2D Seismic Modelling And Reservoir Characterization Using Seismic And Well Data of Balkassar Area, Upper Indus Basin, Pakistan.

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DEDICATION

My Parents, Brothers and Sisters, Teachers

And loving, caring and sweet friends

And all those who helped me in this work

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ABSTRACT

The dissertation work includes seismic data interpretation, Petrophysical analysis using well logs data; for the identification of possible prospect (H.C) zones. The technique of seismic inversion is also used to get more clear results about possible hydrocarbon zone. Facies modeling for the confirmation of lithology's. Two-dimensional seismic data interpretation has been carried out in Upper Indus Basin, Balkassar area to confirm the reservoir characteristics of Chorgali and Sakesar Formation. Time and Depth contour maps of Chorgali and Sakesar help us to confirm the presence of anticlinal structure in the given area. Surface contour maps of Chorgali and Sakesar Formation give the real shape of sub-surface structure, which is anticlinal. This anticlinal structure acts as a trap in the area, which is best for hydrocarbon accumulation.

Petrophysical analysis of well BALKASSAR OXY-01 is carried out for Chorgali, Sakessar formations to depict the probable hydrocarbon producing zones. The results suggest that both Chorgali and Sakessar formations are possible hydrocarbon reservoirs. One zone is marked in Chorgali having SW 33% and H.C Saturation 67% and three zones in Sakessar having SW 2942% and H.C Saturation 58-71% which is most prominent and possible hydrocarbon zones.

Facies modeling is done for the confirmation of lithologies for this purpose different cross plots has been generated which gives the result that we have pure limestone, and carbonaceous shale (limy shale) but didn‘t get pure shale in our reservoir zone.

Seismic inversion results are also showing that Chorgali and Sakesar act as a reservoir. The post stack colored inversion is performed to confirm the possible hydrocarbon prospects. On inverted section Chorgali and Sakesar shows low value of impedance i.e. strong indicator for the presence of hydrocarbons, it is also confirmed from Petrophysical results.

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CHAPTER 01

INTRODUCTION

1.1 Introduction to Hydrocarbon Exploration

Global hydrocarbon industry plays vital and irreplaceable role in development and economy of a country especially in developing countries like Pakistan, and act as a major pillar in the economy and well-being of a country. As the energy demand increases exploration industry determine to discover and develop new hydrocarbon reserves and increase production from existing reserves through the application of the best available technologies. The energy used usually comes from three major sources of hydrocarbons: Coal, Oil and gas.

The search for exploration of hydrocarbon in Pakistan started in 1868 when the first drilling was made at Kundal near Mianwali, that continue till present day. Most of the rocks in Pakistan are sedimentary and quite rich in petroliferous material. The exploration companies search for structural and stratigraphic traps where most of the hydrocarbons accumulate. Most of such structures are present in areas where there is intense folding and faulting i-e Potwar area. The possibility of major discoveries, either in on-shore or offshore areas, is considered quite bright.

Geophysicists have been trying for hydrocarbon exploration since a long time ago and developed many techniques in this regard. Seismic reflection method is used for deep hydrocarbon exploration in petroleum geology. Petroleum geology refers to the specific set of geological disciplines that are used for hydrocarbons exploration. Investigation of the earth's interior using geophysical methods, involves taking measurements at or near the surface of the earth for analysis that can expose both vertical and lateral variations of the physical properties of the earth's subsurface, logs ranging from electrical, nuclear and acoustic have been in use for deriving these parameters.

1.2 Introduction to the study area

Balkassar is an important hydrocarbon production area of the Potwar plateau on the southern flank of Soan syncline in the Himalayan collision regime and part of the upper Indus basin Pakistan. The Kohat-Potwar region, located in the sub-Himalayas, contains a significant amount of hydrocarbons trapped in compressional / transgressional subterranean structures related to the post-Himalayan orogeny (Jaume and Lillie, 1988).

1.2.1 Geographical Boundaries

Geographically, Balkassar shares borders with Kalar Kahar to the south and east with the town of Chakwal and to the west lies the town of Talagang. The area is now easily accessible due to the construction of Lahore Islamabad Highway(M-2).The Kohat-Potwar (study area) belongs to the category of extra continental watersheds, which account for 48% of the world's known oil resources (Hasany & Saleem, 2001).The area lies in UTM (Universal Transverse Mercator) zone 43N in the world Geodetic System.

Longitude: 72.320˚ -72.470˚ N

Latitude: 32.510-33.020˚ E

1.2.2 Tectonic boundaries of Potwar Basin

The left lateral fault of Jhelum (submitted by Mukherjee) marks the eastern boundary of the plateau. The western margins are delimited by the Kalabagh fault (Gee, 1989). In the south, the plateau is delimited by the thrust of the salt range, while the northern boundary is marked by the main boundary thrust (Rana and AsrarUllah,1982, Jaswal, 1997).

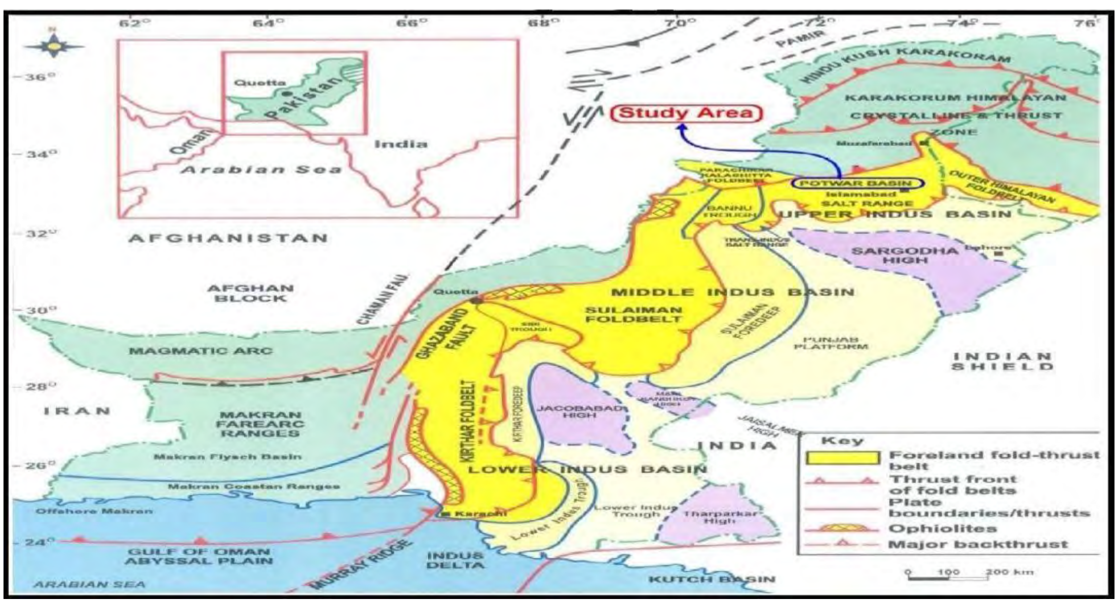


Figure 1.1 Location map of the study area (Highlighted)(Banks and Warburton, 1986)

1.3 Production History of Potwar Area

The first commercial oil discovery took place in 1914 when Attock Oil Company (AOC) completed a 214 foot well on a thrust faulted anticline near the town of Khaur. Since the discovery, there have been more than 396 wells drilled in the field. Khaur's production . Drilling from 1920 to 1935 resulted in Dhullian, a structural dome located 17 km southeast of Khaur. Other discoveries followed with Joya Mair in 1944, Balkassar in 1946, Karsal in 1956 and Tut in 1967 (Khan, 1986).

The first commercial gas field Adhi was found in 1979. The Adhi gas field produced from rocks ranging from Cambrian to Eocene. Eighteen oil fields and three gas fields were discovered in the geological province of Kohat-Potwar between 1915 and 1996, and several prospects that were unsuccessfully tested in the 1950s and 1960s are now being re-examined with good result. Production in the geological province of Kohat-Potwar comes mainly from defective anticline traps in Cambrian-Miocene rocks (Jaswal, 1997).

The largest oil and gas field to date is the Dhurnal field with an aerial closure of 13.5 km2 and a vertical closure of 500 m. The initial in-place oil estimate for Dhurnal was 102 MMBO (million barrels of oil) (Jaswal, 1997).

At the time of independence (1947), Pakistan inherited four productive fields, Khaur, Dhullian, Joya Mair and Balkassar.

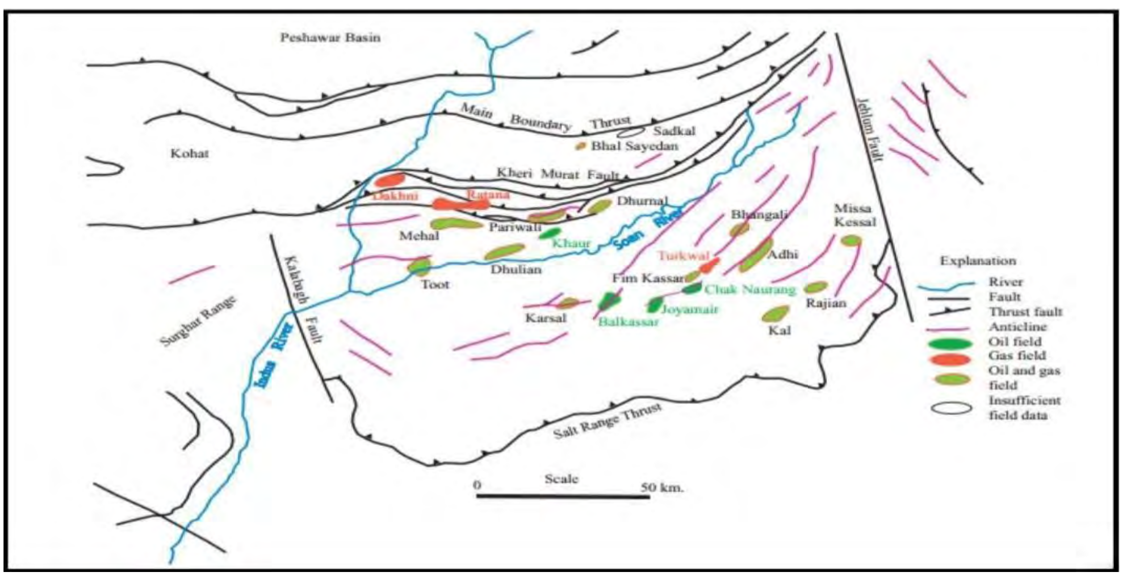


Figure 1.2 Generalized structure map of Potwar Plateau (Jaswal, 1997).

Since then, four other fields have been discovered: Karsal, Tut, Sarang and Mayal. All these fields are in the Potwar Plateau. Traces of hydrocarbons occur in several other localities and exploration continues in Punjab, Sind, and Baluchistan by arrangement between various foreign companies and the Oil and Gas Development Corporation (OGDC) (Jaswal, 1997).

1.4 Exploration History of the Balkassar Oil Field

Balkassar, Development & Production (D & P) Lease is located about 105 km south-west of Islamabad in the Chakwal district. Field was discovered in 1946 by Attock Oil Company, establishing the potential of fractured Eocene limestone. The Chorgali (Bhadrar) and Sakesar formations are the main reservoirs of oil production in the field (Adil & Sohail, 2014).

In total, 21 wells were drilled in Balkassar, Development & Production (D & P) Lease, one of which was off-structure, two wells could not reach to the total depth and 18 wells reached at the target. Some wells were abandoned prematurely and some were plugged due to mechanical problems after a small production, whereas only six wells (A-3, A-5, A-7, P-2, POL-1, A-6 and Balkassar X-1) currently produce. Wells A-3, A-5, A-7 and B-2 (P-2) are in regular production while A-6, POL-1 and Balkassar X-1 are intermittent producers. All regular producers and A-6 are in the northwestern compartment of the field, while POL-1 is located in the southeast compartment (Adil & Sohail, 2014).

The maximum output was about 3700 BOPD in 1965 which has since dropped to about 420 BOPD and 0.05 MMSCFD of gas. The field produced on natural reservoir pressures until 1961, and then it was converted to the gas lift and produced until 1974. The average depth of the wells targeting the Eocene reservoir is about 9000 ft. Most wells are drilled in the western compartment which is structurally lower than east. While three wells are in the eastern compartments that are all non-producing, only POL-1 contributes with minor rates.

The fractured carbonates of the Sakesar and Chorgali formations of the Eocene age are the main producing reservoirs of Balkassar. Minor oil production comes from Paleocene Lockhart Formation. The OIIP calculated internally is estimated at 174 MMSTB. The recoverable oil reserves are estimated at 38.37 MMstb and the gas at 234.86 MMscfd. Cumulative oil productions at 31 March 2015 is approximately 35.56 MMstb (Adil & Sohail, 2014).

1.5 Data Formats

Data for dissertation consist of,

- SEG-Y (Seismic)
- LAS (Well data)
- Navigation

Data was provided by Directorate General Petroleum Concession (DGPC), Government of Pakistan by the request of Chairman of Department of Earth Sciences, Quaid-i-Azam University Islamabad.

1.6 Data Description

1.6.1 Seismic Data

The seismic reflection data was acquired by POL in 1981 and processed by Oil and Gas Development Company Limited (OGDCL) in 1981.Base map shows the ten seismic reflection lines in which some lines are placed along the dip and some are placed along the strike of a structure. The detail description of lines is shown in the table 1.1. Table 1.1 Description of seismic lines

Sr. No	Line Name	Orientation	Nature of line	SP Range	Length of Line (km)
1	SOX-PBJ-01	NW-SE	Dip	85-215	12.6
2	SOX-PBJ-02	NW-SE	Dip	105-213	10.4
3	SOX-PBJ-03	NW-SE	Dip	99-218	10.3
4	SOX-PBJ-04	NW-SE	Dip	92-250	14.9
5	SOX-PBJ-05	NW-SE	Dip	123-248	11.8
6	SOX-PBJ-06	NW-SE	Dip	101-239	13.4
7	SOX-PBJ-08	NE-SW	Strike	106-290	18
8	SOX-PBJ-09	NE-SW	Strike	101-297	19.3
9	SOX-PBJ-10	NE-SW	Strike	99-289	18.4
10	SOX-PBJ-11	N-S	Oblique	99-235	13.8

1.6.2 Well Data

The well data includes LAS file which store all the information about the logs run in the well and well tops. The Balkassar Oxy # 1 was the first exploratory well drilled by Oxy (Pak) in Pakistan. Balkassar OXY-1 well is adjacent to a line PJB-04.

1.6.2.1 Formation Tops

The information of the formation tops encountered in the well are listed below in table 1.2.

Table 1.2 Formation tops encountered in the Balkassar Oxy-01 well

Formations	Formation Age	Tops (m)	Thicknesses (meters)
NAGRI	PLIOCENE	0	478.8
CHINJI	MIOCENE	1408.1	106.6
KAMLIAL	MIOCENE	1514.8	906.7
MURREE	MIOCENE	2421.5	45.72
CHORGALI/BHADRAR	LOWER EOCENE	2467.2	135.6
SAKEASAR	EOCENE	2602.9	21.34
PATALA	PALEOCENE	2624.2	35.05
LOCKHART	PALEOCENE	2659.3	27.43
HANGU	PALEOCENE	2659.3	27.43
SARDHAI	EARLY PERMIAN	2686.7	109.7
WARCHA	EARLY PERMIAN	2796.4	141.7
DANDOT	EARLY PERMIAN	2938.1	60.96
TOBRA	EARLY PERMIAN	2999.1	51.81
KHEWRA SANDSTONE	EARLY CAMBRIAN	30.50.	78.33
SALT RANGE FORMATION	PRE-CAMBRIAN	3129.2	-------

1.7 Base Map

Base map is a map on which primary data and interpretation can be plotted. The base map is important for interpretation point of view because it shows the spatial location of seismic section and also shows how seismic section is interconnected. It includes location of lease and concession boundaries, wells, and seismic survey points with geographic reference such as latitude and longitude or Universal Transverse Mercator (UTM). Geophysicists typically use shot point maps, which show the orientations of seismic lines and the specific points at which seismic data were acquired, to display interpretations of seismic data.

The base map of the area is generated by using Universal Transverse Mercator (UTM, zone 43N) as a geodetic reference system. The base map given in figure 1.3 shows the orientation of the lines and position of well used for study. The lines under study are

- SOX-PBJ-04
- SOX-PBJ-06
- SOX-PBJ-09

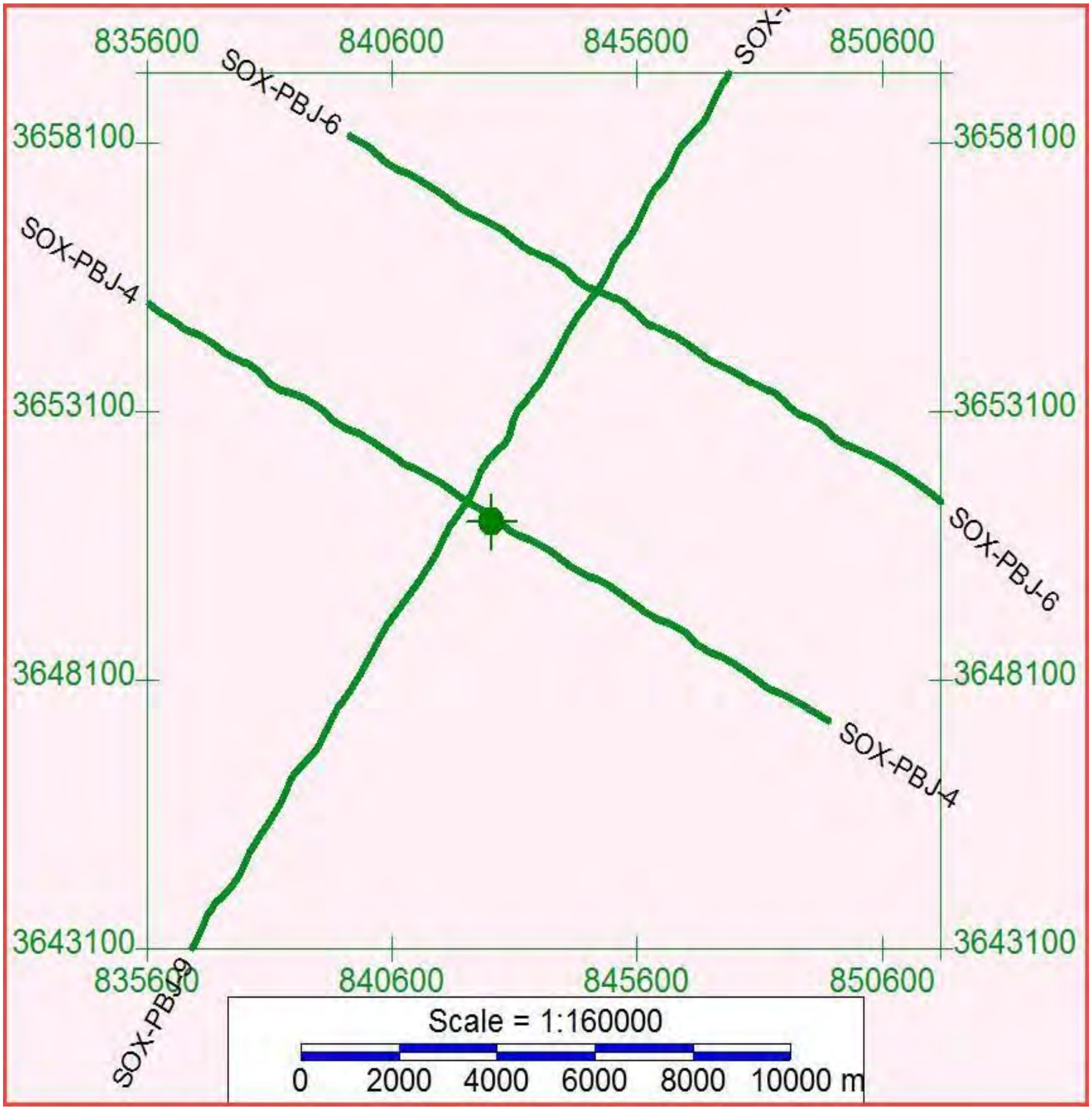


Figure 1.3 2D Base map of Balkassar Area

CHAPTER 02

GEOLOGY, STRATIGRAPHY AND TECTONICS

2.1 Introduction

The information about geology of an area is important part in processing and interpretation of the seismic data. The interpretation of seismic data is based on the stratigraphy and structural geology of an area.

Geological and structural knowledge of the area is a key for interpreter to perform the interpretation of seismic data. The main reason behind is such that, in many cases similar response is obtained from different lithologies and vice versa. To deal with such complexities an interpreter must have background knowledge of geology about the area and its stratification, unconformities and major structures of area under study. If we have no idea about the geological information of an area, we can't recognize the different reflections appearing in the seismic section.

2.2 Structure of The Study Area

Balkassar lies in central part of Potwar Sub-Basin which, in turn, is a piece of Himalayan foreland belt. This structure is situated on the southern limb of Soan Syncline. The Balkassar

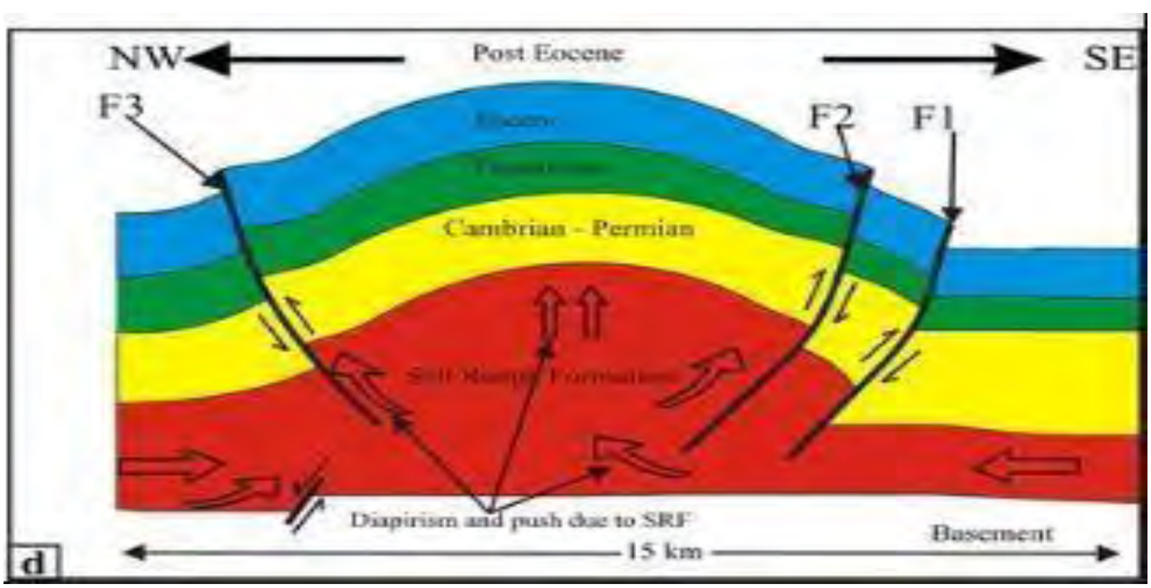


Figure 2.1 Structural Model of Balkassar Area (Iqbal, 2015)

structure is an —anticlinal structures created by both compressional and shear stress regimes. The Eastern flank is bounded by a regional thrust fault. This thrust fault become narrow towards north where a fault bounded syncline plunges into the middle of anticline and hence resulted in its compartmentalization (Iqbal, 2015).

