which are based on interpretation of recorded seismic data, are given below:

- Structural interpretation of the seismic lines with the help of contours maps.
- Preparation of synthetic seismogram and tying it with seismic section to confirm the marked reflector.
- Petro physical analysis to identify the possible hydrocarbons bearing zones using available well data.
- Colored Inversion is applied on the 2D seismic to determine the acoustic impedance of the zone of interest.

1.7 Significance of Research Work:

This research work will be helpful for identification of subsurface structures of Sinjhoro area that is favorable for hydrocarbon accumulation and trapping. Petro-physics analysis that is done with help of the well data, gives information about the reservoir in the required area of Interest. Rock

Physics analysis plays a role of bridge between seismic properties and geologic properties particularly for the zone of interest.

1.8 Softwares Tools Used:

We have used the following software to carry out our thesis work:

- IHS KINGDOM 8.8
- Snagit 11 (Editor)
- MS Office

1.10 Methodology:

- Horizons are marked based on synthetic seismogram generation using well log data. Also fault surface is marked on the section.
- Time information is converted into depth and 2D time/depth contour maps are generated to show subsurface structural pattern to confirm the presence of Horst and Graben Structures.
- Petro physical analysis is done in order to quantify fluid saturations and mark potential zones using well logs.
- Seismic Attributes Confirms our seismic interpretation
- Colored inversion of post stacks data.
- Conclusions

Workflow for the dissertation is given in Figure 1.4

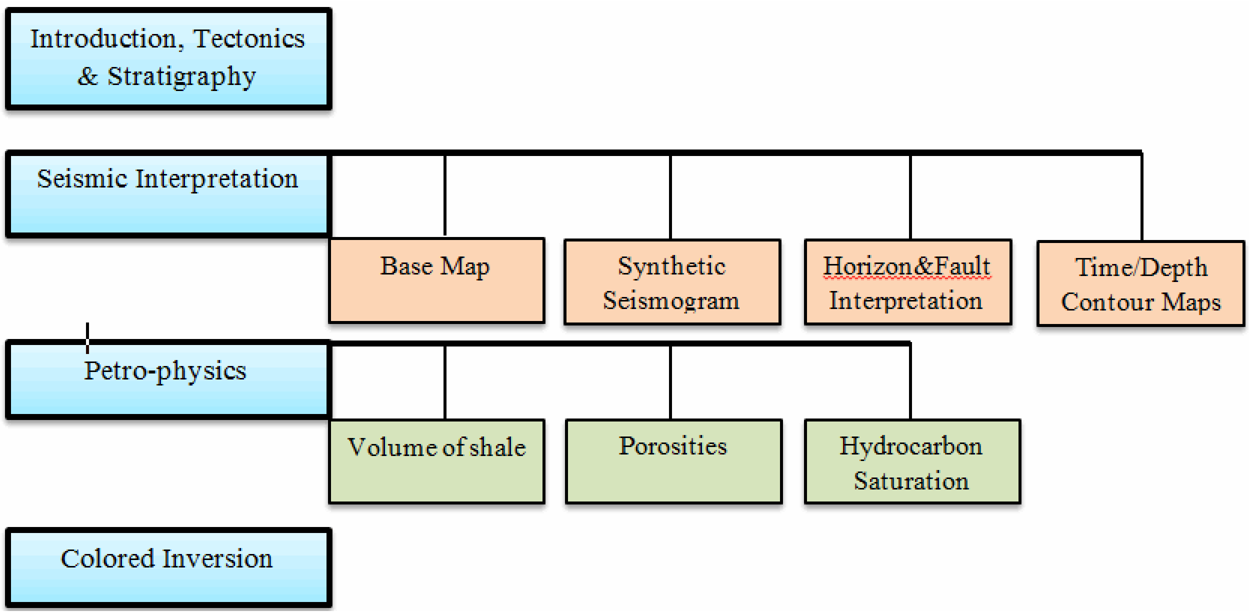

Figure 1.4 Dissertation Workflow

Chapter: 2

General geology and Stratigraphy of Study Area

2.1 Regional Settings:

It is considered that in the geological history of indo-Pakistan shield was a part of Gondwanaland, which got separated from it as a Gondwanaland fragmentation. Indo Pakistan plate started to move northward drift of Indian plate was near the end around 55Ma years ago (Eocene). (Powel etal. 1979). According to Kazmi and Jan (1997), the geology of Pakistan is divided into two regions, which are given below:

- Gondawanian Domain
- Tethyan Domain

The southern part of Pakistan belongs to Gondawanian Domain and is sustained by Indo-Pakistan crustal plate. The north most and western part of Pakistan falls in the Tethyan domain and present complicated geology and complex crustal structure.

2.2 Tectonic Zones of Pakistan:

Pakistan can be divided into eight tectonic zones, which are as follows (Kazmi & Jan, 1997) Figure 2.1.

- Indus Platform and Fore deep
- East Balochistan Fold and Thrust Belt
- Northwest Himalayan Fold and Thrust Belt
- Kohistan-Ladakh Magmatic Arc
- Karakoram Block
- Kakar Khoransan Flysch Basin and Makran Accretionary Zone
- Chagai Magmatic Arc
- Pakistan Offshore

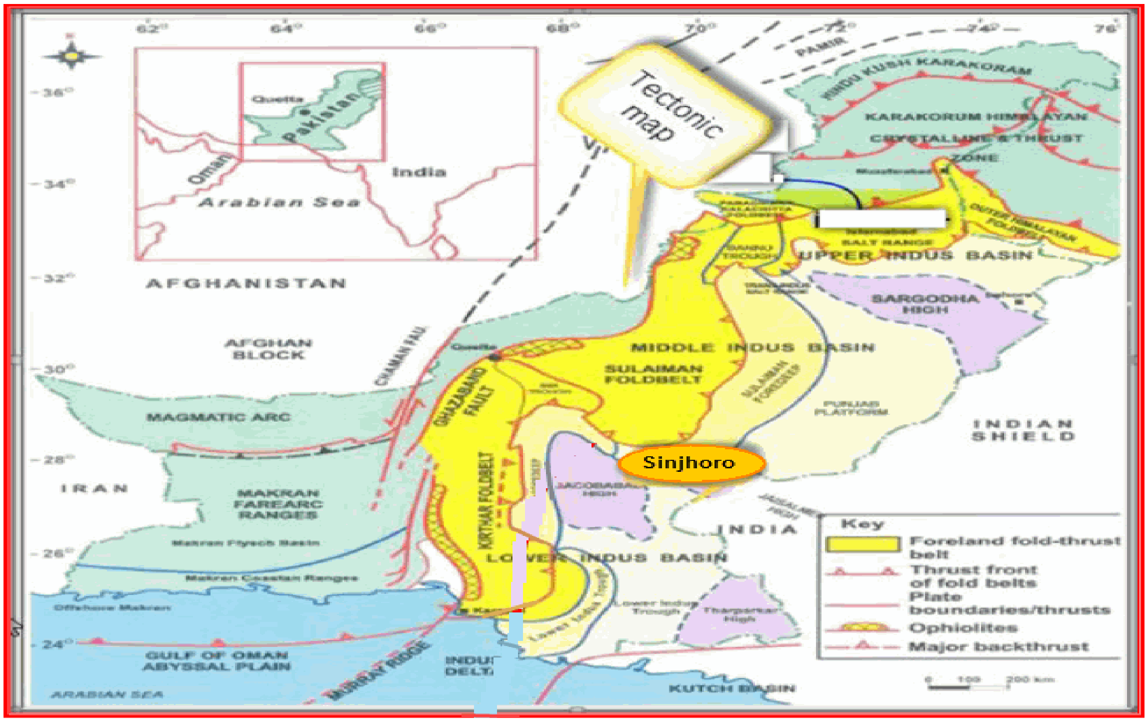

Figure 2.1 Showing the tectonic map of Pakistan (Fateh et al,. 1984)

2.3 Geology of Pakistan Basin:

Pakistan comprises following three sedimentary basins (Riaz Ahmed 1998), Figure 2.2.

- Balochistan Basin
- Pishin Basin

2.3.1 Indus Basin:

The Indus Basin belongs to the class of extra continental Trough Downwarp basins. It is the largest and so for the only producing sedimentary basin of Pakistan. The basin is oriented in NE-SW direction. Basement is exposed at two places, one in NE (Sargodha High) and second in SE corner (Nagar Parker High). It is characterized by a large easterly platform region, which dips gently and monoclinally towards NW, a ring of Trough or depression in which platform dips and a westerly folded and thrusted topographically uplifted region. The convergence between Indian and Eurasian plate has resulted in partitioning of the basin into three parts. Upper, Middle and

Lower called as northern, central and southern respectively. Some basement highs present over platform area serve as dividers. (Riaz Ahmed, 1998)

2.3.2 Northern Indus Basin:

The basin is characterized by complex structural styles and stratigraphic sequence ranging from Precambrian to recent. A number of oil fields occur in this zone. The Dhurnal oil field is the largest and has reserves of about 52 Million Barrel of oil and 0.13 TCF of gas. This basin contains all the Source, Reservoir and Cap rocks. (Kazmi and Jon, 1997)

2.3.3 Central Indus Basin:

This basin is comprised of duplex structure characterized by large anticlines and domes in the passive roof sequence of Suleiman fold belt followed eastward by gently dipping strata of Punjab monocline. The basin contains a sedimentary sequence ranging from pre Cambrian to recent. It contains one of the biggest gas field called Sui gas field with 8.6 TFC. Central Indus basin is bounded by Jacobabad high in south, Sargodha high in north, Suleiman fore deep in west and Indian Shield in east. (Kazmi and Jon, 1997)

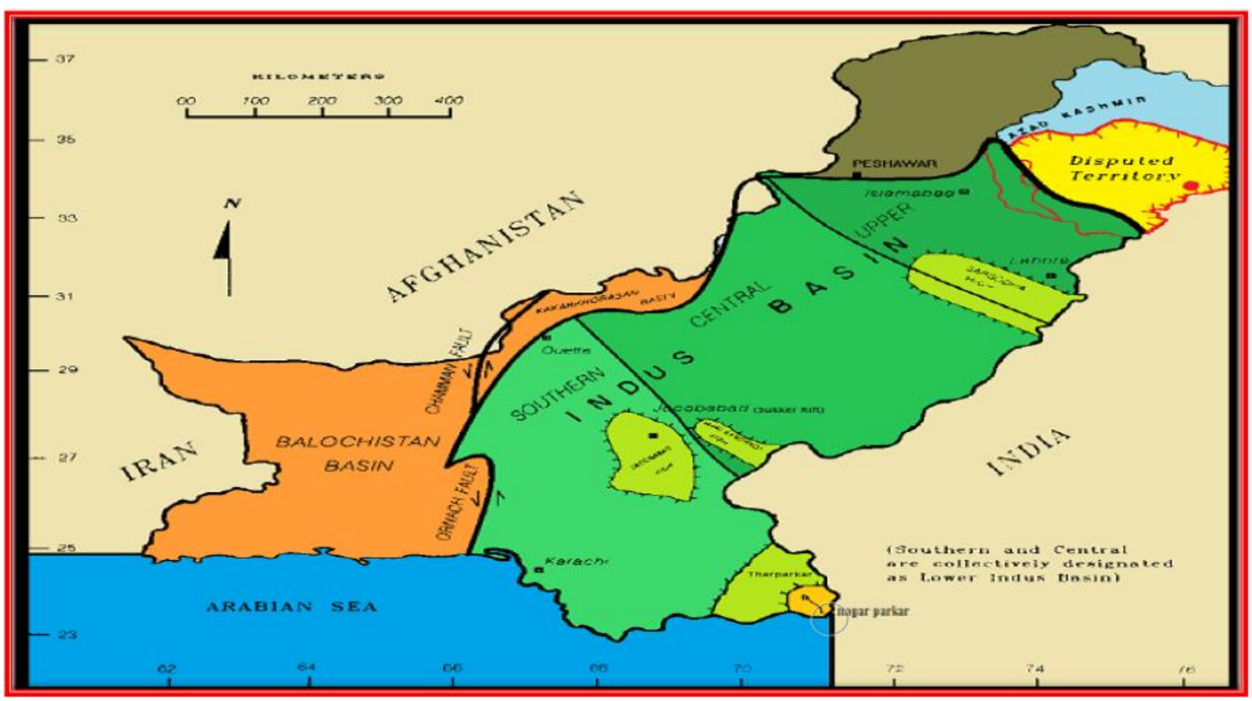

Figure 2.2 Basin division of Pakistan (Hanif et al.)

