CHARACTERIZATION OF BALKASSAR AREA USING 2D SEISMIC AND WELL DATA

BY

HAMZA HAMID

BS GEOPHYSICS 2013-2017

DEPARTMENT OF EARTH SCIENCES

QUAID-I-AZAM UNIVERSITY

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CERTIFICATE

This dissertation submitted by **HAMZA HAMID** S/O **MUHAMMAD HAMID** is accepted in the 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.

RECOMMENDED BY

PROF. DR. MONA LISA --------------------------------

(Chairperson & Supervisor)

EXTERNAL EXAMINAR --------------------------------

DEPARTMENT OF EARTH SCIENCES

QUAID-I-AZAM UNIVERSITY

ISLAMABAD

بسم الله الرحمن الرحيم

"In The Name of ALLAH, the Most Merciful & Mighty"

"PAY THANKS TO ALLAH EVERY MOMENT AND GO TO EXPLORE THE HIDDEN TREASURES, ITS ALL FOR YOUR BENEFIT"

(AL-QURAN).

DEDICATED

TO

My parents, brothers and sisters

And loving, caring and sweet friends

And all those who helped me in this work

ACKNOWLEDGEMENT

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SUMMARY

The dissertation work includes seismic data interpretation, Petrophysical analysis using well logs data; for the identification of possible possible prospect (H.C) zones with the use of seismic inversion. Facies modeling for the confirmation of lithology's and Rock Physics to find out the rock physical properties.

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, Sakesar formations in order to depict the probable hydrocarbon producing zones. The results suggest that both Chorgali and Sakesar Formations are producing reservoirs, we marked one zone in Chorgali having VSH 10%, PHIE 5%, SW 33% and H.C Saturation 67% and three zones in Sakesar having VSH 12-20%, PHIE 2-3%, SW 28-42% and H.C Saturation 58-72% which is most prominent and possible hydrocarbon zones. No major zones can be selected for production testing results as indicated by the high values of water saturation.

Facies modeling is done for the confirmation of lithology's 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. 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. This prepare links between seismic and properties of reservoir (petrophysics) more quantitatively. Different plots of elastic modulus with reservoir depth show low values in productive zones which also confirm our Petrophysical results.

Seismic inversion results are also demonstrating that Chorgali and Sakesar act as a reservoir. The post stack colored inversion is performed to confirm the leads location. 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

Hydrocarbon exploration, no doubt, is a backbone for economy of any country, especially developing countries like Pakistan. As the energy demand increases, exploration sector catch their eyes over unexplored areas for new energy resources excavation. Therefore, our goal is to provide a 2D geological model to petroleum engineers for reservoir performance simulation and for well planning (Slatt, 2006). Investigation of earth through geophysical method involves taking measurement in order to check the variation in the physical properties of the earth both laterally and horizontally (Bust et al., 2010)

In 1915, exploration geophysicists started working on seismic method because of its high resolution and improved accuracy. It became quite useful for imaging subsurface geological features and for identifying structural or stratigraphic traps (Coffeen, 1986). Seismic method is direct result evaluating and accurate geophysical method used for litho-structural analysis especially; Seismic Reflection Method has greater precision than refraction method for deep hydrocarbon exploration.

Seismic Reflection Method most commonly used in hydrocarbon exploration in petroleum geology. Petroleum system mainly comprises of three constituents that are enlisted below.

- Source rocks (contains organic materials which for responsible for generation of hydrocarbons).
- Reservoir rocks (migration of hydrocarbons from source rock and reservoir rock offers suitable conditions for their accumulation).
- Seal or trap rocks (act as a barrier it stops upward movement of hydrocarbons).

Petrophysics uses all kinds of logs, core and production data to obtain physical properties of reservoir such as volume of shale, porosity, water and hydrocarbon saturation which help in identifying probable zones of hydrocarbon (Ali et al., 2014). Facies analysis to support petro-physical results and the Rock Physics analysis to compare the elastic rock properties with the Petrophysical results. In addition, Post-stack seismic Colored inversion is carried out to confirm subtle prospect zones.

1.1 Introduction to Study Area

Southern and northern parts of Pakistan such as Badin, Mari, Potwar kohat plateau has high potential of hydrocarbons. 48% of the world known petroleum resources are belonging to the potwar-kohat which is extra-continental downward basin (Hasany & Saleem, 2001).

Structural traps are dominated in the Potwar sub basin. The study area is lies in the northern part of upper Indus basin. The Balkassar area is located about 105km southwest of capital Islamabad as shown in figure 1.1, in the Chakwal district Punjab Province. It is about 506m above the mean sea level.

Longitude: **72.32^0 -72.47^0 N**

Latitude: **32.51^0 -33.02^0 E**

In north of the Balkassar oil field bikhari kallan, it shares border with Kalar Kahar in south, Chakwal city is situated towards east of it and Talagang is towards south. A satellite image of Pakistan is given in figure highlighting the Balkassar area.

Figure 1.1: Satellite image of Balkassar

Study area belongs to the Kohat-Potwar fold Belt which is in the north of Pakistan. The Kohat-Potwar Fold Belt covers an area of 36000 km^2. The area north of Salt Range is called Potwar Plateau owing to its relatively constants elevation and it encompasses most of the drainage of the Soan River. Potwar is situated in the western foothills of Himalayan in the northern Pakistan.

Potwar sub-basin is filled with thick Pre-Cambrian evaporates overlain by relatively thin platform deposits of Cambrian to Eocene followed by thick Miocene-Pliocene molasses. This whole section has been severely deformed by extremely intensive Himalayan Orogeny in Pliocene to Middle Pleistocene times.

1.1.1 Work Done on Balkassar

Balkassar oil field is located about 105 kilometers Southwest (SW) of Islamabad, in the northern Pakistan. The Balkassar field produces, from Eocene limestone of Sakesar and Chorgali formations. These formations are deformed in an anticlinal structure known as the Balkassar anticline.

Balkassar is an unusual play as it produces oil from a very stiff limestone that have very low porosity and permeability. Epigenetic process of dolomitization creates porosity values of 25% (Malik et al., 1988), whereas tectonic deformation of the Balkassar structure has created fractures through which hydrocarbons can migrate.

Mianwali (Triassic), Dutta (Jurassic), and Patala (Paleocene) formations are major source of oil at Balkassar field (Khan et al., 1986). The shale of Murree formation provides a seal for hydrocarbon catch for underlying reservoirs of Eocene age. The production history of Balkassar oil field shows that the production of oil is unpredictable because success in this play highly depends upon the prediction of fractures.

The Seismic Survey of the Project area was conducted by Occidental Petroleum Corporation (Oxy) in 1981, which is a California-based oil and gas exploration and production company. The survey was conducted for subsurface analysis of Balkassar Oilfield, Eastern Potwar, which lies in the UTM Zone 43N.

1.1.2 Balkassar Oil field

Balkassar is an important hydrocarbon producing area of the Potowar Plateau, Pakistan. Balkassar oil field is located west of Joya Mair in Jhelum District which is situated about 105 km southwest of Islamabad. Attock Oil Company drilled the first well in 1945/6. The field structure is a gentle anticline, with two producing horizons, both of Eocene limestone.

The Balkassar Oil field was one of the main Oil field in Punjab province having daily average production in 1948 was 6,831,920 gallons and in 1949 was 5,991,920 gallons. The oil is asphaltic, suitable for furnace fuel.

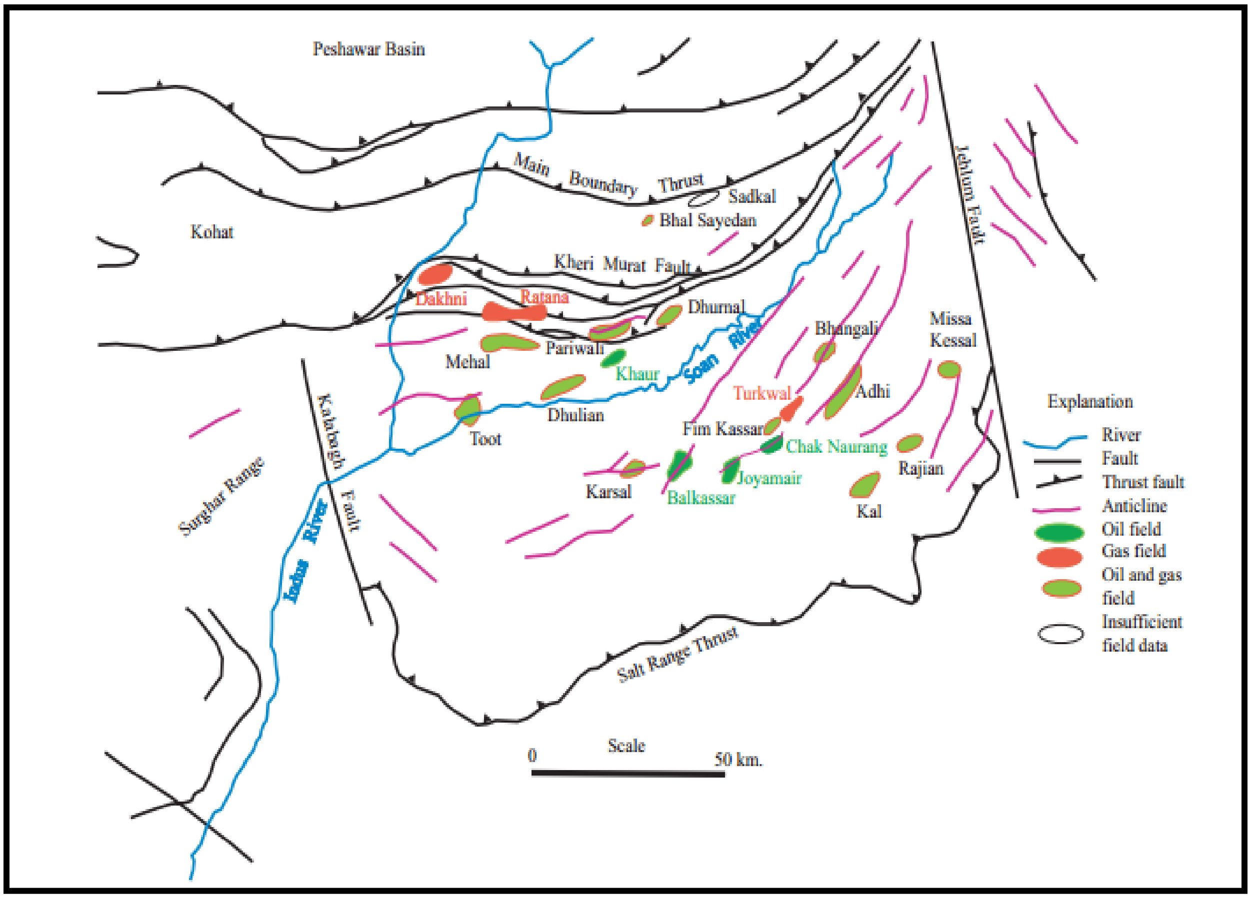


Figure 1.2: Generalized oil and gas field in Potowar, (modified from Kazmi and Rana, 1982, khan and other,2986).

1.2 General description

1.2.1 Technical Well Data

Table 1.1: Technical Well Data			
Operator	**OXY**	**Province**	**Punjab**
Type	**Exploratory**	**Status**	**ABANDONED**
Well Bore Name	**BALKASSAR-(OXY)-01**	**Concession**	
Longitude	**72 39 52.50**	**Latitude**	**32 56 38.80**
Spud Date	**20-June-1981**	**Completion Date**	**26-Sep-1981**
Depth Reference Elevation(m):	**535.53**	**Total Depth(m)**	**3130.60**
Depth Reference	**KB**	**Formation Top**	**SALT RANGE**

1.2.2 Data used

To achieve all the objectives, seismic and borehole data given in Table-1.1 is used provided by DGPC to complete the Thesis project.

Table 1.2: Seismic Data used in interpretation

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

1.2.3 Well Data:

1.2.4 Base Map

We obtain data of well Balkassar-Oxy-01. This well is operated by OXY and completed at 26-Sept-1981. Latitude and longitude of the well are 32.944111and 72.664583 which are in decimal degrees. The information of the formation tops encountered in the well are listed below.

Table 1.3: Formation tops encountered in the Balkassar oxy-01 A well

Formations	Formation Age	Tops (m)	Thicknesses (meters)
NAGRI	**PLIOCENE**	0	478.8
CHINJI	**MIOCENE**	1408.1	106.68

KAMLIAL	**MIOCENE**	1514.8	906.74
MURREE	**MIOCENE**	2421.5	45.72
CHORGALI/BHADRAR	**LOWER EOCENE**	2467.2	135.63
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	109.72
WARCHA	**EARLY PERMIAN**	2796.4	141.73
DANDOT	**EARLY PERMIAN**	2938.1	60.96
TOBRA	**EARLY PERMIAN**	2999.1	51.81
KHEWRA SANDSTONE	**EARLY CAMBRIAN**	30.50.9	78.33
SALT RANGE FORMATION	**PRE-CAMBRIAN**	3129.2	-------

1.3 Software Tools used

For a geophysicist base map is a special type of map which show the orientation of the seis

mic lines and specify the shot points (Sroor, 2010). The base map of the study area is shown in the figure which contains 3 strike lines and 6 dip lines and one oblique line. The 3D view of the

1.4 Objectives

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

- Detailed seismic interpretation for identification of the structures favourable for hydrocarbon accumulation.
- Structural interpretation to find out the structural traps and horizons of interest.
- Preparation of Synthetic seismogram, which use is to confirm us the reflector we have to mark by having TD chart and the combination of Sonic and Density logs.
- Identification of the prominent reflectors and their tentative naming and aging in accordance with the stratigraphy of the area by using well tops and synthetic seismogram.
- Marking of the horizons, and preparation of time and depth maps to be later used in interpretation.
- Marking of faults to understand the nature of geological structures and interpreting the geological framework present in the project area.
- Preparation of fault polygon to extend the trend of the fault on the lines.
- Preparation of grid and then time and depth contours of Murree, Chorgali and Sakesar, which identifies us the sub-surface geological structures there.
- Petrophysical analysis is carried out to obtain physical properties of reservoir such as volume of shale, porosity, water and hydrocarbon saturation, which is the Reservoir characterization.
- Facies Analysis is to confirm the lithology present in our area by using the standard cross plots and check it out with the Petrophysical results.
- Rock physics is to figure out elastic rock parameters and compare it with the Petrophysical properties.
- Also Post stack Seismic Colored Inversion to confirm our prospect zone by having relatively low acoustic impendence.

CHAPTER 02

GEOLOGY, STRATIGRAPHY AND TECTONICS

2.1 Geology

General geology and geological history of an area is very important for exploration of oil and gas. A geological history of basin can be compiled by considering basin forming tectonics and depositional sequence (Kingston et al., 1993).

Geological and structural knowledge of the area is a key for interpreter to perform precise interpretation of seismic data. Interpretation of seismic data requires a comprehension of the subsurface arrangements and how they may influence wave reception. The interpretation of seismic data is based on the stratigraphy and structural geology of an area. The main reason behind that, in many cases similar signature is obtained from different lithology's and vice versa. In order 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 (Kazmi & Jan, 1997). If we have no idea about the geological information of an area we don't recognize the different reflections appearing in the seismic section

2.1.1 Sedimentary basin

.Figure 2.1: Tectonic map of Whole Pakistan

Sedimentary basin are "Geologically depressed area with thick sediments in the interior and thinner sediments at edges"(Shah et al., 2009)

In terms of genesis and different geological histories, Pakistan comprises three main sedimentary basins

- Indus Basin
- Balochistan Basin
- Pishin Basin

Indus and Balochistan basins evolved through different geological episodes and were finally welded together during Cretaceous/Paleocene along Ornach Nal/Chamman strike slip faults (Kazmi and Jan, 1997). The main sedimentary basins of Pakistan after Abdul Fateh et al., (1984) is shown in figure. Also the further subdivision of the Indus basin is shown in the table 2.1. Our study area lies in the Upper part of Indus basin.

Table 2.1: Sub division of Indus Basin

<table>
<tr><td rowspan="11">INDUS BASIN</td><td rowspan="2">UPPER INDUS BASIN</td><td colspan="3">KOHAT SUB-BASIN</td></tr>
<tr><td colspan="3">POTWAR SUB-BASIN</td></tr>
<tr><td rowspan="9">LOWER INDUS BASIN</td><td rowspan="4">CENTRAL INDUS BASIN</td><td colspan="2">PUNJAB PLATFORM</td></tr>
<tr><td rowspan="2">SULAIMAN DEPRESSION</td><td>East Sulaiman Depression</td></tr>
<tr><td>Zindapir Inner Folded Zone</td></tr>
<tr><td colspan="2">SULAIMAN FOLD BELT</td></tr>
<tr><td rowspan="5">SOUTHERN INDUS BASIN</td><td colspan="2">THAR PLATFORM</td></tr>
<tr><td colspan="2">KARACHI TROUGH</td></tr>
<tr><td colspan="2">KIRTHAR FORE DEEP</td></tr>
<tr><td colspan="2">KIRTHAR FOLD BELT</td></tr>
<tr><td colspan="2">OFFSHORE INDUS</td></tr>
</table>

2.2 Potowar Plateau

Plateau is an area which is fairly elevated plain land as compared to the surrounding areas. Potwar plateau is located 100 km north of the salt range and it is an elevated but nearly flat region. In north it is bounded by Kala-chitta and Margalla hills, in south salt ranges are present. Jhelum fault and Hazara Kashmir syntaxes in the east and also the Indus River and the kohat plateau to the west (Kazmi & Jan 1997).

2.3 Major Structures In Potwar

Southern margin of Himalayan collisional zone along with the fold and thrust belt was represented by the Potwar zone. While observing particular zone, faults of different variety were observed. In northern Potwar Plateau, stress is more active than the south. As the Potwar Plateau moves nearer the collision zone some tight fold nappes zones develop which have been thrusted over the NPDZ. According to Moghal et. al, based on the seismic interpretation, the structures in the Potwar area may be divided into following:

- Triangle zone
- Salt cored anticlines.
- Snake head anticlines
- Pop-up anticlines.

2.4 Faults In Potwar Basin

Some of the tectonic features of the Potwar Basin as.

2.4.1 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.. Jadoon et. al., explained that, it soles out in the basal decollement at a depth of about 9 km.citation here and ref down. Jaswel et al observed that, faults that have steep dips at the surface containing high faulted beds of Murree Formation to its north was due to back rotation, where alluvium covered most of the area.

2.4.2 Dhurnal Back Thrust (DBT)

Recent research has proved that DBT (Dhurnal Back Fault) as a different fault. The reason is for with different movement. In previous research, DBT had been considered as the eastward extension of the Kanet Fault (KF). It joins the KF west of Dhurnal and diverts towards the southwest, gradually dying out at the surface. Jadoon, et. al explained that, steep DBT becomes shallower to the south which dies out at a depth of 2 to 4 km. It merges with a north-dipping blind thrust that propagates up as a ramp from a layer of Eocambrian evaporates at a depth of about 8 km and flat along a pelitic horizon in Miocene Molasses strata.

2.4.3 Kanet Fault (KF)

The emerging thrust in the western part of the Potowar is a north-dipping KF. KF bound the Kanet syncline from the north.

2.4.4 Mianwali Fault (MF)

Intra formational thrust at the surface is MF. MF can be traced only in streams. On the basis of faulted Brecca and Shear zones, Outcrop is present only in steams. Steep dips are exposed in the area between MF and KMF representing the northern Siwalik in the rocks having rocks.

2.4.5 Riwat Fault (RF)

In the eastern Potwar Plateau, Hinterland-dipping fault with passive roof trust is RF in south of Soan syncline. Along the southern flank of the Chak Beli Khan anticline, RF dies out. In Northeast RF dies out near the Soan syncline axis.

2.5 Folds In Potwar Basin

Beside major faults, some other structures are also present in the area as follows:

2.5.1 Soan Syncline

Potwar Plateau divided into northern and southern Potwar deformed zone by the Soan Syncline. Soan Syncline is broad, wide and asymmetrical syncline. Its axis is marked by the Soan River. Dhok Pathan Formation overlying the Nagri Formation crops out south of Dhurnal area on the northern limb of Scan syncline. Here crustal shortening is due to the collisional tectonics.

2.5.2 Chak Naurang Anticline

Chak Naurang has two dipping limbs. These limbs are namely, southern limb which is dipping steeply while northern limb dipping moderately. Anticline is an example a fault-propagated fold. A strong northward-dipping basement reflector, which is overlain by a thick evaporite srata shown in the Reflection data.

2.6 Geological Setting

Salt Range escarpment bounds the Potwar basin from south, from north bounded by Main Boundary Thrust (MBT), in east by Jhelum transform fault, and to the west by Kalabagh transform fault (Aamir and Siddiqui,2006).

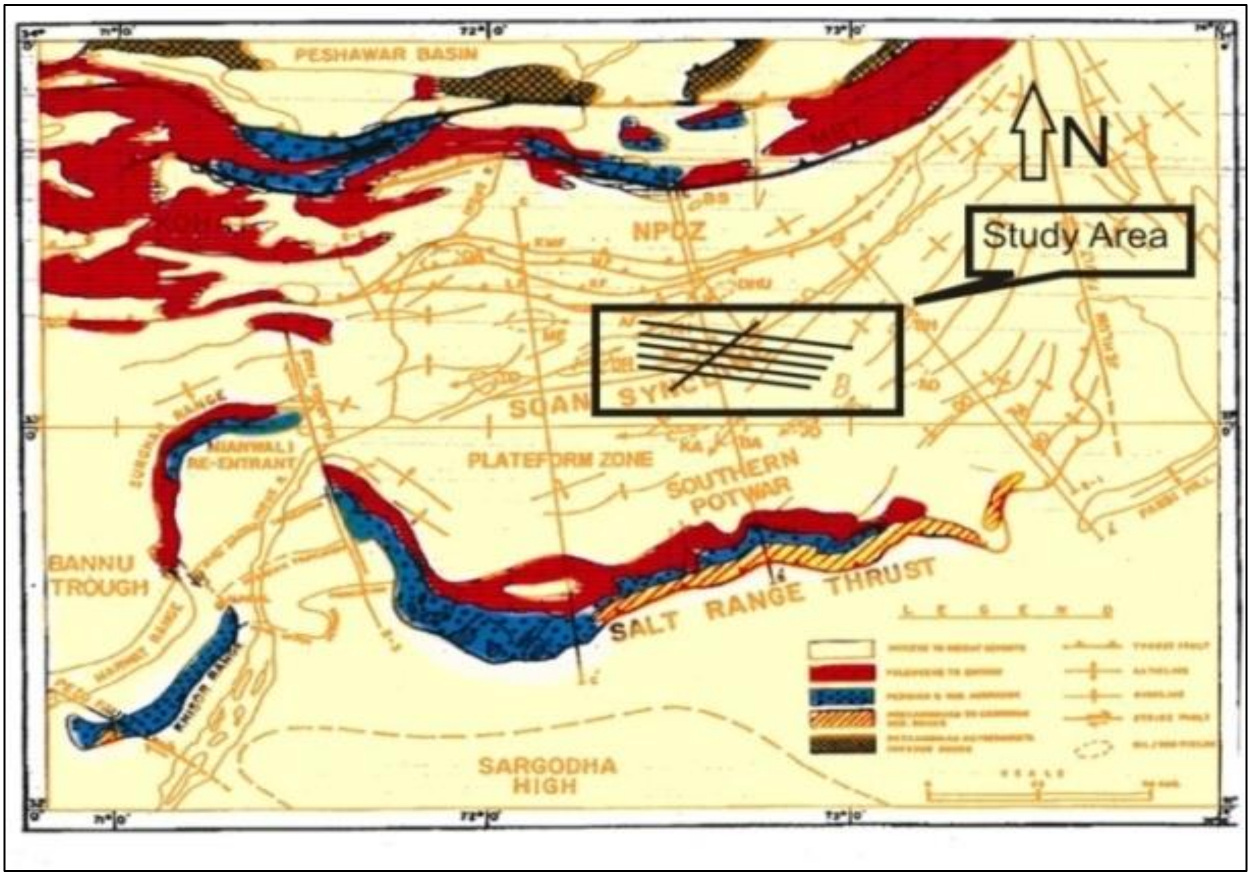


Figure 2.2: Structures in Potowar

Balkassar oil field lies in to the south of Soan Syncline, Upper Indus Basin, in the Platform zone. It is anticline that is bounded by faults at its limbs. The anticline is oriented NE-SW. Various Stratigraphic units that are encountered in wells, thickness and the contacts etc.

2.7 Stratigraphy

Subsurface geological data from wells drilled in Balkassar area indicates presence of Precambrian-Eo-Cambrian, Cambrian-Permian, Permian-Paleocene and Eocene-Miocene breaks in deposition. Eo-Cambrian Salt Range Formation unconformably overlies the basement rocks, composed of metamorphic and volcanic rocks of Indian Shield (Yeats and Lawrence, 1984), and is overlain unconformably by Early Cambrian Khewra Sandstone.