2.3 Faults in Potwar Basin

Some faults in Potwar Basin are given below:

2.3.1 Khair-I-Murat Fault (KMF)

Khair-i-Murat Fault (KMF) is a north-dipping main emergent thrust in the Potwar. Eocene Carbonates of high velocity are thrusted southward over the Molasses of low velocity.

2.3.2 Dhurnal Back Thrust (DBT)

Dhurna Back Thrust had been considered as the eastward extension of the Kanet Fault. It joins the Kanet Fault at the West and extends towards the Southwest. Dhurnal Back Thrust becomes shallower to the South which dies out at a depth of 2 to 4 km.

2.3.3 Kanet Fault (KF)

Kanet Fault is the emerging thrust in the Western part of the Potowar which dip towards North. Kanet Fault bounds the Kanet syncline from the North.

2.3.4 Mianwali Fault (MF)

Mianwali Fault can be traced only in streams. Based on faulted Breccia and Shear zones, Outcrop is present only in steams. Steep dips are exposed, representing the northern Siwalik rocks.

2.3.5 Riwat Fault (RF)

In the eastern Potwar Plateau, Hinterland-dipping fault is Riwat Fault, in South of Soan syncline. Along the Southern flank of the Chak Beli Khan Anticline, Riwat Fault dies out.

2.4 Stratigraphy of The Study Area

Subsurface geological data from wells drilled in Balkassar area indicate the presence of Precambrian-Eco-Cambrian, Cambrian-Permian, Permian-Paleocene, and EoceneMiocene breaks in deposition. Contrary to well data obtained in Rajian; Missa

Keswal and Adhi, Kussak, Jutana and Baghanwala formations were not encountered in Balkassar Oxy01-Well.

In Balkassar area, Permo-Triassic (between Chhidru and Mianwali formations) and Triassic Jurassic (between Kingriali and Datta formations) unconformities occurs which overstep on a Permian-Tertiary (between Sardhi and Hangu formations) composite unconformity. Paleocene sequence comprising of Lockhart and Patala formations. Nmmal, Sakesar and Chorgali formations of lower and middle Eocene age, conformably overlies Paleocene strata.

Rawalpindi Group (Murree and Kamlial formations) with Himalayan provenance was deposited unconformably over middle Eocene Chorgali Formation. Chinji and Nagri formations are present at the top of Miocene molasses sequence in Balkassar area(Chaudhry, 1998).

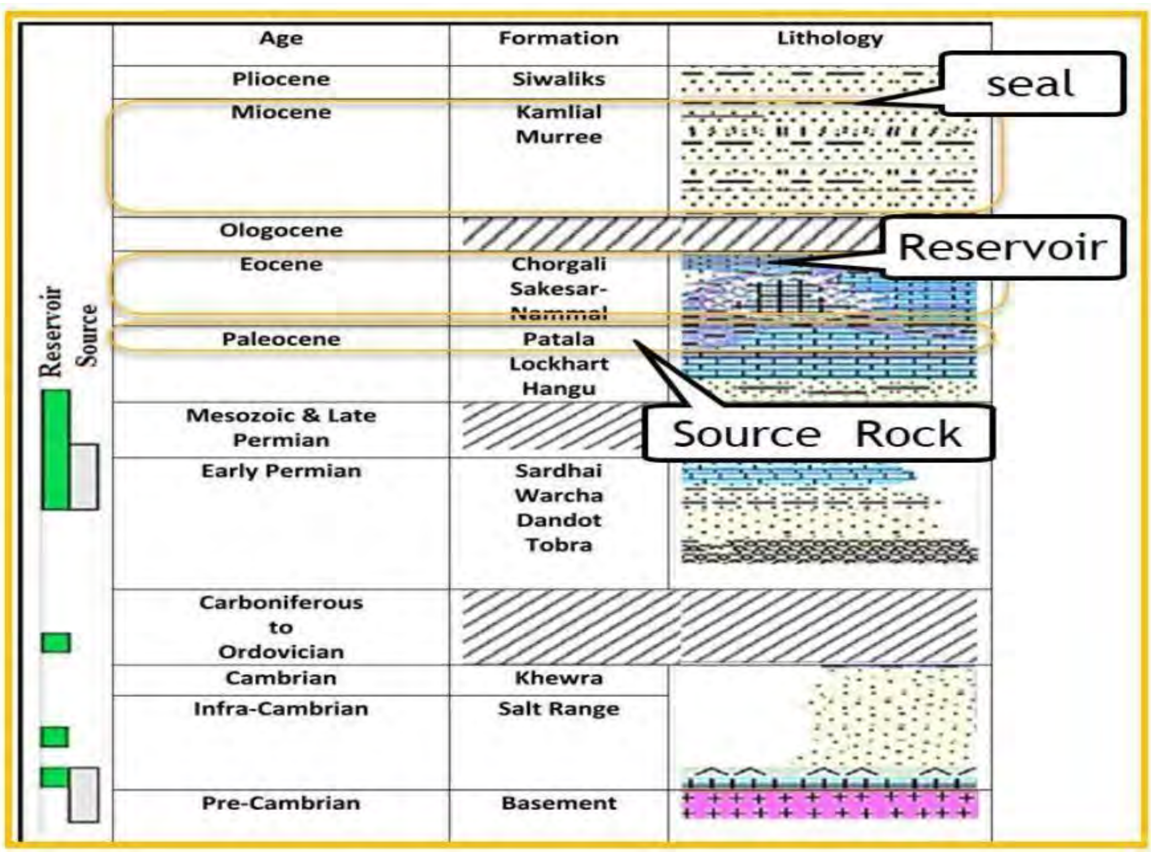


Figure 2.2 Schematic stratigraphic column of the study area (Chaudhry, 1998).

2.5 Petroleum System

Petroleum System of the study area comprises of:

2.5.1 Source Rock

These studies of the area suggest that the organic-rich shales of the Paleocene (Patala Formation) can be considered as the main source rock in Potwar Basin. In Potwar Basin, Patala shales of Paleocene have proven as the main source rocks. Pre-Cambrian Salt Range Formation also contains oil shales, which have source rock potential (Khan & Ahmad, AAPG Bulletin, 1986).

2.5.2 Reservoir Rocks

Paleozoic-Tertiary dominantly marine sedimentary rocks which includes the cracked carbonates of Sakessar and Chorgali Formations are the major generating repositories in Balkassar. The limestones of the Paleocene Patala Formation also contain good reservoirs of hydrocarbons.

Khewra Formation is the main potential Cambrian reservoir. Khewra Formation is generally divided into three units. The basal unit consists of thin bedded, partly shaly, fine to medium grained sandstone with thin clay beds.

The upper and middle units of the formation contain sandstone which is moderately porous and display intergranular primary porosity. This sandstone has excellent reservoir nature (Khan & Ahmad, AAPG Bulletin, 1986).

2.5.3 Seal rock

The clays and shales of the Murree Formation additionally give effective vertical and horizontal seal to Eocene reservoirs (Chorgali & Sakessar) of the Potwar-Foreland Basin (Khan & Ahmad, AAPG Bulletin, 1986).

CHAPTER 03

SEISMIC INTERPRETATION

3.1 Introduction

The geophysicist deals with the seismic section. Seismic methods are physical measurements performed at the surface, which are then interpreted in terms of the surface, position, and behavior of the interfaces. In seismic interpretation, each reflection event being then calculated from their time of arrival. The resulting information is then combined in cross-section, which represents the structure of the geological interfaces responsible for the reflection of seismic waves. These seismic waves carry information about the rock interfaces.

Seismic interpretation and subsurface modeling are key skills used in oil industry. It is used to generate model and predictions about the properties and structure of subsurface. Seismic data interpretation has objective to get or extract all subsurface information from the processed seismic data. Conventional seismic interpretation involves the collection and monitoring of laterally coherent seismic reflectors for the purpose of mapping geological structures, stratigraphy, and reservoir architecture. The goal is to detect the accumulations of hydrocarbons and to delineate their extent.

3.2 Methods of Interpretation

Interpretation is a tool for transforming all seismic information into a structural or stratigraphic 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 area of final anomaly.

There has been considerable progress in data acquisition equipment, computer hardware and seismic processing algorithms in recent past times.

There are two main approaches to the interpretation of seismic sections:

- Structural Interpretation
- Stratigraphic Interpretation

3.2.1 Structural Interpretation

This type of analysis is very appropriate in the case of Pakistan, as most hydrocarbons are extracted from structural traps. It is the study of the geometry of the reflector based on the reflection time. The main application of the structural analysis of the seismic section is the search for structural traps containing hydrocarbons. Most structural interpretations use two way reflection times rather depth and time structural maps are constructed to display the geometry of selected reflections events. Some seismic sections contain images that can be interpreted without difficulty. Discontinue reflections clearly indicate faults and undulating reflections reveal folded beds. (Telford et al., 1990).

3.2.2 Stratigraphic interpretation

Seismic stratigraphy is used to find out the depositional processes and environmental settings, because genetically related sedimentary sequence normally consists of concordant strata that show discordance with sequence above and below it. It also helps to identify formations, stratigraphic traps, and unconformity. This method also facilitates for the identification of the major progradational sedimentary sequences which offer the main potential for hydrocarbon generation and accumulation Stratigraphic analysis therefore greatly enhances the chances of successfully locating hydrocarbon traps in sedimentary basin environment.

Structural interpretation usually includes the identification

- Horizons
- Faults and Folds

3.3 Workflow

The basic workflow for the interpretation of seismic data is preparing a base map by loading Navigation data and SEG-Y in software. Horizons of interest are marked manually. Faults are identified and marked on the basis of criteria for the recognition of discontinuities. Faults polygons are generated, and horizons are contoured to find out structural highs and lows. Then time-depth contour maps of mark horizons are built to show the geometry of chose reflection events. Figure 3.1 shows the step used for seismic interpretation.

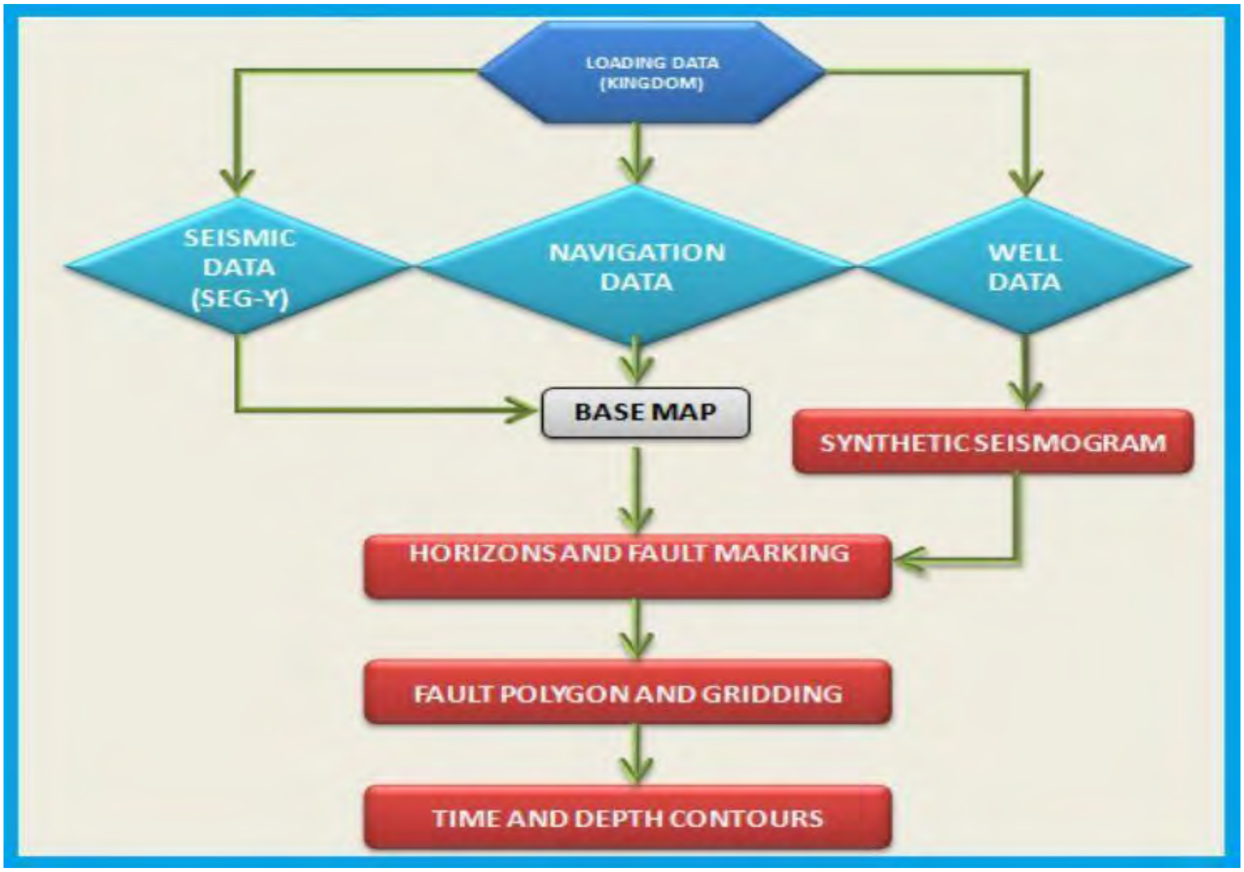


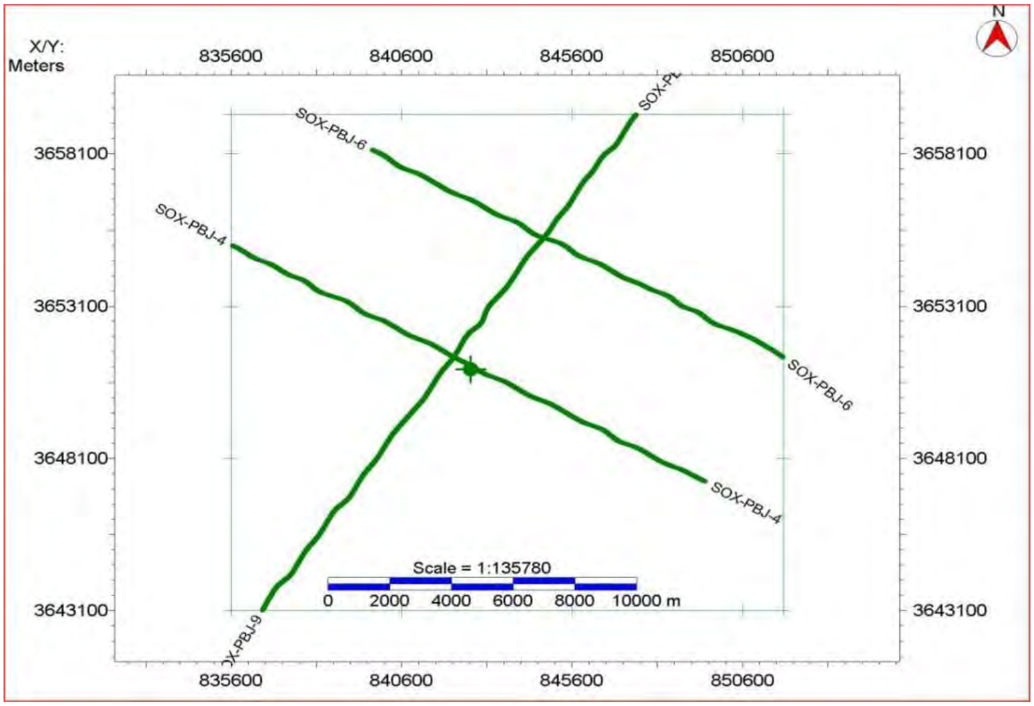
Figure 3.1 Workflow adopted for the seismic data interpretation

3.4 Base Map

After loading the Navigation file and Seismic data (SEG Y), Base map is generated.

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

- PBJ-04 (Dip Line)
- PBJ-06 (Dip Line)
- PBJ-09 (Strike Line)



✦ Figure 3.2 2D Base map of Study Area

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 Balkassar OXY-01 A the synthetic seismogram was constructed in order to mark the horizons. The following steps are adopted during the Generation of the synthetic seismogram using the IHS kingdom.

- ✦ Open 1D forward modeling Project and select the well logs.
- ✦ Load all the information of the well in the software.
- ✦ Load UWI,,KB, Total Depth, Latitude and Longitude of the well.
- ✦ Load the Las file of the well.
- ✦ Create a TD chart for the well from the velocity logs ✦ Load the TD chart of the well.
- ✦ Load the formation tops of the well.

The following process of synthetic seismogram is done by Software automatically, so we explain it manually that how it works.

- Integrate the DT log to rescale from depth in meter to two-way travel time in Sec
- ✦ Compute Acoustic impedance log using velocity and density log.
- Compute the reflection coefficients from the time-scaled velocity log.
- Compute extracted wavelet as a digital filter with two ms increments.
- Two-way travel time; using a frequency in Hertz.
- Convolve the reflection coefficient log with the extracted wavelet to generate the amplitudes of the synthetic seismogram.

Now the generated seismogram is used to confirm the horizon .Basically we have the limited log data only Balkassar OXY-01 A is the only well in our available data that having the DT and ROHB log to generate the synthetic seismogram. Hence from the well data the generated synthetic seismogram confirms the formations. The display of the synthetic seismogram is shown in the Figure 3.2

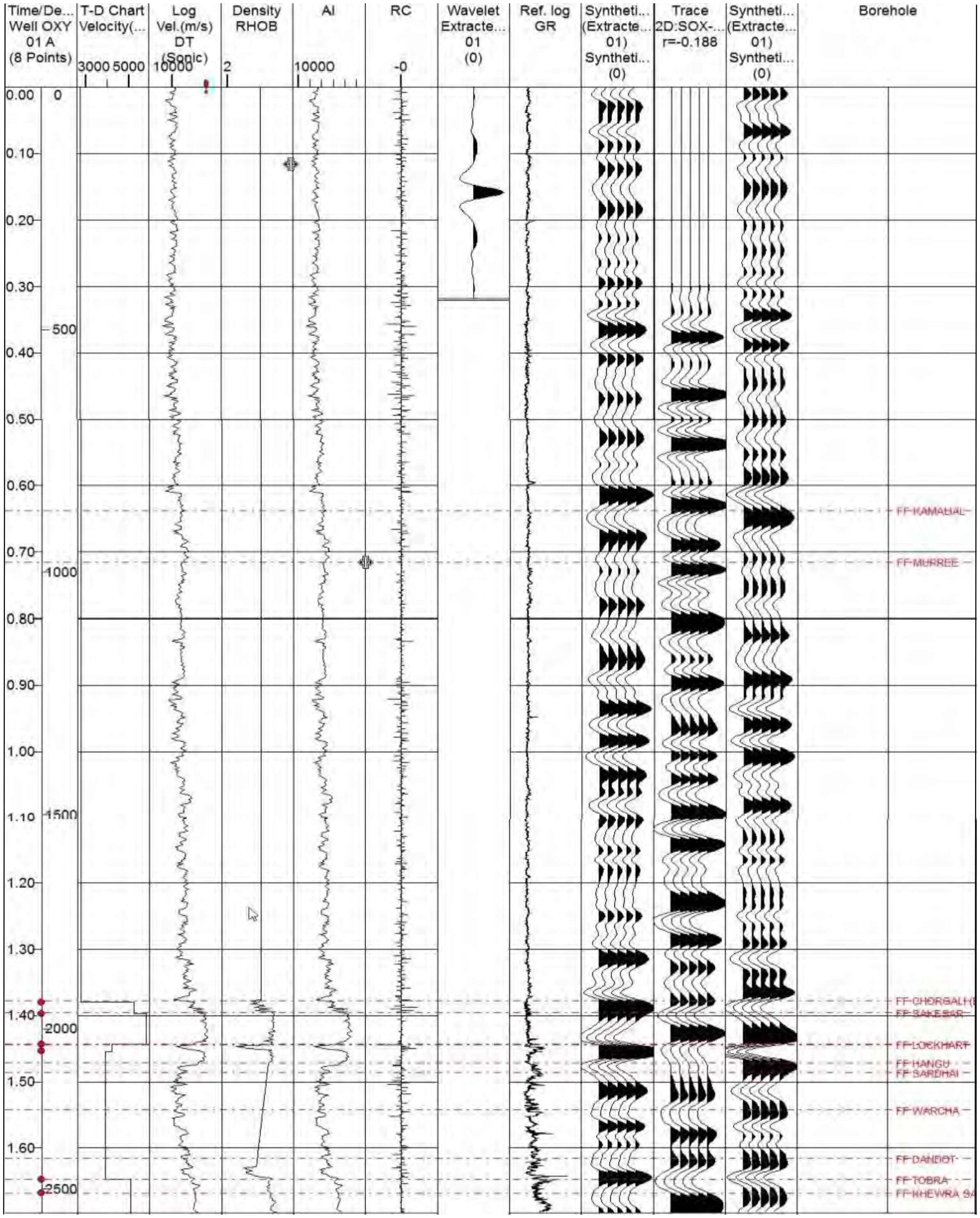


Figure 3.3 Synthetic Seismogram of Well OXY 01

3.6 Seismic to well tie

Well to seismic tie involves comparing the seismic data which is in time domain with well da indepth domain. An accurate synthetic seismogram is the key for performing well to seismic tie. Synthetic seismogram confirms our hypothesis and identifies horizons of interest Polarity either positive or negative so, seismic to well tie is important for the accurate picking of horizons.

3.7 Structural Interpretation of Blakassar Area

Seismic survey is conducted to acquire data for subsurface analysis, to know structural patterns in the subsurface. Seismic interpretation of Balkassar area involves ten seismic lines. While interpreting these seismic lines, it is observed that these seismic lines showing structural changes. These structures are results of compression forces as it falls in the compressional regime or due to Salt diapirism. Mostly the structures present in this area are folds and thrust faults along with triangular zones and pop-up structures.

Tie the synthetic seismogram with the Seismic line, on which well is located (SOX-PJB 4). Seismic data is provided in time scale and well tops are given in depth so we cannot mark horizons in time form.

So, the purpose of generation of synthetic is to find two-way travel time against each depth for marking of horizons. With the help of synthetic seismogram two horizons were marked on this line. Tie marked Seismic with other lines and horizons are marked on these lines. During tie lines mistie shift is applied.

I have been assigned with two dip and one strike line which are interpreted in following sections.

3.7.1 Marking Faults

Over all four faults are marked on the seismic section which indicates the complexity of study area. These are marked on observing the sudden change in the position of the reflectors and distortion or disappearance of the reflection below the faults. All the faults are not basement rooted that gives some indication of thin skin tectonic involvement in the study area but one; the normal faulting is present in basement. These faults indicate that Balkassar is a structurally disturbed area and anticline 'pop up' structure is present bounded by F1 and F2.

Table 3.1 Fault name and its type

FAULT NAME	FAULT NATURE
F1	REVERSE
F2	REVERSE
F3	REVERSE
F4	NORMAL

3.7.2 Marking Horizons

Primary task of interpretation is the identification of various horizons as an interface between geological formations. For this purpose, good structural as well as stratigraphic knowledge of the area is required.