2.3.4 Southern Indus Basin:

The southern Indus basin (550 × 220 km) extends approximately between Latitude 240 and 280N and from Longitude 660 to eastern boundary of Pakistan (V.N.Quadri and S.M. Shoai, 1986). It is characterized by several structural Highs. The slope from the eastern limit of the lower Indus basin, which is bounded by the Indian shield on the east and folded axial belt towards the west. It extends to offshore in the north south, whereas in the north it is separated from the central Indus basin by a positive feature, the Mari Kandhkot High (Ministry of Petroleum and Natural Resources of Pakistan).

It comprises the following five main units:

- Thar Platform
- Karachi Trough
- Kirthar Fore deep
- Kirthar Fold Belt
- Offshore Indus

2.3.5 Boundaries:

Sanghar area is bounded in the east by Indian Shield merges in to Kirthar and Karachi Trough and in the north by Mari bugti inner folded zone. The Indus off shore platform in the south offshore extension of the Thar platform (I.B Kadri 1995).

2.5 Structural History:

Structural history of Sindh area is characterized by extensional regime. Which produced normal faulting, and basement related structure within late Paleozoic to Quaternary sediments. These sediments were deposited on the peneplained Precambrian basements along the stable margin of Indian shield .A series of extensional events during the late Paleozoic, cretaceous as well as mid Tertiary collision between Indo-Pak and Eurasian plate reactive old faults and produced new faults in the area. N_W oriented main structural features of Dalhart fault zone are the results of this extensional tectonics. (Ministry of Petroleum and Natural Resources of Pakistan).

2.6 Generalized Stratigraphy:

Sanghar is located in the Thar platform area of southern Indus basin. The Sanghar area is characterized a series of horst and graben structure present almost below the base Paleocene unconformity within the cretaceous (Gilbert Killing etal, 2002).

2.7 Major Formation of Area (Sanghar):

Following are the major formation of Sanghar Area Figure 2.3.

- Chiltan formation
- Sember formation
- Goru formation
- Parh formation
- Khadro formation
- Ranikot formation
- Laki formation
- Nari Gaj. Siwalik and Alluvium Formation

2.7.1 Chiltan Formation:

This formation of Middle Jurassic is typically massive, thick bedded dark limestone .it contains pisoolitic limestone bed locally. Mazar drrik formation is absent in the area and limestone has direct contact with sembar formation (I.B Kadri, 1995).

2.7.2 Sember Formation:

Sember formation of Early Cretaceous is composed mainly of clastic rocks, primarily shale followed by sandstone and siltstone having minor limestone. The sandstone are more abundant towards the eastern limit of the basin .however ,shale and siltstone decreasing towards east .it is believed that sember formation is a primary source for hydrocarbon found in lower Goru sand (I.B Kadri,1995).

2.7.3 Source of Hydrocarbons:

Sembar Formation is believed to be the source of hydrocarbons in the Badin platform fields and huge gas accumulation in Suleiman province. Potential reservoir occurs within the sandstones of the Formation. The chances of Sember sourced oil migration in to the underlying Jurassic Formations against faults also appear to be relatively favorable.

2.7.4 Goru Formation:

It is divided in two parts

- Upper Goru
- Lower Goru

The lower Goru is main reservoir rock within the area. The lower Goru horizon as a general 5 divisions based on predominant lithologies.

The Basal Sand unit Lower Shale Middle sand unit (which has a good reservoir potential) Upper Shale Upper Sand (Gilbert Killing et al, 2002).

2.7.5 Upper Goru:

The upper Goru sequence of middle to late cretaceous unformable overlies the lower Goru formation which consists of mainly marl and calcareous clay stone occasionally with interbeds of silt and lime stone. (Gilbert Killing et al 2002).

2.7.6 Parh Limestone:

This is very uniform distinct and persistent rock formation. It is thin bedded light gray white or cream colored with a persistent pink, purple to maroon colored band of interbeds of shale and marl.

2.7.7 Khadro Formation:

Khadro formation of early Paleocene age unconformably overlies the Parh Limestone. Basically it consists of basalts and shale. (Gilbert Killing et al 2002)

2.7.8 Ranikot Formation:

The lower Ranikot of early Paleocene consists of quartzarenite type sandstone with shale. The upper Ranikot of early Paleocene is composed of fossiliferous lime stone interbedded dolomitic shale and calcareous sandstone. (I B Kadri, 1995).

2.7.9 Laki Formation:

Laki of early Eocene consists primarily of limestone interbedded with shale (I B Kadri, 1995).

2.7.10 Nari Gaj. Siwalik and Alluvium Formation:

The remaining formations of Cenozoic era are considered as remnants. The formations have not any importance in term of oil and gas (Gilbert Killing et al, 2002).

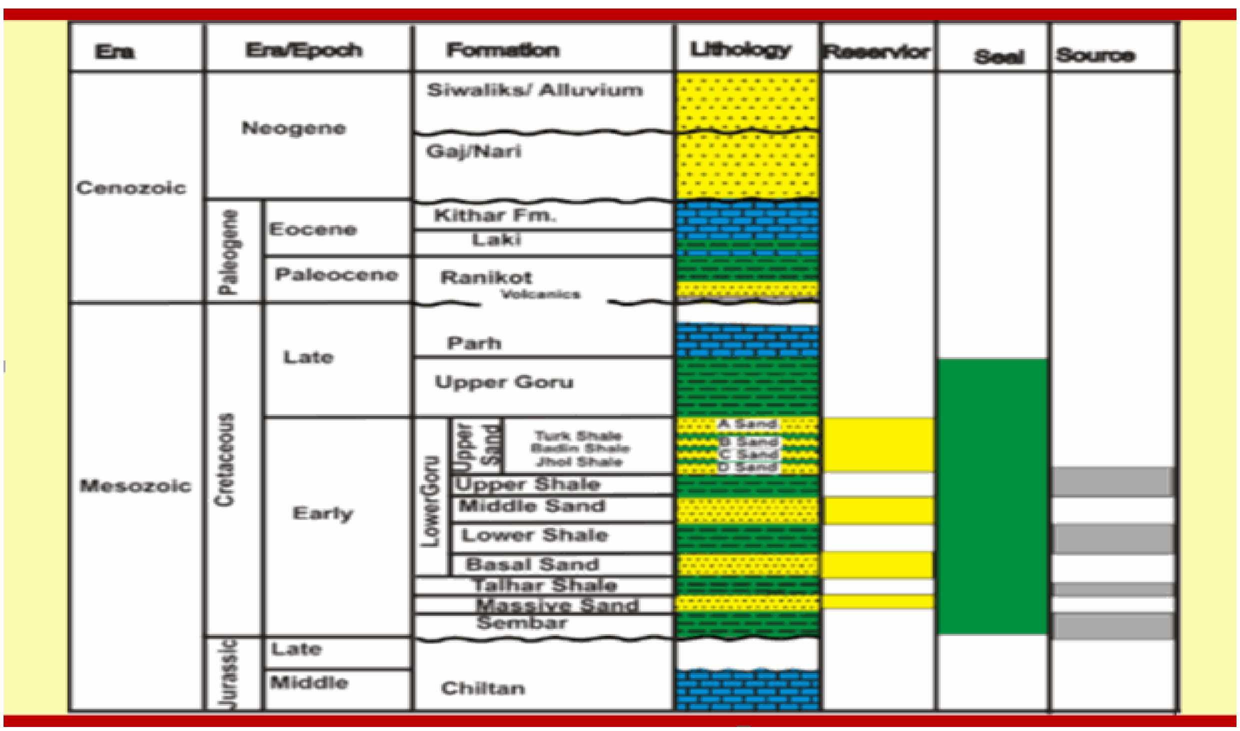

Figure 2.3 Stratigraphic Chart of Lower Indus Basin (Zaigham & Mallick et al 2000)

2.8 Petroleum play:

2.8.1 Source rocks:

Source rock is the productive rocks for hydrocarbons. They also initiated the conversion of organic compound into oil and gas form. The lower cretaceous shales of sember formation are proven source for oil and gas discovered in the Badin Basin because of its organic richness, oil prone kerogen type and thermal maturity. The lower part of the lower goru formation has moderately organic rich shale, which have fair to good genetic potential. Other probable potential source rocks include carbonates and shales of chiltan formation.

2.8.2 Reservoir:

The rocks that contain the hydrocarbons have the porosity as well as permeability is considered as reservoir. Reservoir potential is present throughout the stratigraphic section. Sembar formation of cretaceous age contains good quality sandy reservoir with some gas/oil shows in wells drilled in the area where porosity ranging from 9-36%. Massive sandstone is the main productive oil and gas reservoir in Sinjhoro Block. Intergranular porosities range from 5-40% and permeabilities commonly exceeds one Darcy. Additional objectives include upper Jurassic oolitic carbonates and lower Jurassic clastics. Goru Formation, Parh Limestone, (No oil or gas shows have been found in Parh limestone).

2.8.3 Traps:

Production in the Southern Indus Basin is from structural traps. No stratigraphic accumulations have been identified; the structural traps are tilted fault blocks. The tilted fault traps in the Lower Indus Basin are a product of extension related to rifting and the formation of horst and graben structures. The temporal relationships among trap formation and hydrocarbon generation, expulsion, migration, and entrapment are variable throughout the Greater Indus Basin.

2.8.4 Seal rock:

The rocks that act as a cap rock and used to seal the hydrocarbons are called Seal rocks. The known seals in the system are composed of shales that are interbedded with and overlying the reservoirs, such as Talhar shale. In Sinjhoro field, thin shale beds of variable thickness are effective seals. Additional seal that may be effective include fault (Craig J. Wandrey).

Chapter: 3

Seismic interpretation

3.1 Introduction:

Seismic interpretation is the process of determining subsurface structures from seismic data to locate prospect for exploratory wells. The structural interpretation of an area is usually carried out on the basis of stratigraphy and available well logs (Telford, 1991).

3.2 Seismic Interpretation Workflow:

Procedure adapted for interpretation is given in Figure 3.1. Base map is prepared by loading navigation data and Seg-y in software Kingdom (8.8). Horizons of interest are marked manual and also by 2D hunt technique. In this process faults are identified and also marked. Faults polygons are generated and horizons are contoured to find out structural highs and lows. The different important steps involved in the interpretation workflow as mentioned in Figure 3.1 are discussed in detail as follow.