Contrary to well data obtained in Rajian, Missa Keswal and Adhi (Moghal et al., 2007) Kussak, Jutana and Baghanwala formations were not encountered in Balkassar Oxy-01-Well. Tobra Formation (conglomerates) of lower Permian age unconformably overlies the Khewra Sandstone. Dandot, Warchha and Sardhai formations of lower Permian age mainly composed of sandstone (Dandot and Warchha formations) and shales (Sardhi Formation) successively overly Tobra Formation. The area remains exposed from upper Permian through lower Paleocene. In Danian, Tertiary sequence with Hangu Formation at the base was deposited over Sardhi Formation. In the central and northern Salt Range, like Karsal, Dhurnal, Meyal and Dakhni wells (Moghal et al., 2007), a Permian, Triassic, Jurassic and Cretaceous sequence is present (Shah, 2009).

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

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

2.8 Petroleum Geology

2.8.1 Source Rock

Hydrocarbon Development Institute of Pakistan (HDIP), in collaboration with Federal Institute for Geosciences and Natural Resources (BGR) Hanover, Germany have identified a number of source rock horizons through Infra-Cambrian to Eocene in the Potwar Sub-basin and surrounding areas. These investigations suggest that the organic-rich shales of the Paleocene (Patala Formation) can be considered as the main contender for sourcing the Potwar oil fields.

In Potwar Basin, Patala shales of Paleocene have proven as the main source rocks. These organic shales were partly deposited in anoxic conditions prevailing Paleocene due to buckling of the basin floor. Pre-Cambrian Salt Range Formation also contains oil shale intervals, which show source rock potential.

The oil to source correlation indicates that most of the oil produced in Potwar sub basin has been sourced through Patala Formation. Shales of Khewra Formation are of lacustrine to marine origin and contain woody, coaly to variously amorphous (with significantly woody herbaceous) kerogen, which are capable of generating paraffinic to normal crude and gas.

2.8.2 Reservoir Rocks

Paleozoic-Tertiary dominantly marine sedimentary rocks form petroleum systems in Potwar and are exposed in Salt Range along the Frontal Thrust. 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. These represent the products of arid environment to marginal marine environment.

The upper and middle units of the formation are moderately porous and display intergranular primary porosity, which ranges from 10% - 12%. The uniform grain size and moderate sorting of the sandstone indicates its excellent reservoir nature. The sandstone also displays fracture.

2.8.3 Traps

Traps have been developed due to thin-skinned tectonics, which has produced faulted anticlines, pop-up and positive flower structures above Pre-Cambrian salt. The clays and shales of the Murree Formation additionally give effective vertical and horizontal seal to Eocene reservoirs wherever it is in contact.

CHAPTER 03

SEISMIC INTERPRETATION

3.1 Introduction

Seismic interpretation is the transformation of seismic reflection data into a structural picture by the application of correlation of seismic reflectors with geological boundaries and their time–depth contours.

3.2 Seismic Methods

Seismic method is one of the most important geophysical method in all geophysical methods. This predominance is because of various factors, its high accuracy, high resolution and great penetration. This wide seismic method is mostly used in exploration of petroleum.

This basic technique of seismic exploration is that seismic waves are generated and measured the time required for waves to travel from source to the geophones, which are arranged in specific pattern. There are two types of seismic methods i.e.

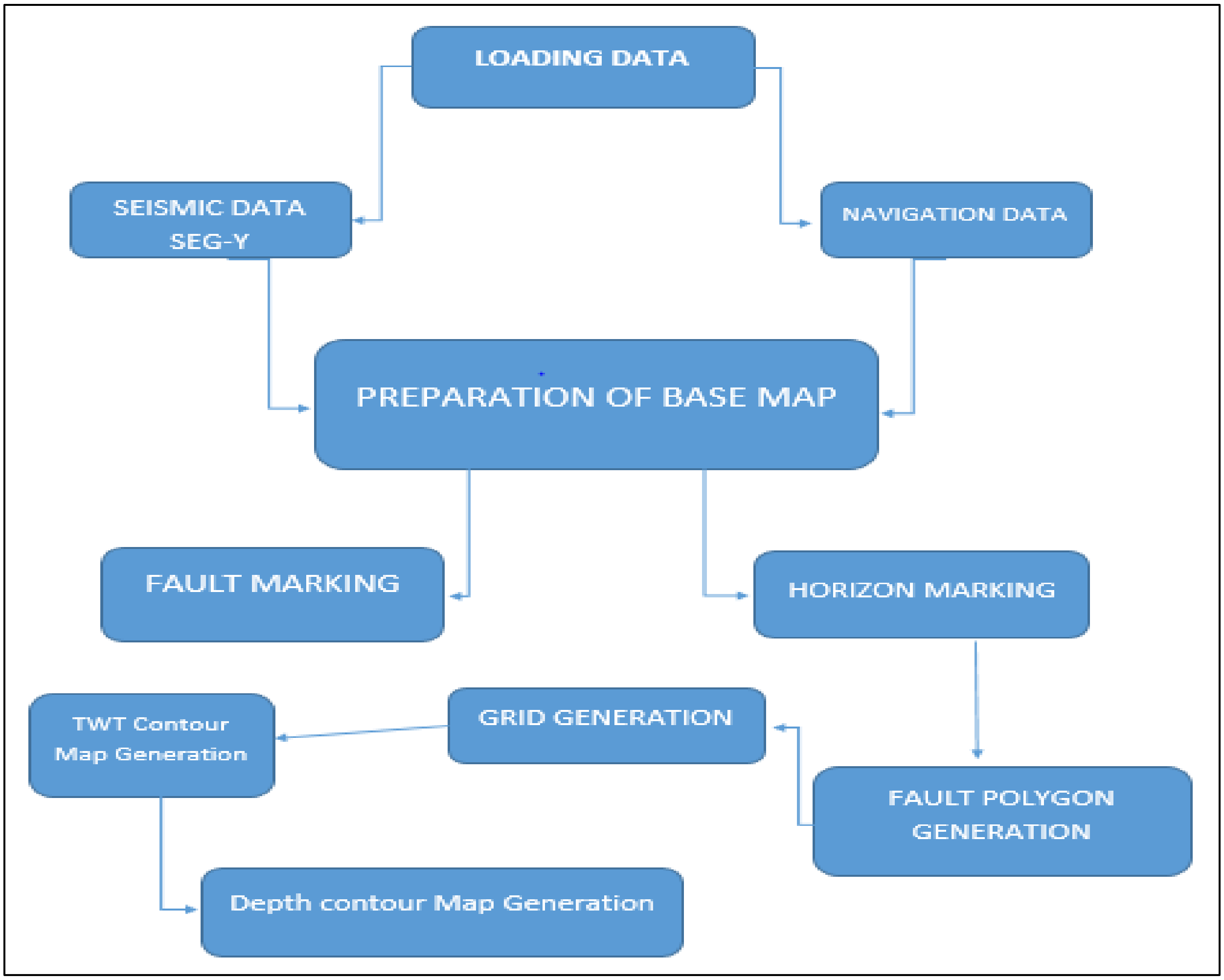
- Seismic reflection method
- Seismic refraction method

The **seismic reflection method** is based on the study to map subsurface geological structures. Measurements are made of the arrival time of events attributed to seismic waves which have been reflected from interfaces where the acoustic impedance changes. The objective usually is to map variations in the depth and attitude of the interfaces which usually are parallel to the bedding.

Seismic refraction method is based on the study of elastic waves refracted along geological layers. This method is generally used to map low velocity zone. This method is used as supplement with reflection method.

Seismic Interpretation Workflow for seismic data interpretation is given in figure where base map is prepared by loading navigation data and SEG-Y in software. Horizons of interest are marked manually. In this process faults are identified and marked. Faults polygons are generated and horizons are contoured to find out structural highs and lows. Then time and depth contours are plotted.

3.3 Work Flow



3.4 Interpretation of the seismic lines:

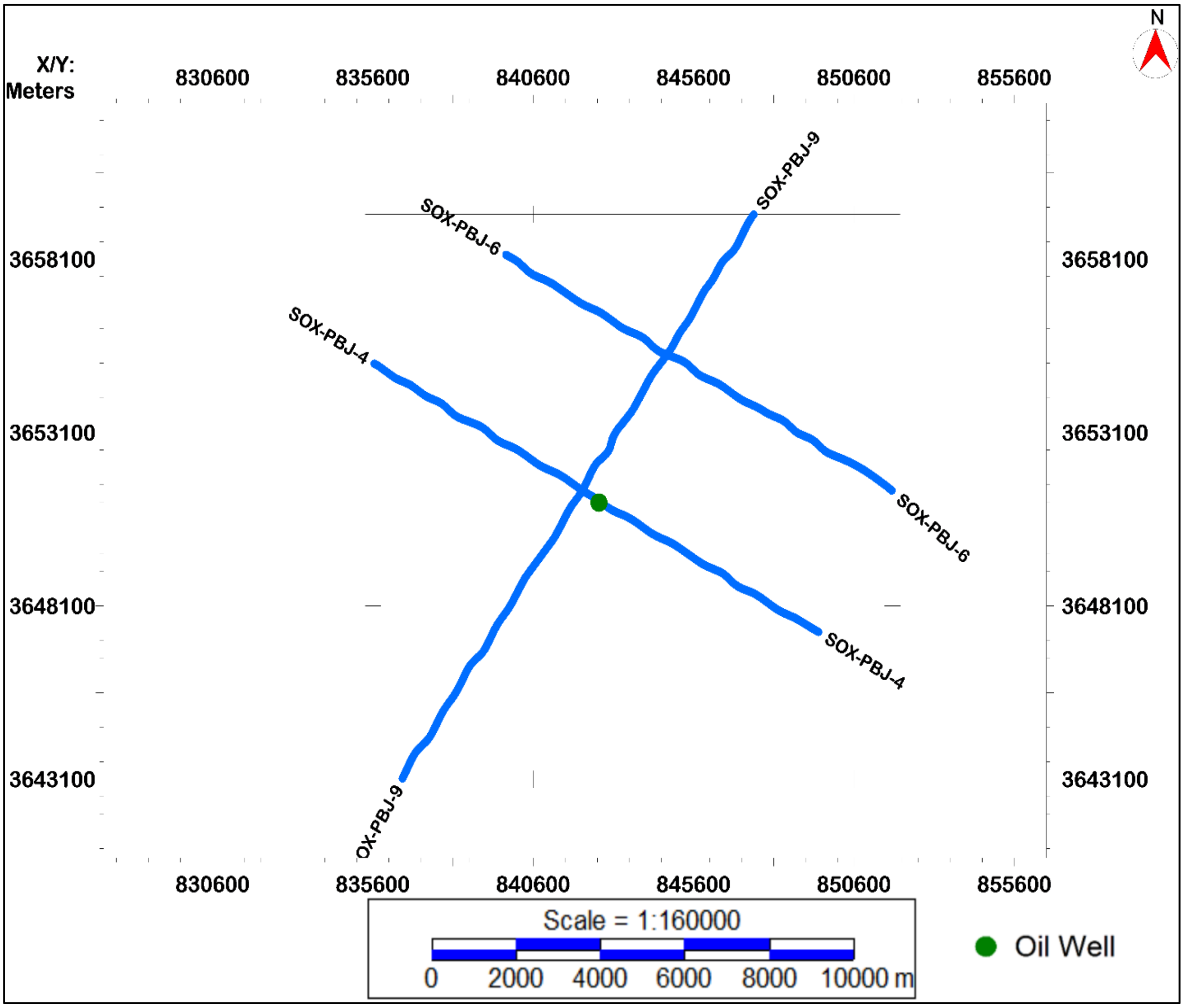
The Primary task of interpretation is the identification of various horizons as an interface among geological formation. For this purpose, good structural as well as stratigraphic knowledge of the area is required (McQuillin et al., 1984). Thus during interpretation process, we marked both, the horizons and faults on the seismic section by the information obtained from the synthetic seismogram generated from OXY-01 A well. We marked the four horizons. The horizons are named on basis of well tops of the well OXY-01 A. Hence the first step before the Marking of the horizons is the generation of the synthetic seismogram. The steps used in the generation of the synthetic seismogram are explained below.

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

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

3.5 Base Map

Figure 3.1: 2D Base map of Study Area



3.6 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 used the constant density for that area. With the help of 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, Elevation, Total Depth, Lattitude 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 sonic log to rescale from depth in meters to two-way travel time in seconds.
- Compute Acoustic impedance log using velocity and density log.
- Compute the reflection coefficients from the time-scaled velocity log.
- Compute a first-order Ricker wavelet as a digital filter with two millisecond increments.
- Two-way travel time; using a frequency in Hertz.
- Convolve the reflection coefficient log with the Ricker wavelet to generate the amplitudes of the synthetic seismogram.

Now the generated seismogram is used to confirm the horizon .Basically we have the limited log data only 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.

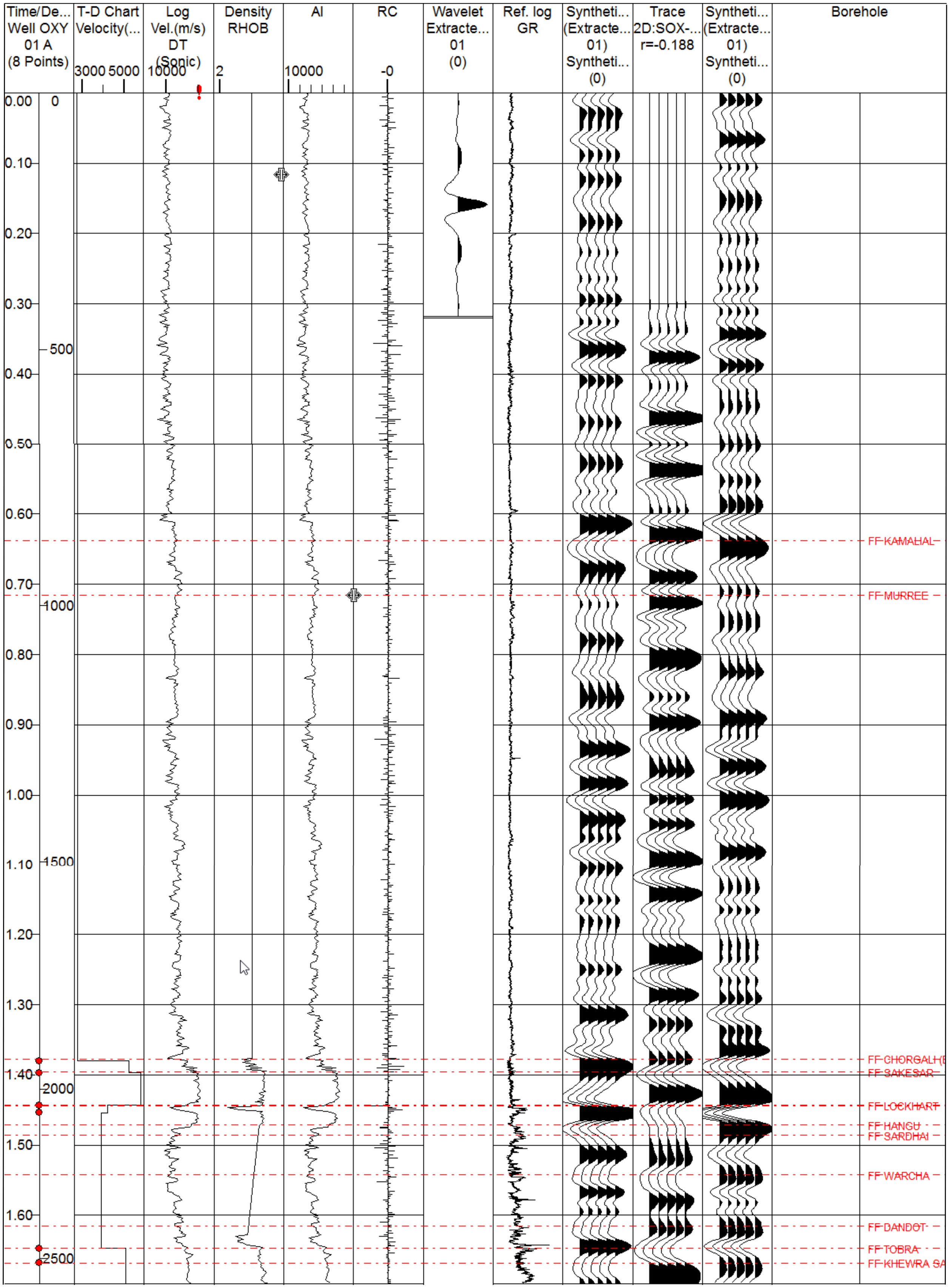


Figure 3.2: Synthetic Seismogram of Well OXY 01

3.7 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.

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

F1 and F2 confine a pop up structure that may generate hydrocarbon.

3.8 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.

During interpretation process, I first generated a synthetic seismogram by the help of DT, RHOB logs and TD chart provided with the data of Well BALKASSAR_OXY_1.

Four horizons are picked on the basis of available information. The horizons are named on basis of well tops of the well BALKASSAR_OXY_1.

The following horizons were picked

- Murree Formation
- Chorgali Formation
- Sakesar Formation
- Basement

3.9 Time Section

Along X-axis we have number of traces along the location while along y-axis we have travel time and also it represents the depth of the section. It is also known as depth section. A seismic time section is actually the reproduction of actual seismic section and represents the reflectors and structures in time domain. It is generalized in two way travel time.

In this seismic section we marked four horizons and 3 reverse fault and one normal fault.

3.9.1 Interpretation of Dip line PBJ-04 and PBJ-06

Figure 3.3 shows well tie with real time domain section. We marked horizons of Murree, Chorgali, Sakesar. Top of the Murree, Chorgali, Sakesar formation on the basis of the change in the acoustic impedance also confirmed by the synthetic seismogram

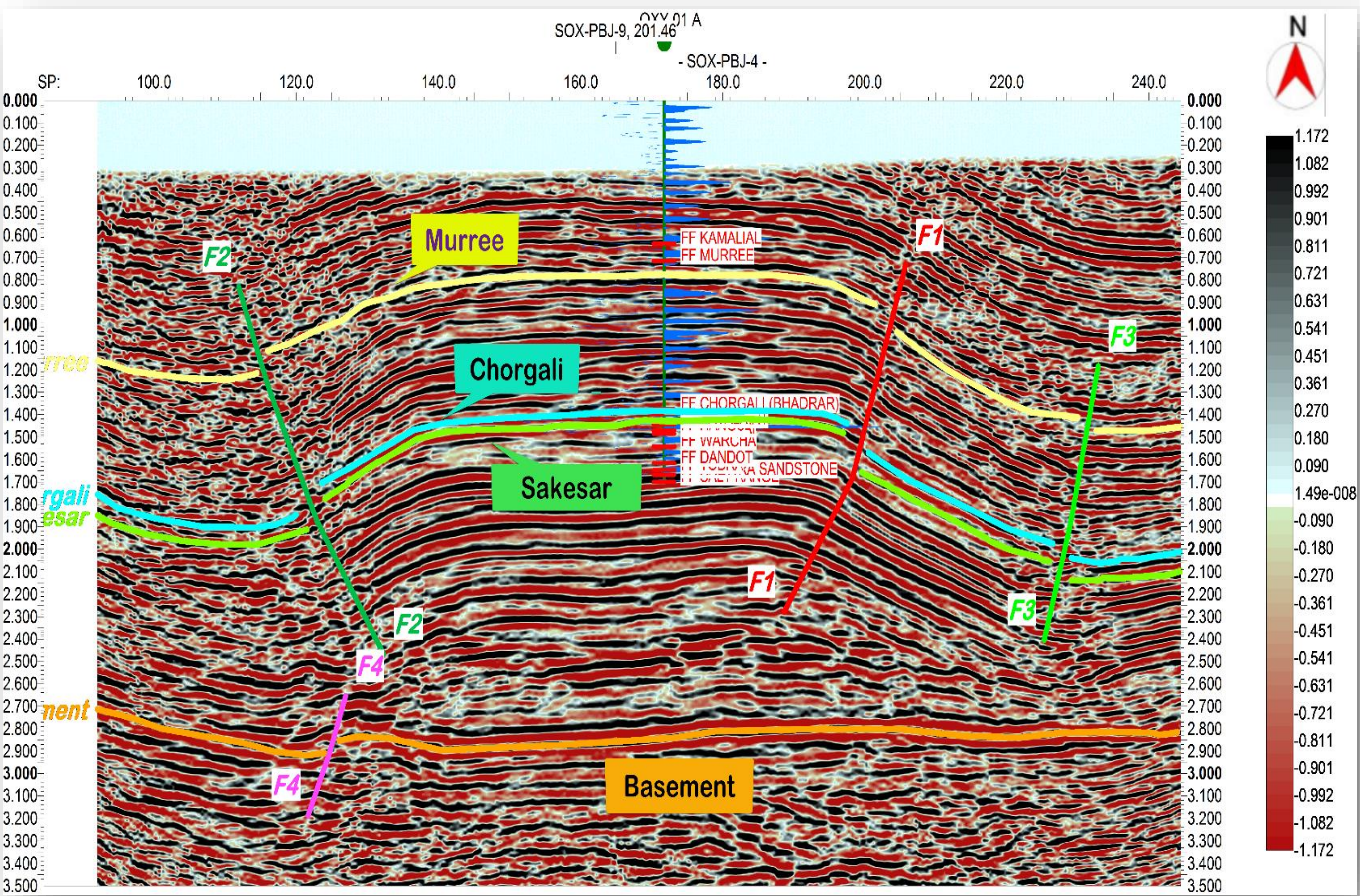


Figure 3.3: Interpretation of seismic strike line PBJ 04

The following color scheme is used to mark the horizon.

- ✦ Murree — Light Yellow
- ✦ Chorgali — Cyan
- ✦ Sakesar — Light Green
- ✦ Basement — Gold

The interpretation shows the Pop up Anticline between Thrust faulting. The fault having almost trend of the NW-SE. The main purpose was to show the favourable structure for petroleum accumulation. The Pop up anticline structures are considered good structural trapes for the petroleum accumulation.

In the interpretation of the line PBJ-04 the thrust faulting can be seen. Due to this thrust faulting the Pop-up anticline structures are formed. These structures are considered favorable for the hydrocarbon accumulation in the compressional regime as in the Balkassar area.