Horizons are marked on the time section on the basis of synthetic seismogram, well tops and prominent reflection. Four horizons are picked on the basis of available information (Well tops and synthetic seismogram of Balkassar OXY-01 has been used in this dissertation). Horizons names are assigned on basis of well tops of the well BALKASSAR_OXY_1. The following horizons were picked:

- Murree Formation
- Chorgali Formation
- Sakesar Formation
- Basement Formation

Sr.No	Formation name	Top(m)	Marking Color
1	Murree	2421,5	Orchid
2	Chorgali	2467.2	Cyan
3	Sakesar	2602.9	Green
4	Basement	3239.7	Tan

Table 3.2 Marked Formation and horizon color

3.8 Interpretation of Seismic Lines (Dip and Strike)

3.9 Interpretation of Dip line PBJ-04

Line SOX-PBJ-04 is a dip line which are NW-SE oriented and it is our major control line as the Balkassar-oxy-01 is located on it. Murree, Chorgali, Sakesar and Patala are marked on these lines which are terminated by reverse faults and formed the pop-up structure; while Basement is terminated by the normal fault which is may be the result of Permian rifting. Balkassar anticline is bounded by two thrust faults, one is in the SE direction which is leading thrust and second one is in the direction of NW which is back thrust. Due to the increase effect of strike slip behavior of thrust faults near Jhelum fault or may be due to salt diapirism, pop-up structure is forming the saddle type structure as figure shows.

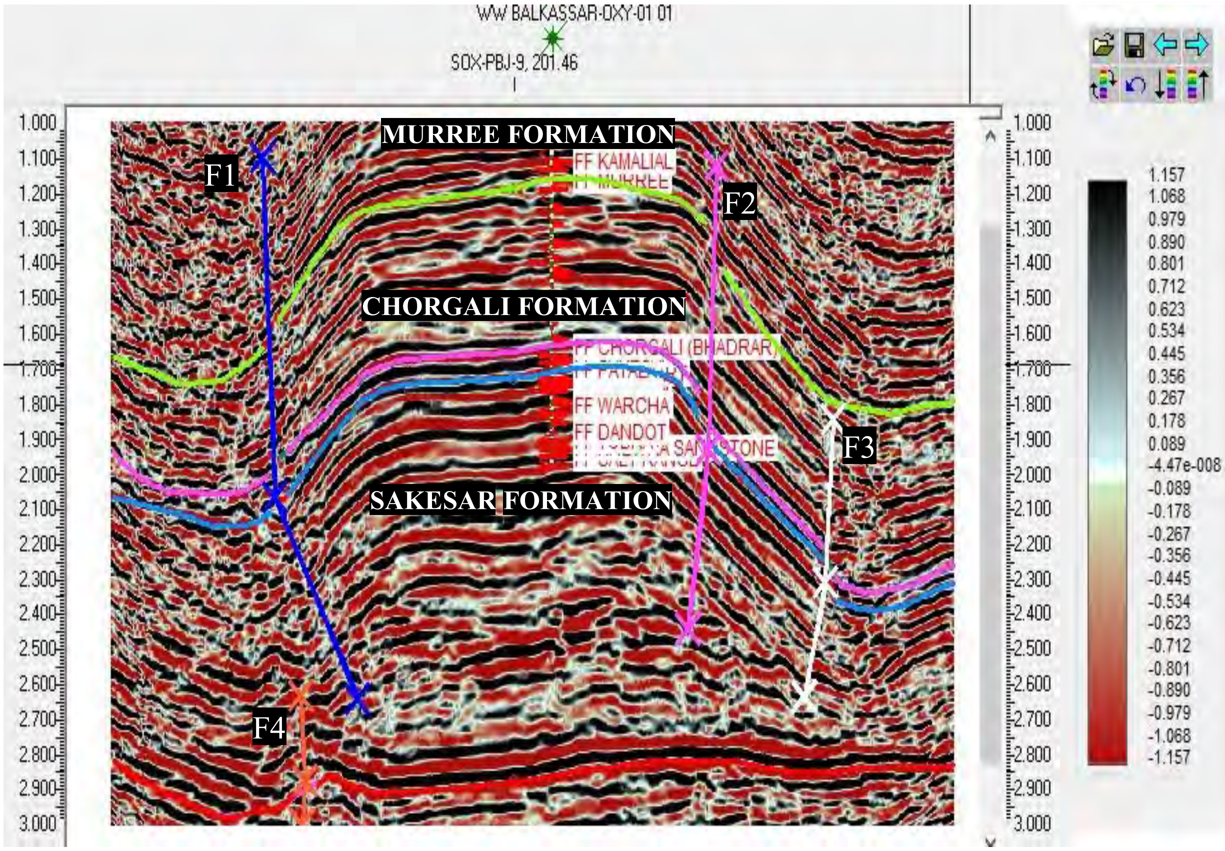


Figure 3.4 Interpretation of seismic Dip line PBJ-04

3.9.1 Interpretation of Strike line SOX-PBJ-09

PBJ-09 is a SW-NE strike-oriented line. Control is transferred to it from PBJ-04. It passes through the crest of the Balkassar anticline, no major structure was found and simple straight horizons were marked because the strike line was parallel to the faults and no fault cut the strike line.

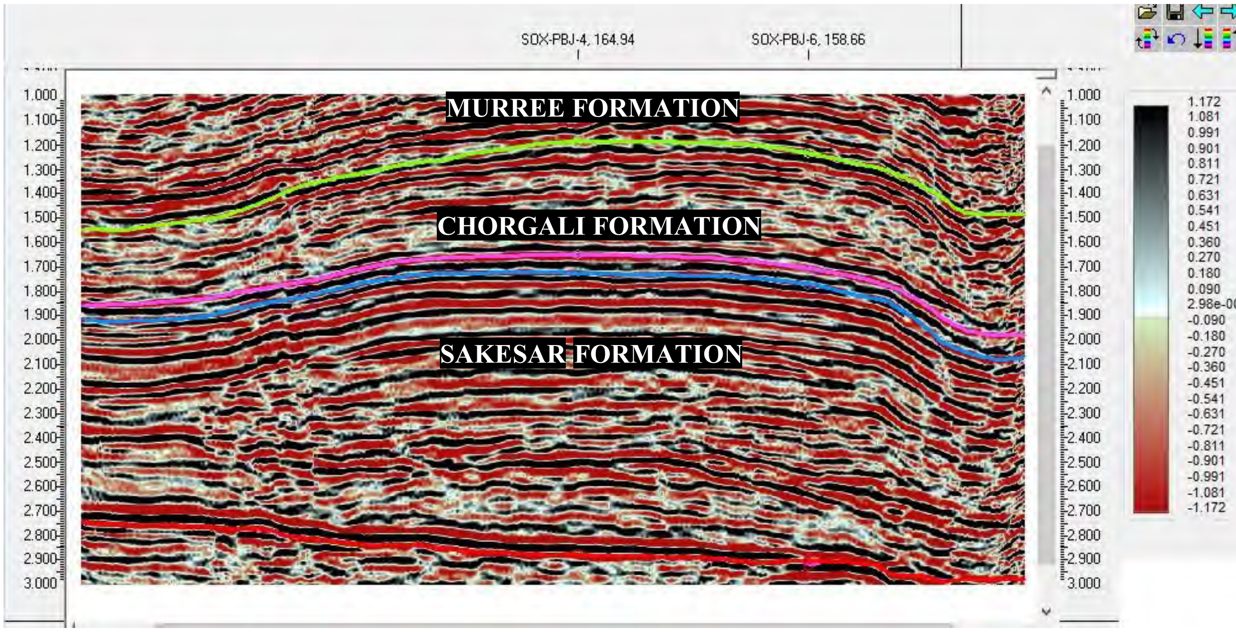


Figure 3.5 Interpretation of seismic Strike line PBJ-09

3.9.2 Interpretation of dip line SOX-PBJ-06

Similarly, control is transferred to PBJ-06 from PBJ-09. It is SE –NW dip-oriented line but it lies to the north most out of these lines so in this region the tectonic forces are much intense. so, same extension of faults are found here (F1, F2,F3,F4),that represent the anticline "pop up" structure and normal faulting observed in Basement. Dip of the faults is almost same. Due to High tectonic forces one feature is observed here that not found in seismic line of PBJ-04 that is structure narrow down and fault bounded syncline plunge appear in the middle of the anti-cline which results in compartmentalization.

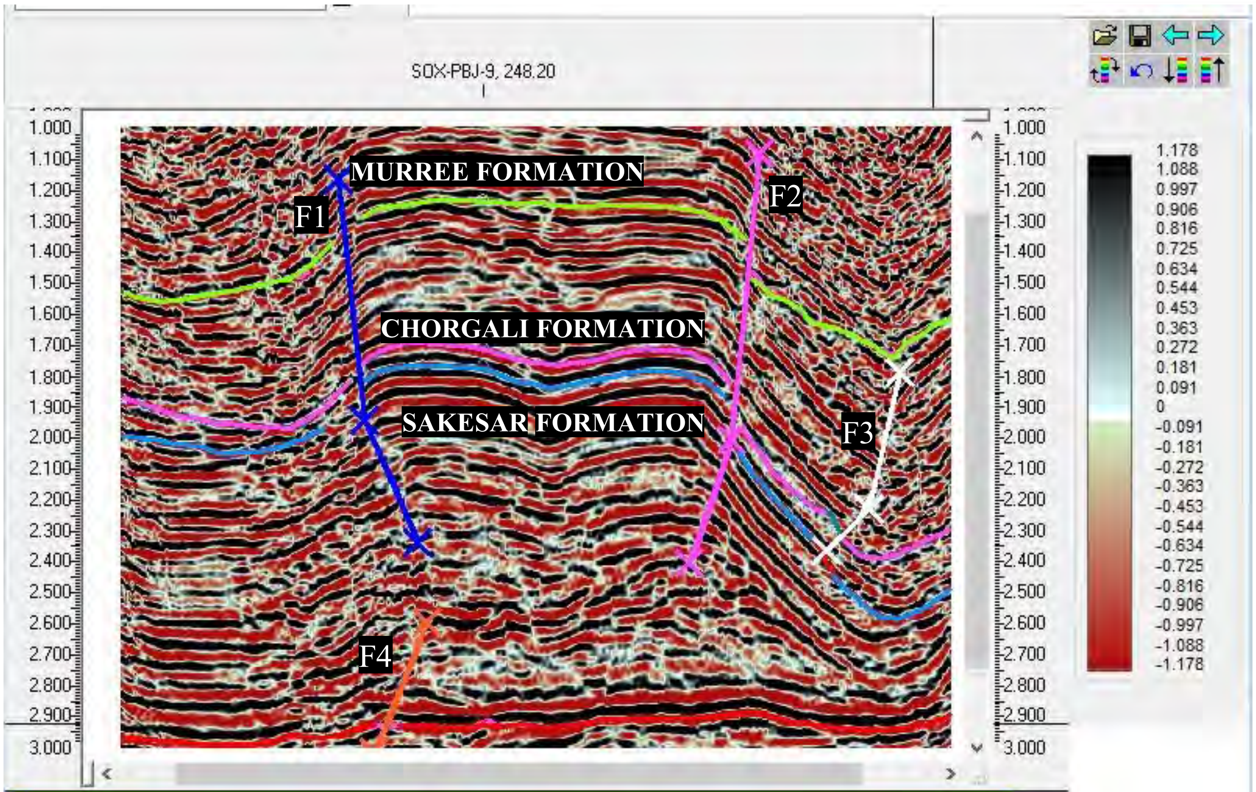


Figure 3.6 Interpretation of seismic Dip line PBJ-06

3.10 Fault polygon

The fault in seismic section is called Fault Segment and the fault on map view is called Fault Polygon (Sroor, 2010). A fault polygon represents the lateral extent of dip faults or strike faults having same trend. Contouring without fault polygon does not represent the clear picture.

In any software for mapping an area the fault should be converted into fault polygon before the contouring. If we do not convert them into fault polygon then the software will not recognize the fault and will not break the contour at the fault location and a wrong picture of the earth will be generated. I construct the fault polygon at Chorgali and Sakesar because both act as a reservoir.

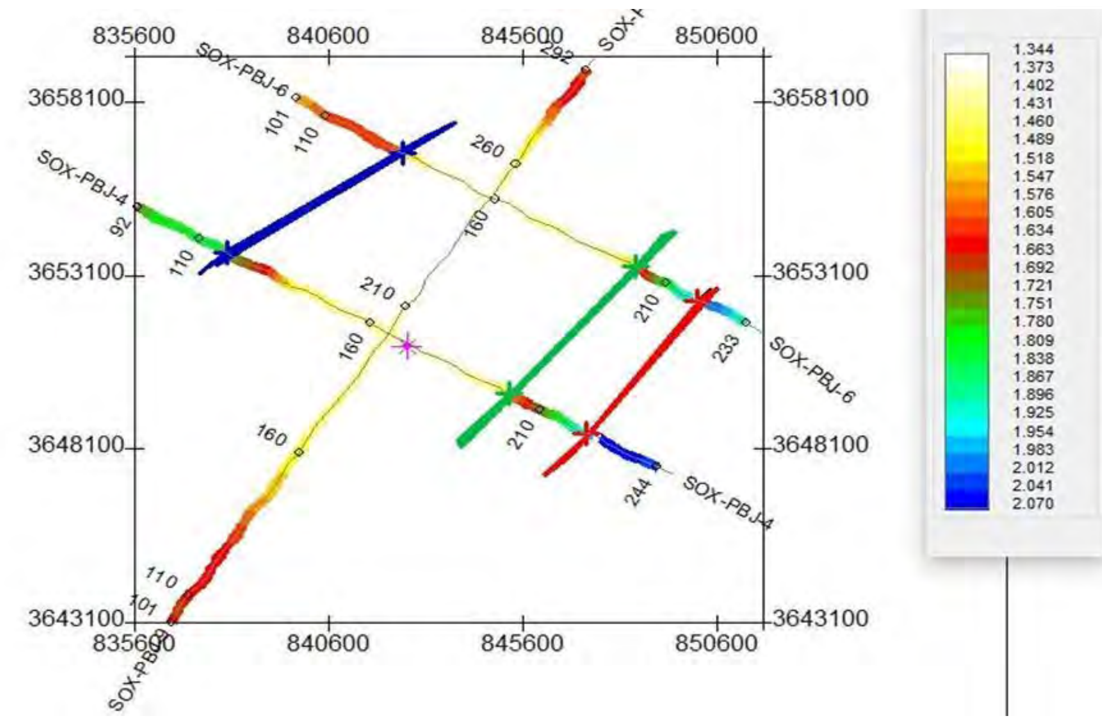


Figure 3.7 Fault Polygon of Murree formation

3.11 Contour Map

The result of seismic data interpretation is typically presented in the form of contour maps of time and depth. Mapping is that part of the interpretation of the data, on which the whole operation depends for its utility. Contours are lines of equal duration or depth roaming around the map as dictated by the data (Coffeen, 1986). Space of the contour lines is a degree of the slope steepness i.e. nearer the spacing, steeper the slope. Contour maps tell the gradient of the formation, structural style of the formation, faulting, folding etc.

3.11.1 Time and Depth contour models

The seismic section is originally a time section and the reflection time values are in milliseconds by plotting the values at an appropriate Common Depth Point (CDP) interval and plot these values on the map. The purpose of time-to-depth conversion is to transform the subsurface time map derived from seismic horizon interpretation to an accurate depth map in which the vertical and horizontal positions as well as the size of the subsurface structure can possibly estimate.

Conversion from time to depth contour is by using the average velocity of the area. Actually, I used the interval velocity but due to limitation of data I can 't use it so I used the average velocity to convert from time to depth by using formula:

$$s = vt \qquad (1)$$

3.11.2 Time and depth contour maps of Murree

Time and depth contour map of Murree formation is shown in figure 3.8 and 3.9. Time and Depth variation is given through color bar. Red color shows the lowest values i.e. shallowest part while the dark blue and black color is showing deeper parts. Murree is deepening NW-SE direction as the time is increasing and Murree formation is shallowing towards NE-SW direction because time is decreasing. Hence the red color is showing low time values and it is a good indicator for hydrocarbon.

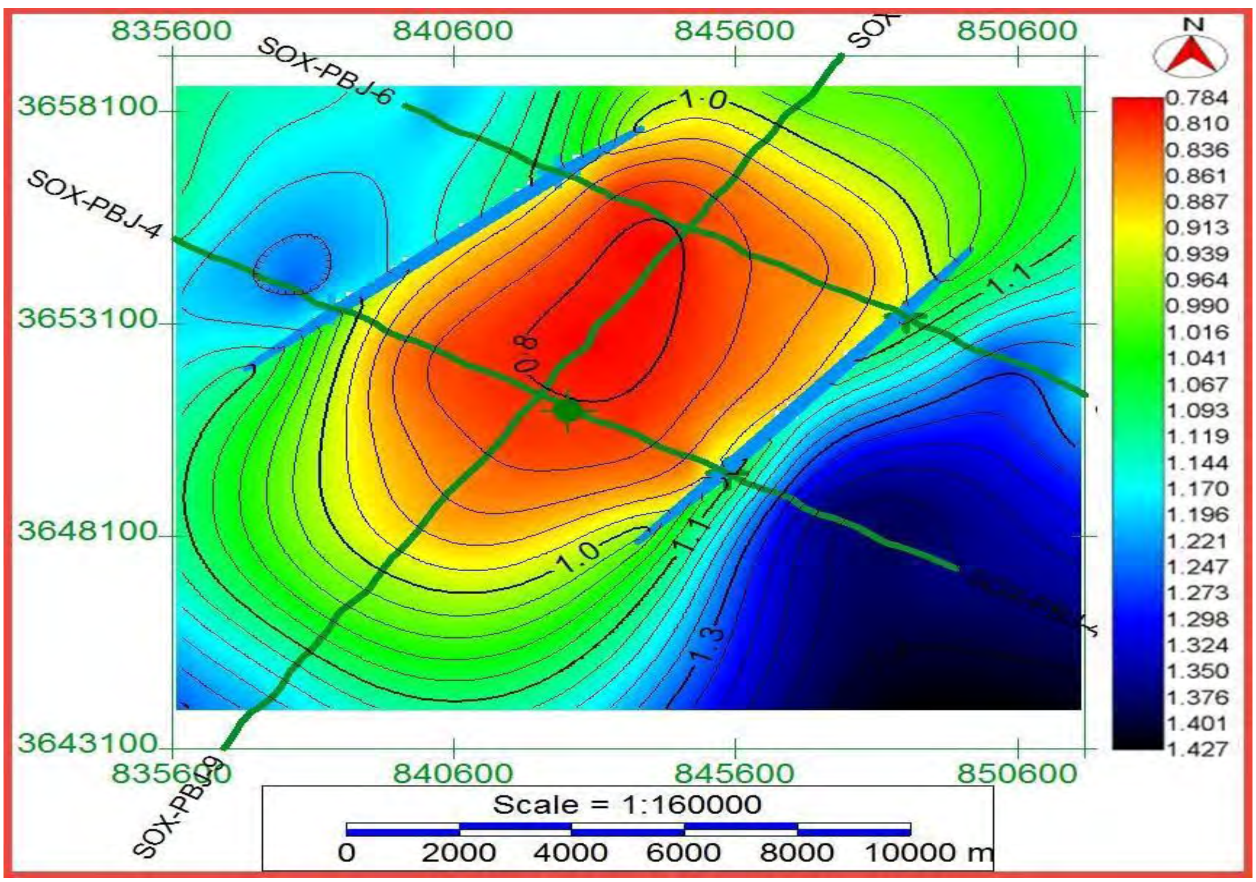


Figure 3.8 Time Contour map of the Murree Formation

Contour interval for time section is 0.04 sec while depth contour interval is 40m. In time and depth contour maps, the red color ranges, for time section is from (0.784sec- 0.897sec) while for depth it ranges from (939m-1087m) showing the shallowest parts. While dark blue color for time section ranges from (1.212sec-1.369sec) while for depth it ranges from (1641m-1900m) showing deeper parts.