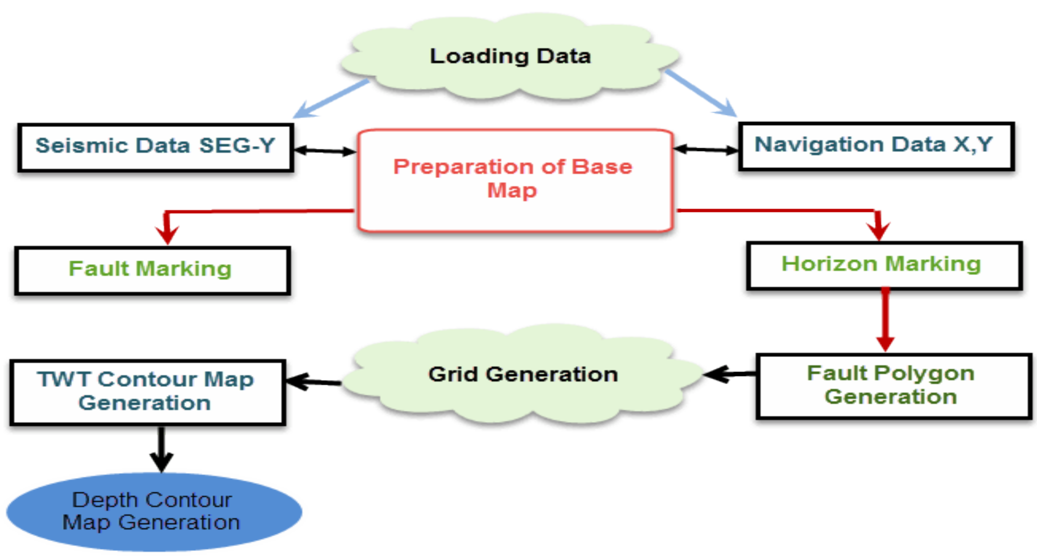

Figure 3.1 Seismic interpretation work flow

3.3 Generating Synthetic Seismogram:

Synthetic seismograms are constructed from sonic and density log. The synthetic seismograms facilitate correlation between the synthetic seismograms and seismic. Several high-amplitude reflectors in the seismic data correlate with high-amplitude events in the synthetic seismogram and are the result of changes in velocity and/or density of the cored interval (A.D. Cunningham et al).

3.4 Step for generating synthetic:

The following are the step to generate synthetic seismogram by using Kingdom Suit (8.8)

- Load formation tops, TD (time-depth) chart and log curve on the well.
- Select a well on which you need synthetic seismogram.
- For velocity used sonic log (DT). Software is automatically using it.
- Now select RHOB (density log) for the density.
- Choose a reference log, GR (Gamma Ray) is selected as reference log here.
- Extract Kaluder wavelet that convolved with refraction coefficient.
- Extract traces from nearest seismic line.

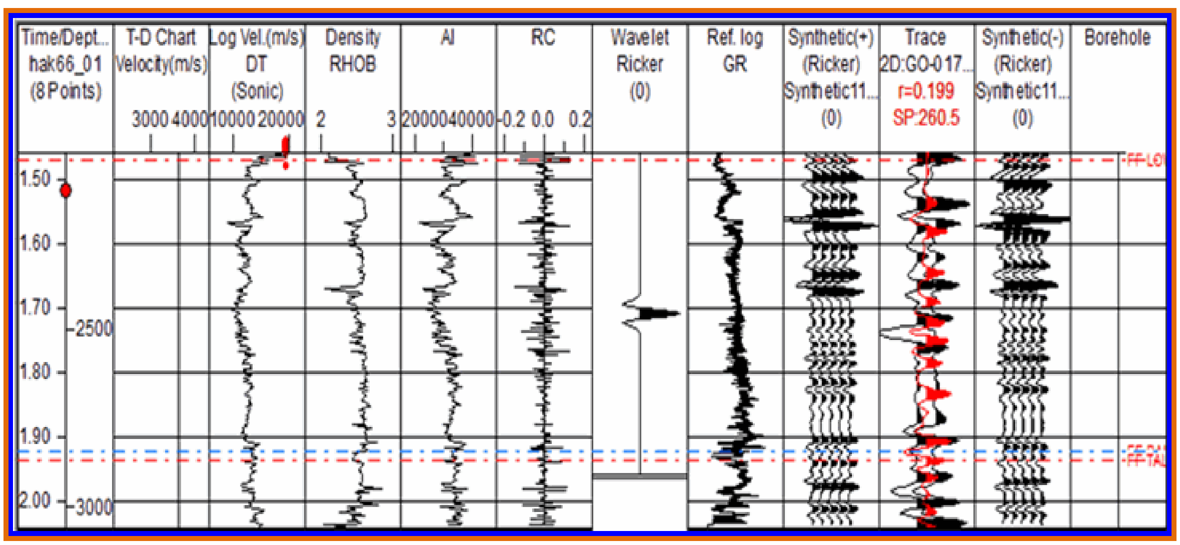

Figure 3.2 Synthetic seismogram of well Chak-66-01

3.5 Results:

Form synthetic display as shown in Figure 3.2 horizons of Massive sands, Talhar, Basal Sands and Lower Goru are confirmed with respect to time.

3.6 Horizons Picking and Fault Identifications:

Using synthetic of well Chak66-01 horizons are marked on dip lines GO-017-SNJ-03 , we used loop tie method to mark horizon on line GO-017-SNJ-22 and on strike line GO-017-SNJ-08, since well is drilled on line GO-017-SNJ-03 between shot points 945 and 950 so ties all available dip lines and horizons are continued on all lines. Loops are created to confirm the interpreted horizons. The deepest horizon, Chiltan Limestone was marked on the basis of prominent acoustic impedance contrast with overlying and underlying reflectors. Finally marked horizons from bottom to top are named as Chiltan Limestone, Massive sandstone, Basal Sands, Lower Goru, Parh Limestone, Ranikot and Laki formation on the basis of well data Figures 3.3, 3.4 and 3.5

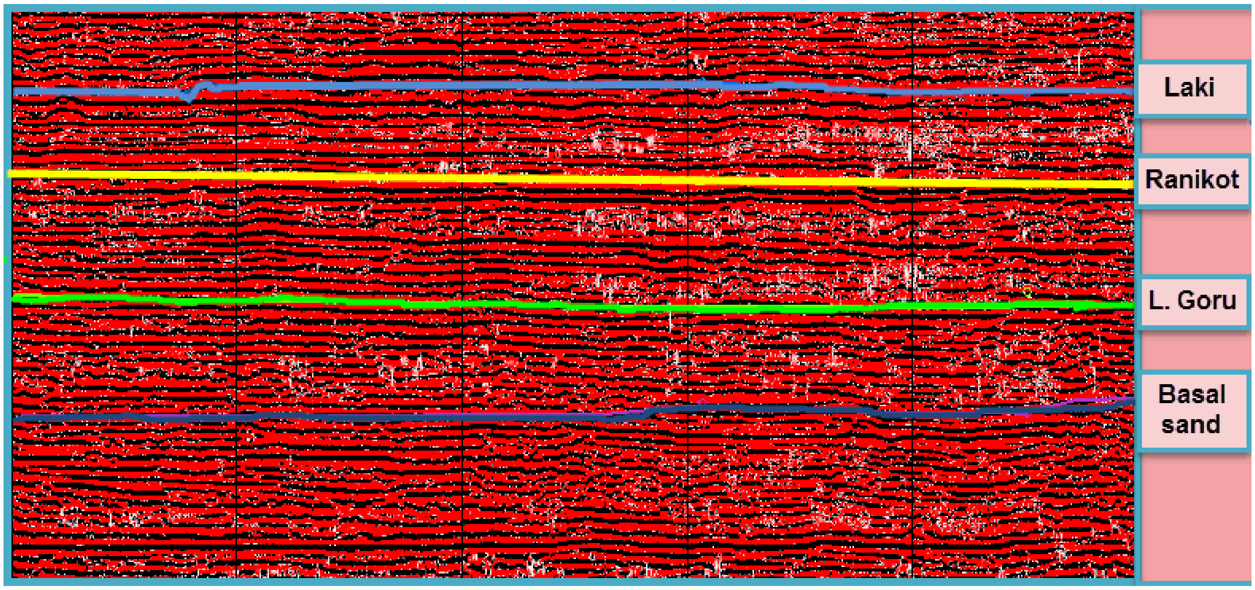

Figure 3.3 Time section of line GO-017-SNJ-08

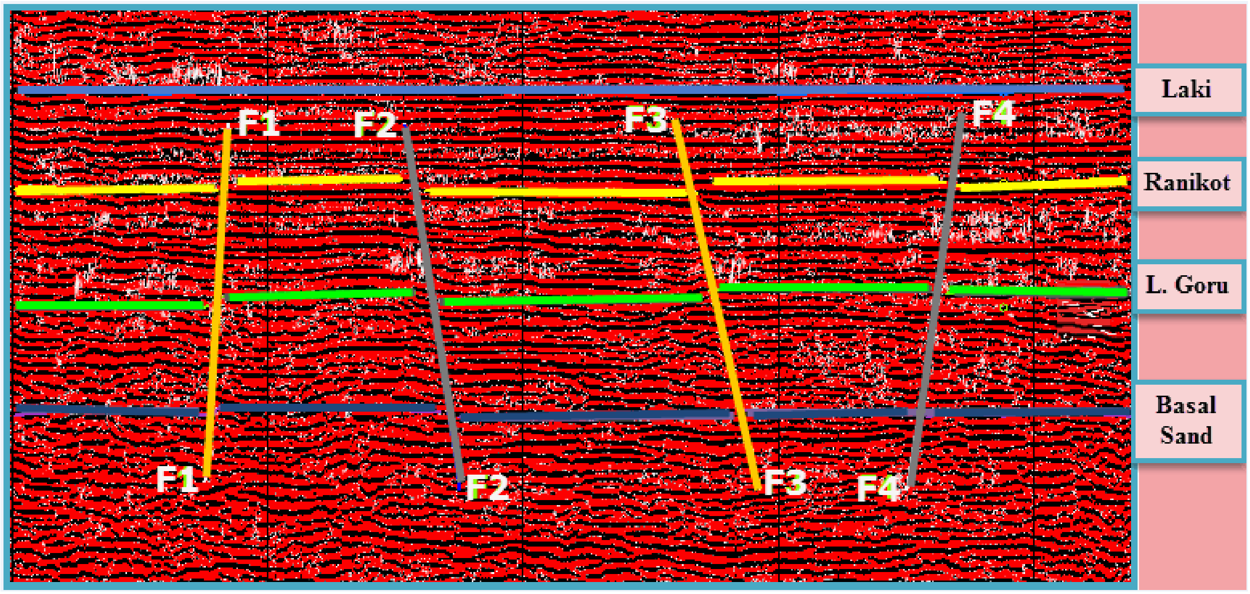

Figure 3.4 Time section of line GO-017-SNJ-022

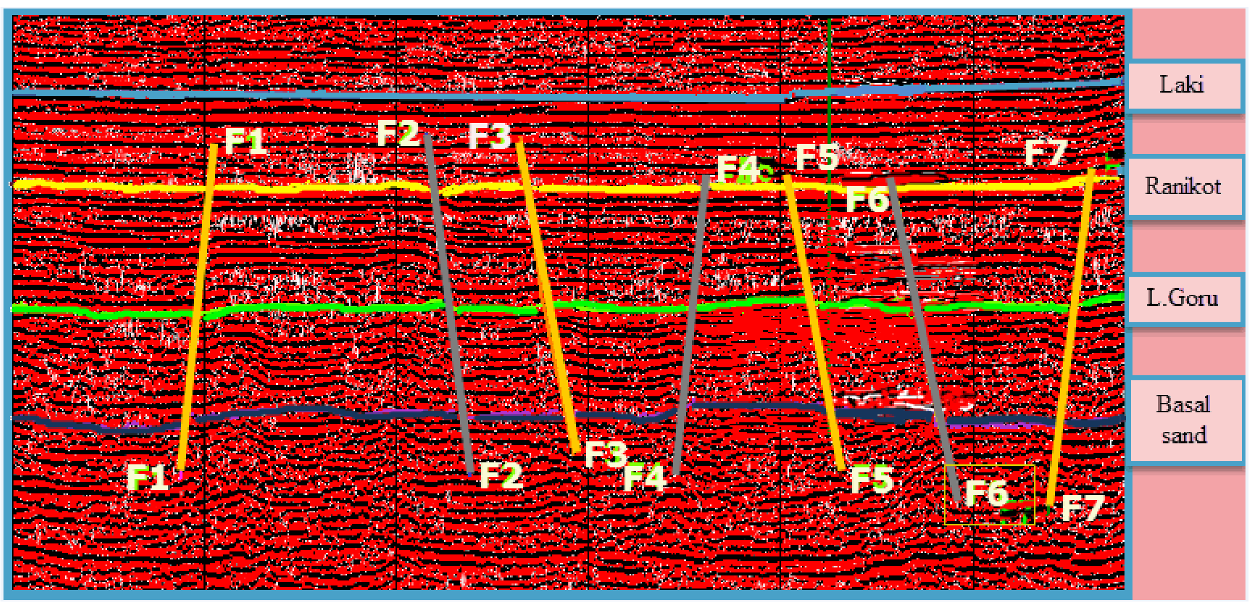

Figure 3.5 Time section of Line GO-017-SNJ-03

Our study area (Sinjhoro) lies in extensional regime dominated by normal faults and associated horst and graben structures. Faults appear to originate from Jurassic level (Chiltan) and normally they die out somewhere in Parh Limestone and above lying younger formations. On the basis of discontinuity in time, many normal faults have been marked on the seismic sections forming the horst and graben features.