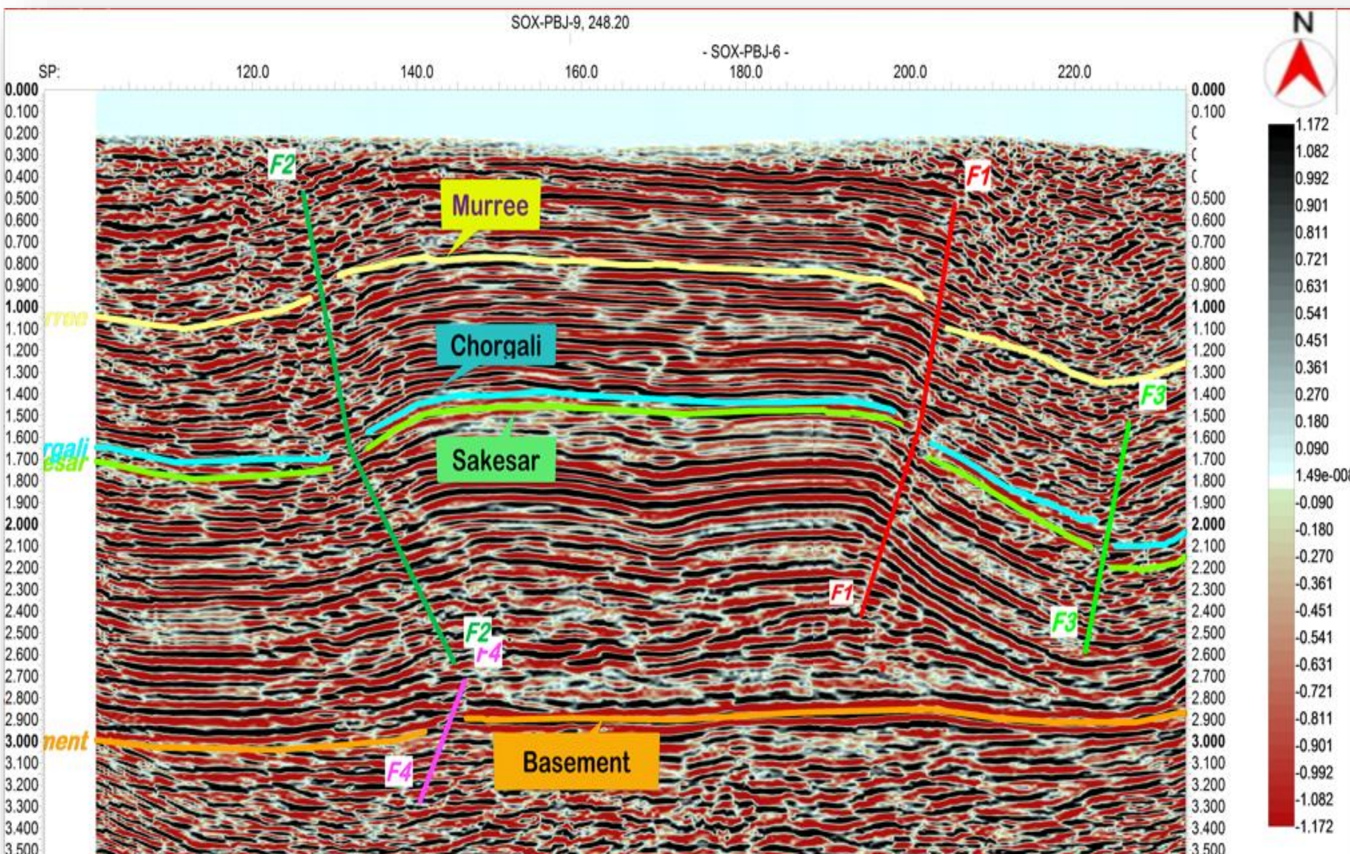


Figure 3.4: Interpretation of seismic strike line PBJ 06

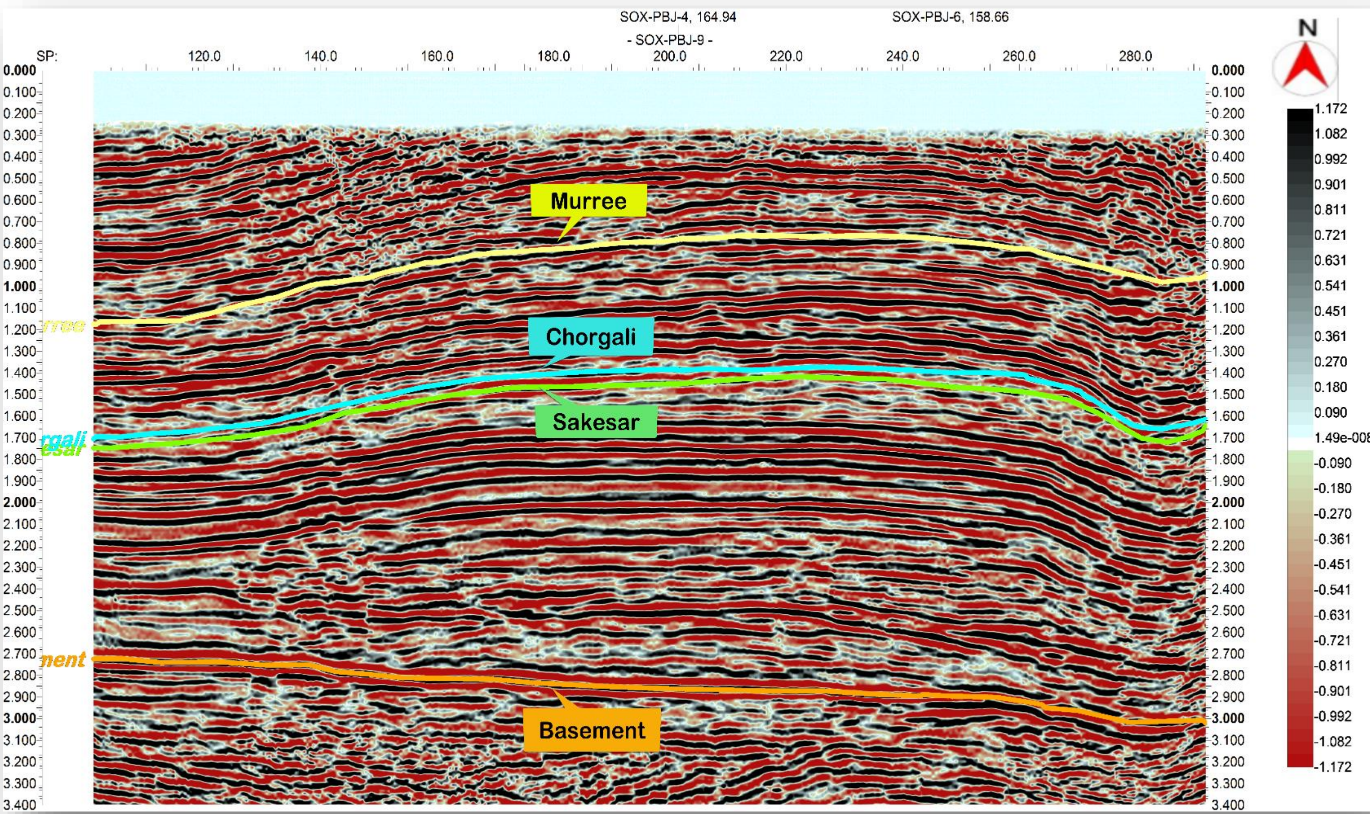
Also we have same structures in the line PBJ-06, because orientation of PBJ 04 and 06 are same only they are placed apart at some distance. In figure 3.4 also we marked 4 horizons and identified 3 reverse faults and one normal fault.

By the faults identified on these lines we form fault polygons and then make grid of time and depth and also form contours along these lines.

3.9.2 Interpretation of Strike line PBJ-09

Orientation of line PBJ-09 is SW-NE. This line can cross two dip lines which is used to tie the horizons. We marked four horizons as on other lines but here we have no fault as sownh in figure 3.5. Also we didn't identified any structure and trend of horizons is nearly straight.

Figure 3.5: Interpretation of seismic Dip line PBJ 09



3.10 Fault polygon construction

We pick the fault on seismic section & find it at the other seismic lines. The fault in seismic section is called Fault Segment and the fault on map view is called Fault Polygon (Sroor, 2010).

In any software for mapping an area total fault should be converted into fault polygon before the contouring. The reason is that if we will not convert them into fault polygon then the software will not recognize it as a barrier due to which a wrong picture of the earth will be generated.

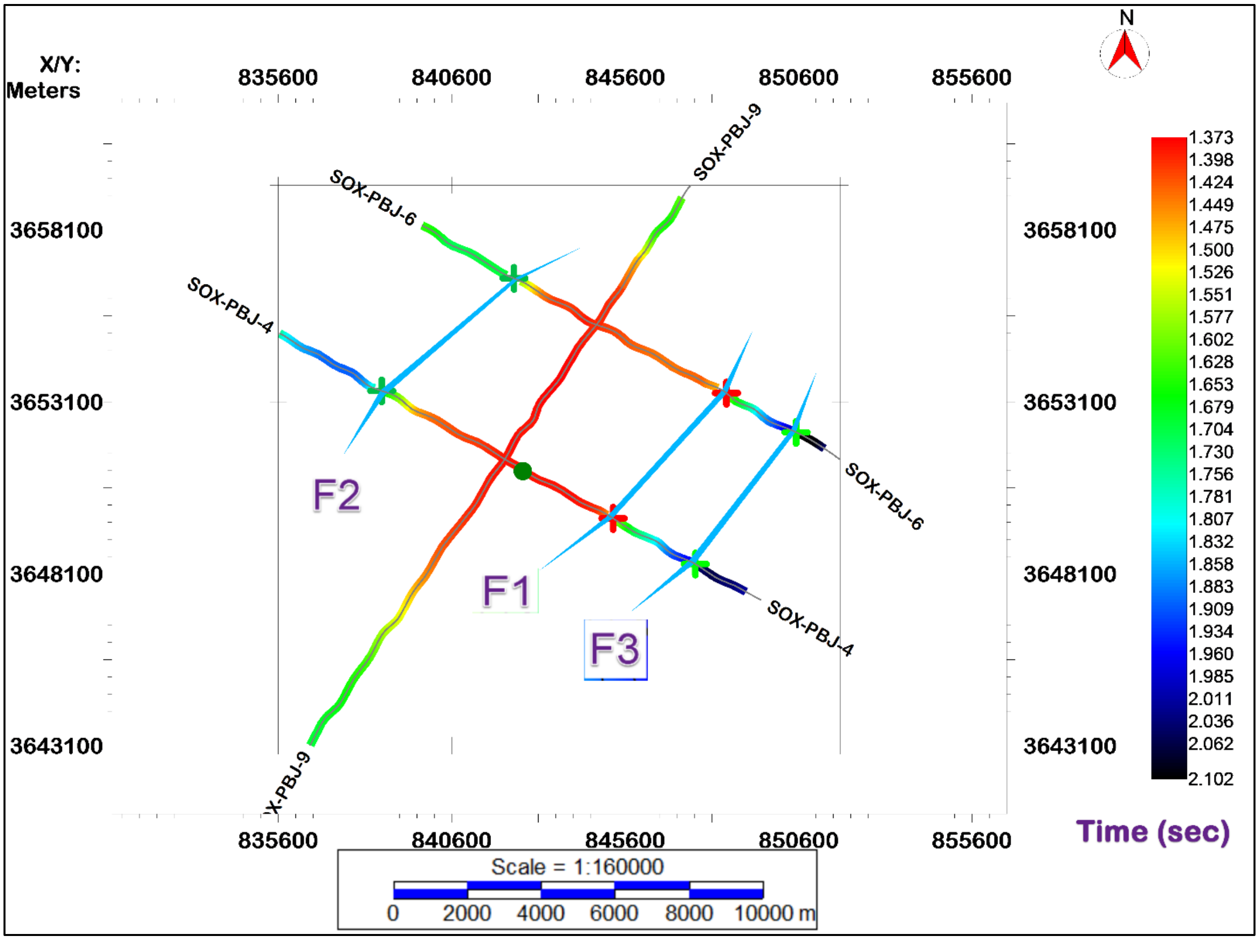


Figure 3.6: Fault Polygon of Murree formation

3.11 Contour Maps

The final products of all the seismic exploration are the contour maps, time or depth. The mapping is one of the most important part of the data interpretation on which entire operations depends upon. The contours are generally the lines which join the point of the equal depth and time (Coffeen, 1986). Contours represent the three dimensional earth surface into the two dimensional earth surface. These contour maps represent the structural relief of the formation, any faulting and folding including dip of the strata.

3.11.1 Time and Depth based contour models

As the seismic section is originally a time section and reflection time values in milliseconds by plotting the values at an appropriate CDP interval and plot these values on the map. Also 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 are not altered (Onajite, 2014).

Conversion from time to Depth contour is by using the average velocity of the area. Actually we have to use the interval velocity but due to limitation of data we can't use it so we use the average velocity to convert from time to depth by using formula. (s=vt). Contour interval for each time model and depth model is different. Below are the models for Murree formation acting as a seal rock, Chorgali and Sakesar formation acting as reservoirs in study area.

3.11.2 Time and depth contour maps of Murree:

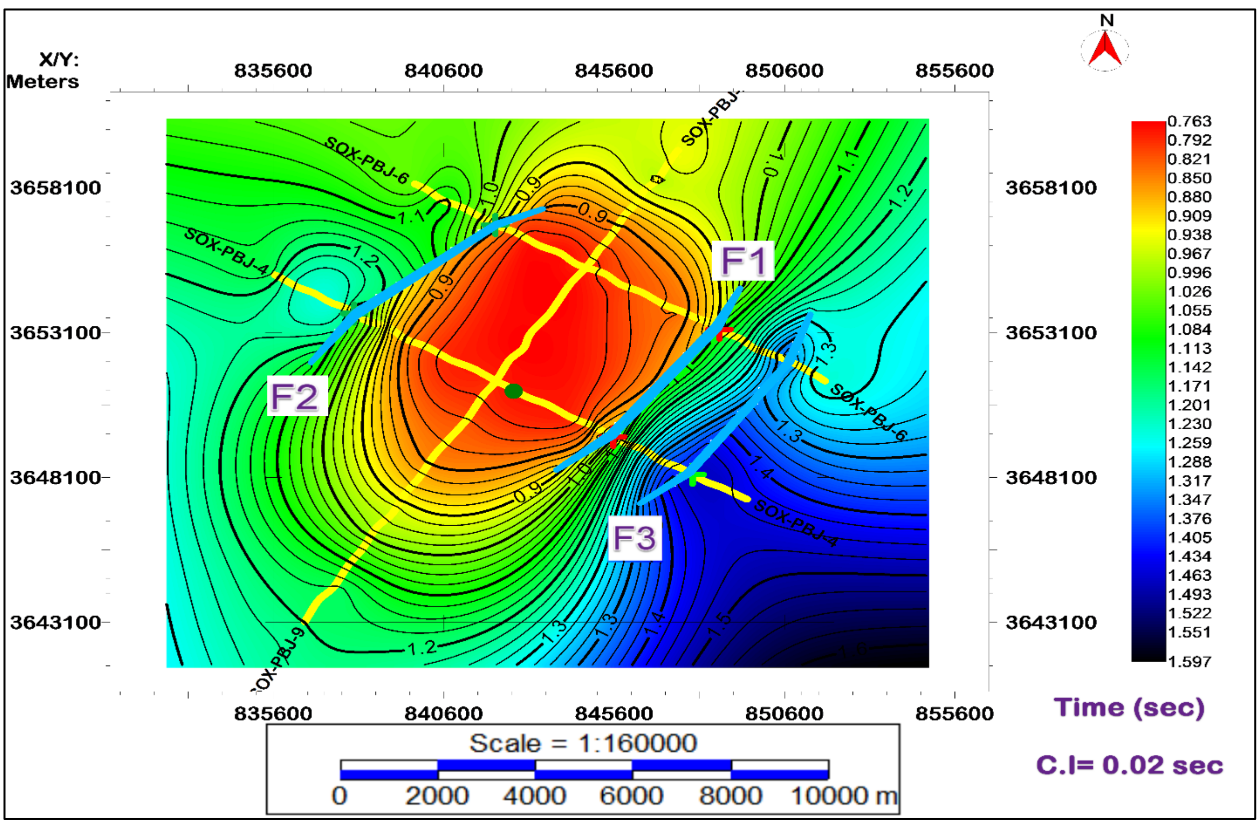


Figure 3.7: Time Contour map of the Murree Formation

Time and depth contour map of Murree formation is shown in figure 3.7 and 3.8. Time and Depth variation is given through color bar.

Orange portion is showing the lowest values i.e shallowest part while the dark blue color is showing deeper parts. It is clear that 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 orange color is showing low time values and it is a good indicator for hydrocarbon.

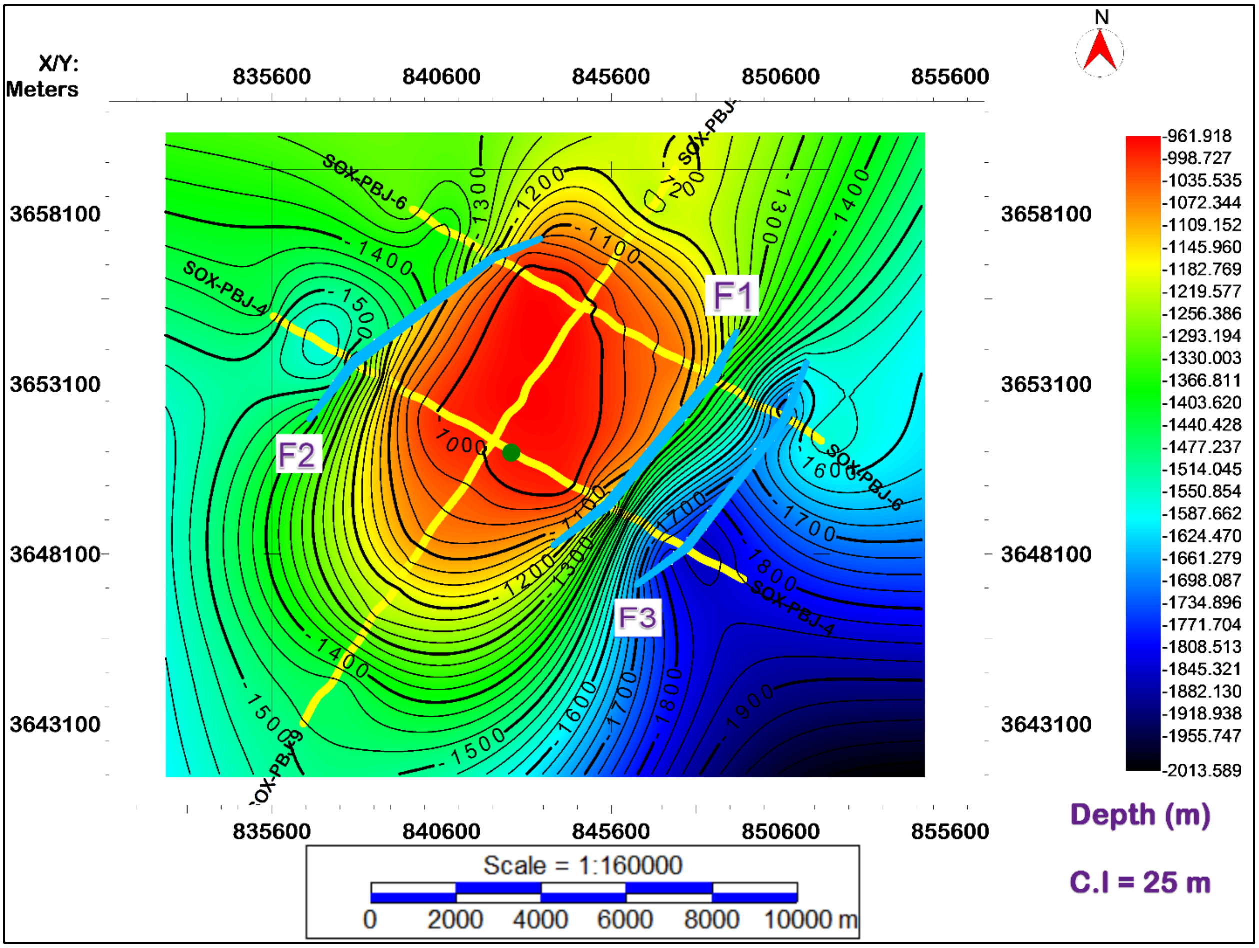


Figure 3.8: Depth Contour map of the Murree Formation

Contour interval for time section is 0.02 sec while depth contour interval is 25m.

In time and depth contour maps orange color ranges for time section from (0.763sec-0.909sec) while for depth it ranges from (961m-1109m) showing the shallowest parts.

While dark blue color for time section ranges from (1.40sec-1.59sec) while for depth it ranges from (1735m-2013m) showing deeper parts.

3.11.3 Time and depth contour maps of Chorgali

Time and depth contour map of Chorgali formation is shown in figure 3.9 and 3.10. Time variation is given through color bar. Orange portion is showing the lowest values i.e shallowest part while the dark blue color is showing deeper parts. It is clear that Murree is deepening NW-SE direction as the time is increasing and Chorgali formation is shallowing towards NE-SW direction because time is decreasing. Hence the orange color is showing low time values and it is a good indicator for hydrocarbon.

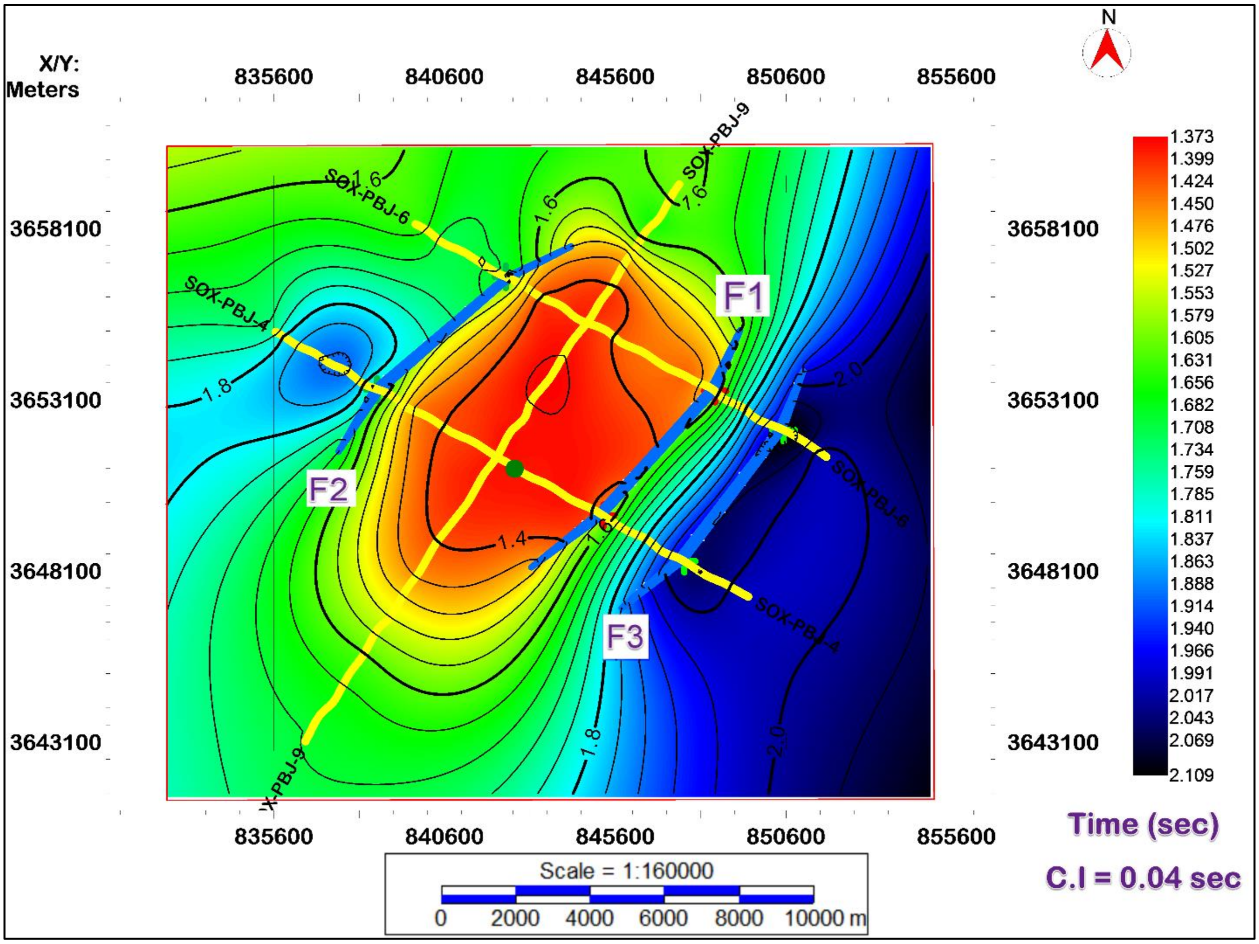


Figure 3.9: Time Contour map of the Chorgali Formation

Contour interval for time section is 0.04 sec while depth contour interval is 50m.

In time and depth contour maps orange color ranges from (1.373sec-1.476sec) for time contours while for depth it ranges from (1870.955m-2000m) showing the shallowest parts.

While dark blue color ranges from (1.966sec-2.109sec) for time contours while for depth it ranges from (2680m-2874.621m) showing deeper parts.

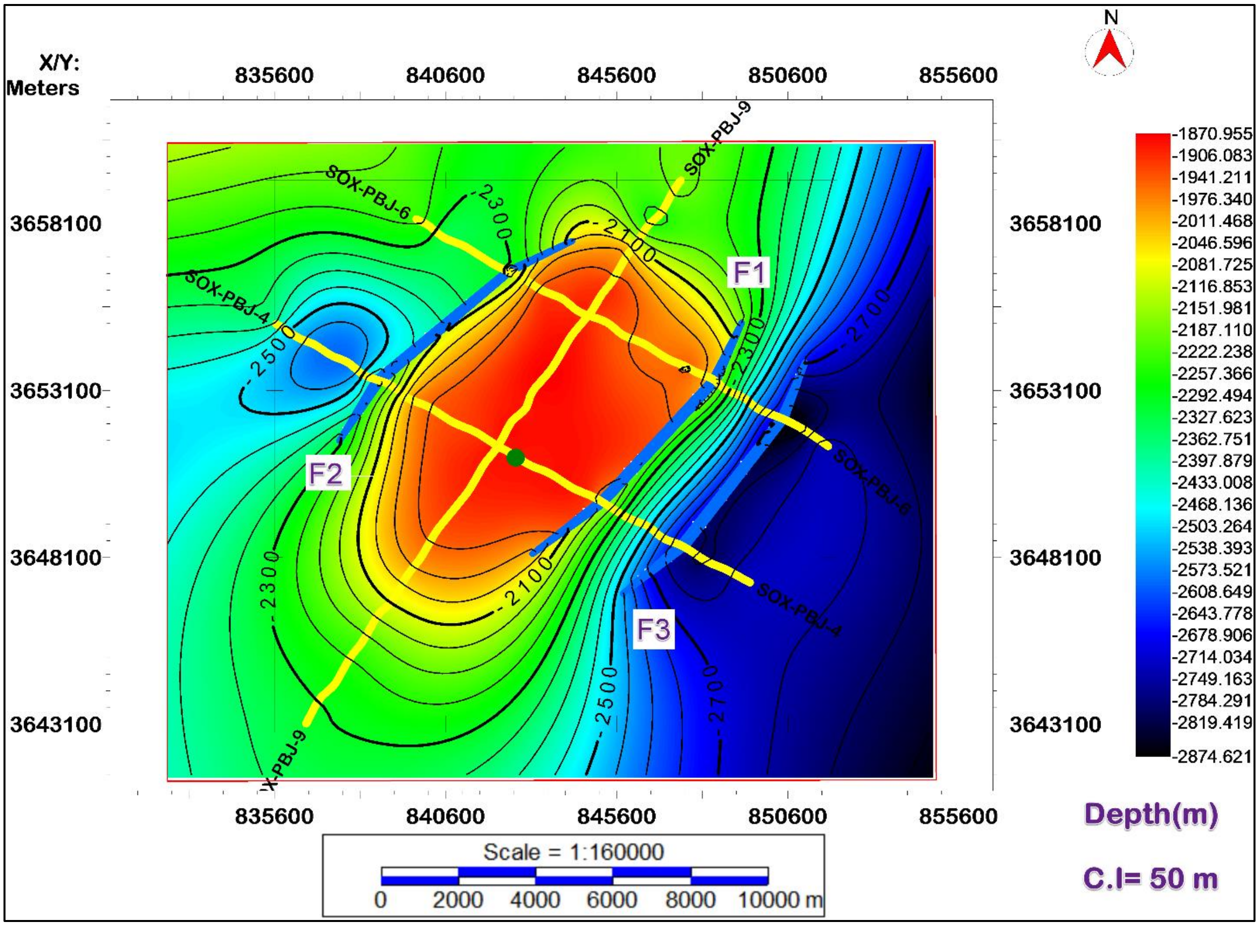


Figure 3.10: Depth Contour map of the Chorgali Formation

3.11.4 Time and depth contour maps of Sakesar:

Time and depth contour map of Sakesar formation is shown in figure 3.11 and 3.12. Time and depth variation is given through color bar. Orange portion is showing the lowest values i.e shallowest part while the dark blue color is showing deeper parts. It is clear that 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 orange color is showing low time values and it is a good indicator for hydrocarbon.