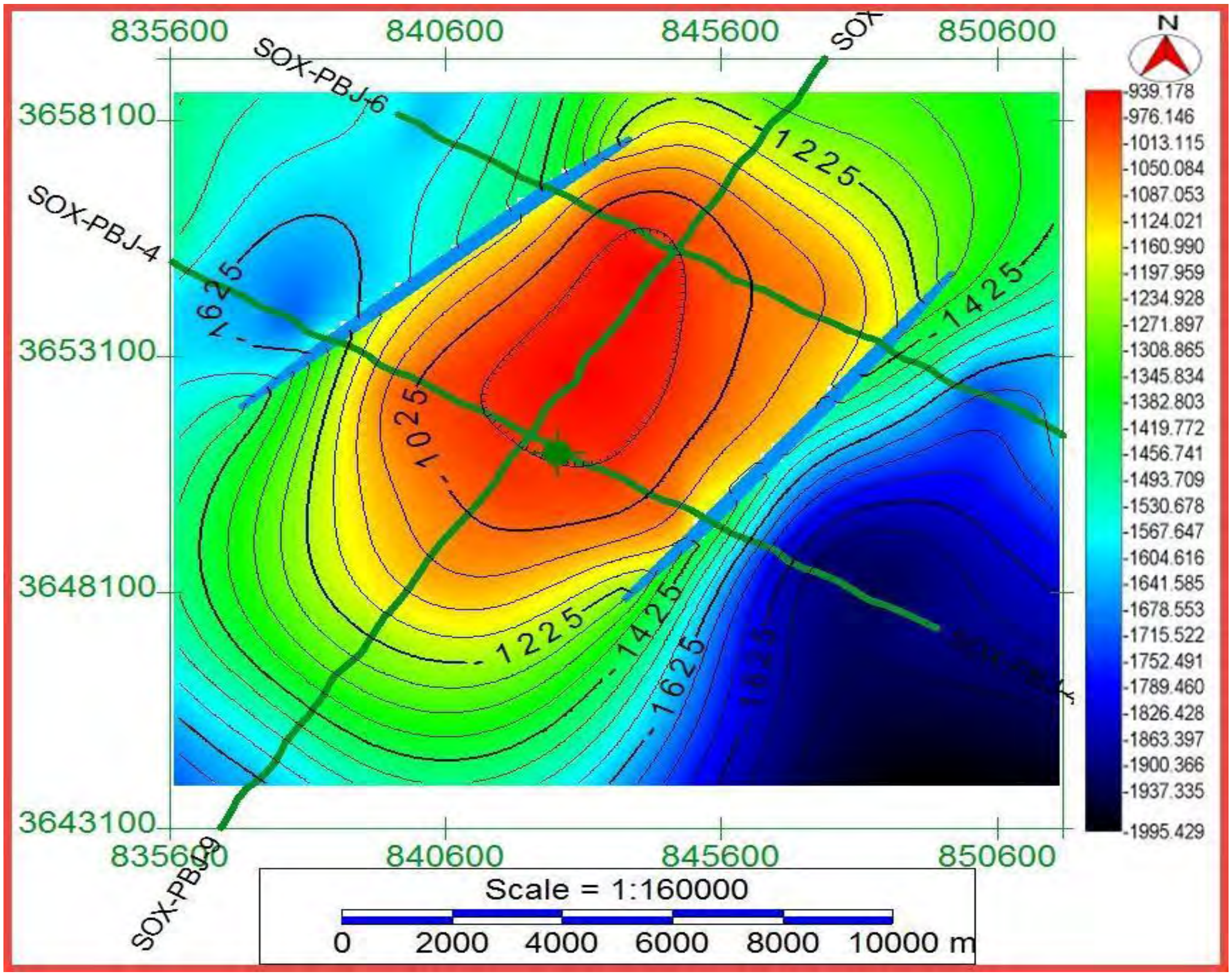
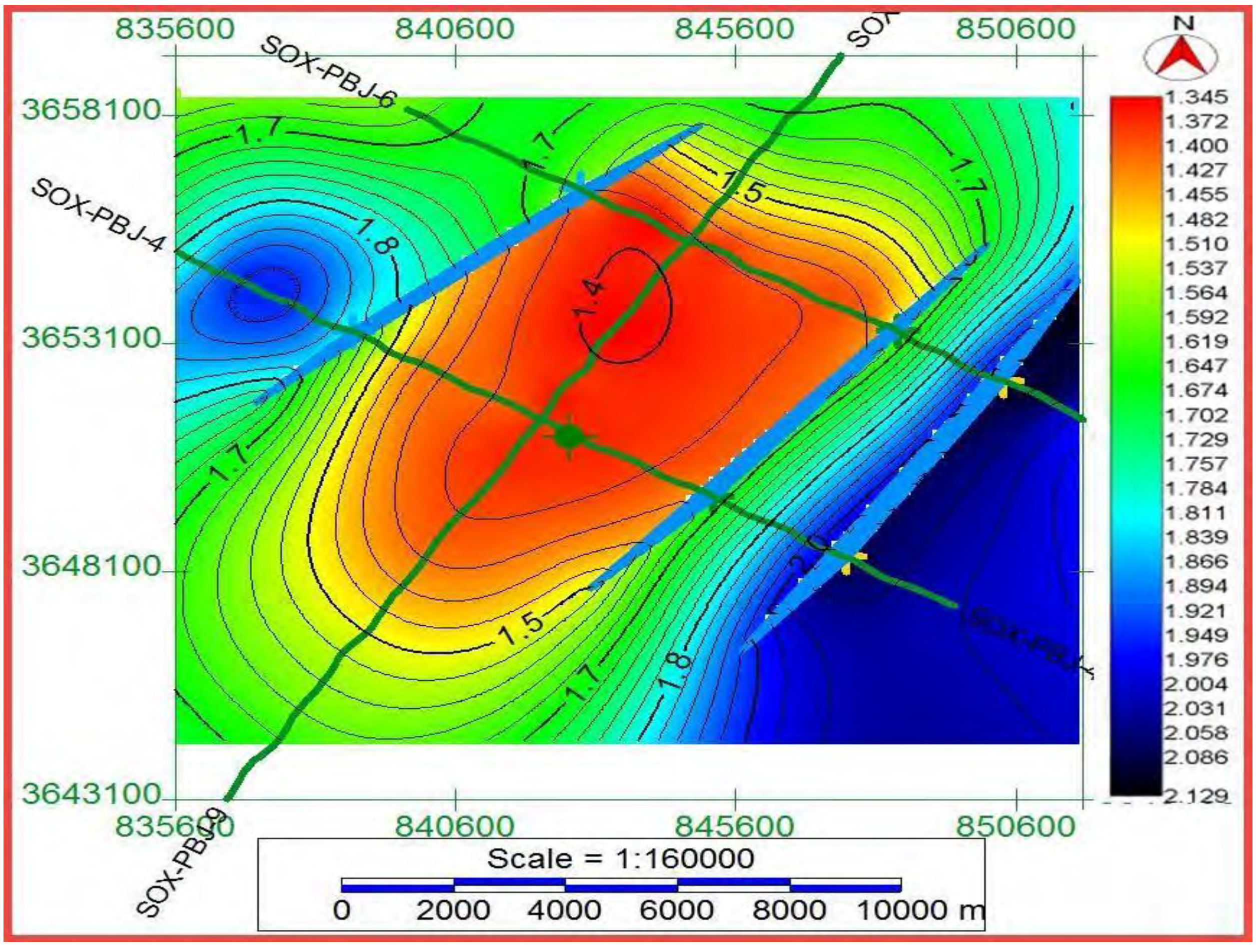


Figure 3.9 Depth Contour map of the Murree Formation

3.11.3 Time Contour map of Chorgali

Chorgali is primary zone of interest; it is oil and gas producing and is composed of limestone with some shale content. Two way travel time (time Contour) map of Chorgali formation is shown in figure 3.10.It depicts the NE-SW oriented Balkassar anticline on the basis of time variation ranges from 1.345 to 2.129 seconds. Central Portion of contour map bounded by F1 and F2 represented by red color whose time value ranges from 1.345 to 1.455 seconds, is shallowest portion while deeper part is represented by blue and black color with time value ranges from 1.894 to 2.129 second.

Contour interval is 0.02 sec Chorgali formation deepening towards NW-SE where time value increases while formation is shallower towards NESW direction. Reverse fault F1 and F2 are dipping towards each other that completely describe the anticlinal feature so, our possible lead area can be mark at the peak point showing by red color (1.345-1.427).



*Figu*re 3.10 Time Contour of Chorgali Formation

3.11.4 Depth contour map of Chorgali Formation

Figure 3.11 shows depth contour map of Chorgali formation. Their structural variation is discussed through color bar and legends. Red color shows the shallowest portion and dark blue and black color represent the deepest portion with contour value ranges from 1841m to 3119 m. Color bar shows the depth with negative value that describe that our study area exists below mean sea level.

Shallowest portion bounded by F1 and F2 that completely indicate the presence of anticline “pop up” structure. It is clear from Fig that the Chorgali formation is deepening NWSE direction as the depth is increasing in this direction, while formation is shallower towards NE-SW because depth is decreasing in this direction. Red color shows the crest point that may our possible lead area.

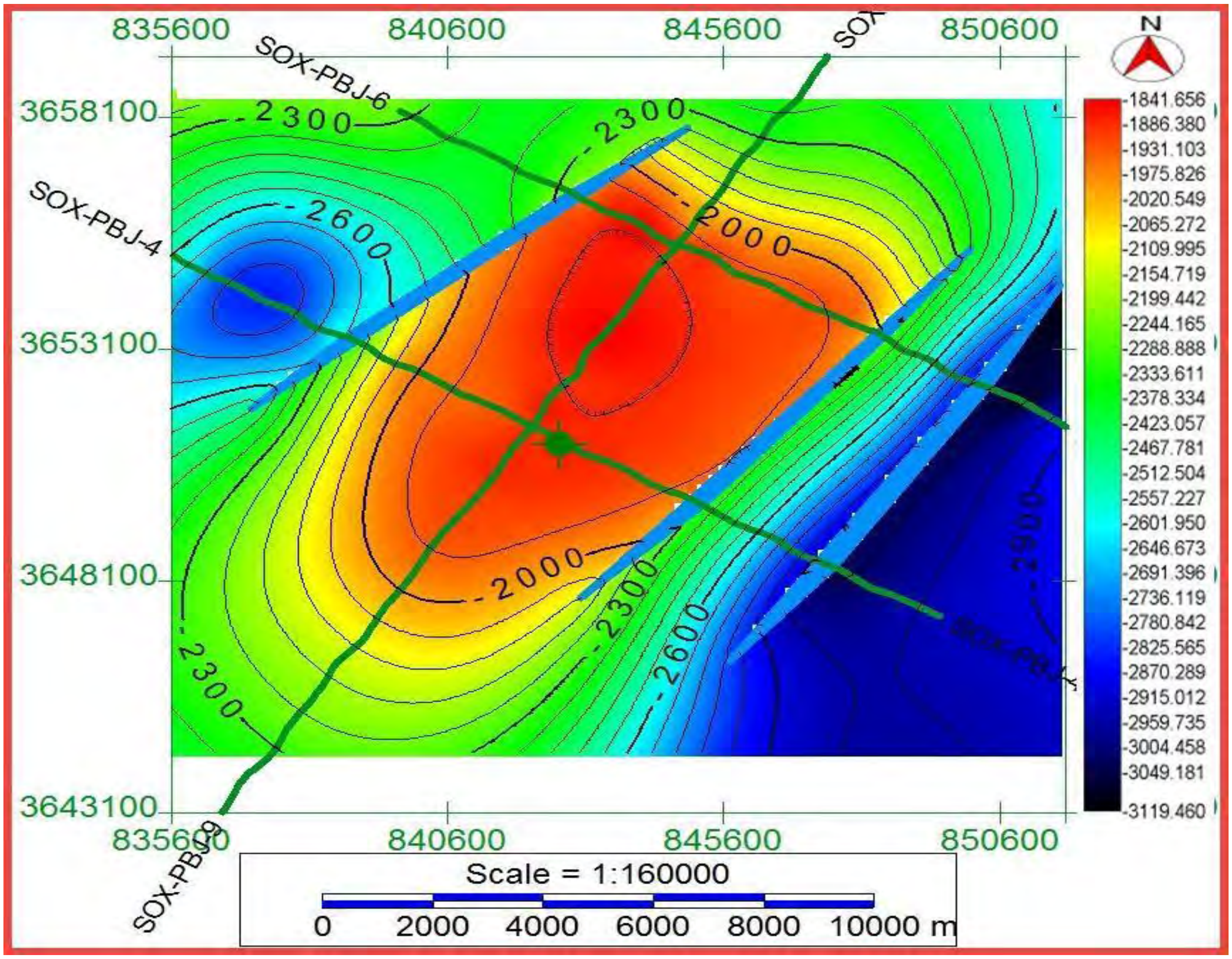


Figure 3.11 Depth Contour map of Chorgali Formation

3.11.5 Time and depth contour maps of Sakesar

Time and depth contour map of Sakesar formation is shown in figure 3.12 and 3.13. Time and depth variation is given through color bar. Red color shows the lowest values i.e. shallowest part while the dark blue and black color is showing deeper parts. Sakesar is deepening NW-SE direction as the time is increasing and Sakesar formation is shallowing towards NE-SW direction because time is decreasing. Hence the red color is showing low time values and it is a good indicator for hydrocarbon. Contour interval for time section is 0.02 sec while depth contour interval is 60m. In time and depth contour maps red color ranges from (1.406sec-1.515sec) for time contours while for depth contour it ranges from (1897.409m-2071.498m) showing the shallowest parts. While dark blue and black color ranges from (1.978sec-2.184sec) for time contours while for depth it ranges from (2767.854m-3149.901m) showing deeper parts.

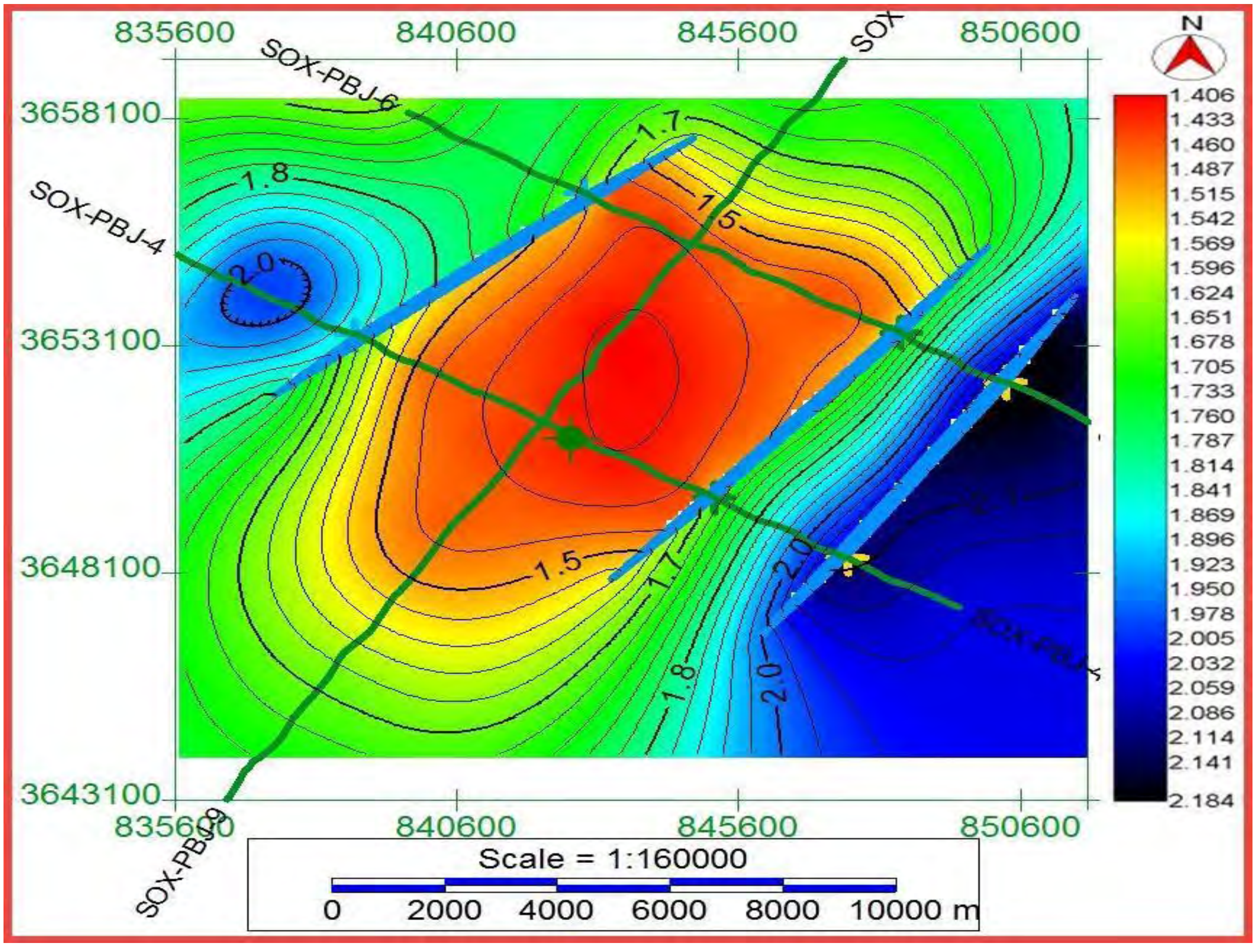


Figure 3.12 Time Contour map of Sakesar Formation

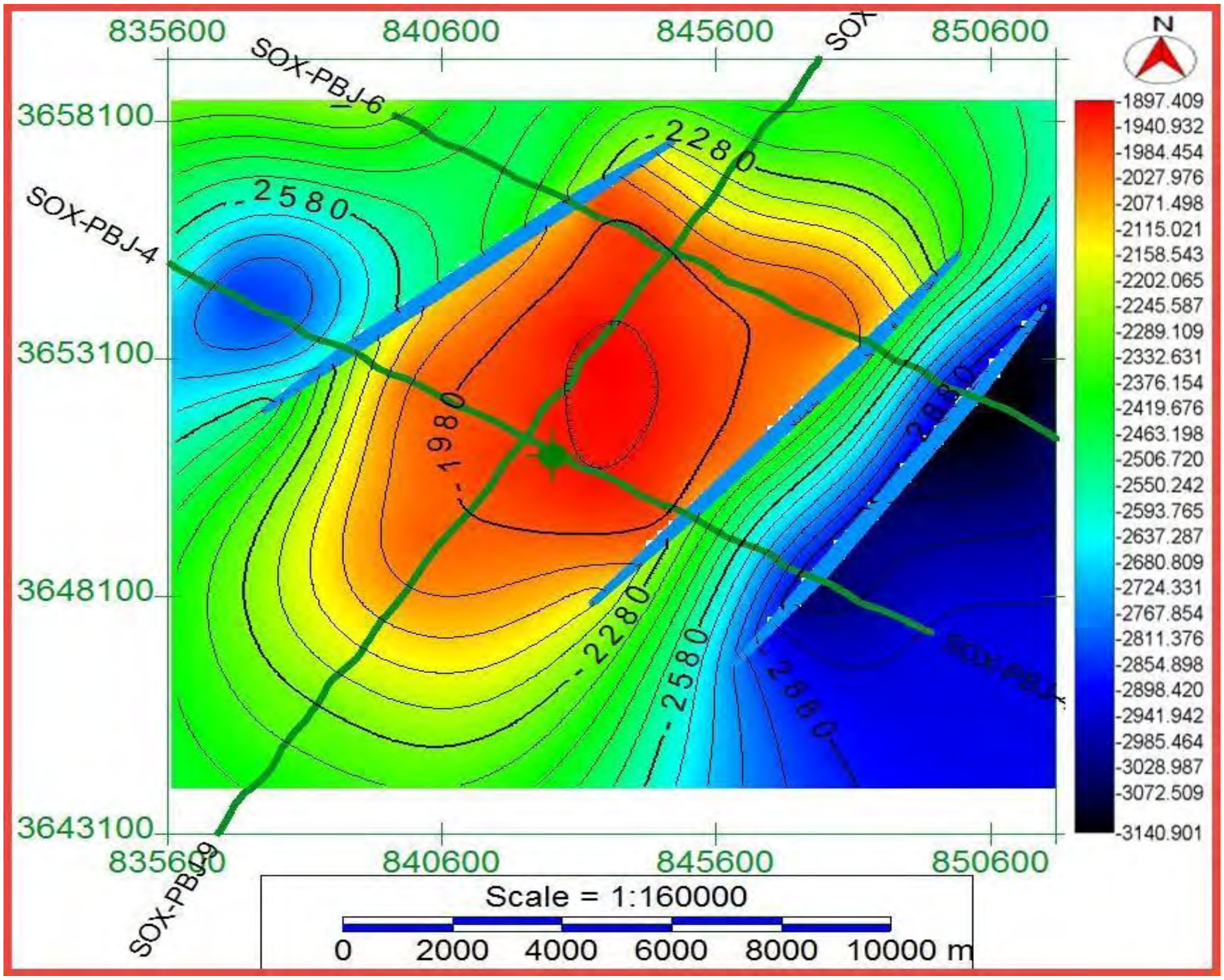


Figure 3.13 Depth Contour map of Sakesar Formation

CHAPTER 04

PETROPHYSICAL ANALYSIS

4.1 Introduction

Petrophysics is the study of the physical and chemical properties that describe the occurrence and behavior of rocks, soils and fluids. Petrophysicists evaluate the reservoir rock properties by employing well log measurements, core measurements and seismic measurements, and combining them with geology and geophysics (Paal Fristad, 2012).

It is mainly used in the hydrocarbon industry to study the behavior of different kinds of reservoirs. It also explains about the chemistry of pores of the subsurface and how they are connected. It helps in controlling the migration and accumulation of hydrocarbons. While explaining the chemical and physical properties, petrophysics also explains many other related terms such as lithology, water saturation, density, Irreducible water saturation, Hydrocarbon saturation, Net pay thickness, permeability, and porosity and many more.

The key role of petrophysics is to evaluate the rock properties by placing measurement tools in the bore hole. It is classified into two major parts namely:

- Rock mechanical properties
- Conventional Petrophysical properties

4.2 Reservoir Petrophysical Properties

Most Petrophysicists are employed to compute what are commonly called reservoir Petrophysical properties. These are:

4.2.1 Lithology

Lithology indicate the type of rock. When combined with local geology and core study, geoscientists use log measurements such as natural gamma, neutron, density, Photoelectric, resistivity or their combination to determine the lithology down the hole.

4.2.2 Porosity (ϕ)

The porosity is the amount of pore (or fluid occupied) space in the rock. This is typically measured using an instrument that measures the reaction of the rock to bombardment by neutrons or by gamma rays. Sonic wave speed and NMR logs are also run to derive rock porosity.

4.2.3 Water Saturation (SW)

The fraction of the pore space occupied by water is called water saturation. Water saturation is measured by running the resistivity log in the well.

4.2.4 Hydrocarbon Saturation

The fraction of the pore space occupied by hydrocarbon is called hydrocarbon saturation. This is typically measured by subtracting the water saturation from one.

4.2.5 Net Pay

Thickness of rock that can deliver hydrocarbons to the well bore at a profitable rate is called net pay.

4.3 Given Data

- Gamma Ray (GR)
- Spontaneous Potential (SP)
- Caliper Log (CALI)
- Velocity (DT)
- Density (RHOB)
- Neutron Porosity (NPHI)
- Deep Laterolog (LLD)
- Shallow Laterolog (LLS)

Basic scheme which has been followed for petrophysical well logging is shown in figure (4.1).

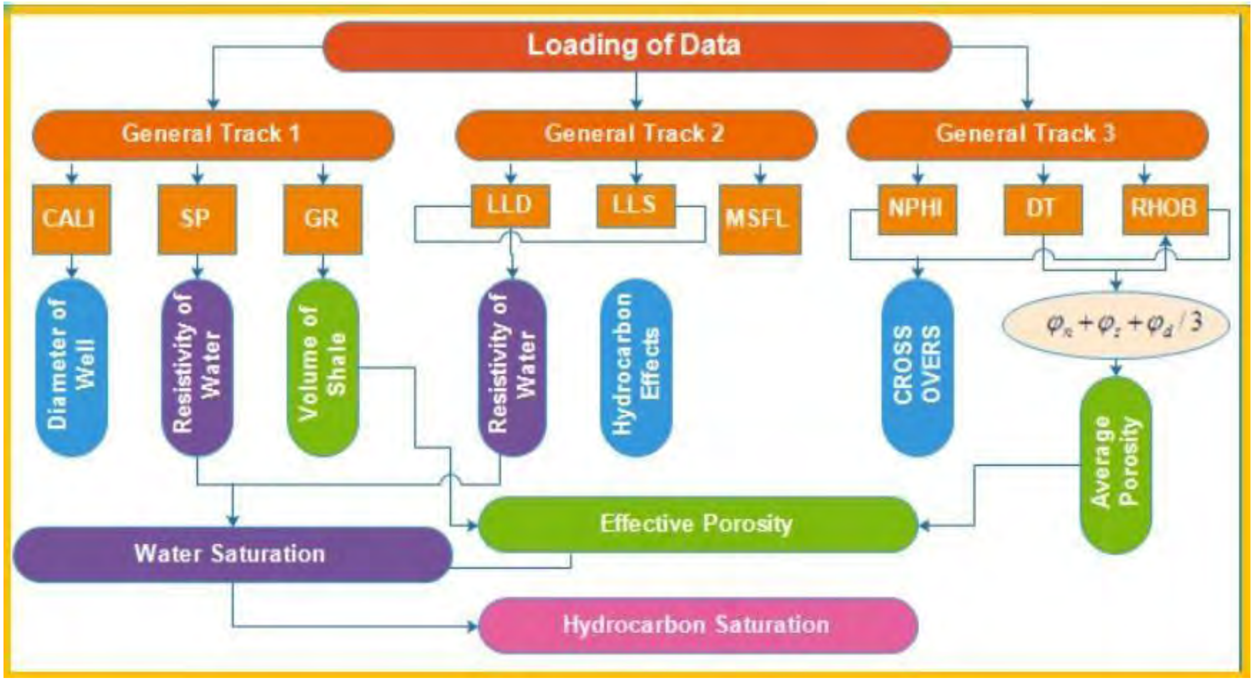


Figure 4.1 Flowchart of scheme used for Petrophysical Analysis

4.4 Tracks

Log is a record. Well log is a profile showing different properties of formation, that is measured through wells. Every log give some information about subsurface. Some logs are correlated with other log to assure our prediction of lithologies. Interpretation of well log data is given below.