3.7 Construction of Fault Polygons:

Construction of fault polygons is very important as horizon is concerned. Any mapping software needs all faults to be converted into polygons prior to contouring. The reason is that if a fault is not converted into a polygon, software doesn't recognize it as a barrier or discontinuity, thus making any possible closures against faults represents a false picture of the subsurface structures. Figure 4.6 shows that after construction of fault polygons, the high and low areas on a particular horizon become obvious. Moreover, the associated color bar helps in giving information about the dip directions on a fault polygon if dip symbols are not drawn. Fault polygons are constructed for all marked horizons and these are oriented in NW-SE direction.

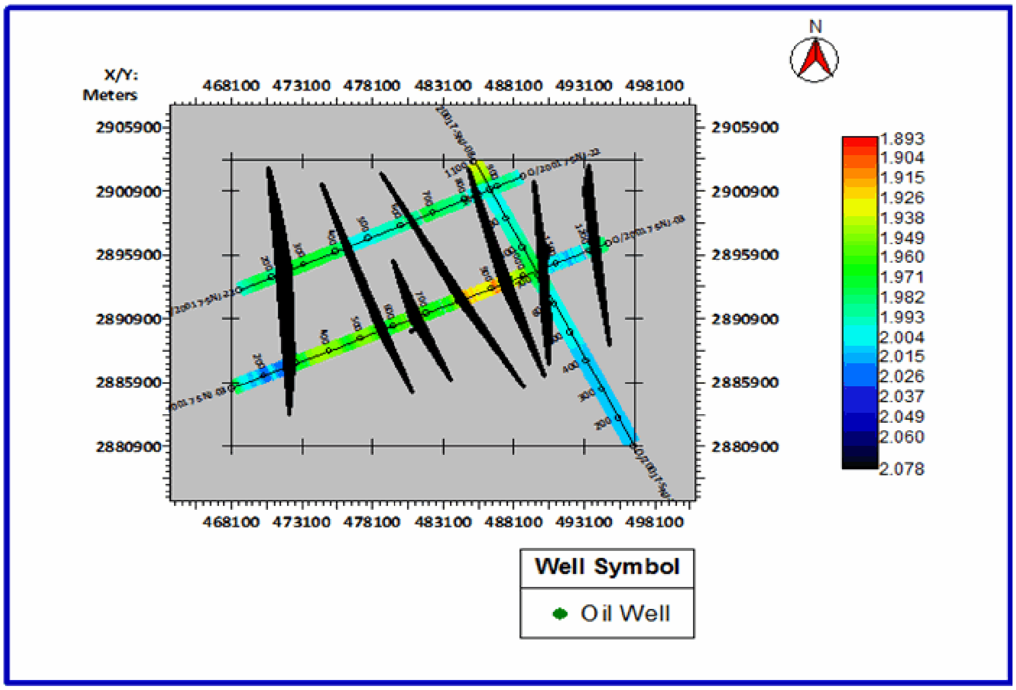

Figure 3.6 Fault Polygon of basal sands

3.8 Contour Maps:

The contours are the lines of equal elevation (time or depth). Mapping is usually final product of exploration, the one on which whole operations depends for its effectiveness (Coffeen, 1986). Contouring represents 3D model on 2D surface. We have generated contour map by using grid.

3.9 Time Contour Map:

Two way time maps are made at different levels which show the position of that formation in time. In this study, time map is constructed for Basal Sand Figure 3.7. Contour interval is kept to 2msec. Time contour maps show the different closures on which already wells have drilled and these are gas condensate. Low Values of time are associated with shallow levels which represent horst blocks. High values of time are associated with deeper levels which represent graben.

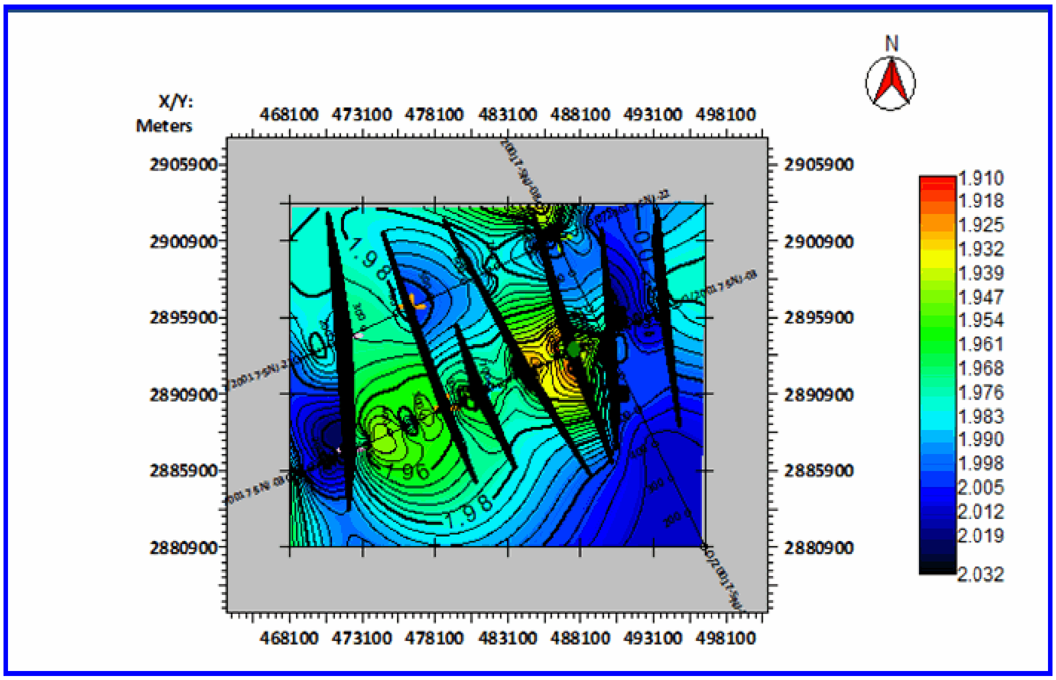

Figure 3.7 Time contours of basal sand.

3.10 Depth Contour Map:

Two way time maps are made at different levels which show the position of that formation in time. In this study, depth maps are constructed for Basal sand Figure 3.8 Contour intervals is kept to 2 m. Depth contour maps show the different closures on which already wells have drilled and these are gas condensate. Low values of depth are associated with shallow levels which represent horst blocks. High values of depth are associated with deeper levels which represent graben.

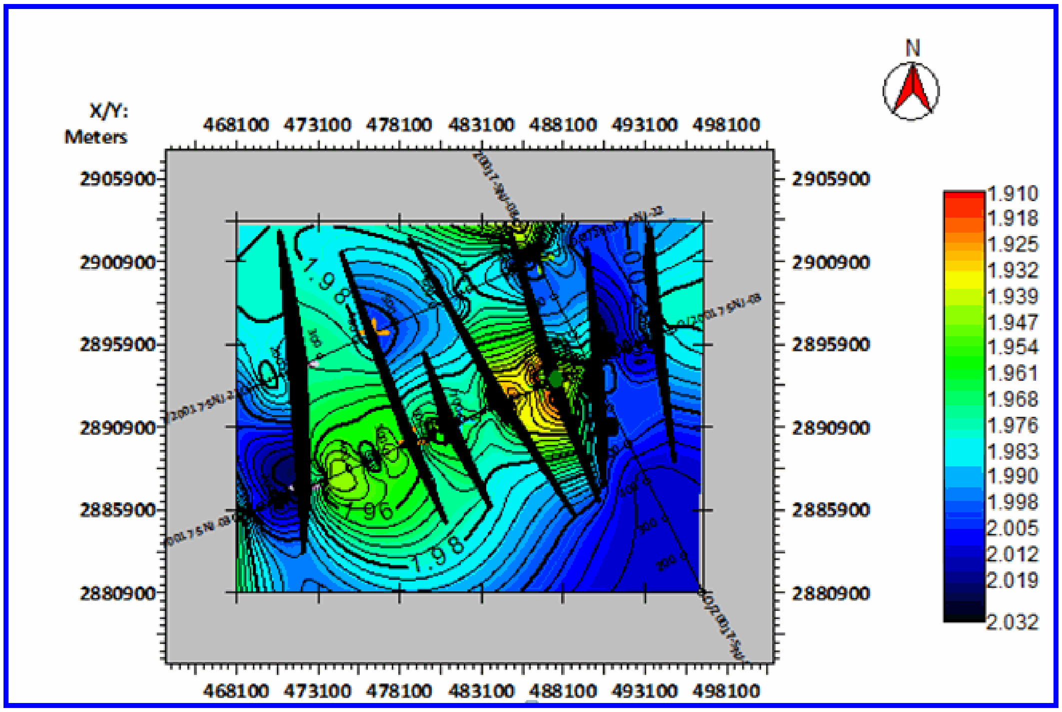

Figure 3.8 Depth contour map of Basal Sand.

Here, faults polygons represent the structure geometry of the area. In Study area (Sinjhoro) mostly fault forming structural traps for hydrocarbon accumulation in the form of horst blocks. Eight fault polygons are marked in these maps showing faults orientation from NW to SE. Yellow colored part of map showing shallowest zone of formation whereas dark Blue colored part is indicator of deepest zone.

Chapter: 4

Petro-physics Analysis

4.1 Introduction:

Petro-physics is study of physical and chemical properties define occurrence and behavior of rocks and fluids. To accurately define hydrocarbons in reservoir, measurements such as density, porosity and resistivity are made in drilled wellbore, from which average porosity, volume of shale, water saturation versus hydrocarbon saturation are calculated. Petro-physics is concerned with using well bore measurements to subsidize reservoir description (Daniel, 2003).

In present study the following Petro physical properties are calculated (Daniel, 2003):

- Volume of shale
- Total porosity
- Effective porosity
- Water saturation
- Hydrocarbon saturation

4.2 Caliper log:

A caliper log is a well logging tool that provides a continuous measurement of the size and shape of a borehole along its depth and is commonly used in hydrocarbon exploration while drilling wells. The measurements that are recorded can be an important indicator of cave-ins or shale swelling in the borehole, which can affect the results of other well logs. Higher values show the shaly material and lower values show sandstone.

Petro-physics analysis is acquired to estimate the reservoir porosity, volume of shale and Saturation of water. Here we are going to find out the petro-physics of well Chak 66-01 from Sinjhoro block. Since we need log curves of Caliper log, Gamma ray (GR, Latro log shallow

(LLS), Latro log deep (LLD), Neutron log, Density log (RHOB), and Sonic log (DT), Micro spherical focused log (MSFL), Spontaneous potential (SP) log, etc.

4.3 Volume of Shale:

Shale is more radioactive than carbonate or sand, gamma ray logs can be used to calculate volume of shale in porous reservoirs. The volume of shale can then be applied for analysis of shaly sands. The following formulae from Schlumberger, 1974.

$$I_{GR}=\frac{GR_{log}-GR_{min}}{GR_{max}-GR_{min}}$$

Where,

I_{GR}= gamma ray index

GR_{log}= gamma ray reading of the formation

GR_{min}= minimum value of gamma ray (clean sand and carbonate)

GR_{max}=maximum value of gamma ray (shale)

Consolidated

V_{shale}= 0.33× $\left[2^{(2\times I_{GR})}-1\right]$

Unconsolidated

V_{shale}= 0.0883× $\left[2^{(3.7\times I_{GR})}-1\right]$

The Gamma ray log shows maximum value when shale is encountered and shows a minimum value when clean lithology like sand is encountered. These values are calculated from given log response and then volume of shale is estimated by using (Asquith and Gibson, 2004) equation.