Contour interval for time section is 0.04 sec while depth contour interval is 50m.

In time and depth contour maps orange color ranges from (1.416sec-1.512sec) for time contours while for depth it ranges from (1914.362m-2028.726m) showing the shallowest parts. While dark blue color ranges from (2.092sec-2.221sec) for time contours while for depth it ranges from (2791.156m-3003.547m) showing deeper parts.

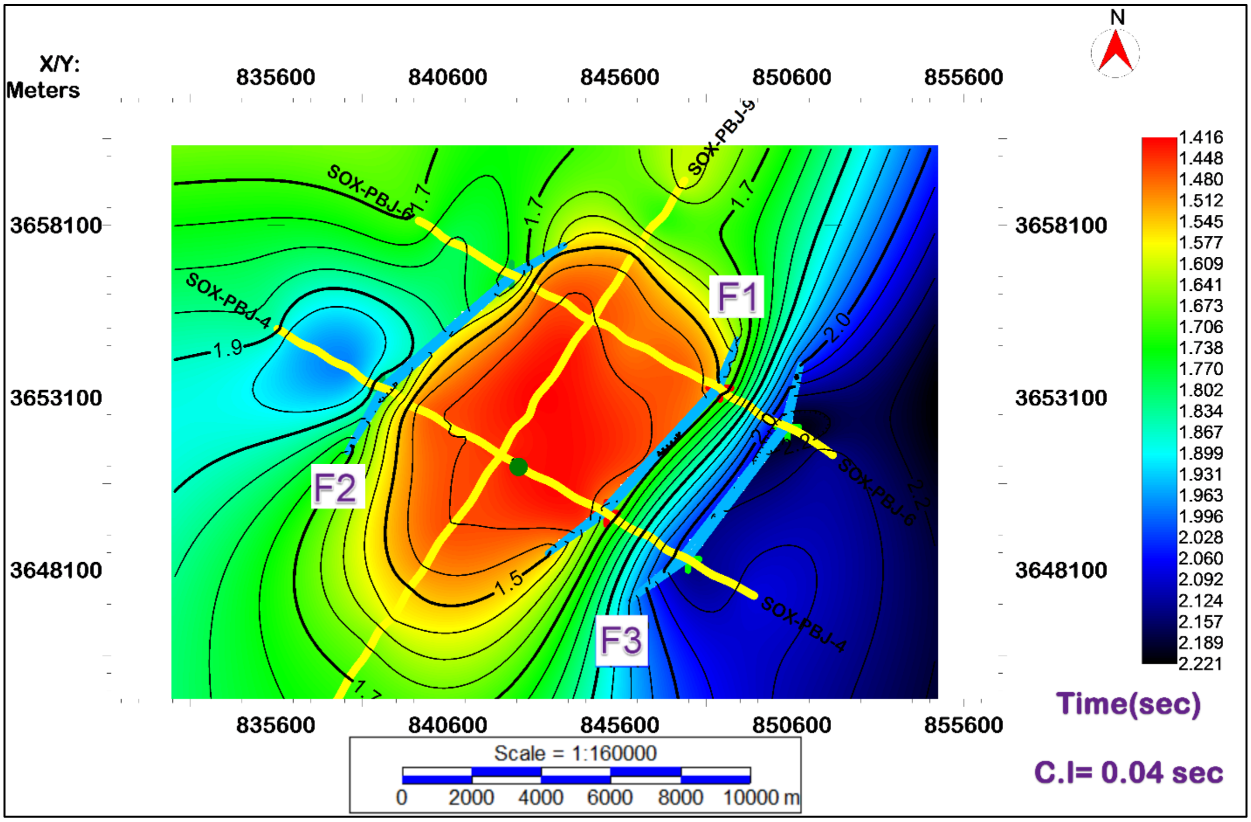


Figure 3.11: Time Contour map of the Sakesar Formation

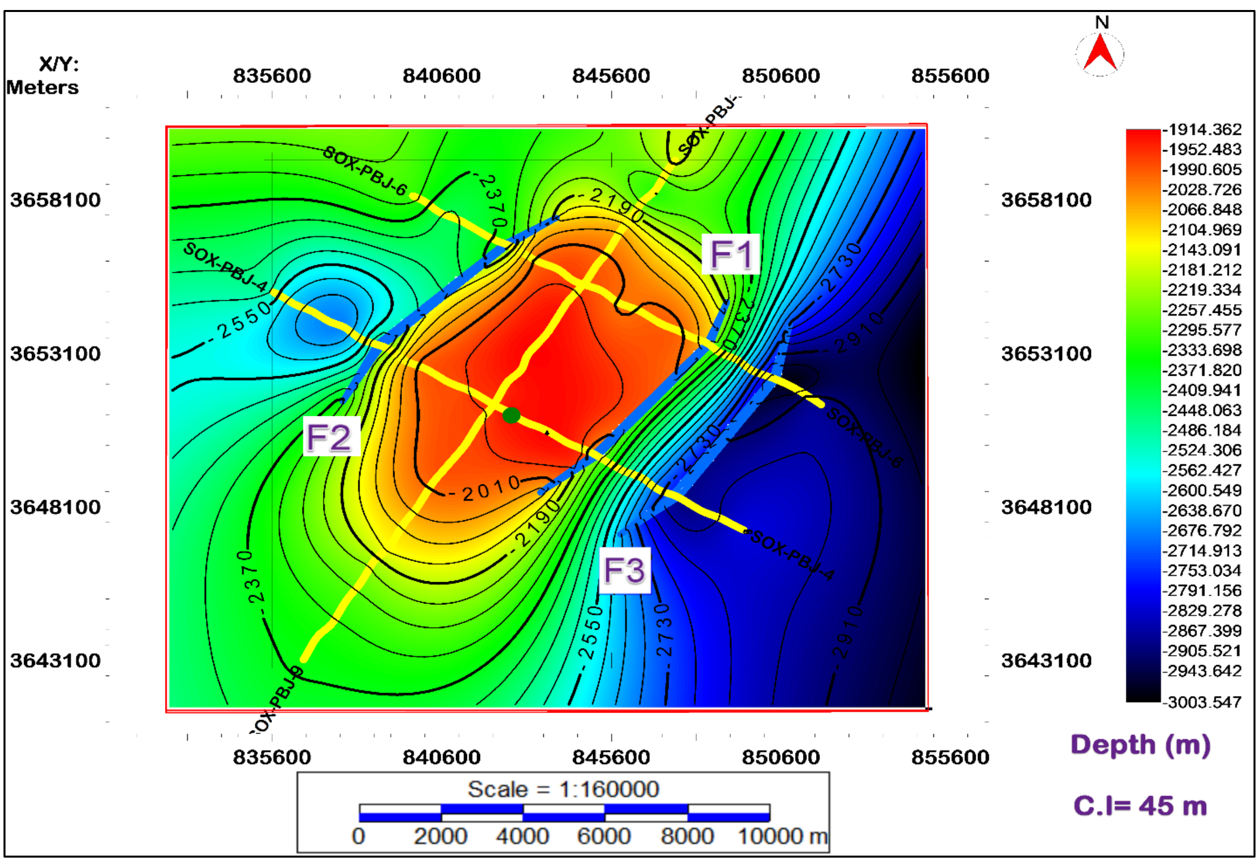


Figure 3.12: Depth Contour map of the Sakesar Formation

3.12 Conclusion

- Time and depth structure map shows a pop up anticlinal structure with faults at limbs.
- Chorgali and sakesar act as a reservoir.
- Murree and kamlial provides a lateral seal.
- Faults extend from the salt range formation to the upper horizons and provide a trap for all hydrocarbon bearing zones.
- Patala act as a source.
- The high area is promising zone for developments.

CHAPTER 04

PETROPHYSICAL ANALYSIS

4.1 Introduction

Petrophysics (petro is Latin for "rock" and physics is the study of nature) 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 sometimes seismic measurements, and combining them with geology and geophysics.

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 three major parts namely

- Rock mechanical properties
- Ore quality
- Conventional Petrophysical properties

These properties provide complete description about the rock, for instance, they provide information about the size of the grains present, composition of the rock and the texture of the rock.

4.2 Reservoir Petrophysical Properties

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

4.2.1 Lithology

What type of rock is it? When combined with local geology and core study, geoscientists can use log measurements such as natural gamma, neutron, density, Photoelectric, resistivity or their combination to determine the lithology downhole.

4.2.2 Porosity ϕ

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 measured to derive rock porosity.

Nuclear magnetic resonance (NMR) logging, including porosity, saturation, hydrocarbon identification, facies prediction, and permeability.

4.2.3 Water saturation (Sw)

The fraction of the pore space occupied by water. This is typically measured using an instrument that measures the resistivity of the rock.

4.2.4 Hydrocarbon saturation (H.C.S)

The fraction of the pore space occupied by hydrocarbon. This is typically measured by subtracting the water saturation from one (1).

4.2.5 Net Pay

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

4.3 Given Data

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

4.4 Logs Available

Table 4.1: Logs available of Balkassar OXY 01 well

	Name	Type
1	CALI	Other
2	CALIPER	Other
3	DRHO	Other
4	DT	Sonic
5	GR	Other
6	ILD	Resistivity
7	LLD	Other
8	LLS	Other
9	MSFL	Other
10	NPHI	Other
11	PE	Other
12	PHIE	Other
13	RHOB	Density
14	Rt	Resistivity
15	Rxo	Other
16	SFLU	Other
17	SMTPERM	Other
18	SMTPHIE	Other
19	SMTPHISW	Other
20	SMTPHISXO	Other
21	SMTPHIX	Other
22	SMTSW	Other
23	SMTSWAR	Other
24	SMTSXO	Other
25	SMTSXOAR	Other
26	SMTVSH	Other
27	SP	Other

4.5 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.

4.6 Lithology Track

4.6.1 GR log

GR logging tool detect the natural Gamma radiations across the formation. These radiations comes 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) have 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.

4.6.2 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.

4.6.3 Caliper log

Caliper log tell us about bore hole diameter. Bore hole 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 hole 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.

4.7 Resistivity Track

4.7.1 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).

4.8 Porosity Track

4.8.1 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 a indicator of Gas/hydrocarbons called Gas Effect,. The overlapping curves indicate the presence of water.

4.8.2 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

4.8.3 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.

4.8.4 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.

4.9 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

4.10 Volume of Shale

We have two methods:

4.10.1 Linear Method

In linear method we compute IGR by following formula.

$$IGR = \frac{\text{GR log} - \text{GR min}}{GR\ \text{max} - GR\ min}$$

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

4.10.2 Non Linear Method

In non linear 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)

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

Where, IGR= Index Gamma Ray

- **Larinov:** (Used for Older rocks)

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

- **Clavier:**

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

4.11 Porosity

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

- **Density Porosity**
- **Sonic porosity**
- **Effective Porosity**
- **Neutron porosity** (Given)

4.11.1 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.

$$RHOB\ \Phi = \frac{(RHOB\ mat - RHOB\ log)}{(RHOB\ mat - RHOB\ fluid)}$$

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.

4.11.2 Sonic porosity

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

$$\Phi\text{s} = \frac{\Delta\text{T log} - \Delta\text{T mat}}{\Delta\text{T fluid} - \Delta\text{T mat}}$$

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.

4.11.3 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:

$$\Phi_e = (1\text{-}V_{sh})*\Phi_{avg}$$

4.11.4 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.

4.11.5 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

φT=Average porosity

4.12 Water Saturation

Water saturation is the percentage of pore volume in rock that is occupied by water of formation. If it is not confirmed that pores in the formation are filled by hydrocarbons, it is assumed that these are filled with water. To determine the water and hydrocarbon saturation is one of the basic goals of well logging. 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 by Spontaneous potential log.

The steps are discussed below

1. Pick SSP from S-P log by using formula given by (Rider, 1996).

$$SSP = SP_{Clean} - SP_{Shale}$$

SSP = Static spontaneous potential.

SP_{Clean}= Spontaneous potential for sand.

SP_{Shale}= Spontaneous potential for shale.

The value of SSP in OXY-01 is calculated to be -19 mv.

2. Determine the Formation temperature TF against the depth (d) using formula shown in equation given by (Rider, 1996).

$$T_f = \frac{d(BHT - T_S)}{T_D + T_S}$$

D =Depth of Formation (3250m).

BHT = Borehole temperature (820F).

T_S = Temperature at surface (260F).

T_D = Temperature at depth.

3. Resistivity of the mud filtrate is calculated 0.48Ωm at surface temperature by using this relation.

$$R_{mf} = R_{mfe} \left(\frac{T_s + 6.77}{f_t + 6.77}\right)$$

T_s = Surface temperature

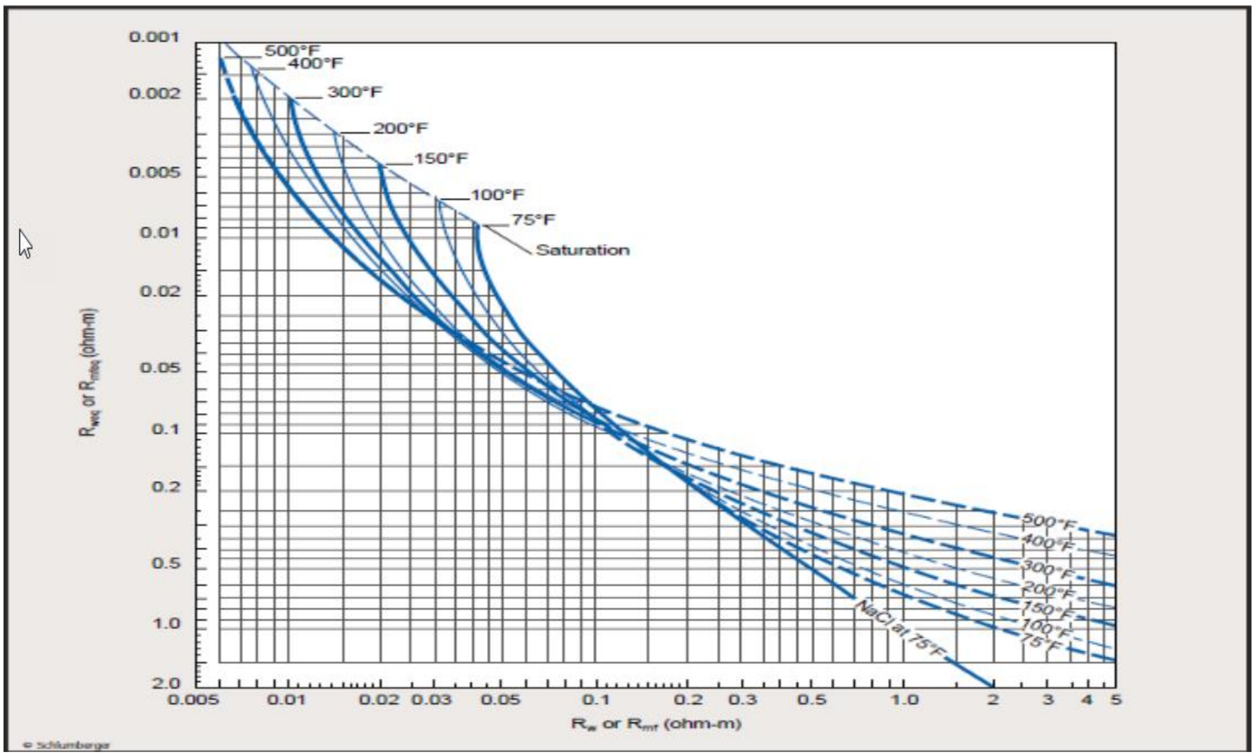
R_{mfe} = Resistivity of mud filtrate equivalent.

f_t = Formation temperature.

4. Now resistivity of the mud equivalent (Rmfeq) is calculated by using Schlumberger chart shown in figure (4.1).

Figure (4.1): Determination of Rweq from SP chart (Schlumberger, 1989).

5. Rweq (Water equivalent resistivity) is determined from the Essp (Static spontaneous potential).
6. This is the last step in this step the value of the resistivity of the water (Rw) is obtained against the value of the Rweq (Resistivity of the water equivalent) and Formation temperature.



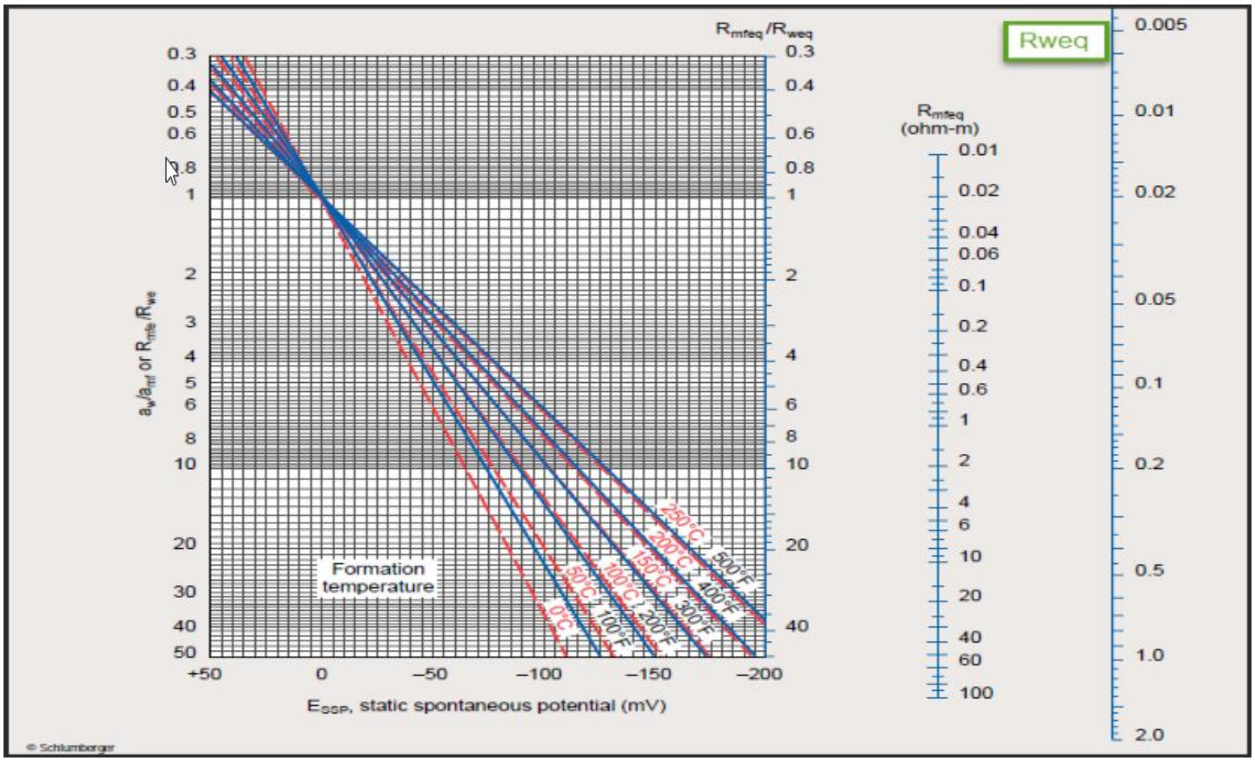


Figure (4.2): Determination of Rw from SP chart (Schlumberger, 1989)

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.

$$Sw = (\frac{Rw * F}{Rt})^{\frac{1}{n}}$$

Table 4.2: Calculated values for Chorgali and Sakeasar formation

Zones	R_w (Ωm)	S_W
Chorgali	0.049	60-70%
Sakesar	0.042	70-80%

4.13 Hydrocarbon Saturation:

The fraction of pore spaces containing hydrocarbons is known as hydrocarbon saturation. The simple relation used for this purpose is given below.

$$S_w + S_H = 1$$

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

$$S_H = 1 - S_w$$

Where, S_H= Hydrocarbon saturation

S_w= Water saturation

4.14 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 (2421m-2467m) while Sakesar Formation is encountered at the depth ranges from (2467m-2602m). The Chorgali and Sakesar Formation is confirmed as a reservoir by different results obtained from well log. The Chorgali and Sakesar Formation is 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.

4.14.1 Interpretation of Chorgali Formation

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

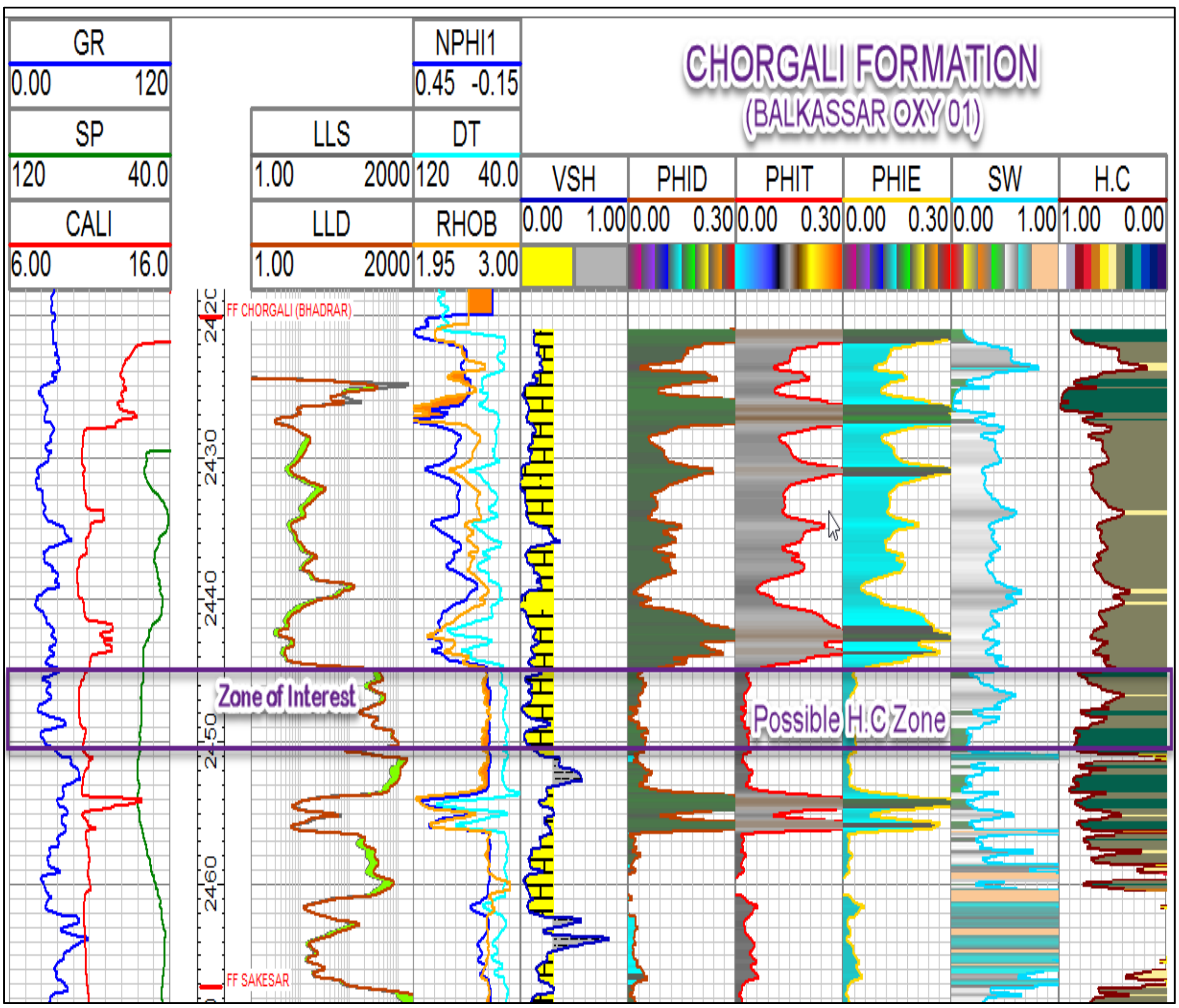
4.14.2 Petrophysical Analysis of Chorgali Zone

Only one main zone of interest is marked. Depth range of Zone of interest varies from 2445m-2452m 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 67%. And water saturation is 33%. This is only one pay zone in which high net pay is expected. This zones bear low value of the GR, high porosity and the greater value of the resistivity.