4.5 Lithology Track

4.5.1 GR log

GR logging tool detect the natural Gamma radiations across the formation. These radiations come from radioactive element like Potassium, Uranium and Thorium etc. GR show maximum deflection for dirty lithologies (Shale) and minimum against clean lithologies. A clean lithology (Sandstone) has smaller quantity of clay minerals while a dirty lithology is enrich in clay minerals (Shale). From GR log we not only interpret lithologies but we can also find Volume of shale.

4.5.2 Spontaneous potential log

The spontaneous potential log (SP) measures the natural or spontaneous potential difference (sometimes called self-potential) that exists between the borehole and the surface in the absence of any artificially applied current. It is a very simple log that requires only an electrode in the borehole and a reference electrode at the surface. These spontaneous potentials arise from the different access that different formations provide for charge carriers in the borehole and formation fluids, which lead to a spontaneous current flow, and hence to a spontaneous potential difference. The SP log has four main uses: The detection of permeable beds, determination of Rw. The indication of the shaliness of a formation and for Correlation.

4.5.3 Caliper log

Caliper log tell us about borehole diameter. Borehole diameter is actually equal to the bit size. A line is drawn on the Caliper log which shows the size of borehole. A simple mechanical measures a vertical profile of borehole diameters. Any deflection from this line show the variation of borehole diameter and it actually gives us clue of the lithology. It is run in track 1 with Sp and GR log.

Increase of borehole diameter indicates Caving and Washouts and similarly decrease in borehole diameter indicates that Mud Cake has formed on the wall of borehole. Caliper log showing the decrease in bore size indicates that mud cake is formed on the walls of bore hole, which is a good indicator of Permeable lithology because mud Cake only form when rock is permeable. Caving and washouts show loose lithology, i.e. Shale, so increase of bore hole diameter is an indication of shale.

4.6 Resistivity Track

4.6.1 Resistivity logs

A log of the resistivity of the formation is expressed in ohm-m. The resistivity can take a wide range of values, and, therefore, for convenience is usually presented on a logarithmic scale from, for example, 0.2 to 2000 ohm-m. The resistivity log is fundamental in formation evaluation because hydrocarbons do not conduct electricity while all formation waters do. Therefore a large difference exists between the resistivity of rocks filled with hydrocarbons and those filled with formation water. Clay minerals and a few other minerals, such as pyrite, also conduct electricity, and reduce the difference. Resistivity logs are of various types these are described below

- **LLD**

  (Deep Laterolog) Laterolog log deep also measures the true formation resistivity beyond the outer boundary of invaded zone.
- **LLS**

  Shallow Laterolog deep measures the resistivity in the invaded zone
- **MSFL**

  Micro spherically focused log measures the resistivity of the flushed zone (Rxo).

4.7 Porosity Track

4.7.1 Density Log

Density porosity log (RHOB) displays the electron density of formation in contact by detecting the scattered gamma rays. It gives an indication of porosity, lithology and can assist to detect gas bearing zone. Cross over of Neutron and density log is an indicator of Gas/hydrocarbons called Gas Effect. The overlapping curves indicate the presence of water.

4.7.2 Sonic log

Sonic log is a porosity log that measures interval transit time of compressional sound waves. It displays travel time of P-waves versus depth. Sonic logs are typically recorded by pulling a tool on a Wireline up the wellbore. The tool emits a sound wave that travels from the source to the formation and back to a receiver. (1).the interval transit time is dependent upon both lithology and porosity. For porous rock the travel time increases and hence the larger deflection occurs on the log display and for denser and nonporous material the traveling velocity increases and hence the travel time decreases.

To calculate porosity from sonic log we must know formation matrix velocity. By Wyllie's formula

$$\varphi_{sonic} = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$$

Where, Δt_{log} is the interval transit time of formation

Δt_{ma} is the interval transit time of the matrix

Δt_f is the interval transit time of the fluid in well bore

4.7.3 Porosity log

Neutron log, density logs and sonic logs are the porosity logs. None of these logs gives direct porosity values. We can find the porosity of the formation by analyzing these logs.

4.7.4 Neutron log

Neutron log is based on effect of the lithology on fast neutrons emitted by a source. Hydrogen has the largest effects on these neutrons in slowing down and absorbing them. Since hydrogen is found in with water and hydrocarbons. This is found mainly in pores, so neutron is direct indicator of porosity.

4.8 Objective

The petrophysics analysis has been carried out in order to measure the reservoir characterization of the Balkassar area using the borehole data of balkassar-oxy-01 well. Log curves including spontaneous potential log (SP), Gamma ray (GR), Sonic log (DT), Latero Log Deep (LLD), Latero Log Shallow (LLS), Neutron log, density log were used for petro physical analysis the following parameters are calculated for reservoir rock.

- Volume of shale
- Porosity
- Water saturation
- Hydrocarbon Saturation

4.9 Volume of Shale

We have two methods for the calculation of volume of shale

4.9.1 Linear Method

In linear method we compute IGR by following formula.

$$IGR = GR_{log} - GR_{max} / GR_{max} - GR_{min}$$

IGR can give us maximum volume of shale and we have to found minimum volume of shale by nonlinear method.

4.9.2 Non-Linear Method

In nonlinear method we have various formulas like Stabier, Larinov and Clavier to compute minimum volume of shale. We utilize the one which give us minimum volume of shale. And mostly Stabier give us minimum volume of shale.

- Stabier: (Most preferable)

$$Vsh = \frac{IGR}{3 - 2IGR}$$

Where, IGR= Index Gamma Ray

- Larinov: (Used for Older rocks)

$$Vsh = 0.33 \times (2^{2IGR} - 1)$$

- Clavier:

$$Vsh = 1.7 - (3.38 - (IGR + 0.7)^2)^{0.5}$$

4.10 Porosity

In the next step we have to calculate Porosity parameters, like

- Density Porosity
- Sonic porosity

- Effective Porosity
- Neutron porosity (Given)

4.10.1 Density Porosity

Density log data is given but we need density porosity for the cross plot with

Neutron porosity to have better interpretation. Porosity values calculated from density log is call density porosity.

$$RHOB\varphi = \frac{RHOB_{mat} - RHOB_{log}}{RHOB_{mat} - RHOB_{fl}}$$

The value of density of matrix given in the exercise is 2.71 gm/cm^3 which is for carbonates and density of fluid is 1gm/cm^3.

4.10.2 Sonic porosity

For Sonic porosity we will use formula of consolidated rocks because we know that these rocks are old and well consolidated.

$$\varphi s = \frac{\Delta t_{log} - \Delta t_{mat}}{\Delta t_{fl} - \Delta t_{mat}}$$

The interval transient time of Formation increased due to presence of hydrocarbon known as hydrocarbon effect. This effect should be removed because it affects the values of calculated porosities.

4.10.3 Effective Porosity

The interconnected pore volume or void space in a rock that contributes to fluid flow or permeability in a reservoir. Effective porosity excludes isolated pores and pore volume occupied by water adsorbed on clay minerals or other grains.

Effective porosity is less than total porosity. Effective porosity log was created by using total porosity logs and volume of shale log.

The mathematical relation for effective porosity is as follows:

$$\varphi_e = (1 - V_{sh}) \times \varphi_{avg}$$

4.10.4 Neutron Porosity

The neutron log is sensitive mainly to the amount of hydrogen atoms in a formation.
Its main use is in the determination of the porosity of a formation. The count rate will be low in high porosity rocks and the count rate will be higher in low porosity rock. Neutron porosity is given in the data and calculated by well log w.r.t depth.

4.10.5 Total Porosity

The total porosity is the sum of all the porosities calculated from different logs divided by the number of logs used for calculating porosities

$$\varphi_T = \frac{\varphi_d + \varphi_n + \varphi_s}{3}$$

Where φ_T = Average porosity

4.8 Water Saturation

Water saturation is the percentage of pore volume in rock that is occupied by water of formation. To calculate saturation of water in the formation, a mathematical equation was developed by Archie shown below. All the parameters of Archie equation can be calculated from resistivity and spontaneous potential logs. The resistivity of water is calculated with the help of Spontaneous potential log.

The resistivity of water calculated is 0.042Ωm for Chorgali and 0.049 Ωm for Sakesar. After calculating all these parameters, we use Archie equation for calculating saturation of water stated below.

$$S_w = \left[\frac{R_w * F}{R_t}\right]^{1/n} \quad (4.9)$$

Table 4.1 Calculated values for Chorgali and Sakesar formation

Zones	R_w (Ωm)	S_w
Chorgali	0.042	65%
Sakesar	0.049	75%

4.9 Hydrocarbon Saturation

The fraction of pore spaces containing hydrocarbons is known as hydrocarbon saturation.

The simple relation used for this purpose is given below:

$$S_w + S_H = 1 \quad (4.10)$$

The saturation of hydrocarbons is percentage of pore volume occupied by hydrocarbon.

Where, $S_H =$ Hydrocarbon saturation and S_w = Water saturation

4.10 Interpretation of Well Log Balkassar Oxy-01

The interpretation of Balkassar OXY-01 is shown in figure given below. Here our reservoirs i.e. Chorgali and Sakesar formation mainly consists of limestone and have some intercalations of limy shale.

The Chorgali Formation is encountered at the depth ranges from (2467m-2602m) while Sakesar Formation is encountered at the depth ranges from (2602m-2624m). The Chorgali and Sakesar Formation are confirmed as a reservoir by different results obtained from well log. The Chorgali and Sakesar Formation are encountered at ideal depth which is required for hydrocarbon accumulation.

The other logs like Gamma ray log shows low value of Gamma ray readings and resistivity logs shows high values. The volume of shale is far less than 50%. The neutron log shows good porosity values for limestone and density and sonic logs shows low values as well.

These results are satisfactory thus we can interpret that Chorgali and Sakesar act as a reservoir.

Petrophysical analysis was carried out for both the reservoirs using different well log curves.

4.10.1 Interpretation of Chorgali Formation

- Volume of Shale = 15%.
- Effective Porosity = 11%.
- Water Saturation = 74%.
- Hydrocarbon Saturation = 26%

4.10.2 Petrophysical Analysis of Chorgali Zone

Only one main zone of interest is marked. Depth range of Zone of interest varies from 2445m2452m in well Balkassar-OXY-01

Shale volume of the whole depth range is 10 %. Effective porosity is about 2.6% and potential of the hydrocarbon is 33%. And water saturation is 67%. This is only one pay zone in which high net pay is expected. These zones bear low value of the GR, high porosity and the greater value of the resistivity

Table 4.2 Calculated values for Zone of interest in Chorgali Formation

Petrophysical properties	Average Values (%)
Volume of shale	10
Effective Porosity	5
Hydrocarbon Saturation	33
Water Saturation	67

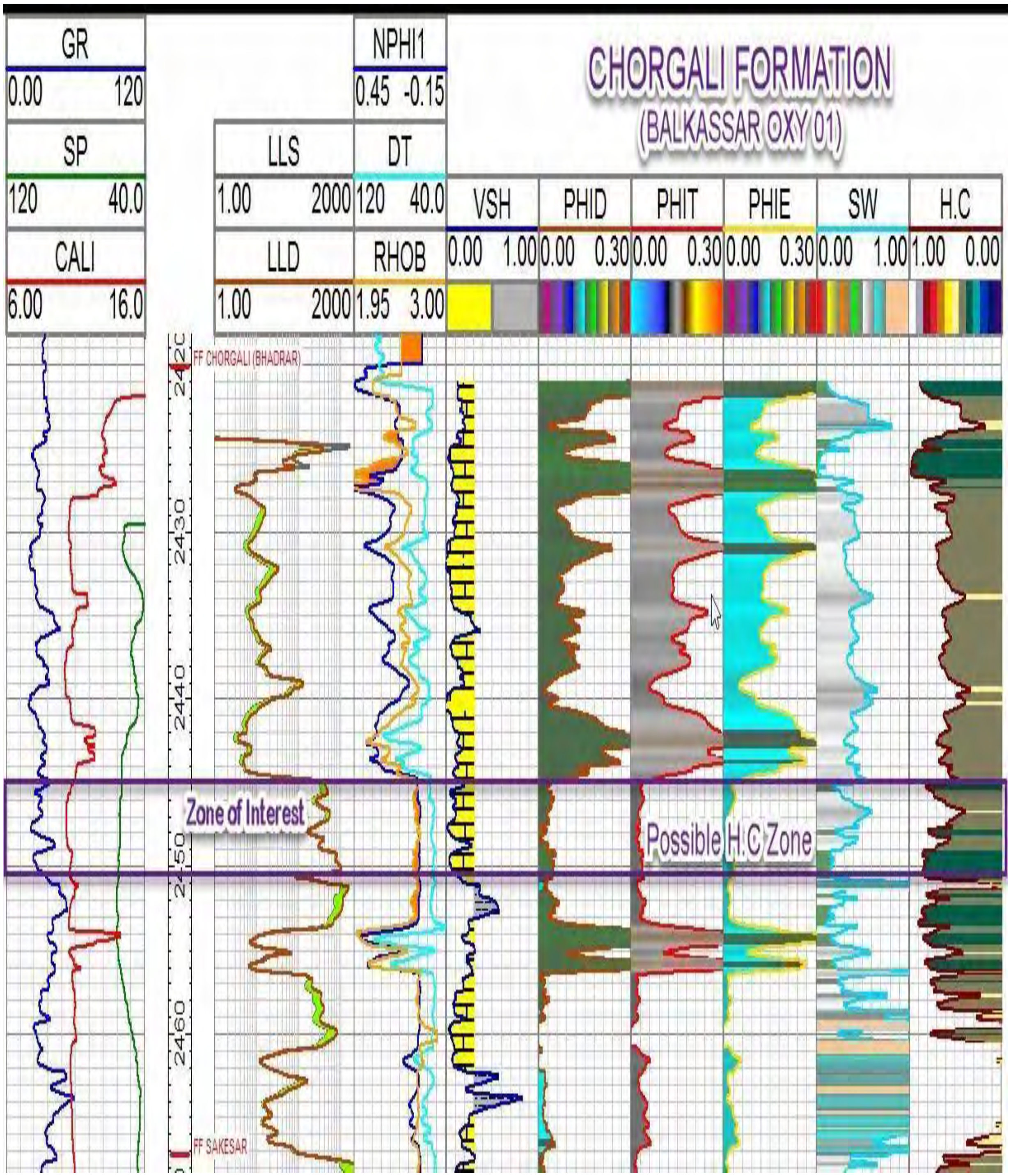


Figure 4.2 Petrophysical Interpretation of Chorgali Formation

4.10.3 Interpretation of Sakesar Formation

- Volume of Shale = 30-35%.
- Effective Porosity = 2-5%.
- Water Saturation = 70-80%.
- Hydrocarbon Saturation = 20-30%

4.10.4 Petrophysical Analysis of Sakesar Zones

Here we have three main zone of interest. Depth range of Zone of interest varies from Zone A (2475m-2482m), Zone B (2490m-2496m) and Zone C (2549m-2559m) in well Balkassar OXY-01.

Table 4.3 Calculated values for Zone of interest in Sakesar Formation

Average Values (%)			
Petrophysical properties	Zone A	Zone B	Zone C
Volume of shale	14	12	19
Effective porosity	2	2	3
Water saturation	70	58	71
saturation	30	42	29

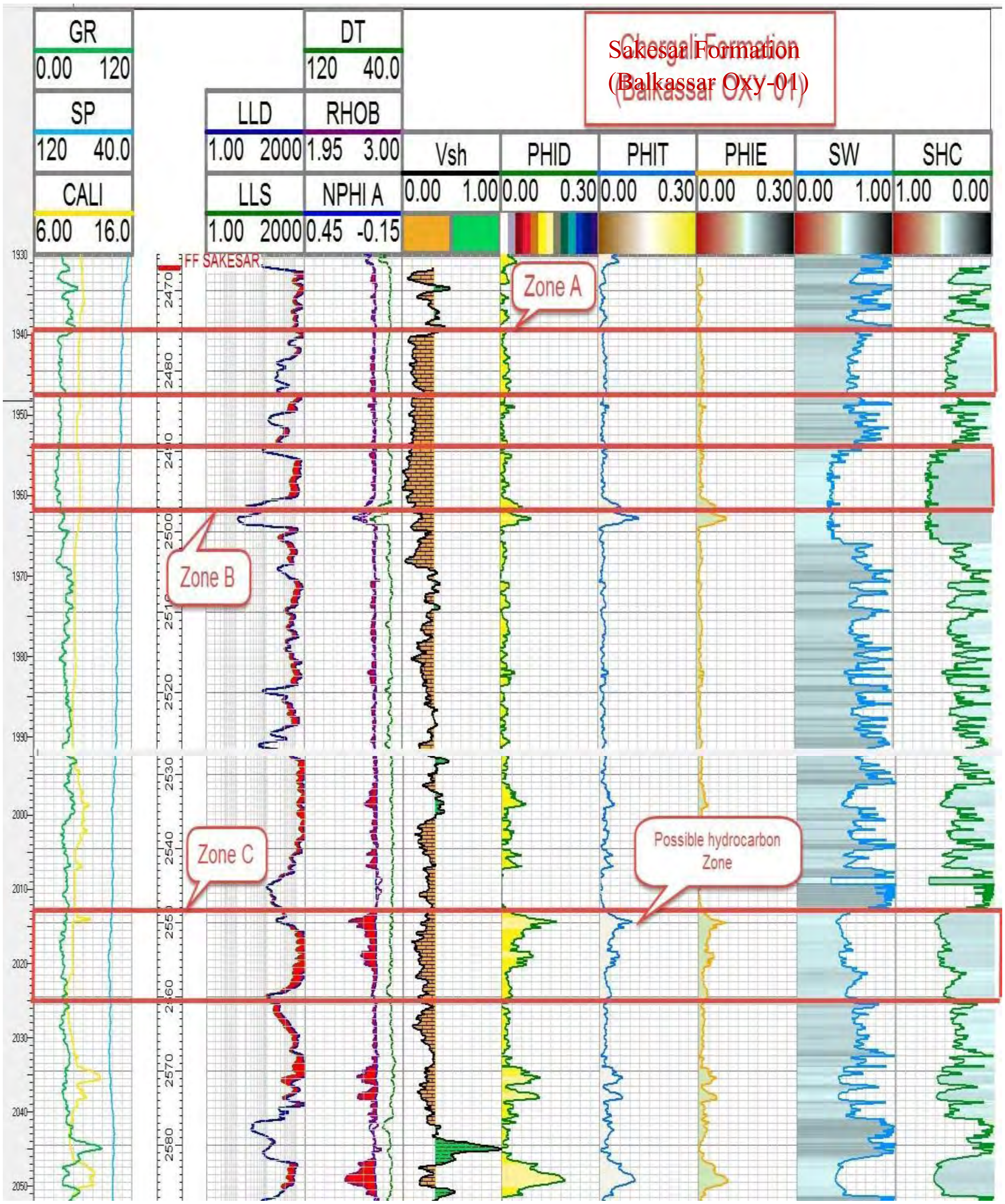


Figure 4.3 Petrophysical Interpretation of Sakesar Formation

4.11 Conclusion

We have concluded that Chorgali and Sakesar formation have reservoir potential as all the Petrophysical parameters support what we concluded. Based on results of the whole formations water saturation is higher than the hydrocarbon saturation. Petrophysical analysis we mark those zones which has higher hydrocarbon saturations. The zones we said as a possible hydrocarbon zone shows that the saturation of hydrocarbon is more than 50%, so petrophysical analysis confirmed that hydrocarbon saturation is in patches in this area.

Based on porosity values we can say that Chorgali formation porosity is higher than that of Sakesar formation which is a tight reservoir. Overall there is a problem with caliper log response especially in Chorgali formation which is mainly due to lithology washouts as our reservoir lithology is limestone. On these basis we have identified a bad borehole zone which indicate anomalously high values of porosities in Chorgali formation, as we know that sonic and density logs are the ones that are most affected due to a bad borehole and this the reason we didn't identified this zone as a possible hydrocarbon zone, as it may be misleading, the bad borehole zone ranges from 2420m-2445m. Identified zones in Chorgali and Sakesar formation shows low GR log values. LLD shows high values and we also identified a cross over between NPHI and RHOB in our zones of interest indicating hydrocarbon.

CHAPTER 05

ROCK PHYSICS

5.1 Introduction

Quantitative Seismic Interpretation shows how rock physics can be functional to predict different parameters of reservoir, such as pore fluids and lithologies, from seismically resulting attributes. It demonstrates how the multidisciplinary combination of rock physics models with seismic data, sedimentological information and stochastic techniques can lead to more powerful results than can be obtained from a single technique. This provides an integrated methodology and practical tools for quantitative interpretation, characterization of reservoirs in the subsurface and assessment of uncertainty, using seismic and well-log data. The aim, in preparing Quantitative Seismic Interpretation, is to aid illustrate the potent role that rock physics can play in integrating both the data and expertise of geology and geophysics for characterization of reservoir (Avseth et al., 2005).

The objective for this research is to prepare links between seismic and properties of reservoir more quantitatively. The Quantitative Seismic Interpretation includes the use of any seismic attribute for which there are specific models and relates them to different rock properties. This technique introduces primary rock physics relations, which help to quantify the fluid properties and geophysical signatures of rock. Since rock properties are outcome of geologic processes, I begin to quantify the seismic signatures of various geologic trends.

One of the main uses of rock physics is for extrapolation. At a well location having good data quality, we can estimate the porosity, lithology, permeability and fluids from logs, cores and cuttings. But we have no idea what is happening as moving away from the well. But by using rock physics, we can extrapolate to geologically probable conditions that might be present away from the well, by knowing how the seismic signatures might change. This is very useful when we have to understand the facies and seismic signatures of fluids that are not represented in the well.

Rock Physics describes a reservoir rock by physical properties such as porosity, rigidity, compressibility, properties that will affect how seismic waves physically travel through the rocks. Rock physics or engineering parameters have been computed using velocity data derived from the velocity functions. In the real earth velocity varies laterally as well as vertically. Thus instead of using a regional averaged velocity function which only shows a vertical mean trend of the velocity with depth, velocity of DT log was used. The RMS and average velocities are not the true representative of a particular subsurface layer as they provide a vertically summed effect of all overlying layers rock properties.

5.2 Elastic Rock Properties

5.2.1 P-Wave and S-Wave Velocity

Sonic travel time of compressional wave is generally used as porosity tool for given lithology. VPVS relations are keys to the determination of lithology from Seismic and Sonic log data as well as for direct seismic identification of pore fluids using e.g. AVO analysis with passage of time as the waves go deeper, its values are decreasing. Introducing shear wave travel time is very helpful in determining mechanical rock properties. It is found that compressional wave is sensitive to the saturating fluid type. The use of the ratio of compressional wave velocity to shear wave velocity, Vp/Vs, is a good tool in identifying fluid type.

Lower values of P-wave and S-wave velocities show the shaly material or fluid substitution and higher values consolidated material. Seismic velocity increases with depth due to compaction of rocks, because of overburden pressure of rocks. S-wave velocity is best indicator of fluids, as these waves can't pass through fluids.