We have different GR models to calculate volume of shale:

4.3.1 Stieber formula (1970):

$$V_{Sh}=\frac{I_{GR}}{3-2I_{GR}}$$

4.3.2 Lorionov Formula (1969):

$$V_{Sh}=0.31(2^{2*I_{GR}}-1)$$

4.3.3 Clavier formula (1971):

$$V_{Sh}=1.7\sqrt{3.38-(I_{gr}+0.7)^2}$$

We have used Steiber formula for finding of volume of shale as it gives lower value of volume of shale than the other models.

4.5 Porosity from Well Logs:

The followings are the logs used for estimating porosity.

4.5.1 Sonic Porosity($\emptyset_s$):

Using sonic log porosity can also be easily calculated which is almost near or equal to actual porosity. The interval transit time (ΔT) is dependent upon both lithology and porosity by the following formula given by Wyllie et al in 1958. Sonic porosity has been calculated by using the following formula:

$$\emptyset_s=\frac{(\Delta T-\Delta T_{mat})}{(\Delta T_f-\Delta T_{mat})}$$

Where,

$\emptyset_s$= sonic porosity µs/ft.

ΔT_{mat}= transit time in matrix

ΔT= log response

ΔT_f= transit time in fluids

Wyllie formula for calculating sonic porosity can be used to determine porosity of consolidated sandstone and carbonates. According to Wyllie interval transit time (ΔT) increased due to the presence of hydrocarbon (i.e. hydrocarbon effect). In order to correct this Wyllie suggested the following empirical correction for hydrocarbon effect.

$\emptyset = \emptyset_s \times 0.7 (For\ gas)$

$\emptyset = \emptyset_s \times 0.9 (For\ oil)$

4.5.2 Porosity from Neutron Log and Density logs:

To measure average porosity of reservoir under study porosities from density and neutron logs were also calculated by using following formula:

$$\emptyset_N = \emptyset\ S_{xo}\ \emptyset_{Nmf} + \emptyset(1 - S_{xo})\emptyset_{nhc} + V_{sh}\emptyset_{sh} + (1 - \emptyset - V_{sh})\emptyset_{nma}$$

Where,

$\emptyset_N$=Recorded parameter

$\emptyset\ S_{xo}\ \emptyset_{Nmf}$= Mud filtrate portion

$\emptyset(1 - S_{xo})\emptyset_{Nhc}$= Hydrocarbon portion

$V_{sh}\ \ \emptyset_{Nsh}$= Shale portion

$(1 - \emptyset - V_{sh})\emptyset_{nhc}$= Matrix portion where $\emptyset$ = True porosity of rock

$\emptyset_N$= Porosity from neutron log measurement

$\emptyset_{Nma}$= Porosity of matrix

$\emptyset_{Nhc}$= =Porosity of formation saturated with hydrocarbon fluid

$\emptyset_{Nmf}$=Porosity saturated with mud filtrate

V_{sh}=Volume of shale

S_{xo} =Mud filtrate saturation in zone invaded by mud filtrate

The density log measures electron density of a formation. It is used to identify evaporate mineral, detect gas bearing zone, determine hydrocarbon density, evaluate shaly sand reservoirs and complex lithology (George & Gibson, 1982). Table 4.1 shows matrix densities of common lithology.

Table 4.1 Table showing Densities of Matrix

Matrix	$\rho_{ma}(gm/cc)$
Sandstone	2.648
Limestone	2.710
Dolomite	2.876
Anhydrite	2.977
Salt	2.032

$$\rho\rho_b = \rho_{ma}(1 - \emptyset) + \rho_f \emptyset$$

$$\emptyset = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Where,

Φden = Density Derived Porosity

ρ_b = Formation Bulk Density/Density Log

ρ_{ma} = Matrix Density (given in table)

ρ_f = Fluid Density (1.0 Fresh Water, 1.1 salt muds and 0.7 gases)

4.5.3 Average Porosity:

Average porosity can be calculated by taking the average of sonic porosity, neutron porosity and neutron density porosity. The peak values in the graph show the unconsolidated material. Figure shows porosity variations with increasing depth. Higher values show the shaly material and lower values stiffer material.

$$\emptyset_{Avg} = \frac{(\emptyset_N - \emptyset_D)}{2}$$

Where,

$\emptyset_{Avg}$ = Average porosity

$\emptyset_N$ = Neutron porosity

$\emptyset_D$ = Density porosity.

4.6 Water Saturation(S_w):

Water saturation has been calculated with help of the Archie's Equation (1942)

$$S_w = \left[\left(\frac{a}{\emptyset_m}\right) \times \left(\frac{R_w}{R_t}\right)\right]^1 /n$$

Where,

S_w= water saturation

R_w= water resistivity (formation)

$\emptyset$= effective porosity

m = cementation factor

a = constant = 1

R_t= log response (LLD)

R_w = has been calculated with help of the following formula:

$$R_w = \emptyset^2 \times R_t$$

Where,

$\emptyset$ = porosity in clean zone

R_t= = observed LLD curve in clean zone

4.7 Saturation of Hydrocarbon(S_{hyc}):

It is denoted as(S_{hyc}) . Saturation of hydrocarbon is calculated by given formula below:

$$S_{hyc} = 1 - S_w$$

Where,

S_{hyc}= saturation of hydrocarbon

S_w= saturation of water

4.8 Result of petro-physical analysis:

Interpreted zone at the depth of 2842-2850m is considered as zone of interest. This zone represents low GR (Gama Ray Log) value that shows low volume of shale and confirm as sandstone. Value of porosity indicates the presence of fluid in this zone, value of saturation of water is used to calculate the hydrocarbon saturation (1-Sw). Using cross plot total porosity is determined by well logs data is 13%, Water Saturation (S_w) is 30% ,net to gross ratio is 62% and hydrocarbon saturation is 70% in Massive Sands reservoir. Figure 4.2

Shale volume(VSH)	**23%**
Effective Porosity(PHIE)	**13%**
Water saturation(SW)	**30%**
Hydrocarbon Saturation(Sh)	**70%**

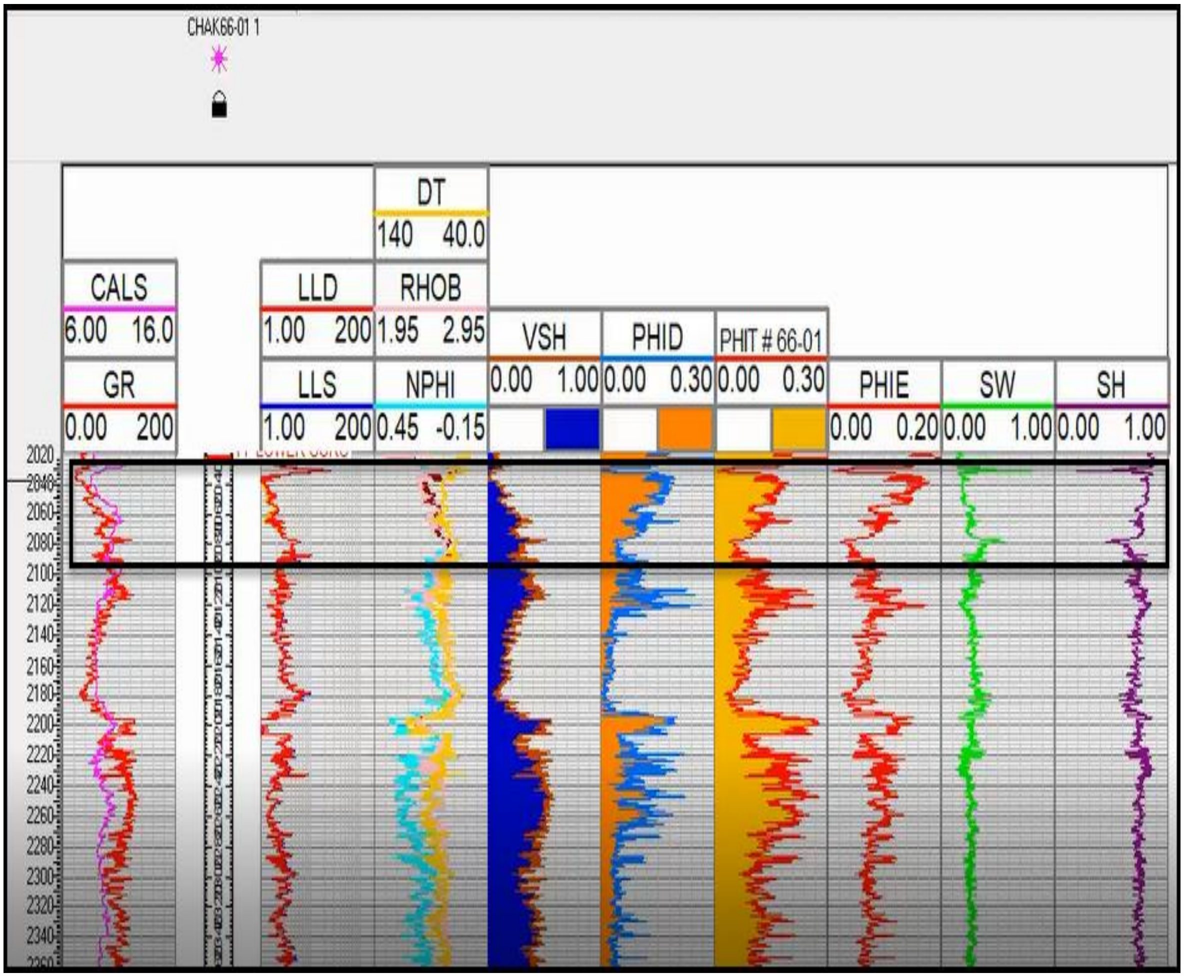

Figure 4.2 Petro-physical response of chak66-01

Chapter: 5

Colored Inversion of Post stack Data

5.1 Wavelet and acoustic impedance:

For many seismic processing applications, it becomes necessary to derive an estimate of the seismic wavelet. Because the character of wavelet is imprinted on seismic traces, it is important to understand its shape in order to decipher the properties of earth‘s interior from seismic traces. In spite of the fact the wavelet is time varying and is expected to be spatially varying, an overall knowledge of wavelet is crucial to enhancing resolution for better imaging of structure and predicting lithology and fluid content. The most common practice is to invert post-stack seismic data for wavelets. A post-stack trace emulates a zero-offset or normal-incidence seismogram, which can be simulated using convolution model assuming 1D earth model. Most seismic data contain noise this problem must be compensated.

In frequency domain, the convolution operation is replaced by a multiplication. Three inverse problems are identified.

- Estimation of the wavelet when the reflection co-efficient is known.
- Estimation of reflection co-efficient or acoustic impedances when the wavelet is known.
- Simultaneous inversion for acoustic impedance of wavelet.
- Inversion of seismic data to Acoustic Impedance is usually seen as a specialist activity, so despite the publicized benefits, inverted data are only used in a minority of cases. To help overcome this obstacle we aimed to develop a new algorithm which would not necessarily be best in class, but would be quick and easy to use and increase the use of inversion products with in BPA. This new technique, “Colored Inversion”, performs significantly better than traditional fast-track routes such as recursive inversion, and benchmarks well against unconstrained sparse-spike inversion.

Once the Colored Inversion operator has been derived it can be simply applied to the data on the interpretation workstation as a “user-defined filter”. In this way inversion can be achieved within hours since the volume data do not have to be exported to another package, and no explicit wavelet is required. The inversion is understood simply by this flow chart.