Table 4.3: Calculated values for Zone of interest in Chorgali Formation

Petrophysical properties	Average Values (%)
Volume of shale	10
Effective porosity	5



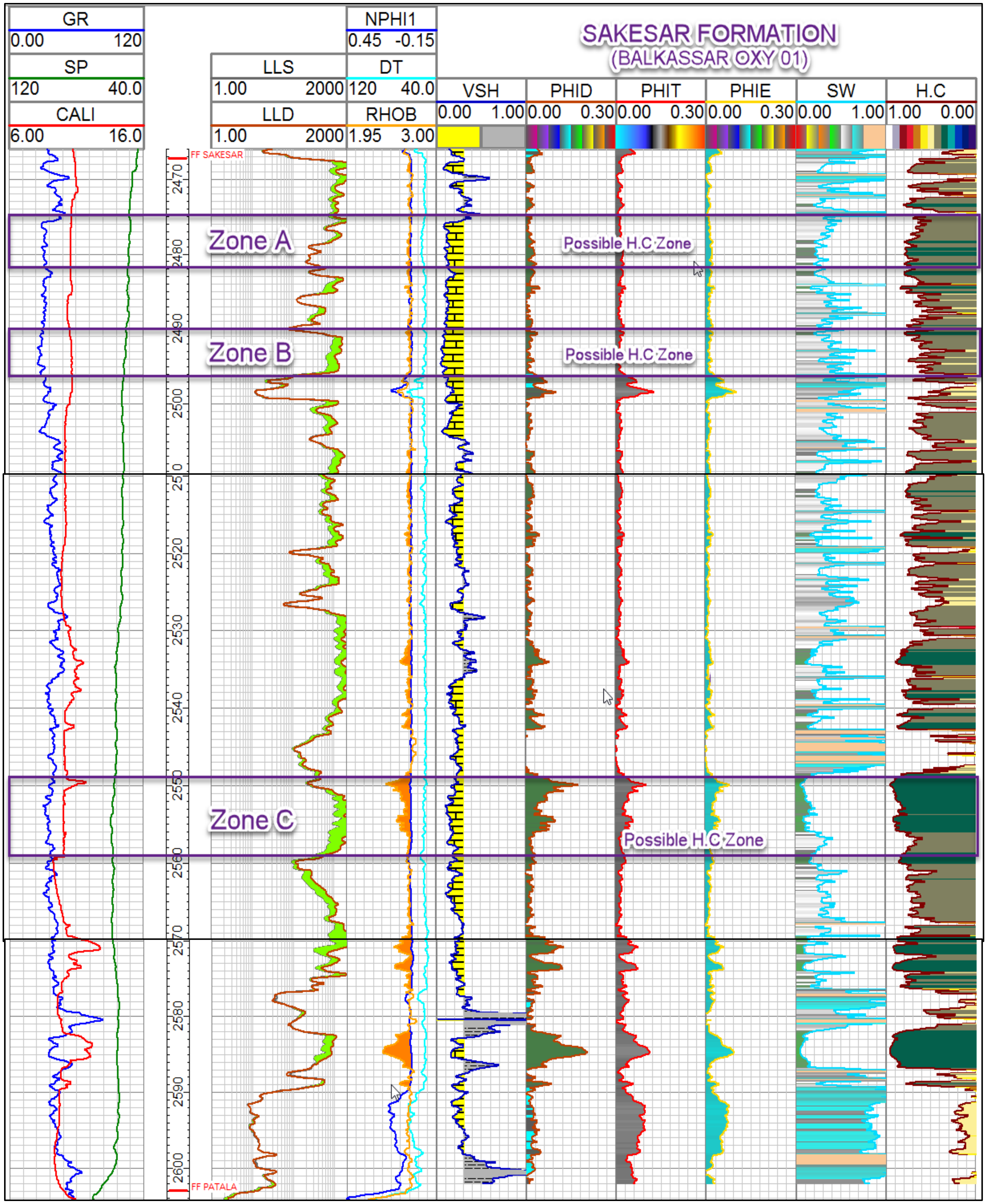


Figure 4.2: Petrophysical Graph of Sakesar Formation of Balkassar OXY 01 well

4.14.3 Interpretation of Sakesar Formation

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

4.14.4 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 4.4: 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
Hydrocarbon saturation	70	58	71
Water saturation	30	42	29

4.15 Conclusion

We have concluded that Chorgali and sakesar formation have reservoir potential as all the Petrophysical parameters support what we concluded. On the basis of results of the whole formations it is clear that there is 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 that sakesar formation and it is a tight reservoir. Over all there is a problem with calliper log response specially 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-2440m. 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 P-Wave Velocity and S-Wave Velocity

Sonic travel time of compressional wave is generally used as porosity tool for given lithology. VP-VS 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.

$$V_S = (0.58321 \times V_P) - (0.07775$$

5.3 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.

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

5.4 Bulk Modulus

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.

$$K = \left(\rho \times {V_P}^2\right) - \frac{4}{3}(\rho \times {V_S}^2)$$

5.5 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.

$$E = \frac{9 \times K \times \mu}{3K + \mu}$$

5.6 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.

$$\mu = \left(\rho \times {V_s}^2\right)$$

5.7 Poisson's Ratio

Poisson's ratio (σ) is the ratio of transverse strain (normal to the applied load) to longitudinal strain (in the direction of the applied load).

$$\sigma = \frac{\frac{1}{2} \times (\frac{V_P}{V_S})^2 - 1}{(\frac{V_P}{V_S})^2 - 1}$$

5.8 Vp/Vs Ratio

Lower values of P-wave and S-wave velocity ratio show the shaly material and higher values stiffer material.

5.9 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:

$$Z = \rho \times Vp$$

5.10 Shear Impedance:

Shear impedance is the product of the secondary wave velocity and density.

Mathematically it can be written calculated by the formula

$$Shear\ Imp = \rho \times Vs$$

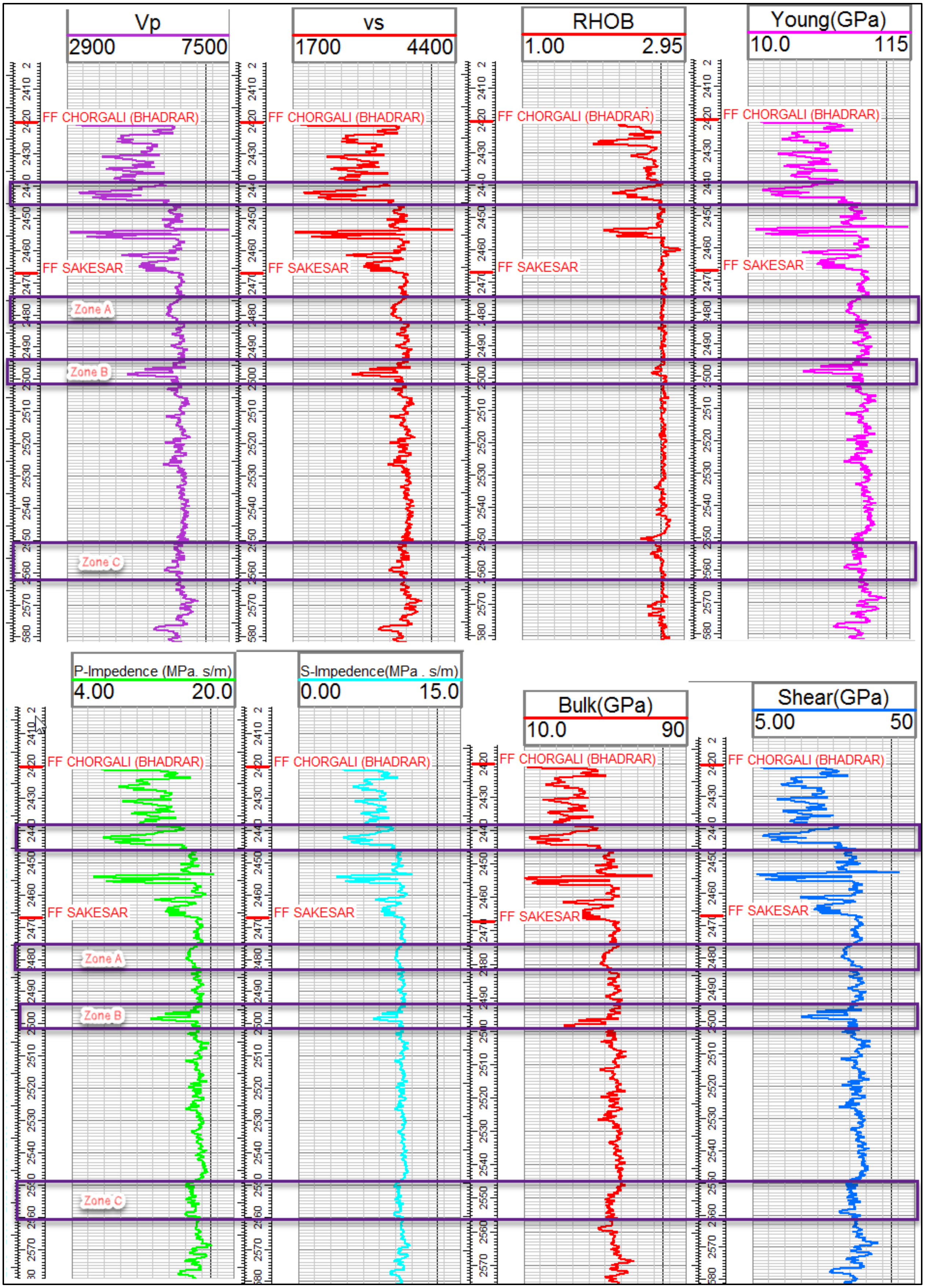


Figure 5.1: Combine figure of Rock physics

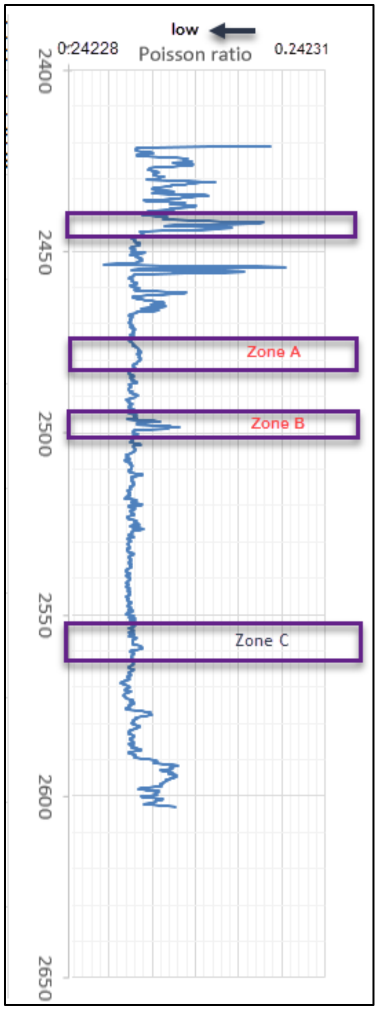


Figure 5.2: Poisson's Ratio

5.11 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 bot decrease in our area of interest hence indicating that hydrocarbons present there.

CHAPTER 06

FACIES MODELING

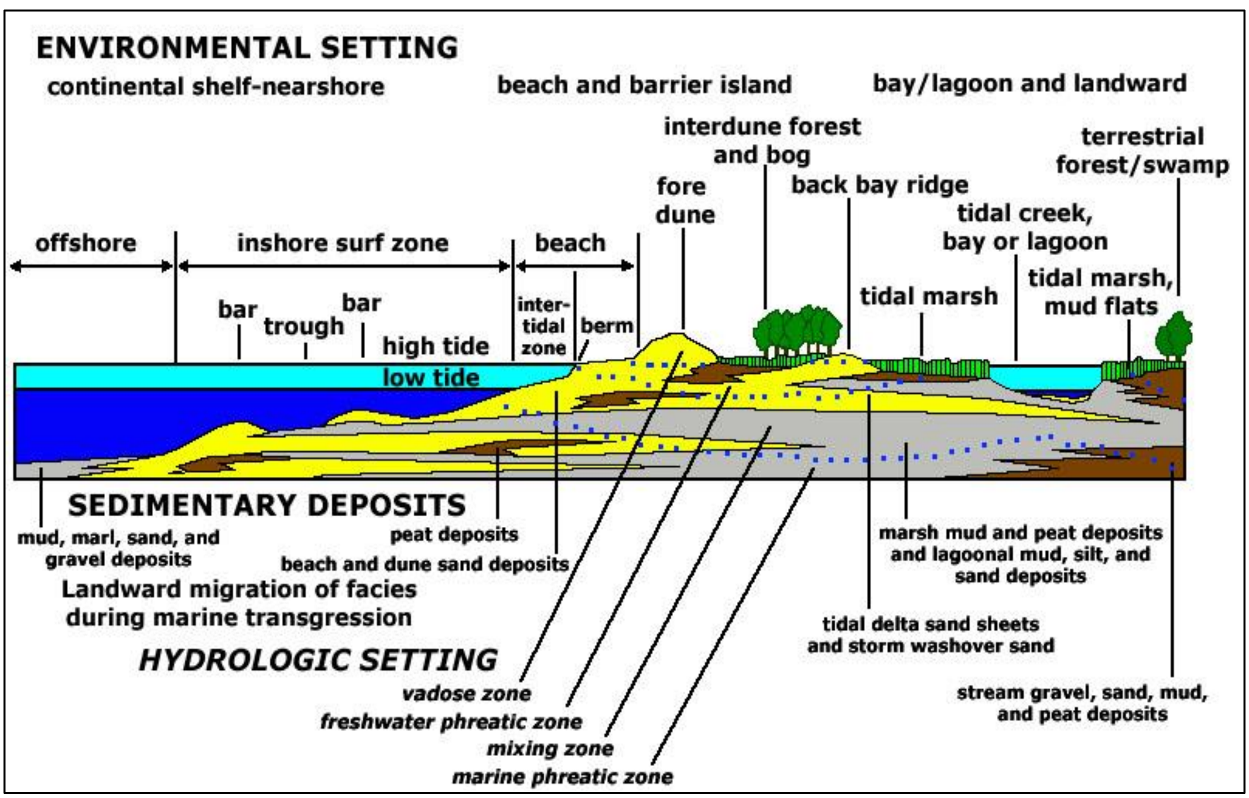
6.1 Introduction

In geology, a 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 effect the reservoir properties. This gives the main indication about the productive zone in the reservoir (Kurniawan, 3005).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

Figure 6.1: Different types of the environment



environment is specific type of place where the facies are deposited. Such as the Glaciers. Lakes, Abyssal plain, Sea bottom. Stream, Delta etc. The different types of the environment are shown in the below figure 6.1.

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 on the basis of their lithology. Similarly, biofacies 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.

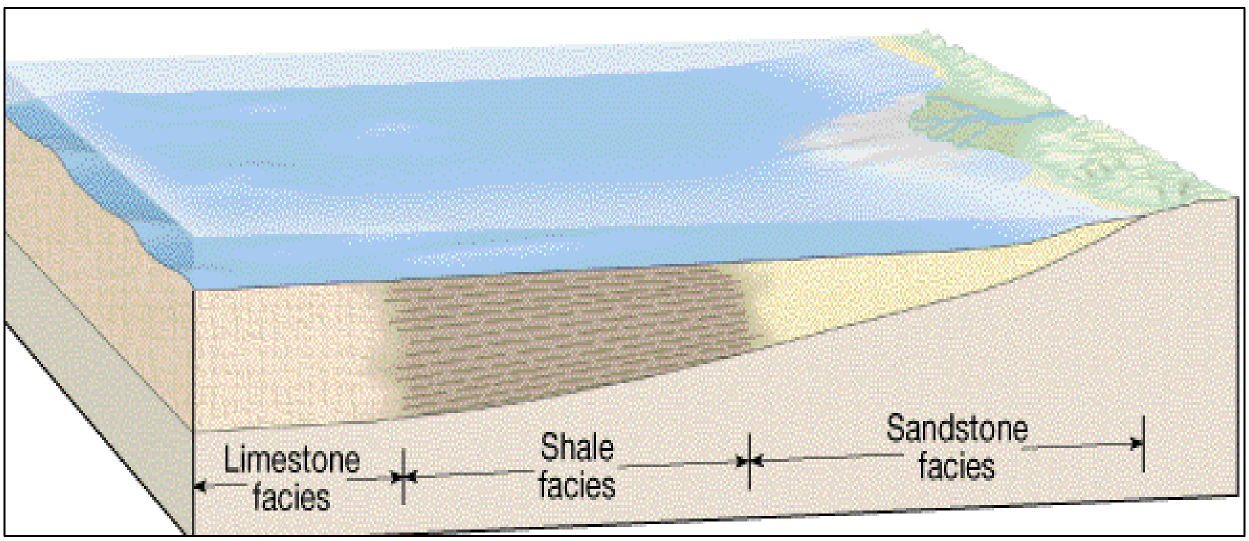


Figure 6.2 Sediment deposited in a different depositional environment.

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 particular challenging interplay between capturing enough information for environmental interpretation. A good understanding of paleoecology always strengthen the interpretation and such studies should be included as part of all depositional facies studies. Depositional textures in turn effect 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 Crossplot

A crossplot 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 lies between depth range 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.

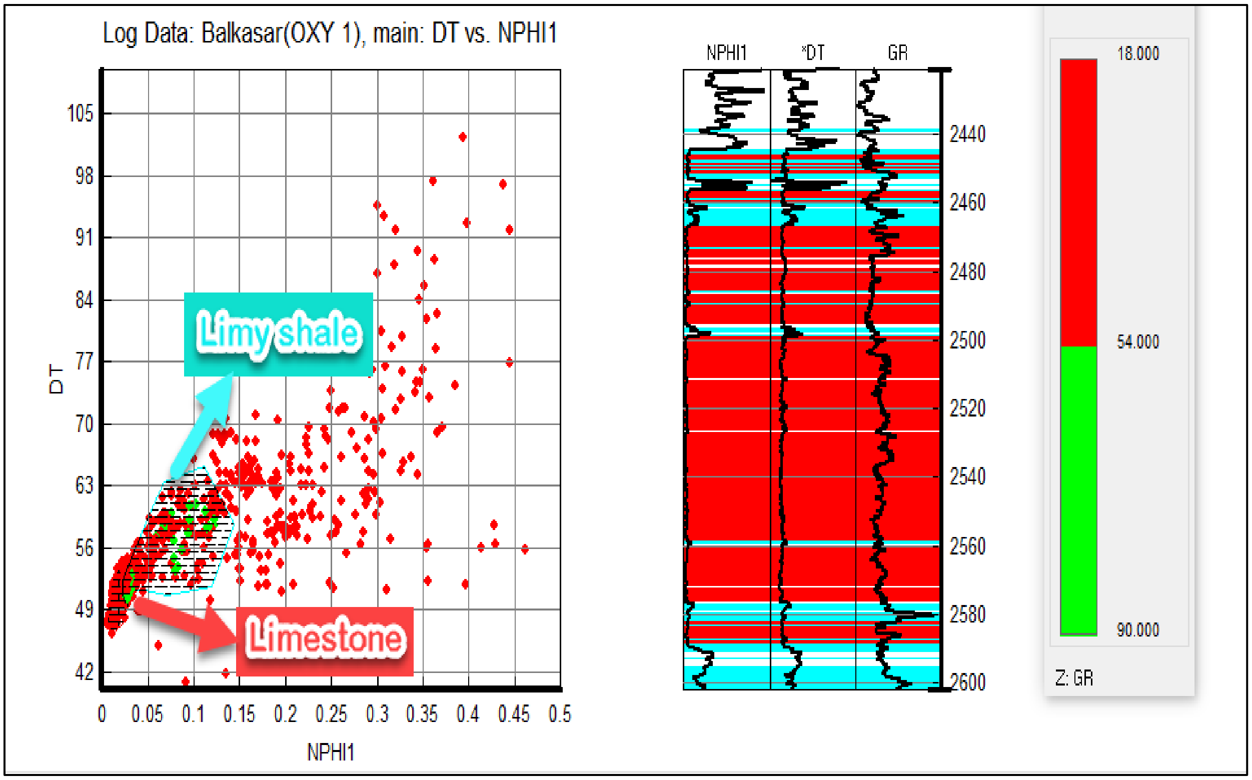


Figure 6.3: Cross plot between **DT vs NPHI**

Cluster of dots indicate the pure lithology here in our reservoir only limestone have cluster of dots. So we concluded that the reservoir is mainly comprises of 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 range 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 5.4. Since density of shale is highly variable in case 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.

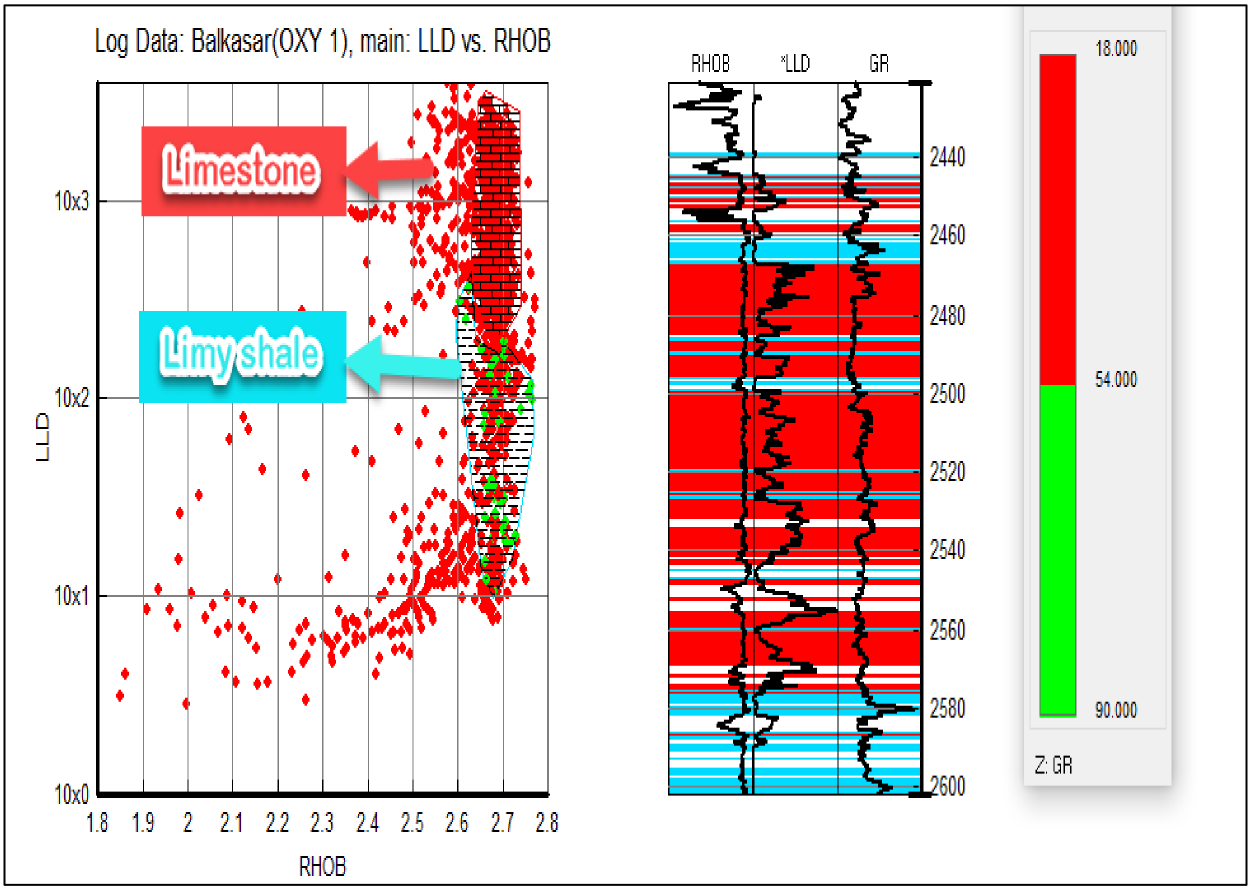


Figure 6.4: Crossplot between **LLD vs RHOB**

High resistivity values associated with higher gamma ray values are indicative of limestone. Finally, high gamma ray values associated with low resistivity values indicate shales but in our reservoir zone we have calcareous shale instead of pure shale. It is also evident from the fact that LLD values decreased in the second polygon which we have designated as calcareous shale.

CHAPTER 07

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 publicised 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 include 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 broad-band zero-phase dataset is obtained which forms the input to colored inversion (Lancaster and Whitcombe, 2000).