From DT log, which has trainset time in µs/ft, we have calculated P-wave velocity in m/s using formula **V=1/DT.**

$$Vp= (1 \times 1000000)/ (DT\times 3.28 \text{ (m/s)}$$

5.2.2 S-wave velocity

S- Wave velocity in m/s has been calculated from P-wave velocity using formula. Castagna suggests a different formulas for Vs depend upon the lithology but it is not reliable for reservoir characterization. I use the formula given by Castagna in 1993 for limestone.

$$Vs = (0.583 \times Vp)\ 0.078 (m/s)$$

5.2.3 Density

A very important property of a rock is density. The density of the material directly affects the P wave velocities passing through it. Lower values of density show the shaly material or fluid substitution and higher values consolidated material.

$$\rho = 0.31 \times (VP)^{0.25}$$

The bulk modulus (K) of a substance measures the substance's resistance to uniform compression. It is the ratio of volume stress to volume strain. It describes the material's response to uniform pressure. For a fluid, only the bulk modulus is meaningful. Bulk Modulus will be low where greater the volume of shale in other words the density would be high. Figure 5.1 shows bulk modulus variations with increasing depth. Lower values show the shaly material or fluid substitution and higher values consolidated material.

$$\mu$$

Standard value for limestone is 65GPa

5.2.4 Young's modulus

Young's modulus or modulus of elasticity (E) is a measure of the stiffness of an isotropic elastic material. It is the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's Law holds. It describes the material's response to linear strain. Young Modulus will be high where greater the volume of shale because it is linear strain. Figure 5.1 shows young modulus variations with increasing depth. Lower values show the shaly material or fluid substitution and higher values consolidated material.

$$E = 9 * k * \mu / 3k + \mu$$

5.2.5 Shear Modulus

Shear modulus or modulus of rigidity (μ), is defined as the ratio of shear stress to the shear strain (angle of deformation). Lower values show the shaly material and higher values stiffer material.

Shear Modulus is good indicator of fluid presence, because fluids have zero value of Shear Modulus.

$$\mu = \rho * Vs^2$$

5.2.6 Poisson ratio (σ)

The ratio of the transverse strain (relative contraction strain normal to the applied stress) to the longitudinal strain (relative extension strain in the direction of the applied stress).49

$$\sigma = \text{Transverse Strain} / \text{Longitudinal Strain}$$

Standard value for a limestone is 0.18-0.33GPa

5.2.7 Vp/Vs Ratio

It is the ratio between the primary wave velocities to the secondary wave velocity and calculated simply by dividing by Vp by Vs. Lower values of P-wave and S-wave velocity ratio show the shaly material and higher values stiffer material.

5.2.8 Acoustic Impedance (Z)

Acoustic impedance is the product of primary wave velocity and density of the rock.

Mathematically it can be written and calculated by the formula:

$$\mathbf{Z = \rho \times Vp}$$

5.2.9 Shear Impedance

Shear impedance is the product of the secondary wave velocity and density. Mathematically it can be written calculated by the formula

$$Shear\ imp = \rho \times Vs$$

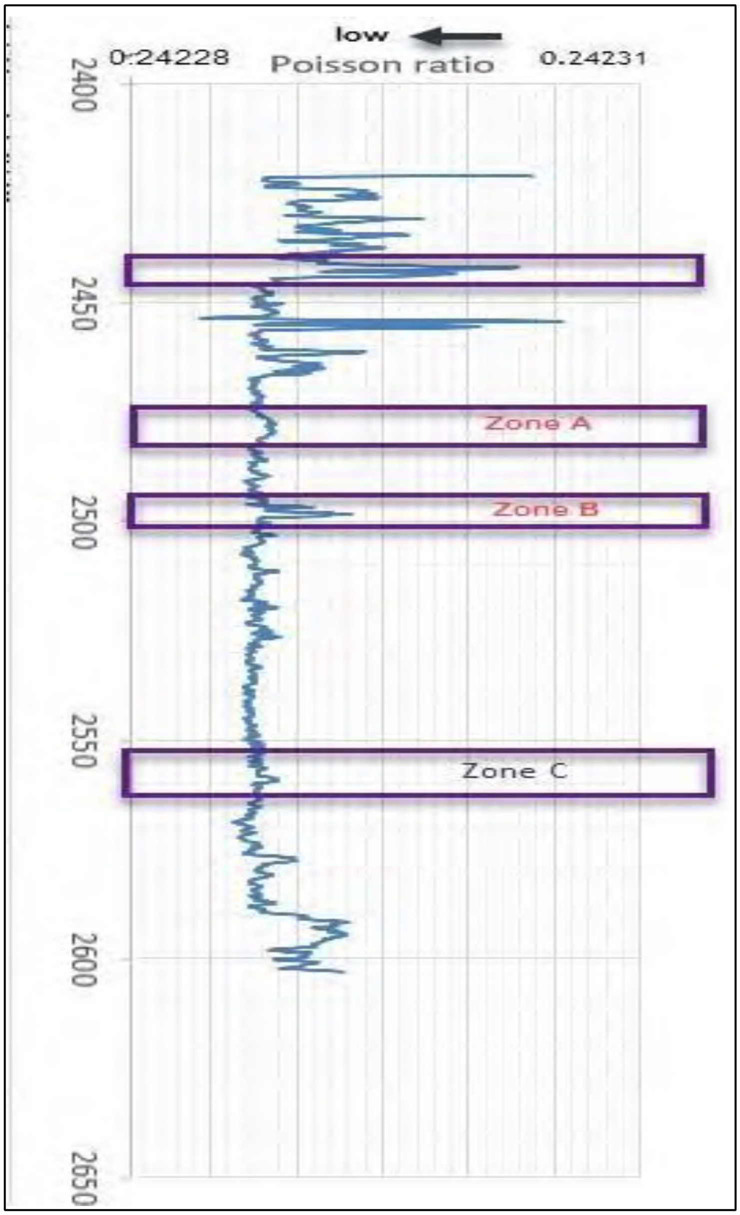


Figure 5.1 Poisson’s Ratio of Chorgali and Sakesar

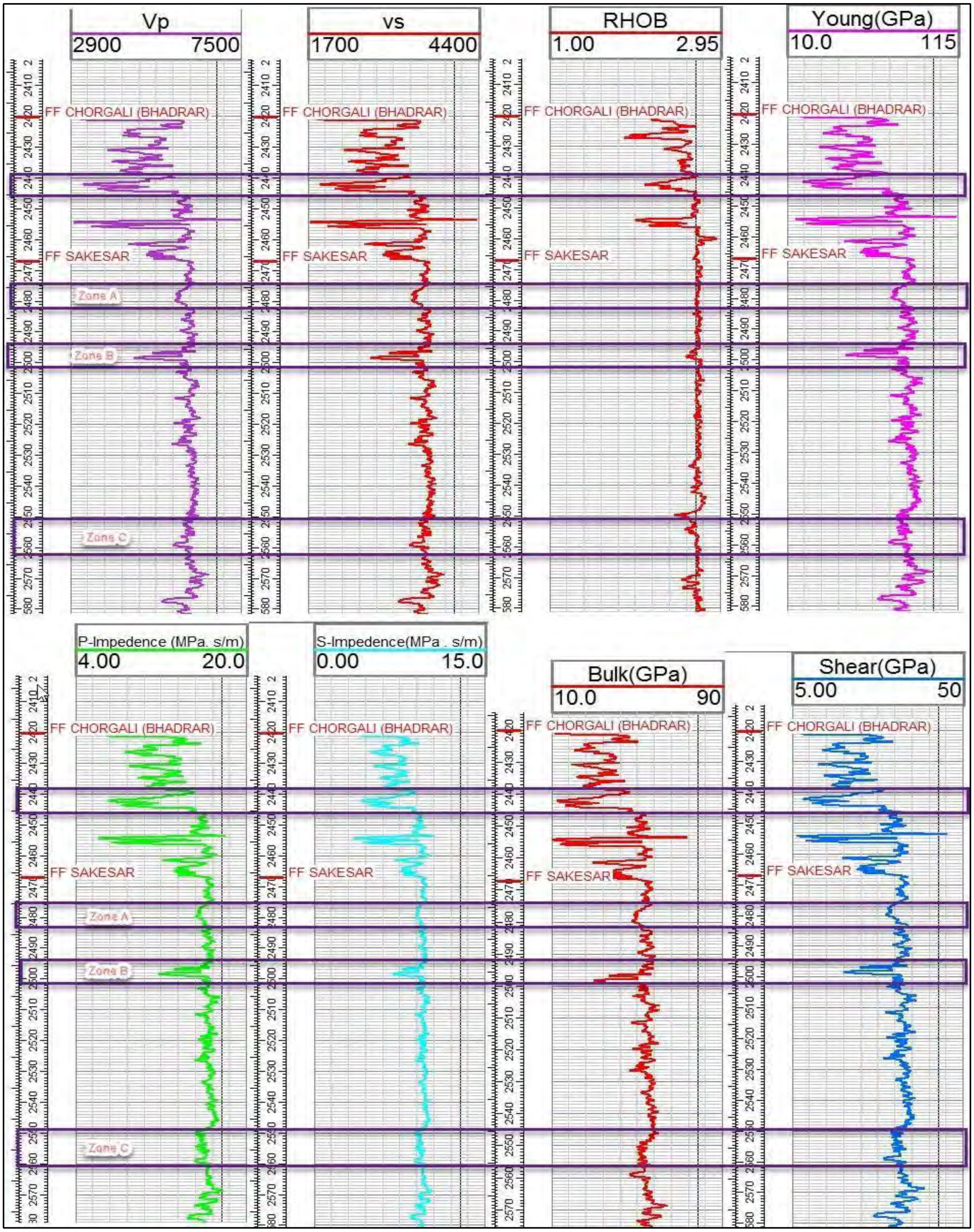

Vp
2900 7500
vs
1700 4400
RHOB
1.00 2.95
Young(GPa)
10.0 115
P-Impedence (MPa. s/m)
4.00 20.0
S-Impedence(MPa . s/m)
0.00 15.0
Bulk(GPa)
10.0 90
Shear(GPa)
5.00 50
FF CHORGALI (BHADRAR)
FF SAKESAR
Zone A
Zone B
Zone C

Figure 5.2 Combine response of elastic rock Properties in Chorgali and Sakesar

5.3 Results

In the presence of hydrocarbon density and velocity can decrease and this is what happening in our zone of interest and this can be confirmed from the results of the Vp, Vs and density which decrease in our prospect zone.

The modulus which we have calculated that is young, bulk and shear modulus all decreases in our zone because of the presence of hydrocarbon, hence they give an idea about the presence of hydrocarbons.

When we talk about poisons ratio, it should increase in our zones and it is increasing in our zone hence, indicating presence of hydrocarbons, the average value of poisons ratio are 0.24 which indicate limestone.

P-impedance and S-impedance decrease in our area of interest hence indicating the presence of hydrocarbons present here.

CHAPTER 06
FACIES MODELING

6.1 Introduction

In geology, facies is a body of rock with specified characteristics. Generally, the facies is distinctive rock unit that form under certain condition of the sedimentation that reveals the environmental process.

The differentiation between the shale and sand has been constantly challenged for the geoscientist. In this process the key challenge is identifying the facies, from logging and core data, and degree to which the shale content affects the reservoir properties. This gives the main indication about the productive zone in the reservoir (Kurniawan, 2005). This problem leads us towards the cross plots which provides us the relationship between the reservoir properties and log response (Naji et al., 2010).

These facies are related to the certain depositional environment. Basically, the depositional environment is specific type of place where the facies are deposit, Such as the Glaciers, Lakes, Abyssal plain, Sea bottom, Stream and Delta etc. The different types of the environment are shown in the below figure 6.1

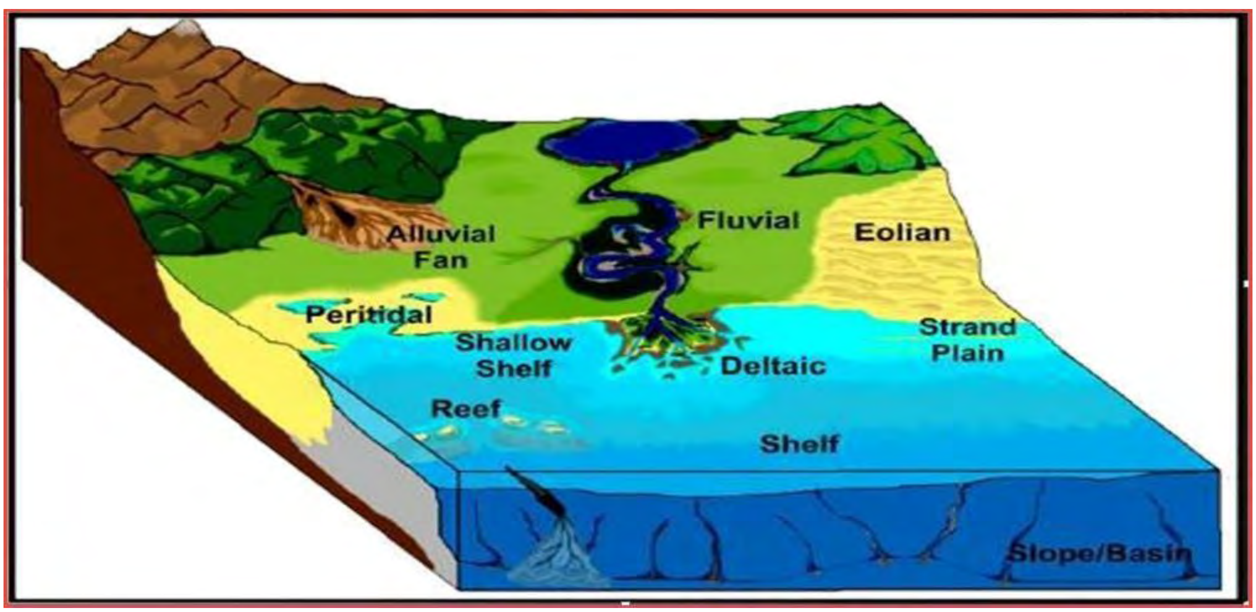


Figure 6.1 Diagram of major depositional environments, (Rais etal, 2012)

6.2 Sedimentary Facies

The sedimentary facies can be differentiated from each other on the basics of the change in the depositional environment Sedimentary facies are defined as a really restricted, three-dimensional bodies of rock or sediment that are distinguished from other bodies by their lithology, sedimentary structures, geometry, fossil content, and other attributes. Lithofacies are defined solely based on their lithology. Similarly, bio facies are defined based on their fossil content. Sedimentary facies analysis is based on the concept that facies transitions occur more commonly than would be expected if sedimentation processes were random.

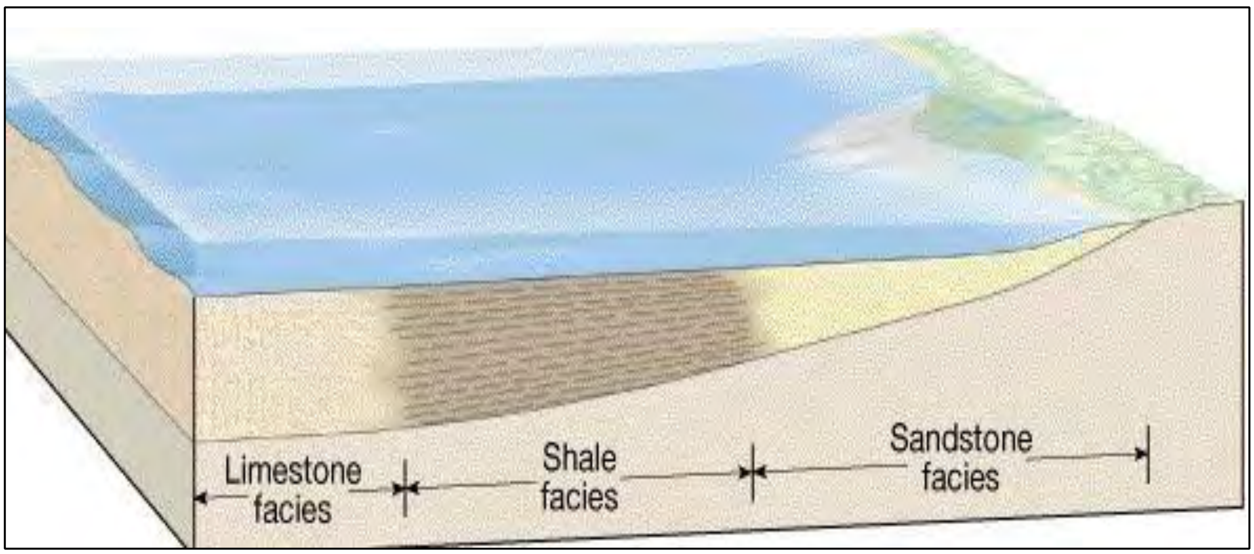


Figure 6.2 Sediment deposited in a different depositional environment.

The characteristics of the rock unit come from the depositional environment and from the original composition. Sedimentary facies reflect their depositional environment, each facies being a distinct kind of sediment for that area or environment.

The sedimentary environment of reservoir formations of Chorgalli and Sakessar are shallow Marine lagoon environment. The only Tobra formation in Potwar area has glacial environment except that all other have shallow marine lagoon environment.

6.3 Walther's Law of Facies

Walther's Law of Facies, or simply Walther's Law, states that the vertical succession of facies reflects lateral changes in environment. Conversely, it states that when a depositional environment "migrates" laterally, sediments of one depositional environment come to lie on top of another. A classic example of this law is the vertical stratigraphic succession that typifies marine transgressions and regressions. However, the law is not applicable where the contact between different lithologies is non-conformable (Lucia 1995).

6.3.1 Transgression

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

6.3.2 Regression

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

6.4 Facies Analysis

Fundamental to all subsurface geologic studies is an analysis of depositional facies. Development of a facies classification scheme is a challenging interplay between capturing enough information for environmental interpretation. A good understanding of paleoecology always strengthens the interpretation and such studies should be included as part of all depositional facies' studies. Depositional textures in turn affect porosity-permeability in carbonates. The vertical and lateral organization of facies is an exercise essential to sequence stratigraphic interpretations (Lucia, 1995)

6.5 Facies Analysis of Chorgali and Sakesar

For the facies analysis of the Chorgali and Sakesar zone we generate cross plots of DT vs NPHI and LLD vs RHOB from the log data of the Balkassar-OXY-01. These cross plots helped us to identify the major lithology of the Chorgali and Sakesar that there is limestone while we have limy shale also present here.

6.6 DT vs NPHI Cross plot

A cross plot between DT vs NPHI is generated with log data, by keeping Gamma
ray log as reference at Z axis. Major reservoir rocks of our area lie between depth ranges of (2421.5-
2602.9) meters. DT log is associated with lower values of the gamma ray logs indicate clean formation i.e. limestone. Due to compactness of limestone we have lower values of DT. NPHI log also have same trend in limestone.

The polygon are drawn and labeled. The group of points is thick in the limestone polygon. It is therefore interpreted that the reservoir is mainly composed of limestone

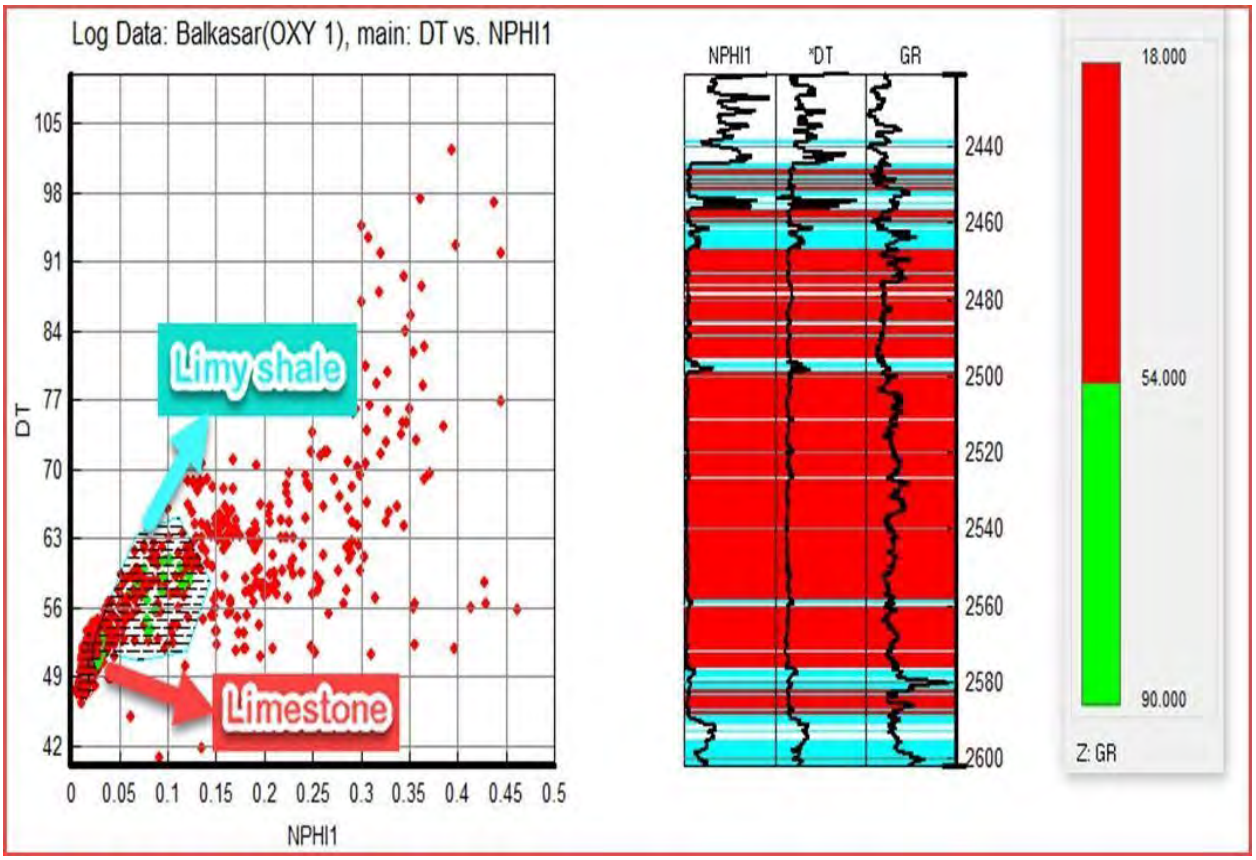


Figure 6.3 Cross plot between DT vs NPHI

6.6.1 Results

Polygon that is designed around a cluster point shows the limestone. We categorized it as a limestone because limestone does not show radioactive behavior and their general value of GR ranges from 10-40 API. DT value of limestone ranges from 47 us/ft- 52 us/ft in our study that matches with the standard range of transient time for limestone. Higher values of DT associated with higher gamma ray values indicate shale but in our reservoir zone we have calcareous shale (limy shale) instead of pure shale. It is also evident from the fact that DT log values increased in the second polygon which we have designated as calcareous shale.

6.7 LLD vs RHOB Cross plot

A cross plot between LLD vs RHOB is generated with log data, by keeping Gamma ray log as reference at Z axis. Major reservoir rocks of our area lies between depth ranges of (2421.5- 2602.9) meters.