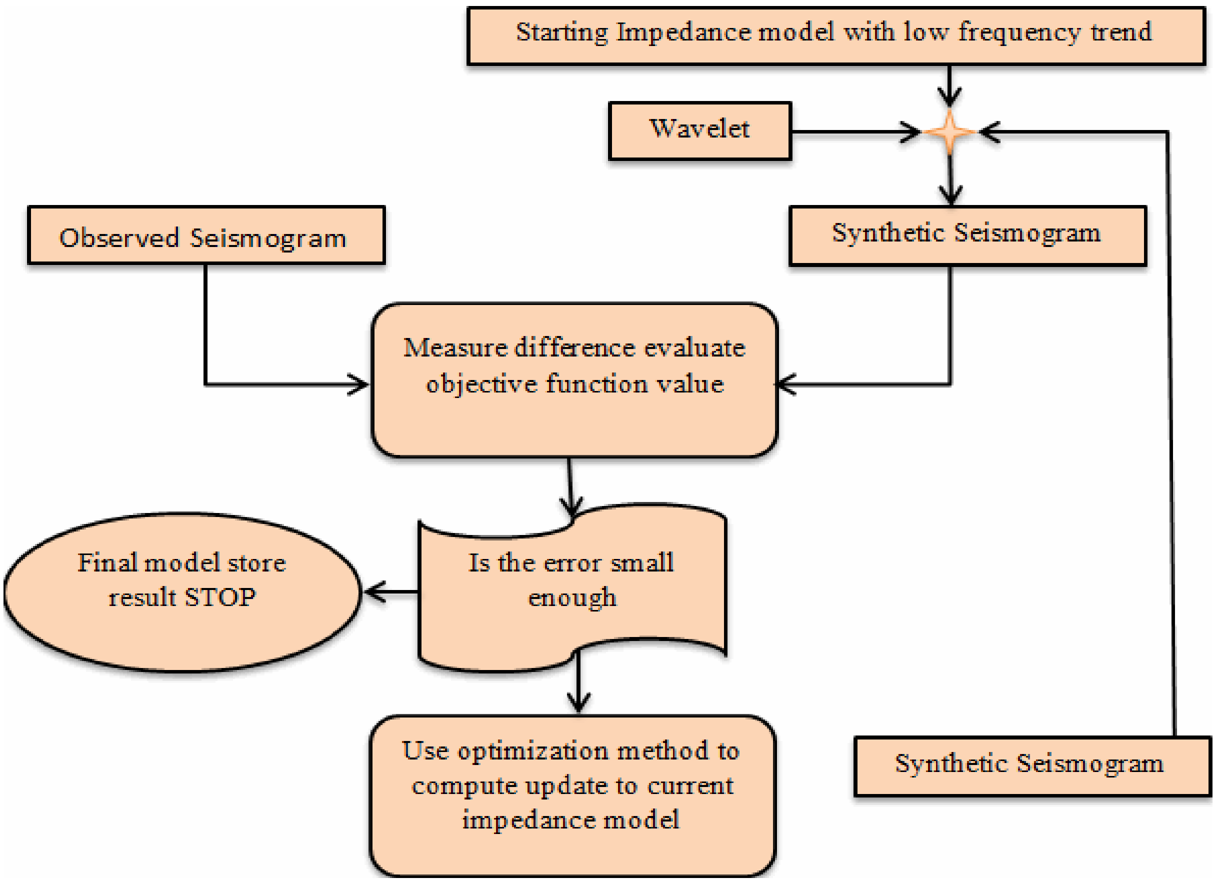

Figure 5.1 Flow chart showing impedance and wavelet extraction scheme.

5.2 Methodology:

The well data and information of logs is required for the performing the colored inversion in Kingdom Software.

- The velocity is obtained from sonic log and density is obtained from density log and values of densities are obtained from density log by convolving these values.
- We get acoustic impedance by cross-matching these impedance data with the input reflection data.

- We derive a single optimal matching filter Figure (5.8). Convolving this filter with the input data we see in figure (5.7) that the result is very much similar, everywhere.
- This Empirical observation indicates that inversion can be approximated with a simple filter and that it may be valid over a sizeable region.

The phase of the operator is a constant -90o which is in agreement with the simplistic view of inversion being akin to integration, and the concept of a zero-phase reflection spike being transformed to a step AI interface, provided the data are zero-phase.

Walden & Hoskins‘s (1984) empirical observation tells us that earth reflection coefficient series have spectra that exhibit a similar trend that can be simply described as constant function. The term is a positive constant and is frequency arrives at a similar observation theoretically may vary from one field to another but tends to remain reasonably constant with in any one field (Velzeboer 1981). It therefore follows that if our seismic data are inverted correctly they too should show the same spectral trend as logs in the same area.

5.3 Non uniqueness and convolution:

The process of convolution for constructing a seismogram using a wavelet and acoustic impedance is performed to generate an operator. Note that wavelet is smoothly varying function, while the reflectivity is a series of delta functions placed at two-way normal time of each reflector (Cooke and Schneider 1983). The spectra of the wavelet and reflectivity series for synthetic are also shown in figure. We observe that wavelet is a band-limited, while reflectivity series is a broad-band. Because the convolution is equivalent to multiplication in frequency domain the spectrum of resulting seismogram is band-limited as well. We can imagine the complexity of the problem further we can take into account the loss of high frequencies of wavelet caused by attenuation. In other words series cannot be assumed to be stationary. Even under stationary conditions the data does not contain all the frequencies. The most common approach to deriving the wavelet is based on well-log data that produce a true reflectivity series.

5.4 Wavelet extraction:

The wavelet is shown in Figure (5.2) is extracted on the basis of the well log data that provides the true reflectivity series (i.e. compressional wave velocity and density computed into acoustic impedance logs, which are mapped into normal incidence reflectivity series). An initial guess of wavelet is convolved with reflectivity series and synthetic normal incidence trace is generated. The difference between the observed and synthetic traced is minimized using a suitable chosen norm with smoothness constraints (Mrinal K. Sen).

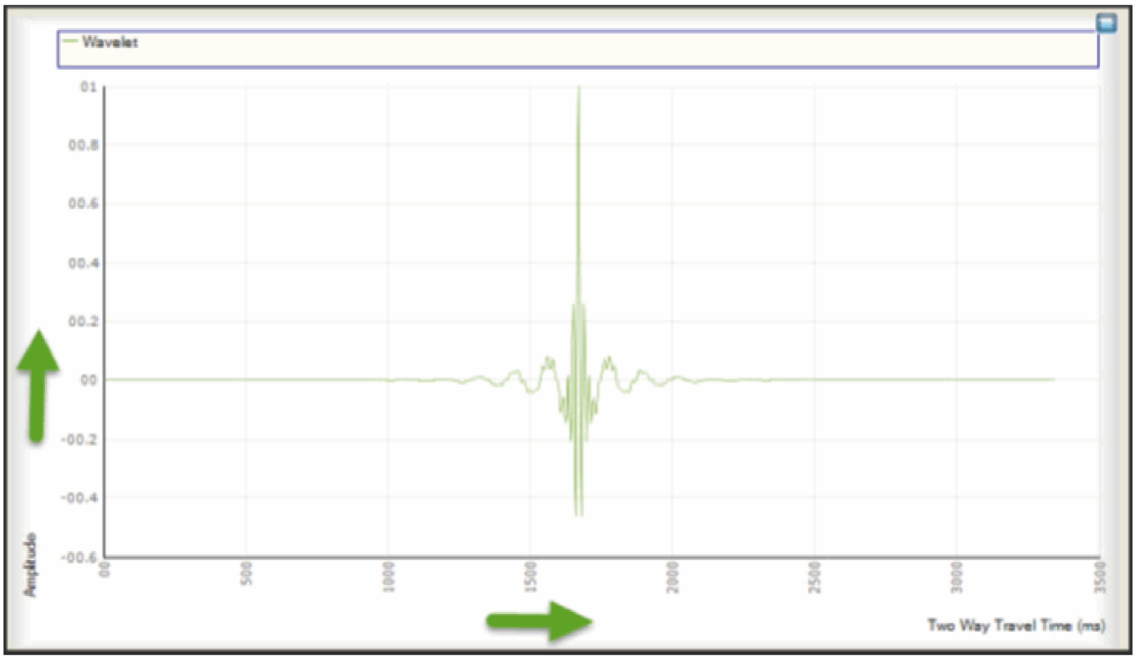

Figure 5.2 Extracted Wavelet

5.5 Impedance estimation:

Now our approach is to convolve this wavelet with acoustic impedance (reflectivity series). The acoustic impedance is also computed from well log data as described previously. The impedance spectrum is shown in figure (5.3) is estimated after removing source wavelet; noise must be absent; all multiple reflections must be removed; spherical spreading including all plane reflections (Ghosh 2000).

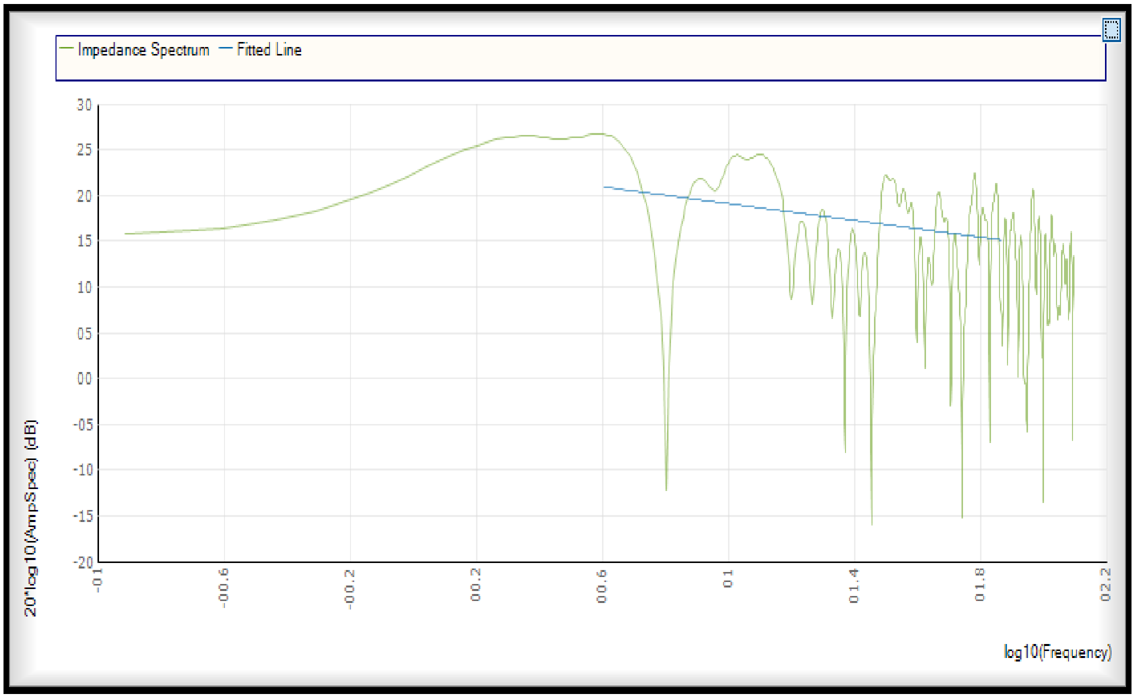

Figure 5.3 Impedance spectrum with fitted line.

5.6 Butterworth filter:

The Butterworth filter is a type of signal processing filter designed to have as flat a frequency response as possible in the pass band. It is also referred to as a maximally flat magnitude filter. It was first described in 1930 by the British engineer and physicist Stephen Butterworth in his paper entitled "On the Theory of Filter Amplifiers.

An ideal electrical filter should not only completely reject the unwanted frequencies but should also have uniform sensitivity for the wanted frequencies. This filter is used here for convolution of the wavelet and reflectivity series for formulation of seismogram. The Butterworth filter is shown in Figure (5.4).