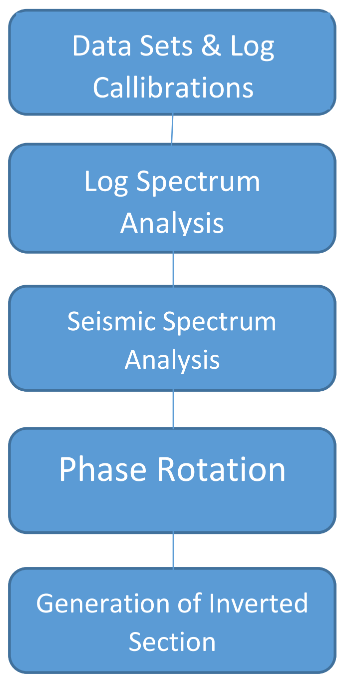
Colored inversion converts the seismic data to a relative impedance data set. The advantages of colored inversion are the speed of calculation and avoidance of artefacts that may be introduced by a model. Colored inversion, whether acoustic or elastic impedance (Connolly, 1999), is an excellent qualitative interpretation tool.

A method was developed by Lancaster and Whitcombe (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.

Coloured 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 Work Flow

We followed the following work flow 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 -90^o 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

Coloured 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.

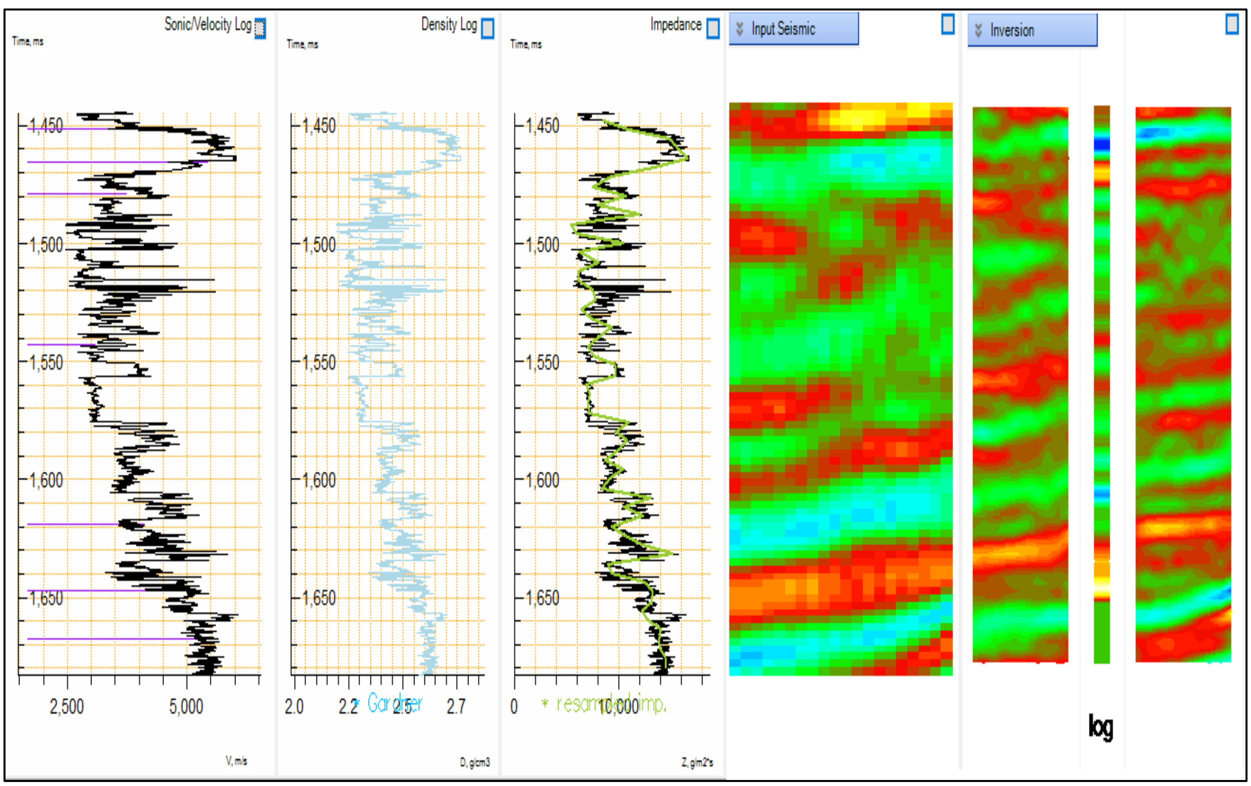


Figure 7.1: Generation of Acoustic Impedance and Inverted section

7.4 Log Spectrum Analysis

Here the impedance spectrum of the log is generated on the log 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 rises with frequency the impedance logs tends to decay with frequency – having effectively undergone the process of integration relative to the reflectivity data.

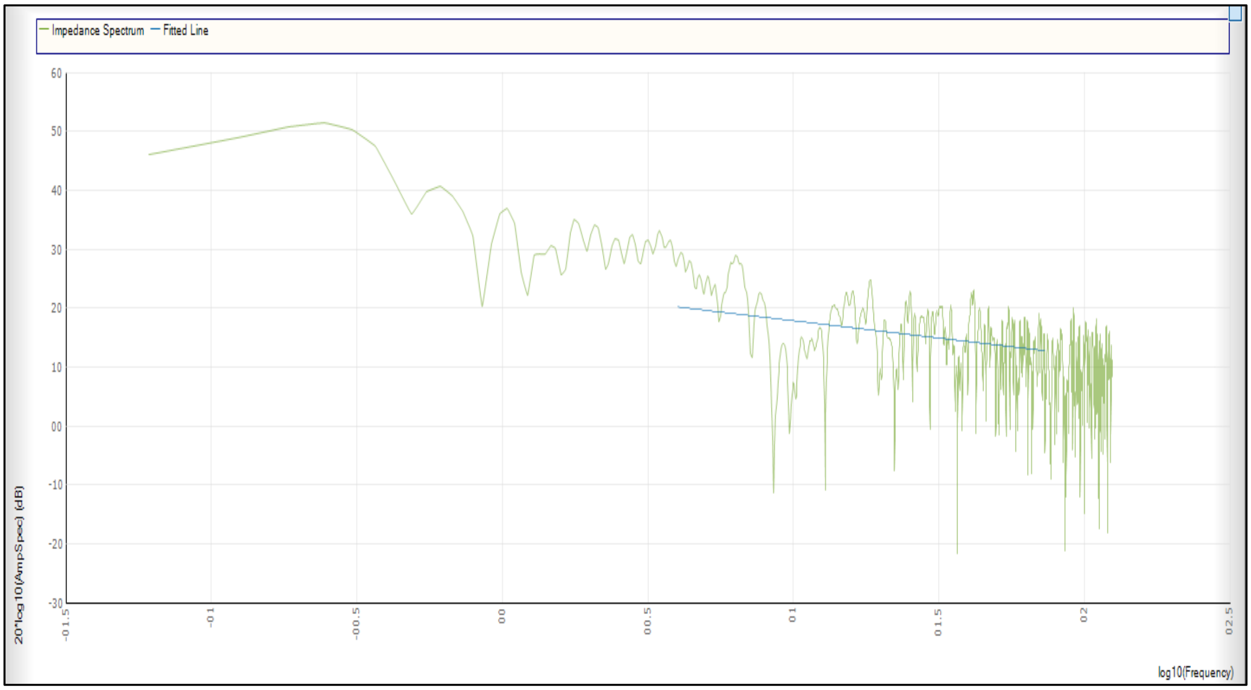


Figure 7.2: Impedance log spectrum with a best fitted line.

7.5 Butterworth Filter

Butterworth filter is used to smooth and constrain the impedence 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. The Butterworth filter is shown in figure.

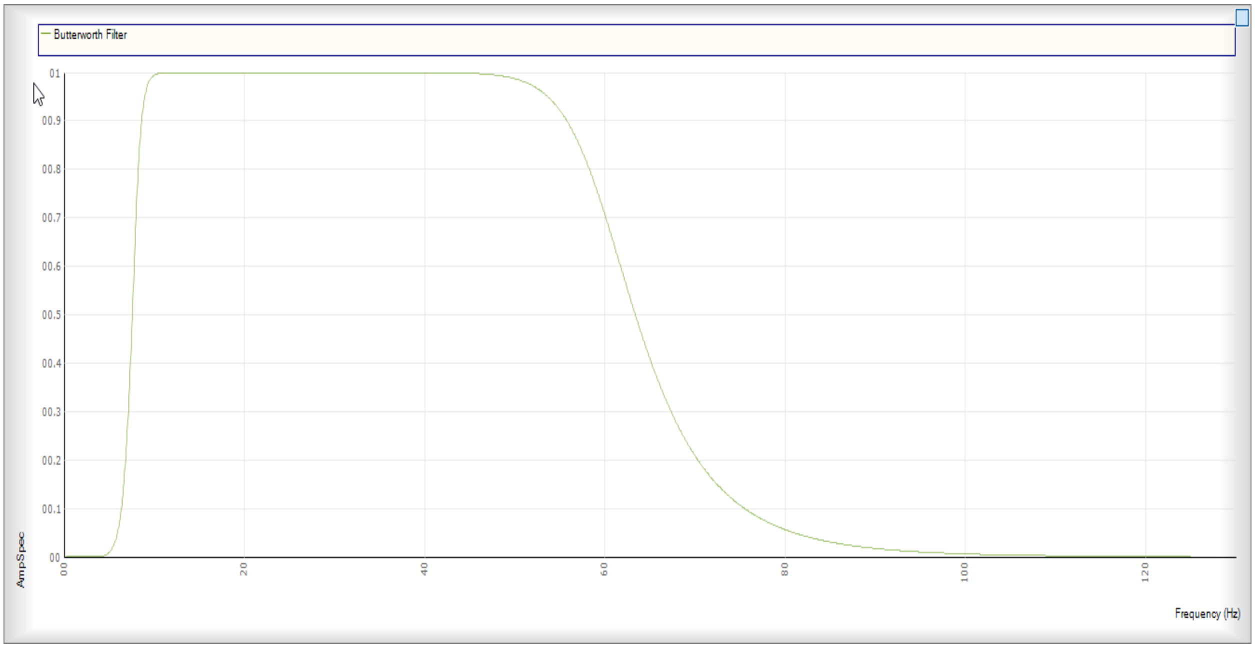


Figure 7.3: Butterworth filter

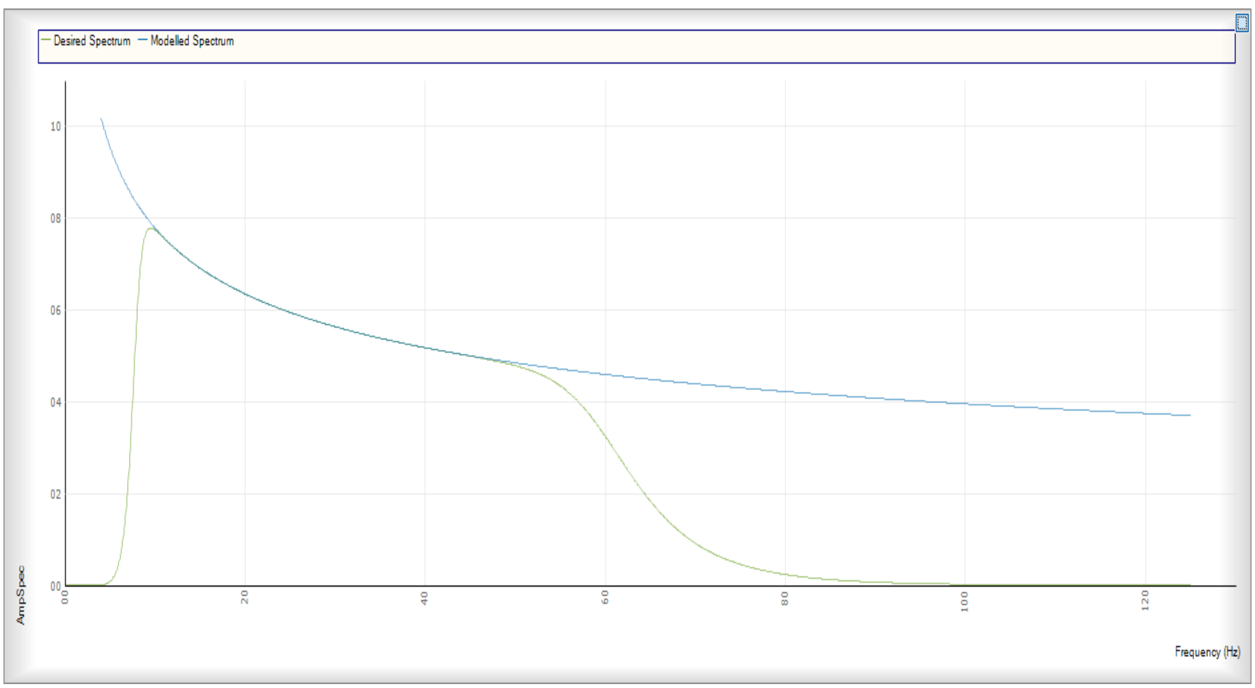


Figure 7.4: Desired impedance log spectrum constrained by the Butterworth filter

We get modelled 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 above figure.

7.6 Seismic Spectrum Analysis

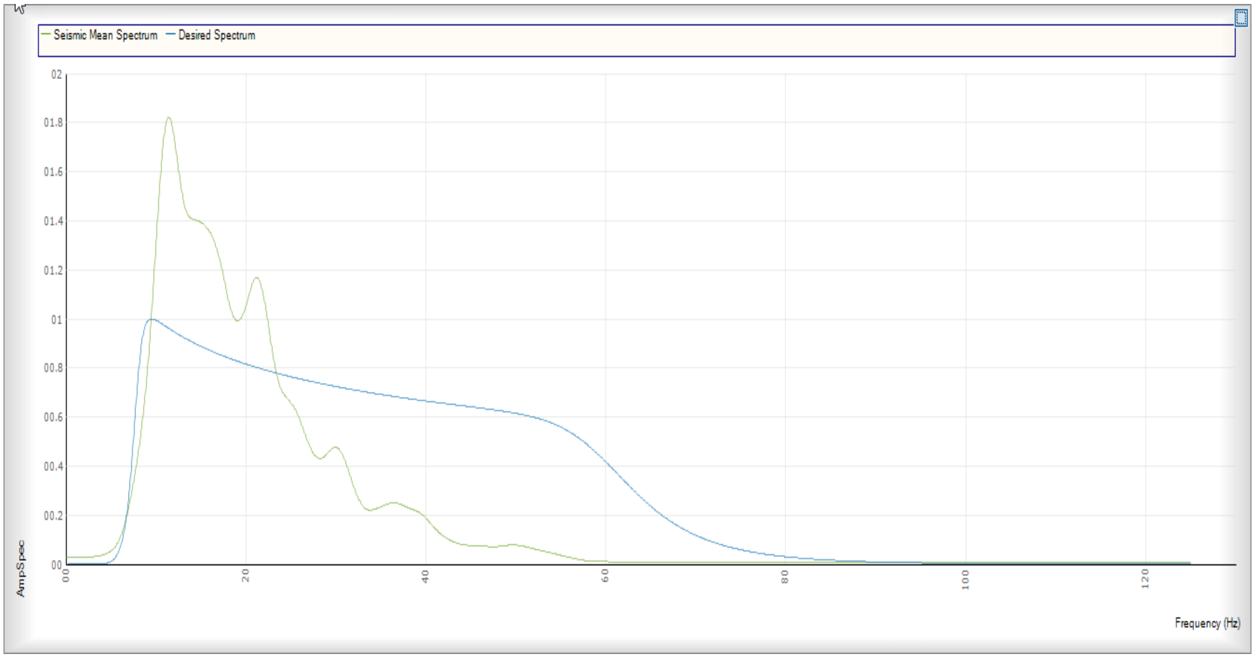


Figure 7.5: Seismic spectrum compared with desired impedance log spectrum

In the above figure we have an average spectrum of seismic data which is superimposed with the desired impedence log spectrum 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 impedence log spectrum.

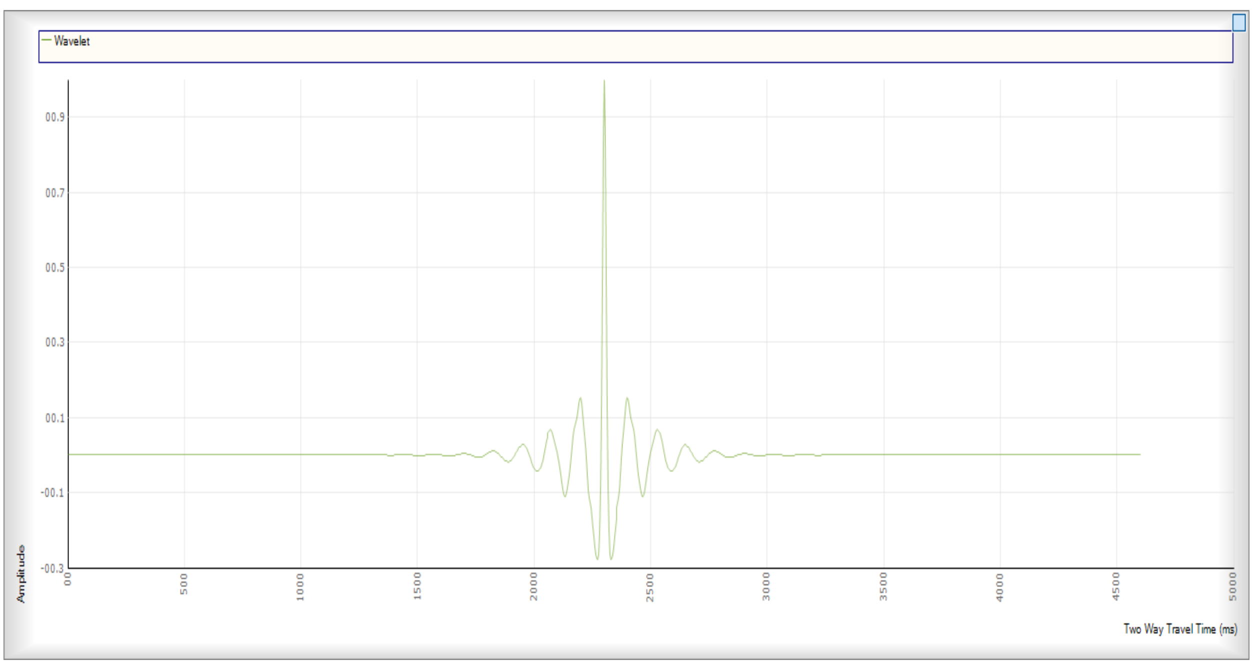


Figure 7.6: Extracted Wavelet (Operator in Time Domain)

The wavelet shown in te 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). 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).

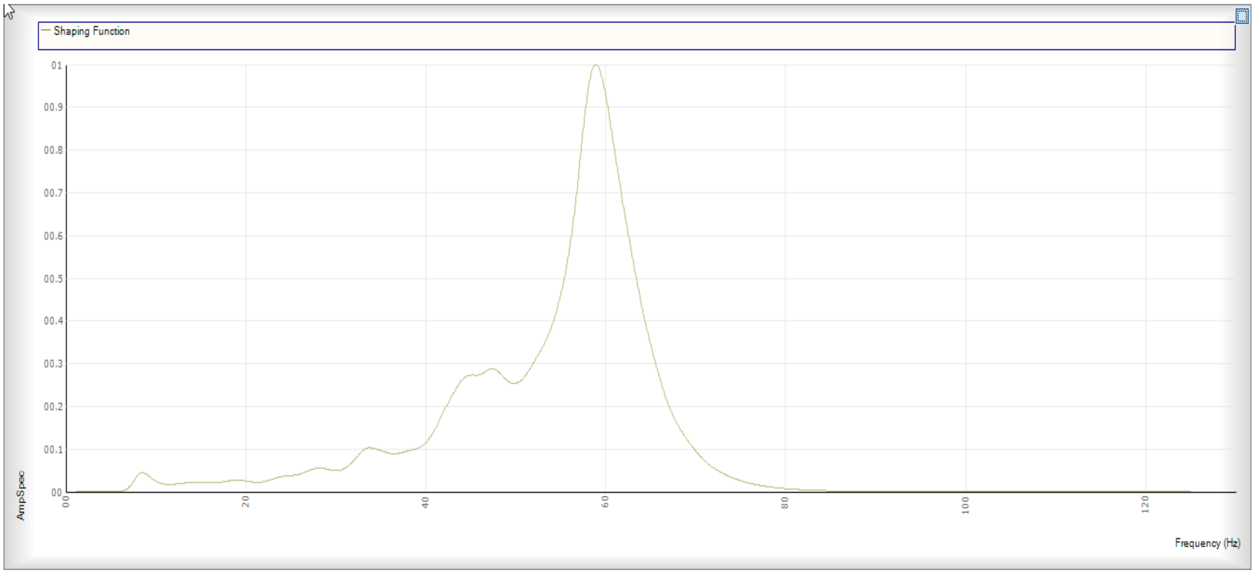


Figure 7.7: Shaping Spectrum

In the figure above we have a derived operator i.e shaping function in frequency domain which will shape and match the seismic and desired impedence log spectrum.

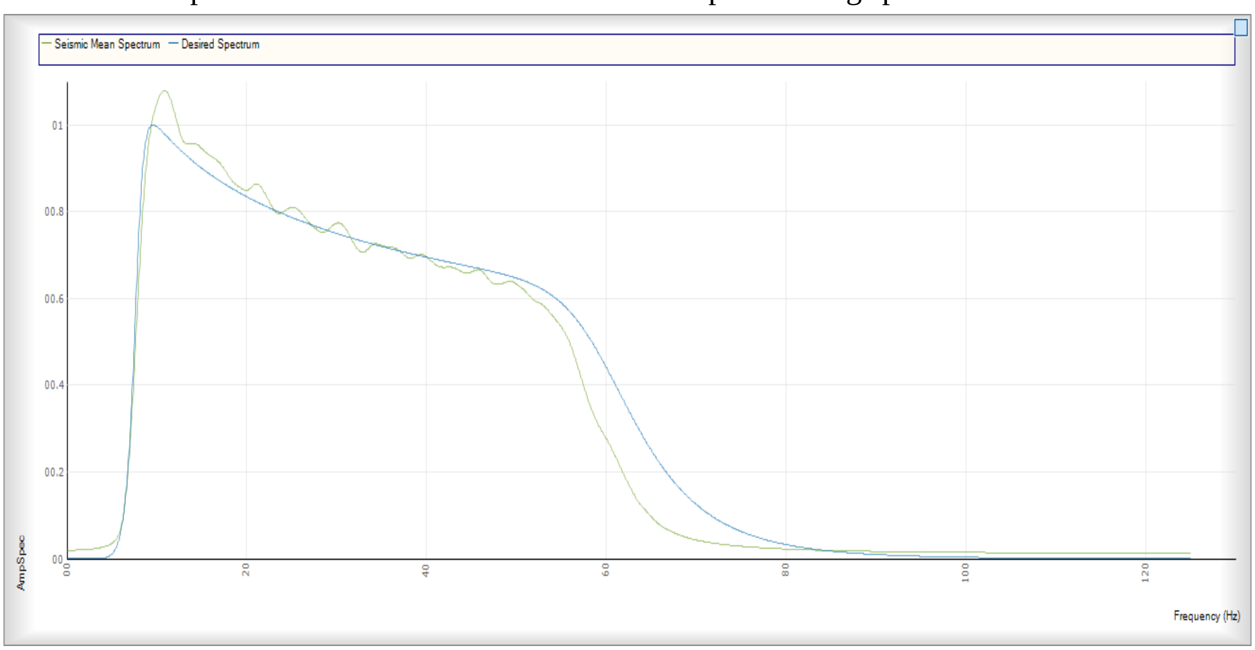


Figure 7.8: Shaped seismic spectrum compared with the desired impedance log spectrum

Now finally after the derived shaping function in the frequency domain is applied on the seismic mean spectrum, it has done some spectral shaping of the seismic data and almost matched it with the desired impedence log spectrum.

7.7 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.

7.8 Generation of Inverted Section

I had a single well data available that is why I used one well to derive operator i.e balkassar-oxy-01. 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 (white) and low (blue) acoustic impedance. The inverted section is shown in figure 7.9.