Since resistivity and density of limestone is higher than shale so limestone facies are marked at higher values as shown in figure 6.4. Since density of shale is highly variable and if the concentration of organic contents is lower in shale, the density of limestone and shale can overlap so Gamma log is used as reference log for further separation of facies. The light green color shows the shale while the red color shows the limestone.

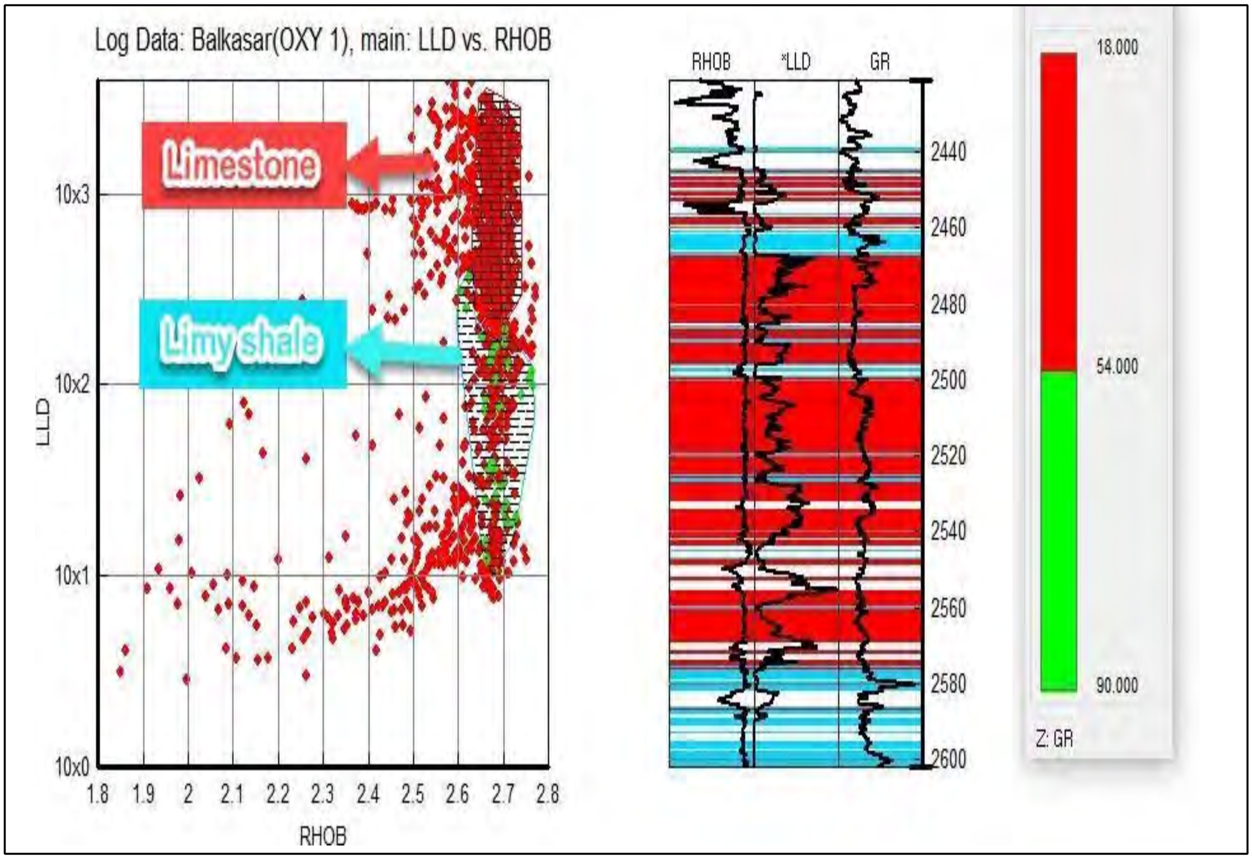


Figure 6.4 Cross plot between LLD and RHOB

6.7.1 Result

High resistivity values corresponding to low gamma rays value as compare to sandstone indicate limestone.so, the polygon that is designed at the top of cross plot indicate limestone by showing high resistivity values associated with low GR values(Generally radioactivity of limestone ranges from 10-40 API)

High gamma ray values associated with low resistivity values indicate shale but in Chorgali and Sakesar formation we do not have a pure shale,found a calcareous shale or limy shale (major content is calcite) whose density ranges from 2.6 to 2.7g/cm3.Polygon that is designed at the bottom of cross plot shows the limy shale.

CHAPTER 07

COLORED INVERSION

Introduction to Inversion

Seismic inversion is the process of extracting from seismic data, the underlying geology that gave rise to the seismic (Russell, 2005). It does that by deriving impedance from seismic data, which is an interval property useful for estimating properties such as porosity. Impedance as discussed by Veeken (2007), is an important tool as it contains essential data from the logs and seismic. Unlike seismic data, which is an interface property, acoustic impedance is a rock property which shows geologic layer and is also closely related to lithology and reservoir characteristics such as porosity and hydrocarbon saturation.

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. 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.

7.1 Colored Inversion

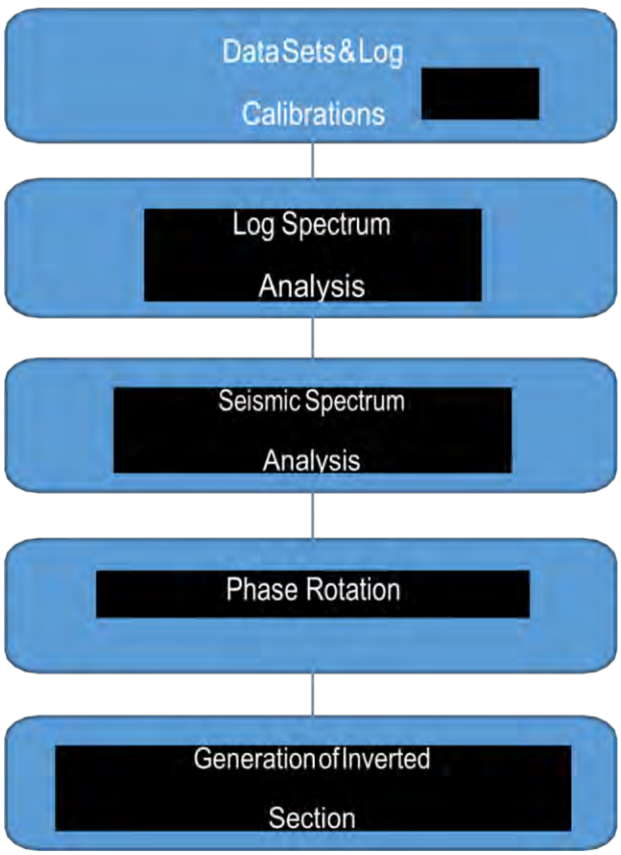
Colored inversion is designed to approximately match the average spectrum of inverted seismic data with the average spectrum observed impedance (Lancaster and Whitcombe, 2000). The earth's reflectivity can be considered fractal, and the resulting amplitude spectrum favors high frequencies (spectral blueing). If there was no preferred frequency, then you would have a "white spectrum", but as there are some frequencies with more energy, then it is called "colored". Colored Inversion includes preparation of the well logs, investigating relationships between impedance and reservoir properties and tying the well logs to the seismic. After tying to the seismic, the well log data is used to estimate a seismic wavelet. By application of zero phase deconvolution a broadband zero-phase dataset is obtained which forms the input to colored inversion (Lancaster and Whitcombe, 2000). Colored inversion converts the seismic data to a relative impedance data set. The advantages of colored inversion are the speed of calculation and avoidance of artefacts that may be introduced by a model. Colored inversion, whether acoustic or elastic impedance (Connolly, 1999), is an excellent qualitative interpretation tool.

A method was developed by Lancaster and Whit comb (2000) which called Colored Inversion (CI). The CI method is a simple and fast technique to invert the band-limited seismic data to relative impedance and can be done by generating a single operator to match the average seismic spectrum to the shape of the well log impedance spectrum.

Colored Inversion enhances the seismic signal and adds the auto-picker. Often it can enhance features such as bed resolution, minor faulting, fracture zones and discontinuities due to channels and possibly the presence of hydrocarbons.

7.2 Workflow

We followed the following workflow to perform the colored inversion. For the Colored inversion we require well data and information of logs



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 from the log and then we pass a best fit line which is our desired spectrum for seismic. This defines the amplitude spectrum of the required operator. Then we apply phase rotation of the 90o shift which is in agreement with the simplistic view of inversion to integration, and the concept of a zero-phase reflection spike being transformed to a step AI interface, provided the data are zero-phase. The color Inversion operator is converted to the time domain and simply applied to the seismic volume using a convolution algorithm.

7.3 Data Sets and Log Calibration

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. So, the product of velocity log and density log is used to calculate its spectral trend in the frequency domain from which an inversion operator can be derived. Before going further the logs have to be calibrated with seismic data because the resolution of the sonic log can be measured in centimeters whereas the seismic resolution is in meters so log data must be averaged for the comparison between logs and seismic. 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.

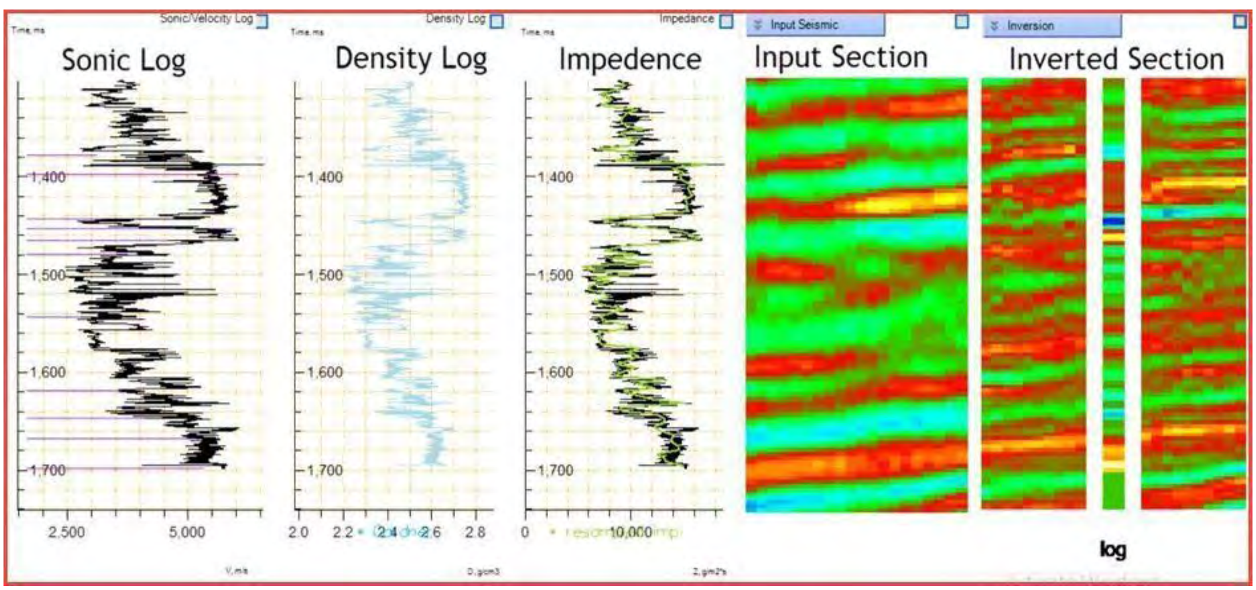


Figure 7.1 Generation of Acoustic Impedance and Inverted section

7.4 Log Spectrum Analysis

Here the impedance spectrum of the log is generated on the log paper by passing the best fit line in the range of the seismic frequency range. At the beginning we have almost the same impedance but as the amplitude spectrum trend gently rise with frequency the impedance logs tend to decay with frequency – having effectively undergone the process of integration relative to the reflectivity data.

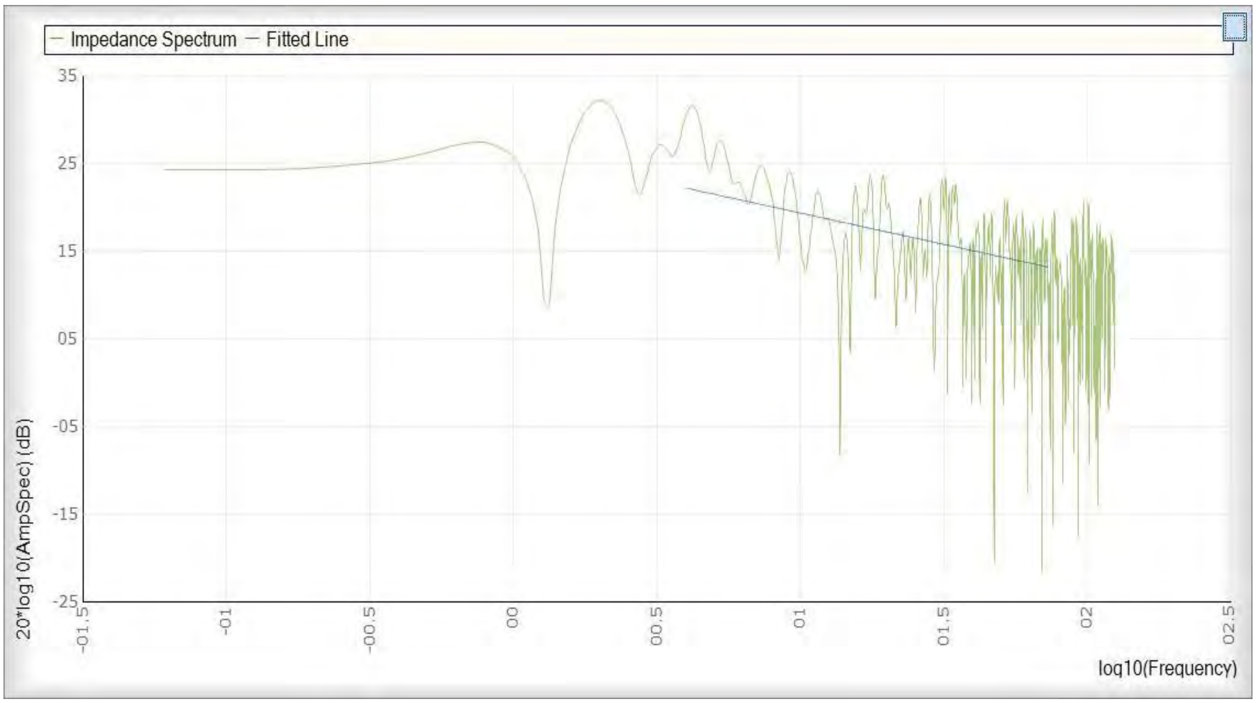


Figure 7.2 Impedance log spectrum with a best fitted line

7.5 Seismic Spectrum Analysis

Figure 7.3 shows that an average spectrum of seismic data which is superimposed with the desired impedance log spectrum derived from the well data and we can clearly see that there is a vast difference between these two spectrums and in order to match them we need a shaping filter/wavelet which will shape the seismic spectrum and match it with our desired impedance log spectrum.

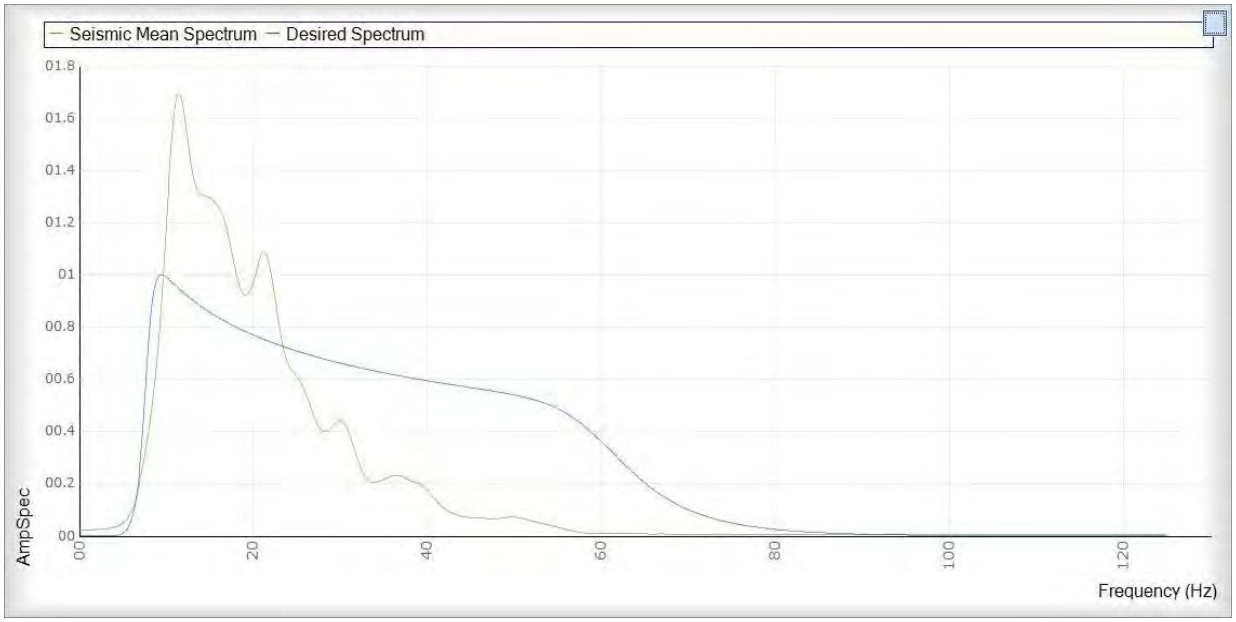


Figure 7.3 Seismic spectrum compared with desired impedance log spectrum

7.6 Spectral Shaping of Seismic Data

Figure 7.4 shows a shaping function; it may be called as pre-whitening which helps to acquire desired amplitude spectrum. In figure 6.6 we have a shaped seismic spectrum which is a result of convolution of pre whiting filter, wavelet, and a desired seismic spectrum. We can see now shaped seismic spectrum is much closer to our desired seismic spectrum.

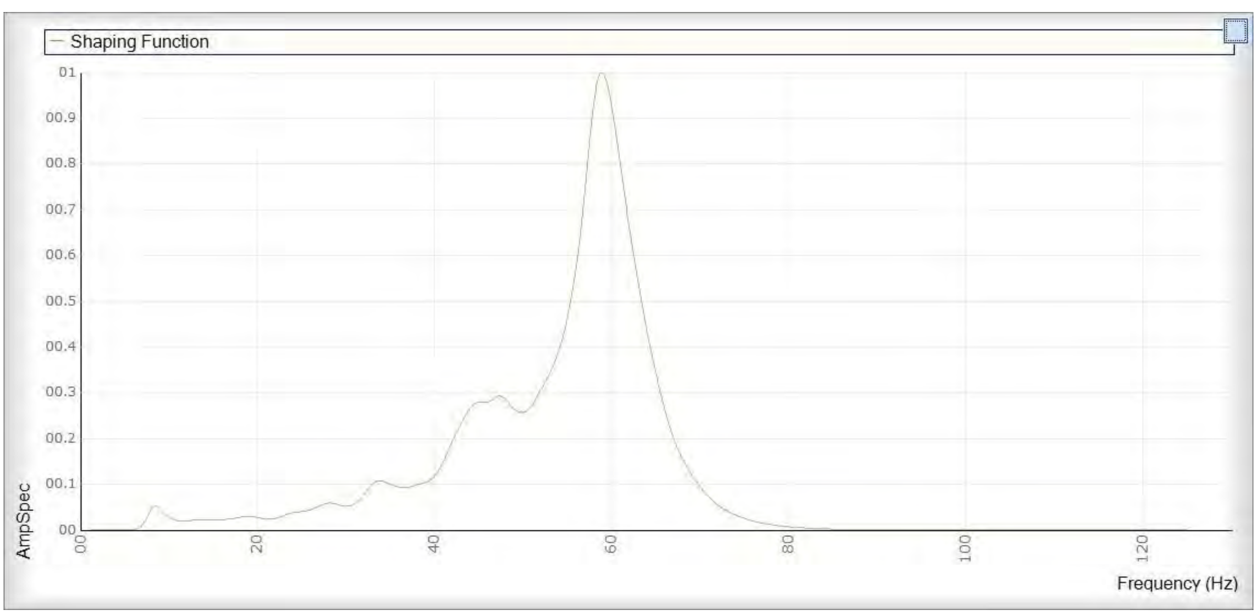


Figure 7.4 Shaping Function

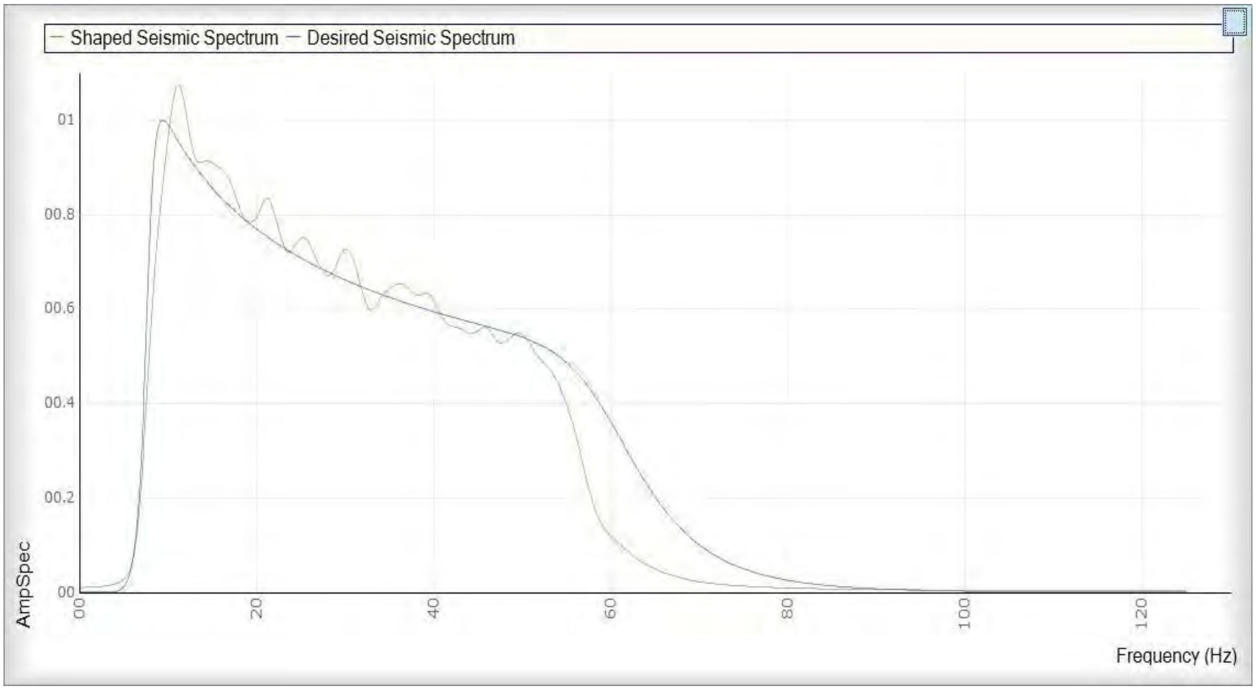


Figure 7.5 Shaped seismic spectrum compared with the desired seismic spectrum

7.7 Butterworth Filter

Butterworth filter is used to smooth and constrain the impedance log spectrum. The Butterworth filter is a type of signal processing filter designed to have as a flat 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. A Butterworth filter needs to be defined by low and high cut frequencies and their corresponding slopes. 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.