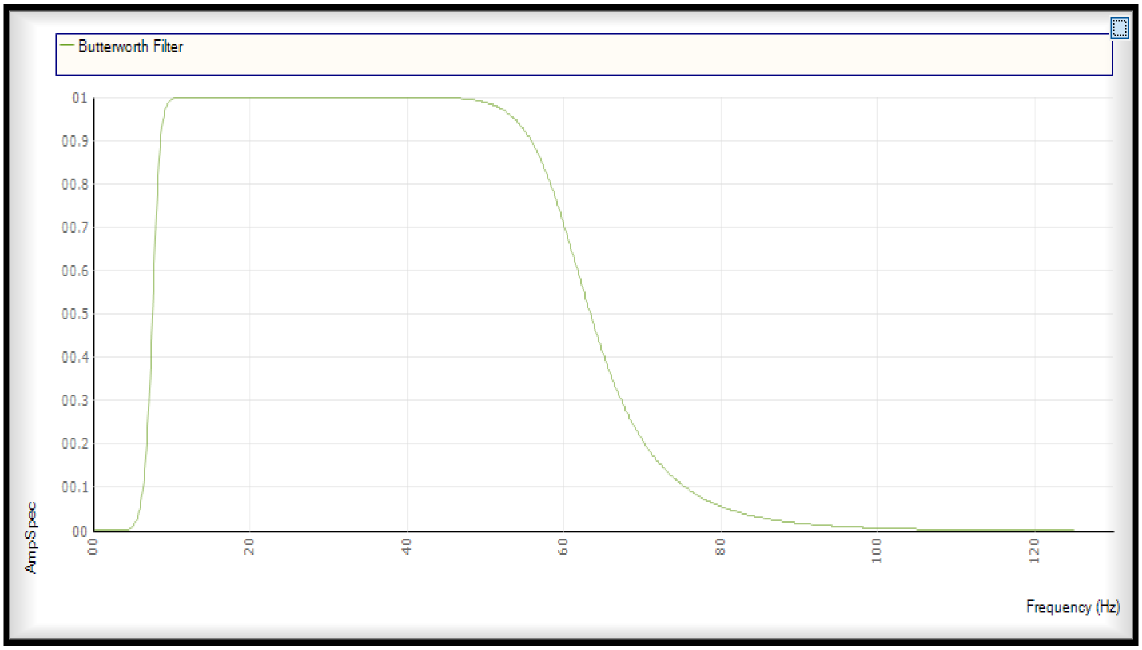

Figure 5.4 Butterworth filter.

After the process of convolution is performed we get the seismogram (operator). There is a vast difference between the seismogram of our desire and the seismogram we obtained from the convolution.

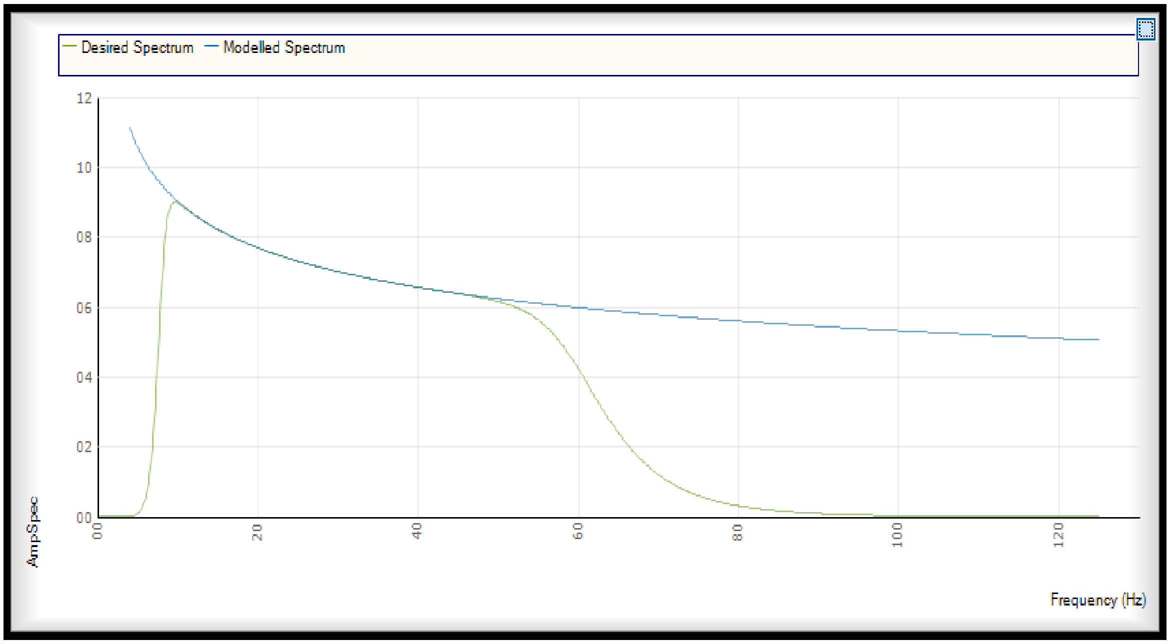

Figure 5.5 Desired and modeled spectrum.

There are two spectrums shown in Figure (5.5) both are of different colors. The blue color shows the spectrum obtained from convolution of wavelet and acoustic impedance and the spectrum in blue color shows a desired spectrum. Now we need to obtain a spectrum of our desire for this purpose we have to convolve this spectrum with another spectrum known as shaping spectrum which is obtained by applying Fourier transformation on desired spectrum. The shaping spectrum is shown in Figure (5.6).

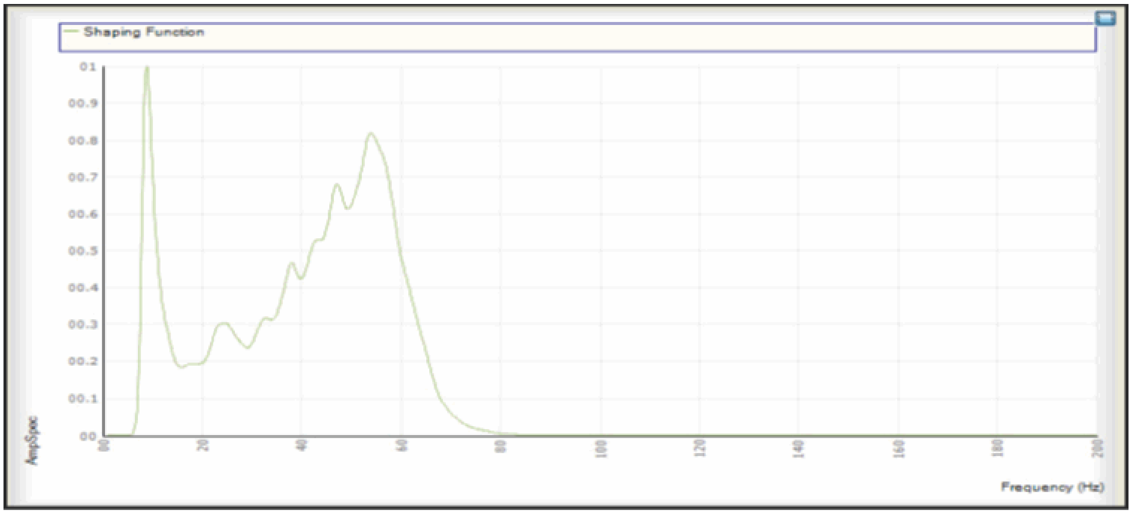

Figure 5.6 Shaping spectrum.

The Figure (5.6) shows us the shaped seismic spectrum and desired seismic spectrum.

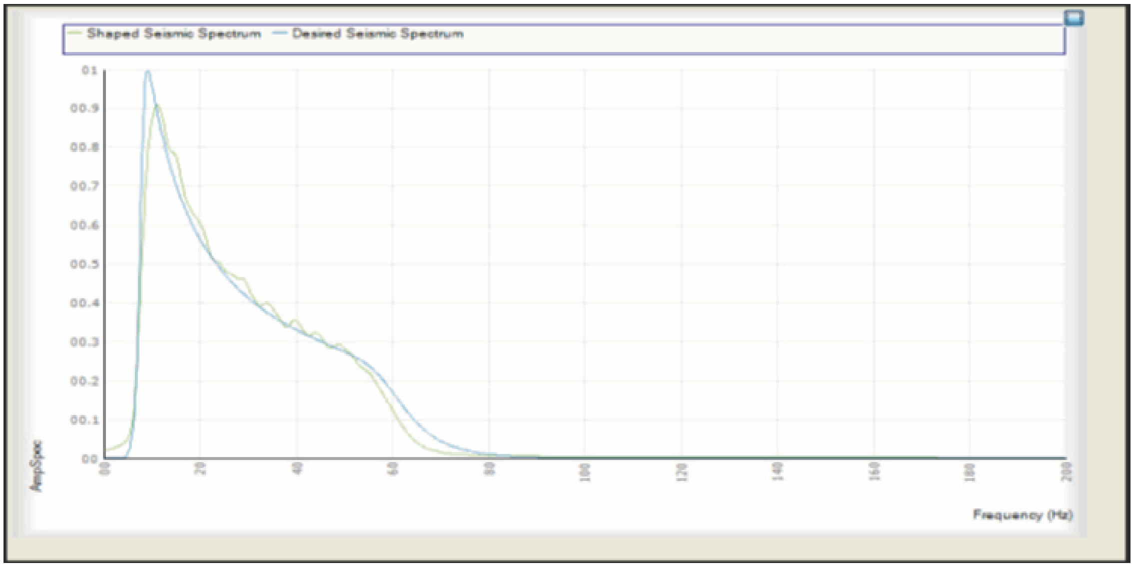

Figure 5.7 Convolution of shaped seismic spectrum and desired spectrum.

A seismogram for specific window (as values of acoustic impedance is obtained from well data) is developed now we develop a seismogram to invert whole section. For this purpose we convolve desired spectrum with seismic mean spectrum. After convolving seismogram with 49 seismic mean spectrum we are able to apply it on whole seismic section. The Figure 5.8 shows seismic mean spectrum and desired spectrum.

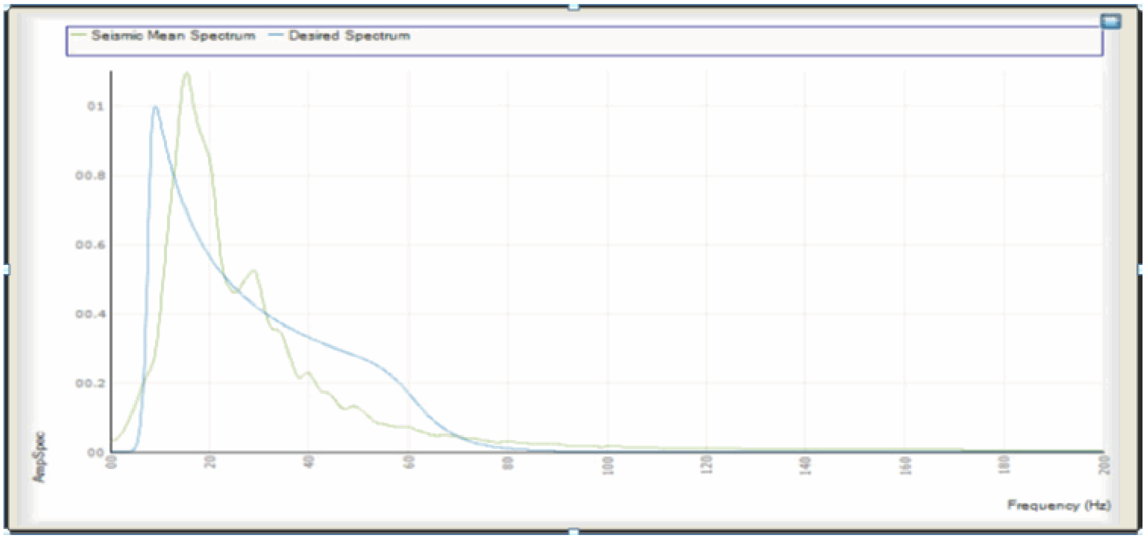

Figure 5.8 Convolution of seismic mean spectrum and desired spectrum.

After completion of the process of generating synthetic seismogram, the section is inverted an acoustic impedance is shown on section instead of amplitude as shown in Figure (5.9).