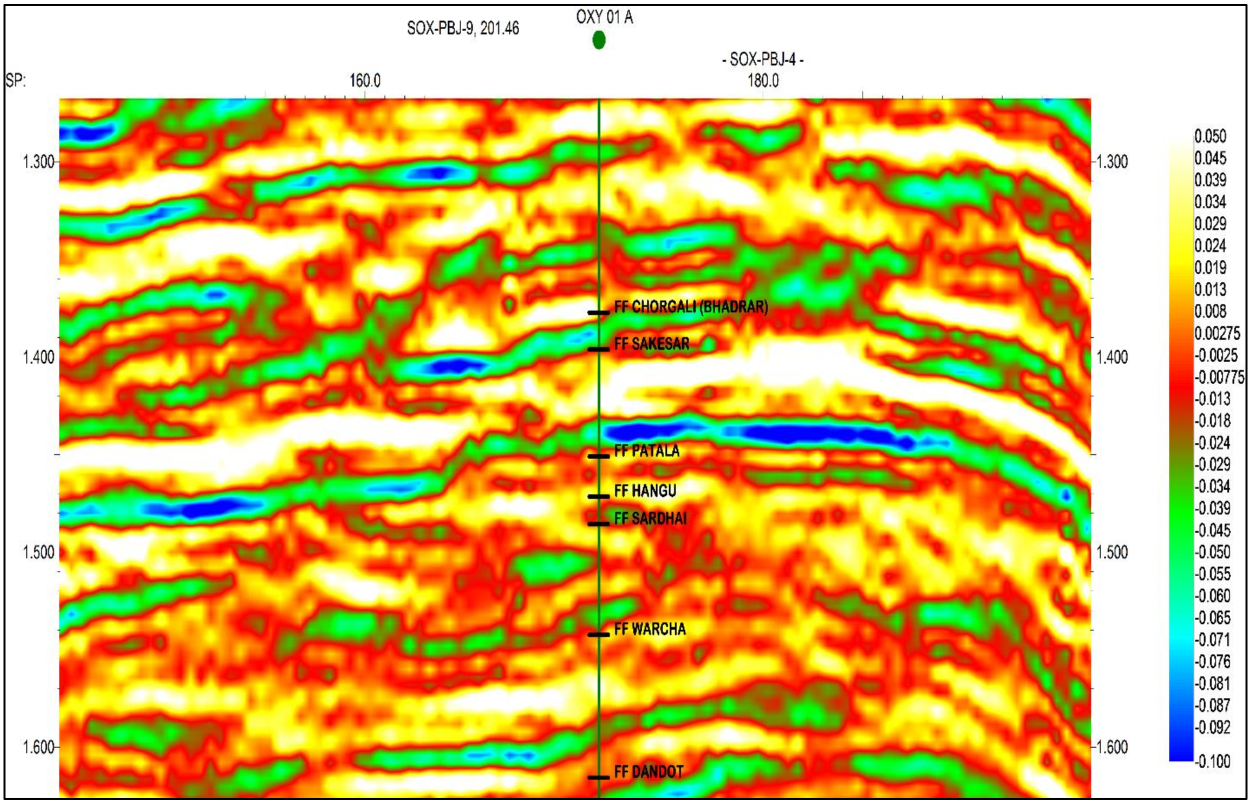
7.9 Interpretation of inverted section:

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 7.9: Inverted seismic section.



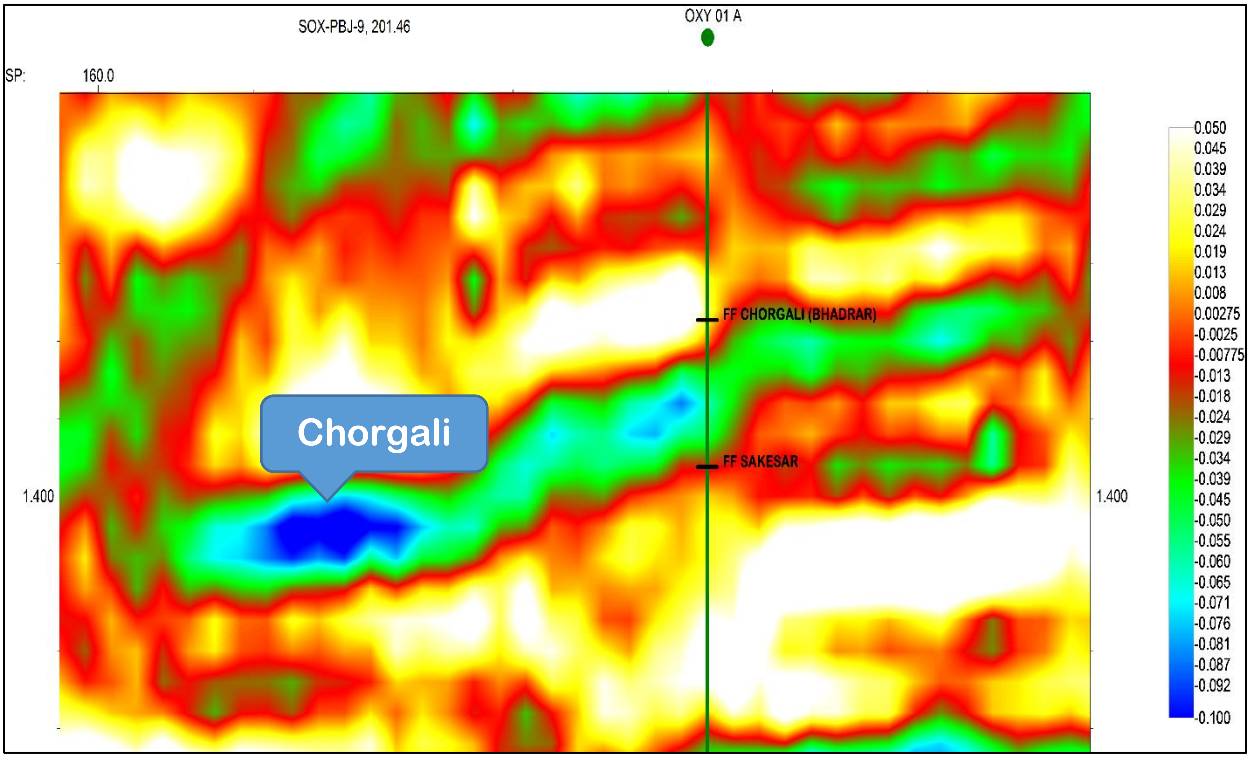


Figure 7.10: Zoomed view of Chorgali inverted section

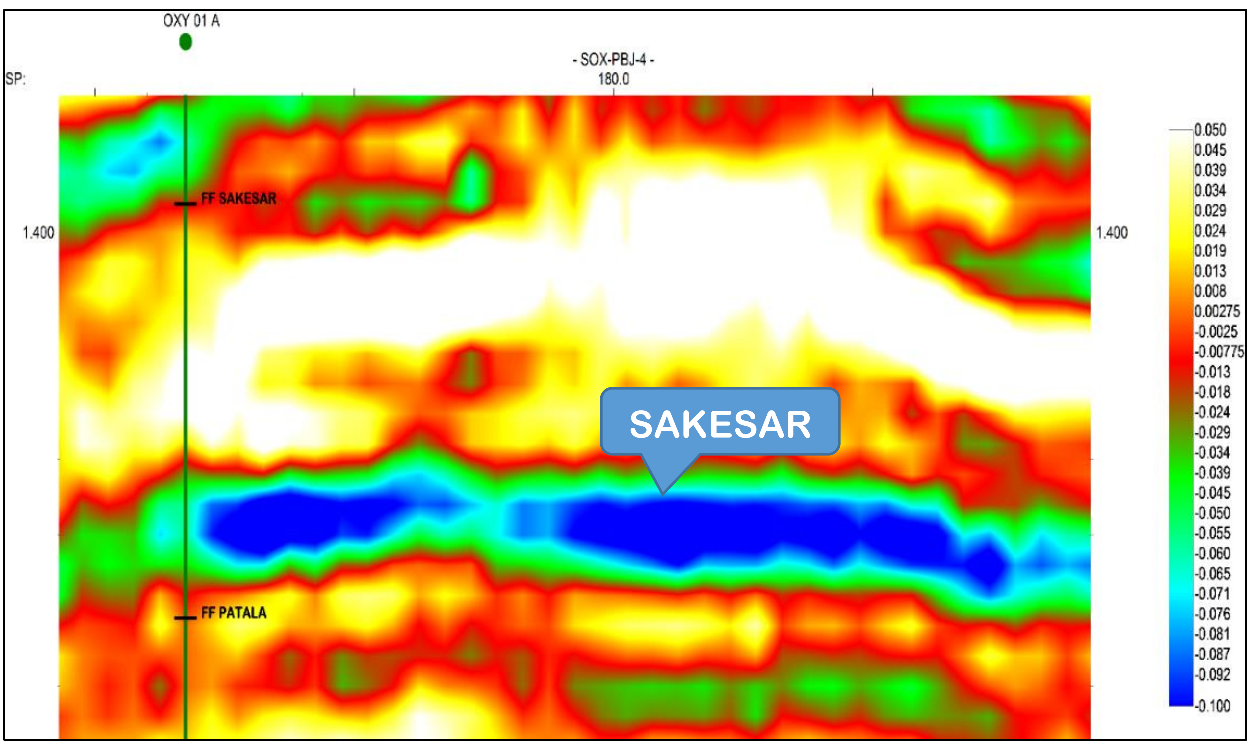


Figure 7.11: Zoomed view of Sakesar inverted section

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CHAPTER 01
INTRODUCTION

Hydrocarbon exploration, no doubt, is a backbone for economy of any country, especially developing countries like Pakistan. As the energy demand increases, exploration sector catch their eyes over unexplored areas for new energy resources excavation. Therefore, our goal is to provide a 2D geological model to petroleum engineers for reservoir performance simulation and for well planning (Slatt, 2006). Investigation of earth through geophysical method involves taking measurement in order to check the variation in the physical properties of the earth both laterally and horizontally (Bust et al., 2010)

In 1915, exploration geophysicists started working on seismic method because of its high resolution and improved accuracy. It became quite useful for imaging subsurface geological features and for identifying structural or stratigraphic traps (Coffeen, 1986). Seismic method is direct result evaluating and accurate geophysical method used for litho-structural analysis especially; Seismic Reflection Method has greater precision than refraction method for deep hydrocarbon exploration.

Seismic Reflection Method most commonly used in hydrocarbon exploration in petroleum geology. Petroleum system mainly comprises of three constituents that are enlisted below.

- Source rocks (contains organic materials which for responsible for generation of hydrocarbons).
- Reservoir rocks (migration of hydrocarbons from source rock and reservoir rock offers suitable conditions for their accumulation).
- Seal or trap rocks (act as a barrier it stops upward movement of hydrocarbons).

Petrophysics uses all kinds of logs, core and production data to obtain physical properties of reservoir such as volume of shale, porosity, water and hydrocarbon saturation which help in identifying probable zones of hydrocarbon (Ali et al., 2014). Facies analysis to support petro-physical results and the Rock Physics analysis to compare the elastic rock properties with the Petrophysical results. In addition, Post-stack seismic Colored inversion is carried out to confirm subtle prospect zones.

1.1 Introduction to Study Area

Southern and northern parts of Pakistan such as Badin, Mari, Potwar kohat plateau has high potential of hydrocarbons. 48% of the world known petroleum resources are belonging to the potwar-kohat which is extra-continental downward basin (Hasany & Saleem, 2001).

Structural traps are dominated in the Potwar sub basin. The study area is lies in the northern part of upper Indus basin. The Balkassar area is located about 105km southwest of capital Islamabad as shown in figure 1.1, in the Chakwal district Punjab Province. It is about 506m above the mean sea level.

Longitude: **72.32^0 -72.47^0 N**

Latitude: **32.51^0 -33.02^0 E**

In north of the Balkassar oil field bikhari kallan, it shares border with Kalar Kahar in south, Chakwal city is situated towards east of it and Talagang is towards south. A satellite image of Pakistan is given in figure highlighting the Balkassar area.

Figure 1.1: Satellite image of Balkassar

Study area belongs to the Kohat-Potwar fold Belt which is in the north of Pakistan. The Kohat-Potwar Fold Belt covers an area of 36000 km^2. The area north of Salt Range is called Potwar Plateau owing to its relatively constants elevation and it encompasses most of the drainage of the Soan River. Potwar is situated in the western foothills of Himalayan in the northern Pakistan.

Potwar sub-basin is filled with thick Pre-Cambrian evaporates overlain by relatively thin platform deposits of Cambrian to Eocene followed by thick Miocene-Pliocene molasses. This whole section has been severely deformed by extremely intensive Himalayan Orogeny in Pliocene to Middle Pleistocene times.

1.1.1 Work Done on Balkassar

Balkassar oil field is located about 105 kilometers Southwest (SW) of Islamabad, in the northern Pakistan. The Balkassar field produces, from Eocene limestone of Sakesar and Chorgali formations. These formations are deformed in an anticlinal structure known as the Balkassar anticline.

Balkassar is an unusual play as it produces oil from a very stiff limestone that have very low porosity and permeability. Epigenetic process of dolomitization creates porosity values of 25% (Malik et al., 1988), whereas tectonic deformation of the Balkassar structure has created fractures through which hydrocarbons can migrate.

Mianwali (Triassic), Dutta (Jurassic), and Patala (Paleocene) formations are major source of oil at Balkassar field (Khan et al., 1986). The shale of Murree formation provides a seal for hydrocarbon catch for underlying reservoirs of Eocene age. The production history of Balkassar oil field shows that the production of oil is unpredictable because success in this play highly depends upon the prediction of fractures.

The Seismic Survey of the Project area was conducted by Occidental Petroleum Corporation (Oxy) in 1981, which is a California-based oil and gas exploration and production company. The survey was conducted for subsurface analysis of Balkassar Oilfield, Eastern Potwar, which lies in the UTM Zone 43N.

1.1.2 Balkassar Oil field

Balkassar is an important hydrocarbon producing area of the Potowar Plateau, Pakistan. Balkassar oil field is located west of Joya Mair in Jhelum District, which is situated about 105 km southwest of Islamabad. Attock Oil Company drilled the first well in 1945/6. The field structure is a gentle anticline, with two producing horizons, both of Eocene limestone.

The Balkassar Oil field was one of the main Oil field in Punjab province having daily average production in 1948 was 6,831,920 gallons and in 1949 was 5,991,920 gallons. The oil is asphaltic, suitable for furnace fuel.

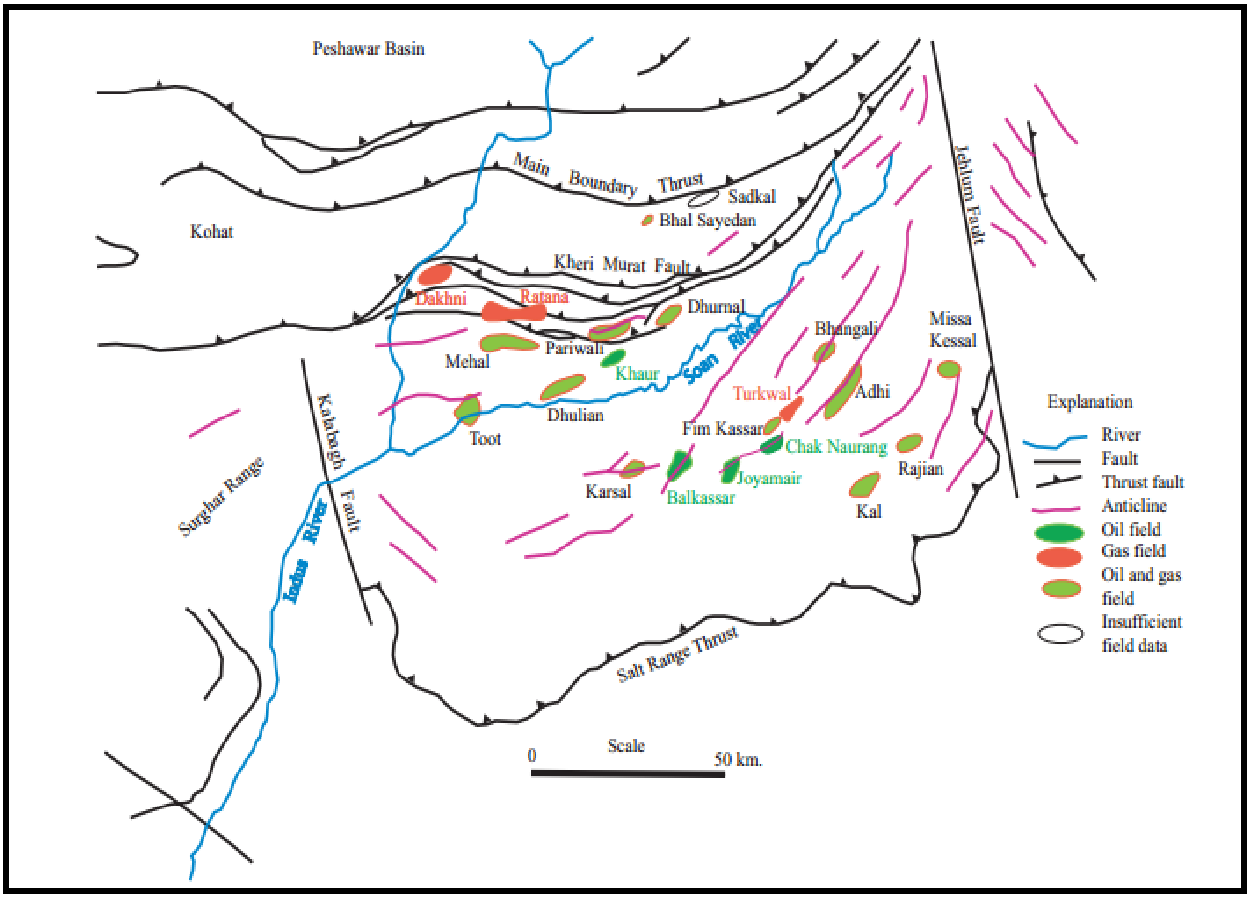


Figure 1.2: Generalized oil and gas field in Potowar, (modified from Kazmi and Rana, 1982, khan and other,2986).

1.2 General description

1.2.1 Technical Well Data

Table 1.1: Technical Well Data

Operator	OXY	**Province**	Punjab
Type	Exploratory	**Status**	ABANDONED
Well Bore Name	BALKASSAR-(OXY)-01	**Concession**	
Longitude	72 39 52.50	**Latitude**	32 56 38.80
Spud Date	20-June-1981	**Completion Date**	26-Sep-1981
Depth Reference Elevation(m):	535.53	**Total Depth(m)**	3130.60
Depth Reference	KB	**Formation Top**	SALT RANGE

1.2.2 Data used

To achieve all the objectives, seismic and borehole data given in Table-1.1 is used provided by DGPC to complete the Thesis project.

Table 1.2: Seismic Data used in interpretation

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

1.2.3 Well Data:

We obtain data of well Balkassar-Oxy-01. This well is operated by OXY and completed at 26-Sept-1981. Latitude and longitude of the well are 32.944111and 72.664583 which are in decimal degrees. The information of the formation tops encountered in the well are listed below.

Table 1.3: Formation tops encountered in the Balkassar oxy-01 A well

Formations	Formation Age	Tops (m)	Thicknesses (meters)
NAGRI	PLIOCENE	0	478.8
CHINJI	MIOCENE	1408.1	106.68
KAMLIAL	MIOCENE	1514.8	906.74
MURREE	MIOCENE	2421.5	45.72
CHORGALI/BHADRAR	LOWER EOCENE	2467.2	135.63
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	109.72
WARCHA	EARLY PERMIAN	2796.4	141.73
DANDOT	EARLY PERMIAN	2938.1	60.96
TOBRA	EARLY PERMIAN	2999.1	51.81
KHEWRA SANDSTONE	EARLY CAMBRIAN	30.50.9	78.33
SALT RANGE FORMATION	PRE-CAMBRIAN	3129.2	-------

1.2.4 Base Map

For a geophysicist base map is a special type of map which show the orientation of the seismic lines and specify the shot points (Sroor, 2010). The base map of the study area is shown in the figure which contains 3 strike lines and 6 dip lines and one oblique line. The 3D view of the base is also shown to understand the seismic lines orientation easily in figure 1.3.

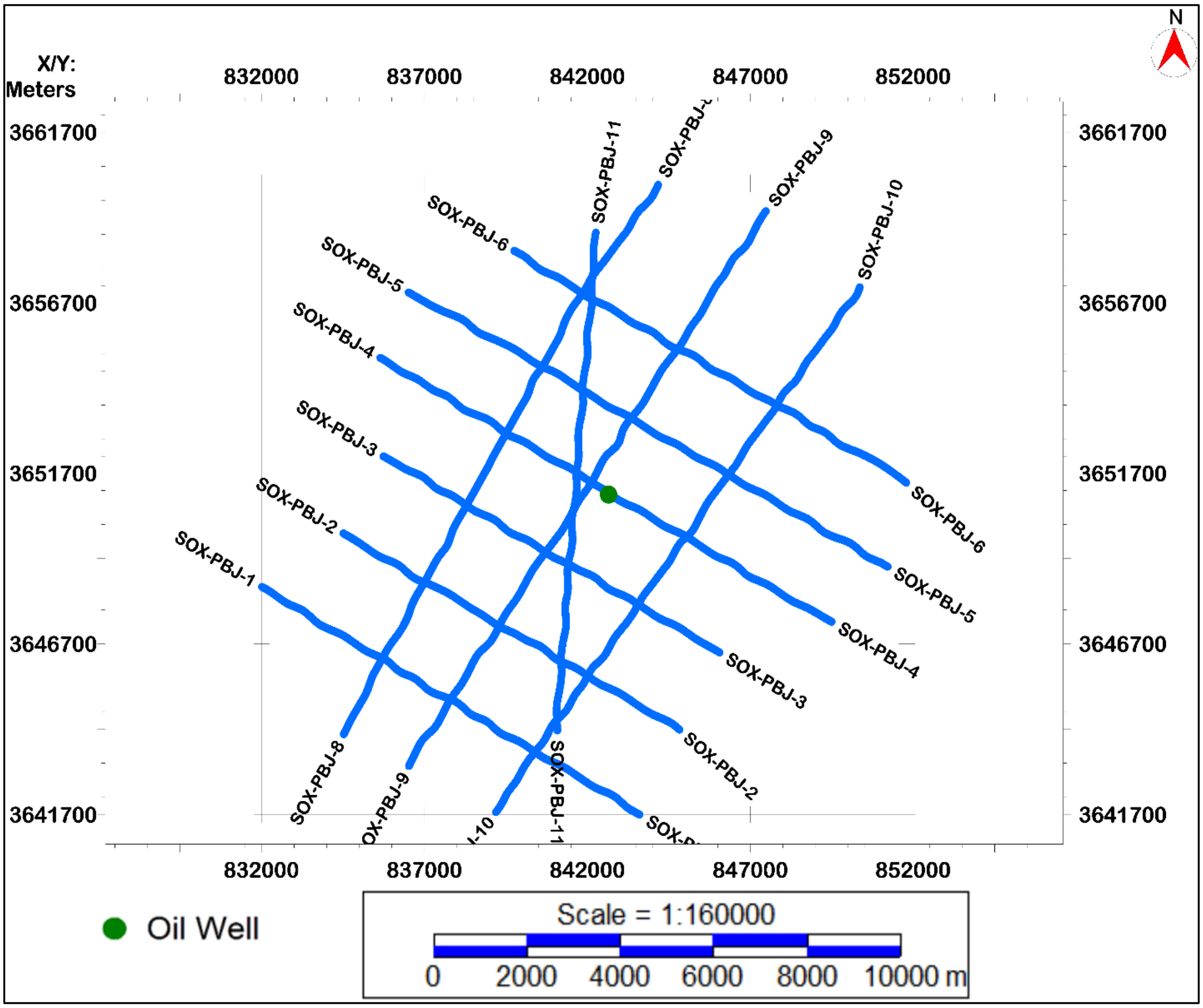


Figure 1.3: 2D Base Map of the study area by IHS kingdom

1.3 Software Tools used

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

- SMT KINGDOM 8.6
- IHS KINGDOM 8.8
- SNAGIT 13

1.4 Objectives

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

- Detailed seismic interpretation for identification of the structures favourable for hydrocarbon accumulation.
- Structural interpretation to find out the structural traps and horizons of interest.
- Preparation of Synthetic seismogram, which use is to confirm us the reflector we have to mark by having TD chart and the combination of Sonic and Density logs.
- Identification of the prominent reflectors and their tentative naming and aging in accordance with the stratigraphy of the area by using well tops and synthetic seismogram.
- Marking of the horizons, and preparation of time and depth maps to be later used in interpretation.
- Marking of faults to understand the nature of geological structures and interpreting the geological framework present in the project area.
- Preparation of fault polygon to extend the trend of the fault on the lines.
- Preparation of grid and then time and depth contours of Murree, Chorgali and Sakesar, which identifies us the sub-surface geological structures there.
- Petrophysical analysis is carried out to obtain physical properties of reservoir such as volume of shale, porosity, water and hydrocarbon saturation, which is the Reservoir characterization.
- Facies Analysis is to confirm the lithology present in our area by using the standard cross plots and check it out with the Petrophysical results.
- Rock physics is to figure out elastic rock parameters and compare it with the Petrophysical properties.
- Also Post stack Seismic Colored Inversion to confirm our prospect zone by having relatively low acoustic impendence.