We get modeled spectrum from the logs which is impedance spectrum and it is smoothed and constraint by the Butterworth filter in order to proceed towards the seismic spectrum and match it with this desired spectrum. The desired spectrum is of blue color in the figure 7.7.

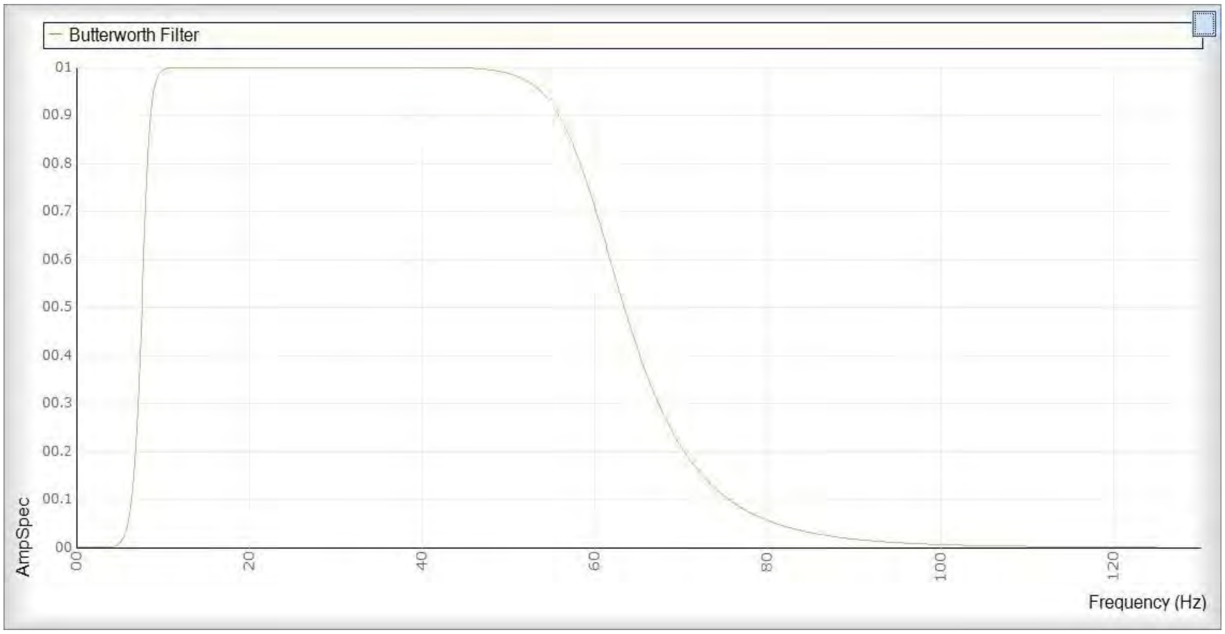


Figure 7.6 Butterworth filter

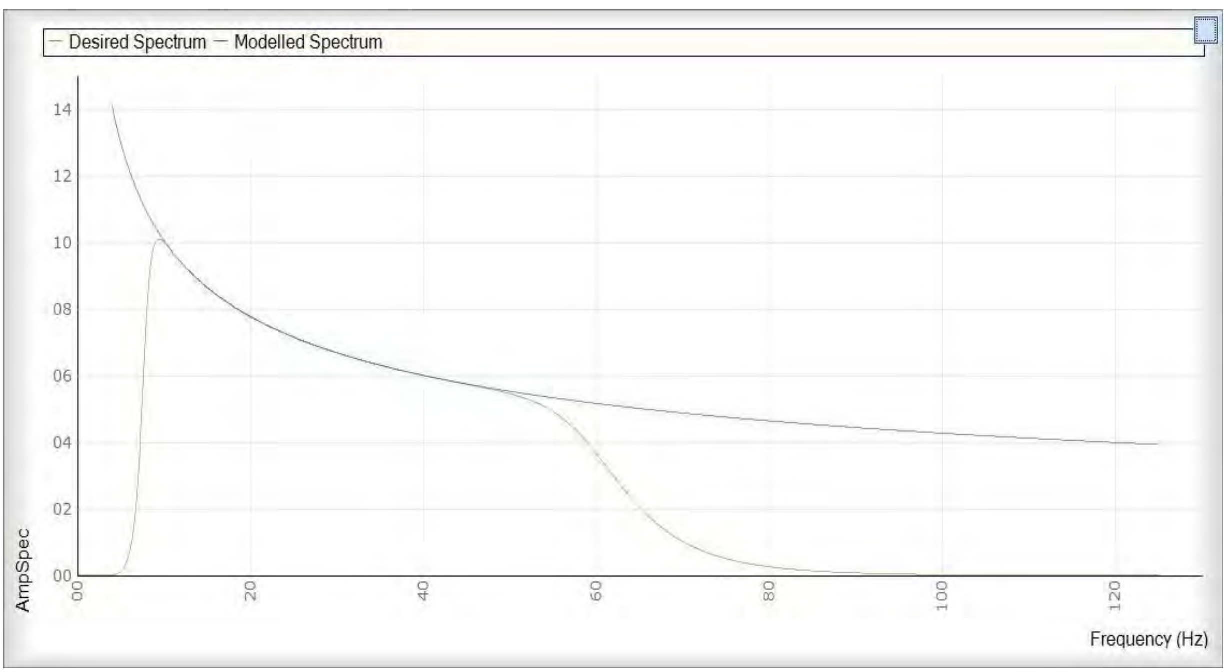


Figure 7.7 Desired impedance log spectrum constrained by the Butterworth filter

7.8 Wavelet Extraction

The wavelet shown in the above figure 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). 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 seismic mean spectrum, we can apply it on whole seismic section. 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).

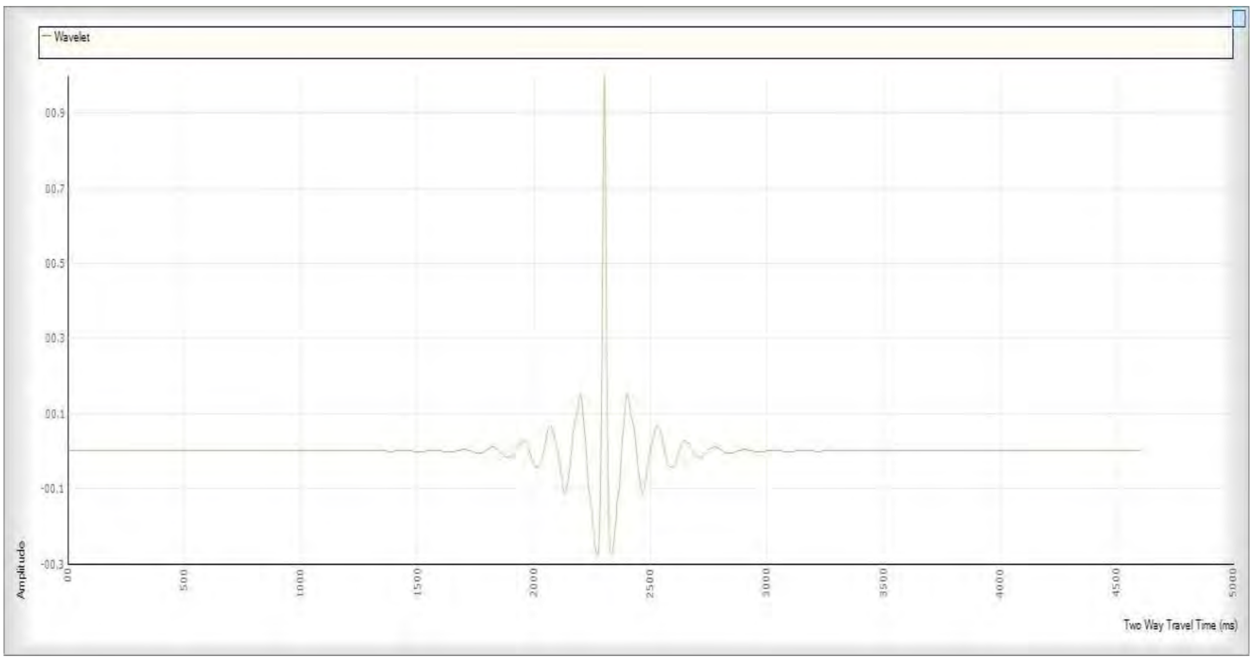


Figure 7.8 Extracted Wavelet (Operator in Time Domain)

7.9 Phase Rotation

The phase of the operator is a constant -90o which is in agreement with the simplistic view of inversion to integration, and the concept of a zero-phase reflection spike being transformed to a step AI interface, provided the data are zero-phase. When the input seismic traces have been accurately zero-phased relative to the reflectivity sequence at wells, the colored inversion process requires a phase shift of -90° to complete the match with the impedance log as well as the estimated amplitude spectral trend. There is an opportunity in the inversion package to apply a phase shift that will optimize the tie with impedance log traces, or the program can be requested to calculate the phase. The program estimates the phase rotation angle by comparing band-pass filtered impedance logs with the shaped seismic data assuming that well ties are reasonably good. This phase value will be used to rotate the shaped seismic data to complete the colored inversion process.

7.10 Seismic Color Inversion Display

After performing all above operations, we apply it on our seismic volume. In figure 7.9 we have a sonic log and density log which is impedance log, on impedance log we see a calibrated impedance log in green color. First we have extracted a single trace from our seismic, a single trace from impedance log and then we have incorporated it to do a color inversion. We see a resemblance in input seismic and inverted seismic data. The following figure displays the density and sonic log which are used to generate impedance log. In case, if value of density logs is missing then Gardner equation is used to estimate missing densities values. Gardner is an empirically derived equation that relates seismic P-wave velocity to the bulk density of the lithology in which the wave travels.

$$\boldsymbol{\rho = \alpha V_p{}^{\beta}}$$

Where $\boldsymbol{\rho}$ is bulk density given in g/cc, is P-wave velocity given in ft/s, and and are empirically derived constants that depend on the geology.

7.11 Generation of Inverted Section

Single well data is available that's why we used only one well to derive operator i.e Balkassaroxy01. When we apply operator then we have an inverted section which is shown in figure 7.9. The inverted log is applied on the whole section. At the well location we have optimum results as we

go far away from the well the control will be lost because software do interpolation and we didn't get good result. The seismic section is displayed w.r.t relative acoustic impedance having high (yellow & red) and low (blue) acoustic impedance. The inverted section is shown in figure 7.9

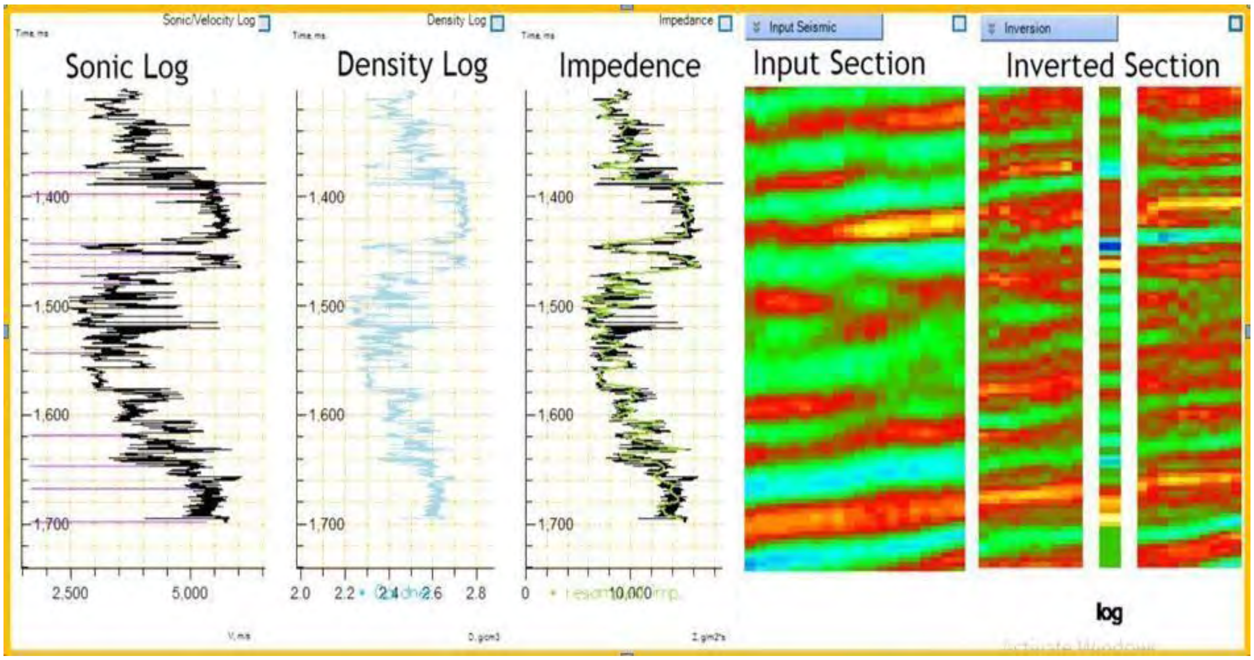


Figure 7.9 Input seismic section and inverted section along with logs

7.12 Interpretation of inverted section

The inverted seismic section is generated as shown in above figures 7.9, 7.10, 7.11. The inverted section can be interpreted by using color bar. The white to yellow color shows high values of acoustic impedance and blue to green color shows low impedance. The hydrocarbons accumulation is associated with low acoustic impedance. The given inverted section is shown with T-D chart and it shows Formations as well. The Formation circled in figure 7.10 is Chorgali and it yields a response of low acoustic impedance it is related to presence of hydrocarbon accumulation it is also confirmed from Petrophysical results.

The Chorgali is interpreted as most producing reservoir in Balkassar area. Because results obtained from seismic inversion shows low values of impedance and structure formed is anticline both conditions give indication for presence of hydrocarbons. The zoomed view Sakesar in figure 7.11 also confirms our results.

If we zoom the highlighted area then we can interpret this area yields low acoustic impedance values. As Chorgali and Sakesar is most producing reservoir rock in Upper Indus Basin also found to be most producing rock in Balkassar area.

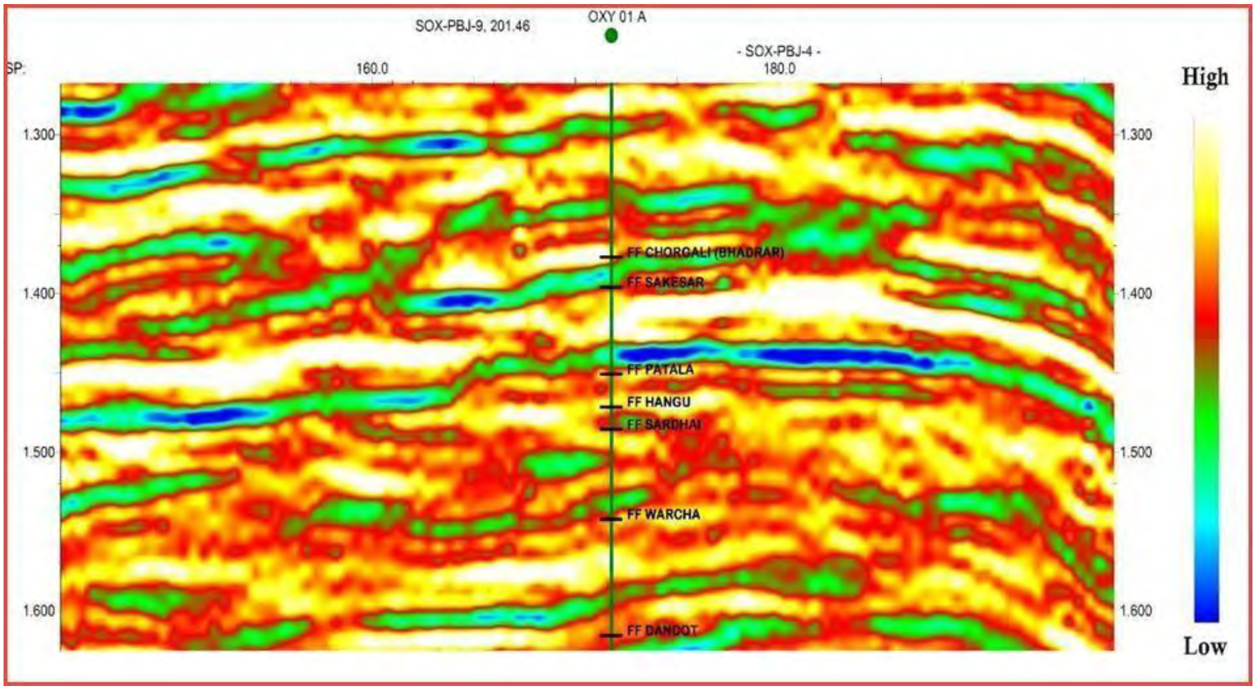


Figure 7.10 Inverted seismic section

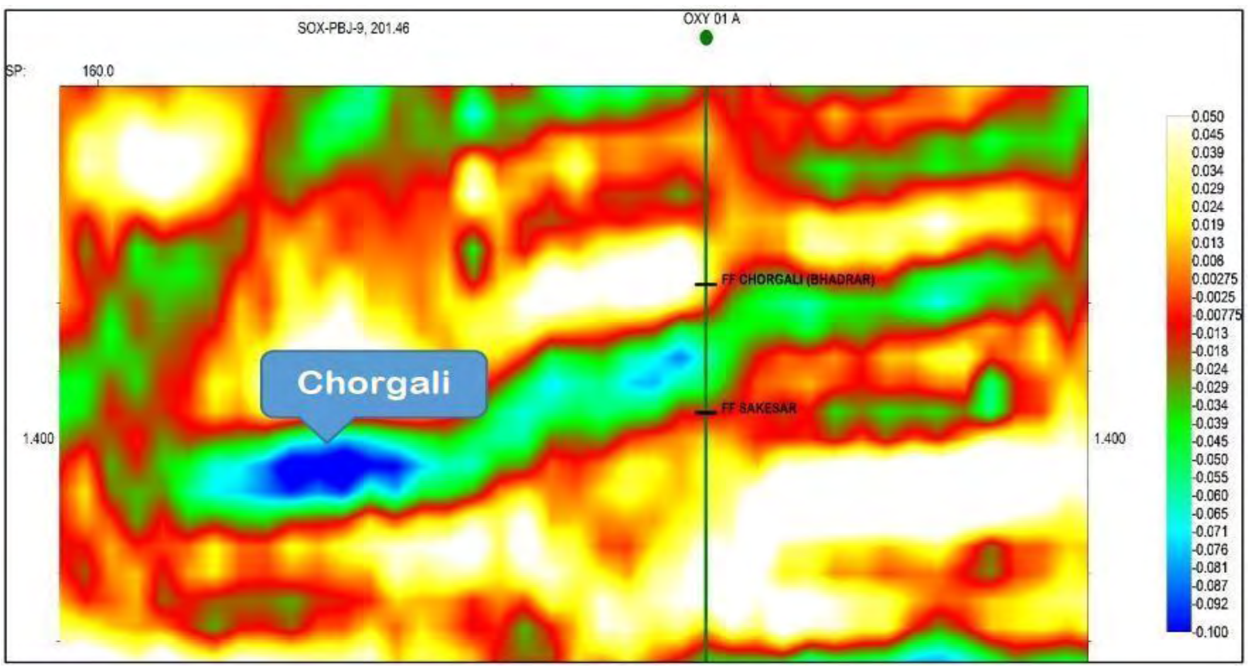


Figure 7.11 Zoomed view of Chorgali inverted section

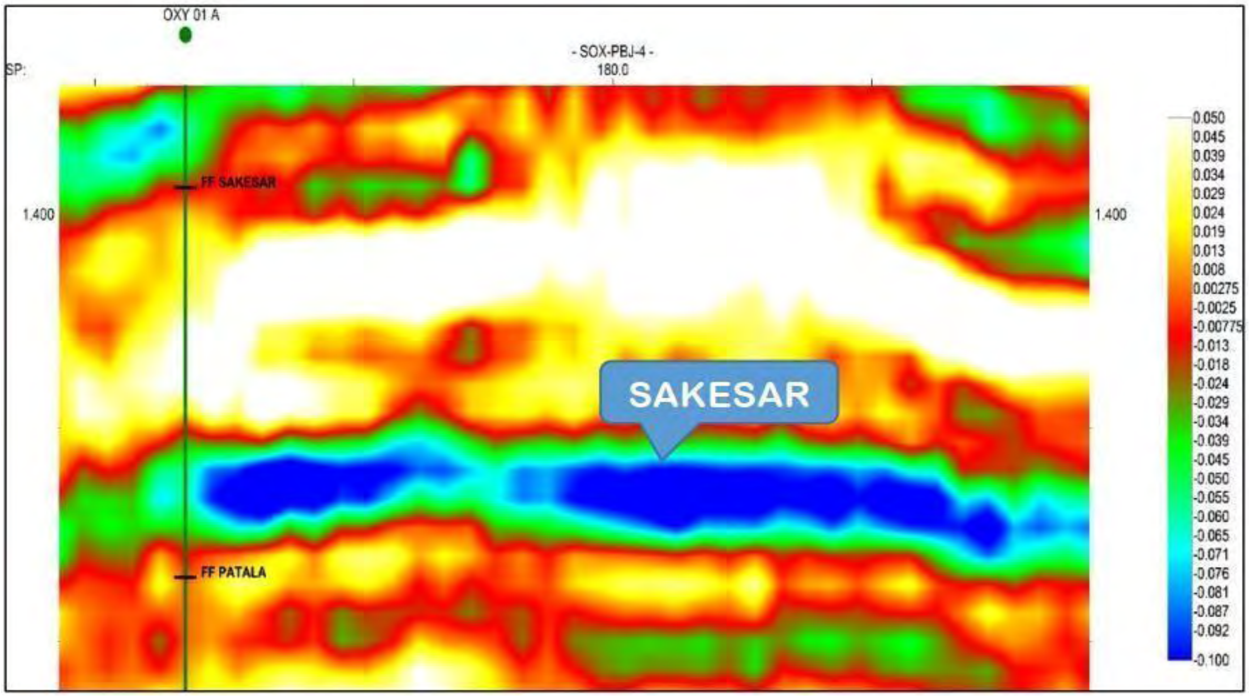


Figure 7. 12   Zoomed view of Sakesar inverted section

Conclusions

- Seismic data interpretation of Balkassar area indicates an anticlinal "pop up "structure associated with fracturing and faulting on limbs of the anticline.
- The anticlinal structure acts as a trap in the area, which is best for hydrocarbon accumulation. This shows that the study area is dominated by compressional tectonic forces.
- The synthetic trace, generated via well data, confirms the marking of right seismic sections.
- Petrophysical analysis shows that Chorgali formation have good reservoir potential while the reservoir potential of Sakesar formation is less & is not an economical due to less porosity.
- Facies analysis shows that reservoir rocks are mainly comprised of limestone with minor shaly limestones packages.
- The reservoir characterization is distributed over the whole seismic survey through seismic inversion technique, which also supports the results of petrophysical analysis by showing low impedance value in Chorgali which is the character of reservoir potential and high impedance value in Sakesar that indicates the character of tight reservoir (low porosity).

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