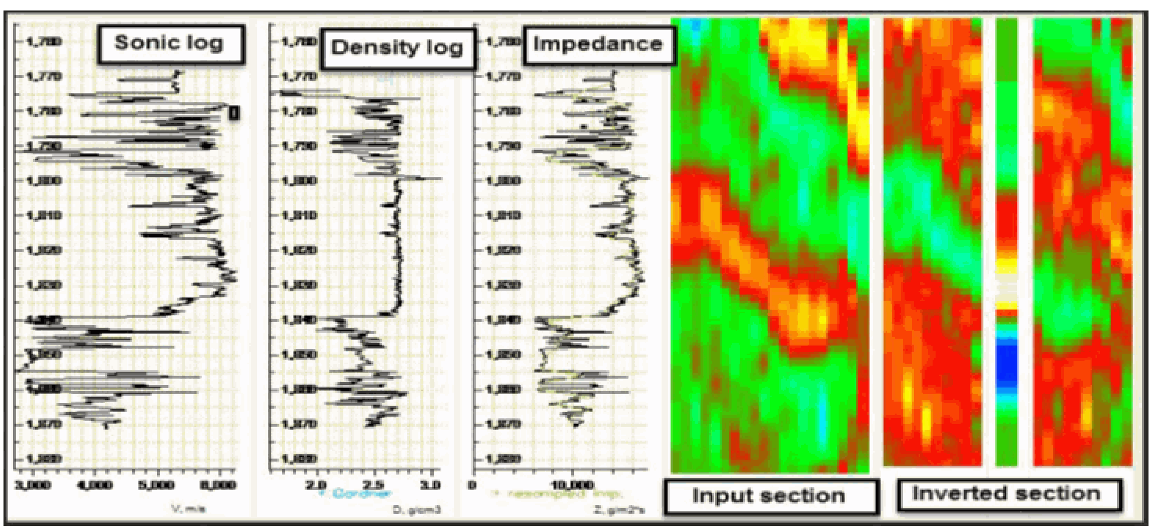

Figure 5.9 Input seismic section and inverted section along with logs.

This window displays sonic log and density logs. These logs are used to compute the acoustic impedance. If values of density log are missing then Gardner equation is used to estimate these densities. This equation is very popular in petroleum exploration because it can provide information about the lithology from interval velocities obtained from data these values are calibrated from sonic and density well log information but in the absence of these, Gardner's constants are a good approximation for density. At the right corner of the window input seismic section is shown on left side and inverted section is shown on the right hand side. The inverted section is shown on the both sides of logs sides of the well the log is inverted to invert the seismic section.

The zoomed picture of inverted section is shown in the figure (5.10) given below.

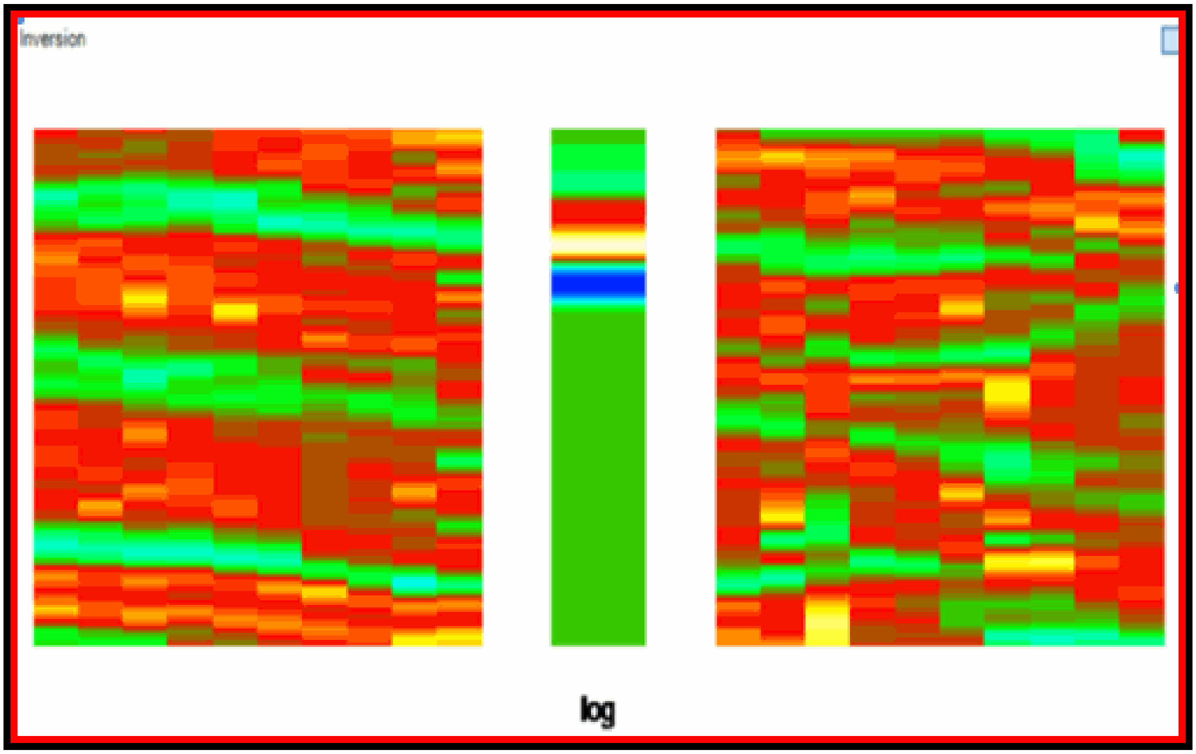

Figure 5.10 Inverted section with inverted logs.

Now inversion is applied to the whole section shown in Figure 5.11.

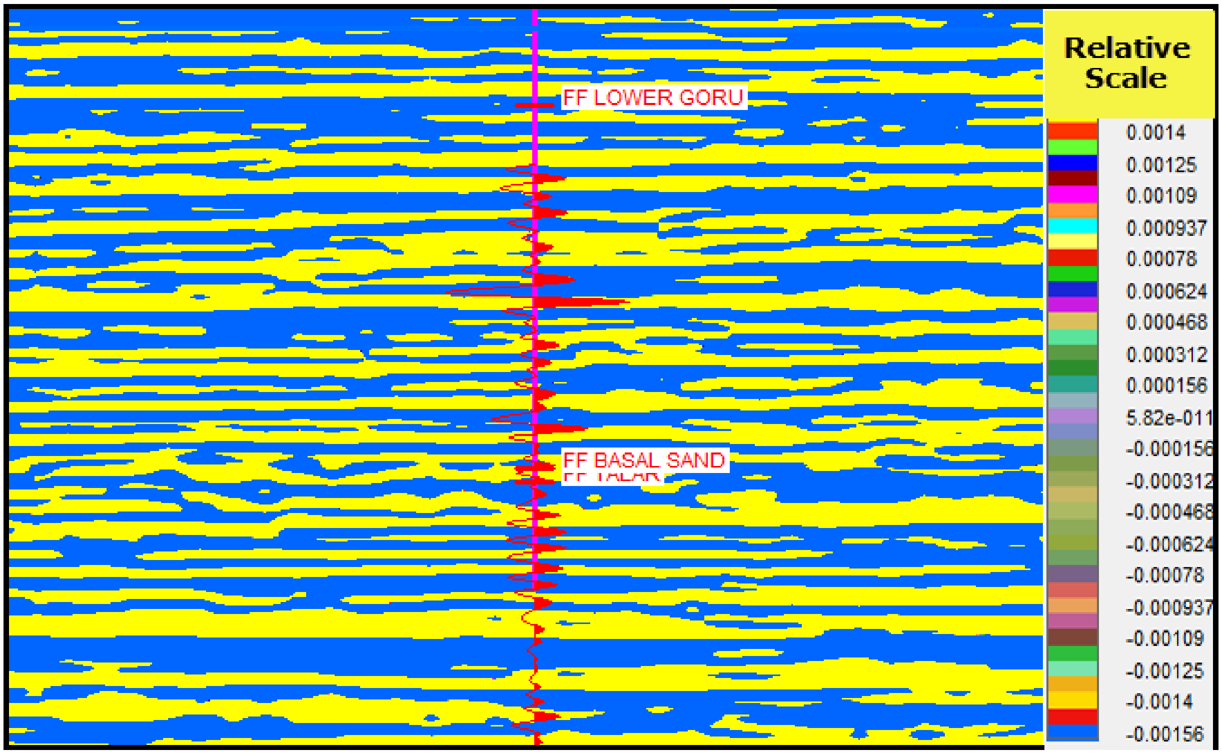

Figure 5.11 Inverted seismic section.

Conclusion:

- Horizons of Basal Sands and Lower Goru are confirmed by synthetic seismogram.
- Time and depth maps show different horst and graben structures that are extended from NW-SE and are favorable for accumulation of hydrocarbons in the study area.
- Petro-physical interpretation of well Chak66-01 leads to probable zone for hydrocarbon extraction in Lower Goru Sands.
- Porosity of thick reservoir (Massive Sands of Cretaceous) is 13% with 70% hydrocarbon saturation.
- Colored Inversion shows that Lower Goru comprises of low accostic impedance which is the indicative of high porosity zone.

References:

- Al-Sadi H.N. (1980), “Seismic Exploration Technique and Processing”, Birkhauser Verlag, Boston. 259p.
- Badley, M.E. (1985), “Practical Seismic Interpretation”, IHRDC publishers, Boston, 266-70p.
- Craig J. Wandrey, Petroleum Systems and Related Geologic Studies in Region 8, South Asia , U.S. Geological Survey Bulletin 2208-C
- Cunningham, A.D., 1998. The Neogene evolution of the Pedro Channel carbonates system, northern Nicaragua Rise [Ph.D. thesis]. Rice Univ., Houston.
- Dobrin M.B & Savit C.H. (1988), “Introduction to Geophysical Prospecting”, 4th Edition.
- Doughty, P.Ted, 2003, Clay smear seals and fault sealing potential of an exhumed growth fault, Rio Grande rift, New Mexico: AAPG Bulletin, v.87, p. 427-444.
- Hasany, S.T., and Saleem, U., 2001, an Integrated Subsurface, Geological & Engineering Study of Meyal Field, Potwar Plateau, Pakistan.
- Jones, R. M. and R. R. Hillis, 2003, an integrated, quantitative approach to assessing fault seal risk: AAPG Bulletin, v. 87, p. 507-524.
- Kadri, I.B. (1995) “Petroleum Geology of Pakistan” PPL Pakistan.
- Kaldi, J., 2008, Evaluating reservoir quality, seal potential and net pay: GEO India pre-conference training.
- Kazmi, A.H. & Jan, M.Q. (1997) “Geology and Tectonic of Pakistan” Graphic publishers, Karachi, Pakistan.
- Kearey, P & Brooks M.1984, an Introduction to Geophysical Exploration”, Blackwell Scientific Publications, Oxford, 1-98p.
- Killings, Umer and Kassi, 2002,”Geology of Badin Area of Pakistan”. PAPG, Bulletin.
- Lindsay, N. G., F. C. Murphy, J. J. Walsh, and J. Watterson, 1993, Outcrop studies of shale smear on fault surfaces: International Association of Sedimentologists Special Publication 15, p. 113–123.
- Powell, C. (1979). A speculative Tectonic history of Pakistan and surroundings: some constrain form Indian Ocean.

- Rose, P.R. (2001) Risk analysis and management of petroleum exploration Ventures. AAPG, p. 26. 55
- Telford W.M. Geldart, L.P., Sheriff, R.E. & Keys, D.A, (1976). "Applied Geophysics", Cambridge University Press, London.
- Yielding, G., B. Freeman, and D. T. Needham, 1997, Quantitative fault seal prediction: AAPG Bulletin, v. 81, p.897–917.
- Zaigham & Mallick, (2000), “Prospects of hydrocarbons associated with fossil rift structure of southern Indus basins”. AAPG Bulletin, November 2000, v. 84, p.1833-1848.