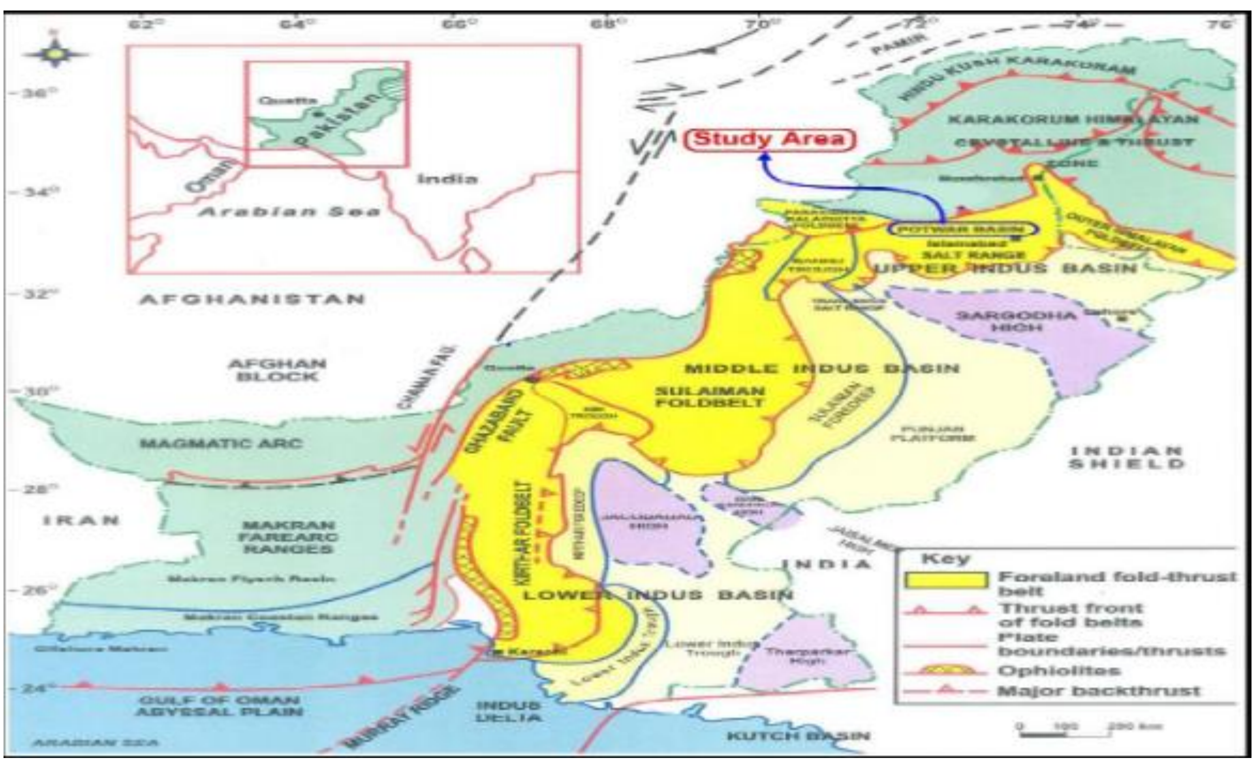
CHAPTER 02
GEOLOGY, STRATIGRAPHY AND TECTONICS

2.1 Geology

General geology and geological history of an area is very important for exploration of oil and gas. A geological history of basin can be compiled by considering basin forming tectonics and depositional sequence (Kingston et al., 1993).

Geological and structural knowledge of the area is a key for interpreter to perform precise interpretation of seismic data. Interpretation of seismic data requires a comprehension of the subsurface arrangements and how they may influence wave reception. The interpretation of seismic data is based on the stratigraphy and structural geology of an area. The main reason behind that, in many cases similar signature is obtained from different lithology's and vice versa. In order 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 (Kazmi & Jan, 1997). If we have no idea about the geological information of an area we don't recognize the different reflections appearing in the seismic section

2.1.1 Sedimentary basin



.Figure 2.1: Tectonic map of Whole Pakistan

Sedimentary basin are "Geologically depressed area with thick sediments in the interior and thinner sediments at edges"(Shah et al., 2009)

In terms of genesis and different geological histories, Pakistan comprises three main sedimentary basins

- Indus Basin
- Balochistan Basin
- Pishin Basin

Indus and Balochistan basins evolved through different geological episodes and were finally welded together during Cretaceous/Paleocene along Ornach Nal/Chamman strike slip faults (Kazmi and Jan, 1997). The main sedimentary basins of Pakistan after (Abdul Fateh et al., 1984) is shown in figure. Also the further subdivision of the Indus basin is shown in the table 2.1. Our study area lies in the Upper part of Indus basin.

Table 2.1: Sub division of Indus Basin

<table>
<tr><td rowspan="12">INDUS BASIN</td><td rowspan="2">UPPER INDUS BASIN</td><td colspan="3">KOHAT SUB-BASIN</td></tr>
<tr><td colspan="3">POTWAR SUB-BASIN</td></tr>
<tr><td rowspan="10">LOWER INDUS BASIN</td><td rowspan="5">CENTRAL INDUS BASIN</td><td colspan="2">PUNJAB PLATFORM</td></tr>
<tr><td rowspan="3">SULAIMAN DEPRESSION</td><td>East Sulaiman Depression</td></tr>
<tr><td>Zindapir Inner Folded Zone</td></tr>
<tr><td>Mari Bugti Inner Folded Zone</td></tr>
<tr><td colspan="2">SULAIMAN FOLD BELT</td></tr>
<tr><td rowspan="5">SOUTHERN INDUS BASIN</td><td colspan="2">THAR PLATFORM</td></tr>
<tr><td colspan="2">KARACHI TROUGH</td></tr>
<tr><td colspan="2">KIRTHAR FORE DEEP</td></tr>
<tr><td colspan="2">KIRTHAR FOLD BELT</td></tr>
<tr><td colspan="2">OFFSHORE INDUS</td></tr>
</table>

2.2 Potowar Plateau

Plateau is an area which is fairly elevated plain land as compared to the surrounding areas. Potwar plateau is located 100 km north of the salt range and it is an elevated but nearly flat region. In north it is bounded by Kala-chitta and Margalla hills, in south salt ranges are present. Jhelum fault and Hazara Kashmir syntaxes in the east and also the Indus River and the kohat plateau to the west (Kazmi & Jan 1997).

2.3 Major Structures In Potwar

Southern margin of Himalayan collisional zone along with the fold and thrust belt was represented by the Potwar zone. While observing particular zone, faults of different variety were observed. In northern Potwar Plateau, stress is more active than the south. As the Potwar Plateau moves nearer the collision zone some tight fold nappes zones develop which have been thrusted over the NPDZ. According to (Moghal et al., 1997), based on the seismic interpretation, the structures in the Potwar area may be divided into following:

- Triangle zone
- Salt cored anticlines.
- Snake head anticlines
- Pop-up anticlines.

2.4 Faults In Potwar Basin

Some of the tectonic features of the Potwar Basin as.

2.4.1 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.. Jadoon et. al., explained that, it soles out in the basal decollement at a depth of about 9 km.citation here and ref down. Jaswel et al observed that, faults that have steep dips at the surface containing high faulted beds of Murree Formation to its north was due to back rotation, where alluvium covered most of the area.

2.4.2 Dhurnal Back Thrust (DBT)

Recent research has proved that DBT (Dhurnal Back Fault) as a different fault. The reason is for with different movement. In previous research, DBT had been considered as the eastward extension of the Kanet Fault (KF). It joins the KF west of Dhurnal and diverts towards the southwest, gradually dying out at the surface. Jadoon, et. al explained that, steep DBT becomes shallower to the south which dies out at a depth of 2 to 4 km. It merges with a north-dipping blind thrust that propagates up as a ramp from a layer of Eocambrian evaporates at a depth of about 8 km and flat along a pelitic horizon in Miocene Molasses strata.

2.4.3 Kanet Fault (KF)

The emerging thrust in the western part of the Potowar is a north-dipping KF. KF bound the Kanet syncline from the north.

2.4.4 Mianwali Fault (MF)

Intra formational thrust at the surface is MF. MF can be traced only in streams. On the basis of faulted Brecca and Shear zones, Outcrop is present only in steams. Steep dips are exposed in the area between MF and KMF representing the northern Siwalik in the rocks having rocks.

2.4.5 Riwat Fault (RF)

In the eastern Potwar Plateau, Hinterland-dipping fault with passive roof trust is RF in south of Soan syncline. Along the southern flank of the Chak Beli Khan anticline, RF dies out. In Northeast RF dies out near the Soan syncline axis.

2.5 Folds In Potwar Basin

Beside major faults, some other structures are also present in the area as follows:

2.5.1 Soan Syncline

Potwar Plateau divided into northern and southern Potwar deformed zone by the Soan Syncline. Soan Syncline is broad, wide and asymmetrical syncline. Its axis is marked by the Soan River. Dhok Pathan Formation overlying the Nagri Formation crops out south of Dhurnal area on the northern limb of Scan syncline. Here crustal shortening is due to the collisional tectonics.

2.5.2 Chak Naurang Anticline

Chak Naurang has two dipping limbs. These limbs are namely, southern limb which is dipping steeply while northern limb dipping moderately. Anticline is an example a fault-propagated fold. A strong northward-dipping basement reflector, which is overlain by a thick evaporite srata shown in the Reflection data.

2.6 Geological Setting

Salt Range escarpment bounds the Potwar basin from south, from north bounded by Main Boundary Thrust (MBT), in east by Jhelum transform fault, and to the west by Kalabagh transform fault (Aamir and Siddiqui, 2006).

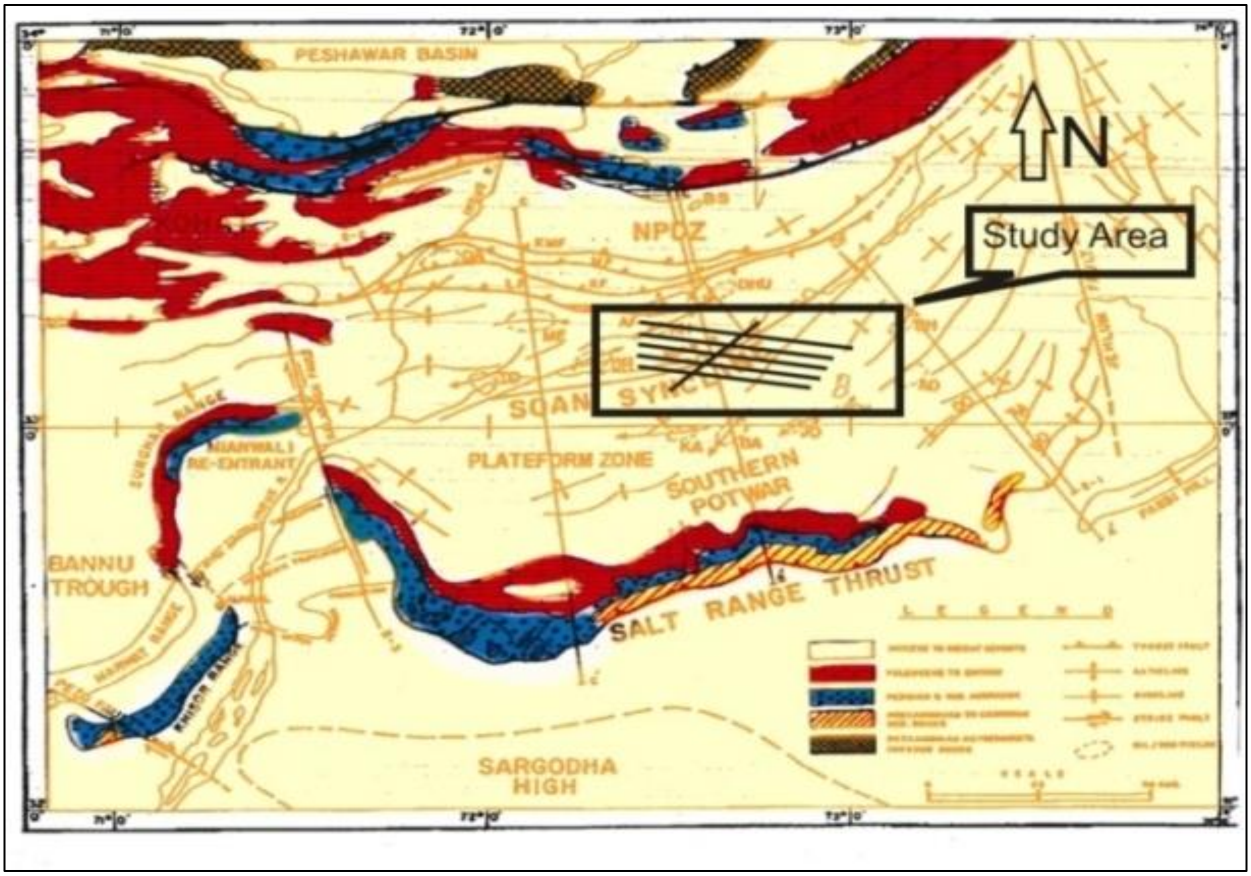


Figure 2.2: Structures in Potowar

Balkassar oil field lies in to the south of Soan Syncline, Upper Indus Basin, in the Platform zone. It is anticline that is bounded by faults at its limbs. The anticline is oriented NE-SW. Various Stratigraphic units that are encountered in wells, thickness and the contacts etc.

2.7 Stratigraphy

Subsurface geological data from wells drilled in Balkassar area indicates presence of Precambrian-Eo-Cambrian, Cambrian-Permian, Permian-Paleocene and Eocene-Miocene breaks in deposition. Eo-Cambrian Salt Range Formation unconformably overlies the basement rocks, composed of metamorphic and volcanic rocks of Indian Shield (Yeats and Lawrence, 1984), and is overlain unconformably by Early Cambrian Khewra Sandstone.

Contrary to well data obtained in Rajian, Missa Keswal and Adhi (Moghal et al., 2007) Kussak, Jutana and Baghanwala formations were not encountered in Balkassar Oxy-01-Well. Tobra Formation (conglomerates) of lower Permian age unconformably overlies the Khewra Sandstone. Dandot, Warchha and Sardhai formations of lower Permian age mainly composed of sandstone (Dandot and Warchha formations) and shales (Sardhi Formation) successively overly Tobra Formation. The area remains exposed from upper Permian through lower Paleocene. In Danian, Tertiary sequence with Hangu Formation at the base was deposited over Sardhi Formation. In the central and northern Salt Range, like Karsal, Dhurnal, Meyal and Dakhni wells (Moghal et al., 2007), a Permian, Triassic, Jurassic and Cretaceous sequence is present (Shah, 2009).

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

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

2.8 Petroleum Geology

2.8.1 Source Rock

Hydrocarbon Development Institute of Pakistan (HDIP), in collaboration with Federal Institute for Geosciences and Natural Resources (BGR) Hanover, Germany have identified a number of source rock horizons through Infra-Cambrian to Eocene in the Potwar Sub-basin and surrounding areas. These investigations suggest that the organic-rich shales of the Paleocene (Patala Formation) can be considered as the main contender for sourcing the Potwar oil fields.

In Potwar Basin, Patala shales of Paleocene have proven as the main source rocks. These organic shales were partly deposited in anoxic conditions prevailing Paleocene due to buckling of the basin floor. Pre-Cambrian Salt Range Formation also contains oil shale intervals, which show source rock potential.

The oil to source correlation indicates that most of the oil produced in Potwar sub basin has been sourced through Patala Formation. Shales of Khewra Formation are of lacustrine to marine origin and contain woody, coaly to variously amorphous (with significantly woody herbaceous) kerogen, which are capable of generating paraffinic to normal crude and gas.

2.8.2 Reservoir Rocks

Paleozoic-Tertiary dominantly marine sedimentary rocks form petroleum systems in Potwar and are exposed in Salt Range along the Frontal Thrust. 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. These represent the products of arid environment to marginal marine environment.

The upper and middle units of the formation are moderately porous and display intergranular primary porosity, which ranges from 10% - 12%. The uniform grain size and moderate sorting of the sandstone indicates its excellent reservoir nature. The sandstone also displays fracture.

2.8.3 Traps

Traps have been developed due to thin-skinned tectonics, which has produced faulted anticlines, pop-up and positive flower structures above Pre-Cambrian salt. The clays and shales of the Murree Formation additionally give effective vertical and horizontal seal to Eocene reservoirs wherever it is in contact.

CHAPTER 03
SEISMIC INTERPRETATION

3.1 Introduction

Seismic interpretation is the transformation of seismic reflection data into a structural picture by the application of correlation of seismic reflectors with geological boundaries and their time–depth contours.

3.2 Seismic Methods

Seismic method is one of the most important geophysical method in all geophysical methods. This predominance is because of various factors, its high accuracy, high resolution and great penetration. This wide seismic method is mostly used in exploration of petroleum.

This basic technique of seismic exploration is that seismic waves are generated and measured the time required for waves to travel from source to the geophones, which are arranged in specific pattern. There are two types of seismic methods i.e.

- Seismic reflection method
- Seismic refraction method

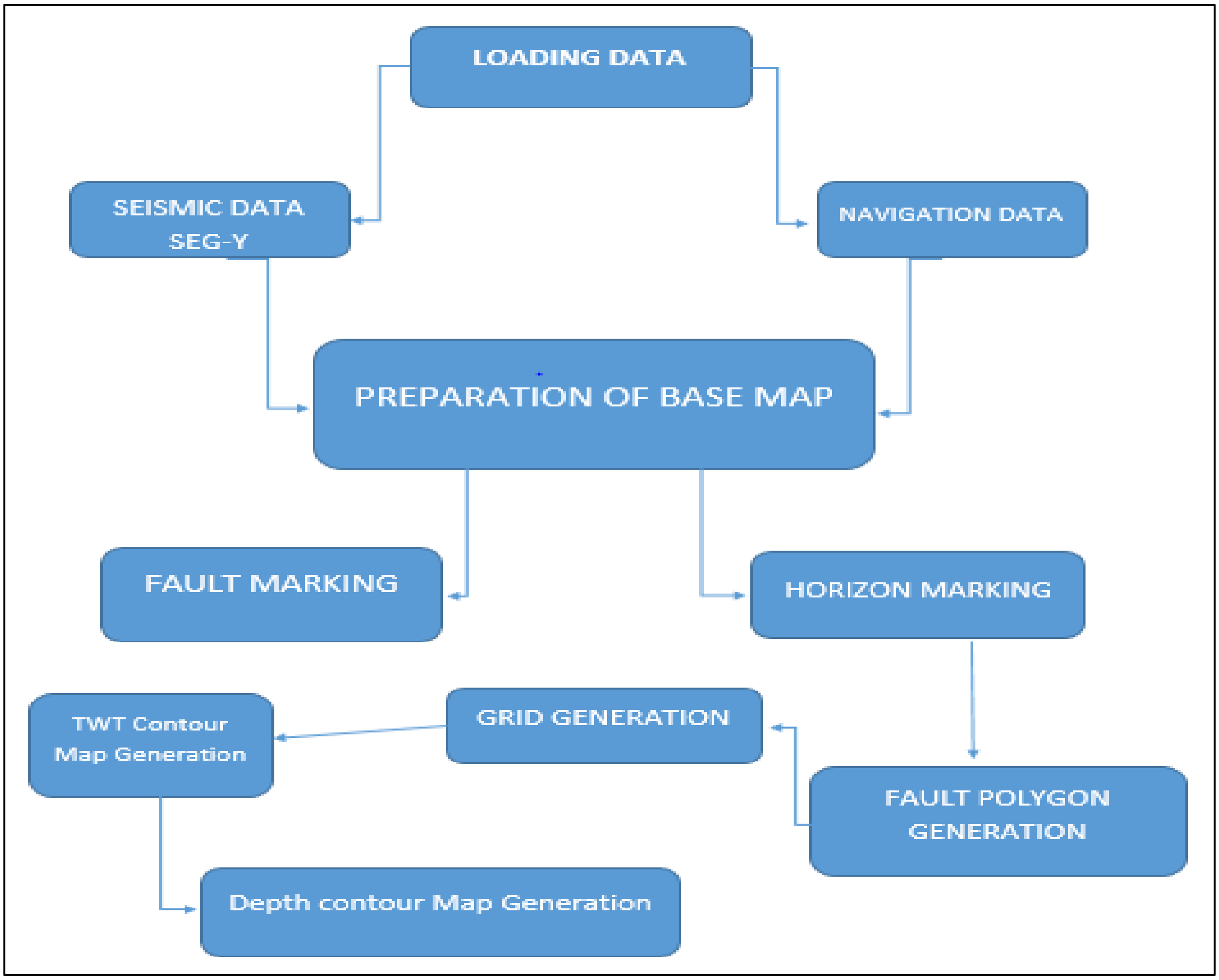
Seismic reflection method is based on the study to map subsurface geological structures. Measurements are made of the arrival time of events attributed to seismic waves which have been reflected from interfaces where the acoustic impedance changes. The objective usually is to map variations in the depth and attitude of the interfaces which usually are parallel to the bedding.

Seismic refraction method is based on the study of elastic waves refracted along geological layers. This method is generally used to map low velocity zone. This method is used as supplement with reflection method.

Seismic Interpretation Workflow for seismic data interpretation is given in figure where base map is prepared by loading navigation data and SEG-Y in software. Horizons of interest are marked manually. In this process faults are identified and marked. Faults polygons are generated and horizons are contoured to find out structural highs and lows. Then time and depth contours are plotted.

3.3 Work Flow

We followed the following workflow to process the seismic data interpretation.



3.4 Interpretation of the seismic lines:

The Primary task of interpretation is the identification of various horizons as an interface among geological formation. For this purpose, good structural as well as stratigraphic knowledge of the area is required (McQuillin et al., 1984). Thus during interpretation process, we marked both, the horizons and faults on the seismic section by the information obtained from the synthetic seismogram generated from OXY-01 A well. We marked the four horizons. The horizons are named on basis of well tops of the well OXY-01 A. Hence the first step before the Marking of the horizons is the generation of the synthetic seismogram. The steps used in the generation of the synthetic seismogram are explained below.

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

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

3.5 Base Map

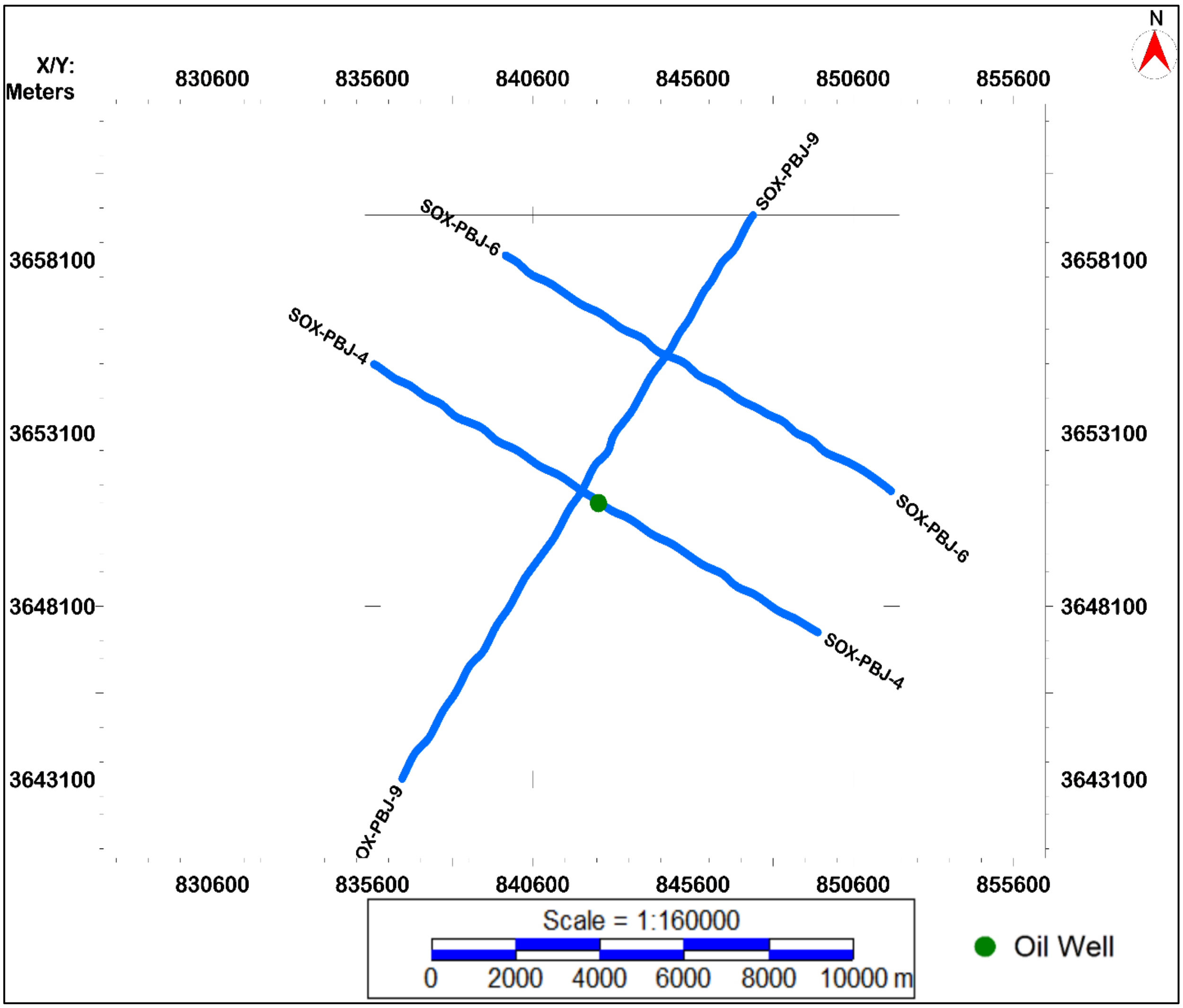


Figure 3.1: 2D Base map of Study Area

3.6 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 used the constant density for that area. With the help of 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, Elevation, Total Depth, Lattitude 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 sonic log to rescale from depth in meters to two-way travel time in seconds.
- Compute Acoustic impedance log using velocity and density log.
- Compute the reflection coefficients from the time-scaled velocity log.
- Compute a first-order Ricker wavelet as a digital filter with two millisecond increments.
- Two-way travel time; using a frequency in Hertz.
- Convolve the reflection coefficient log with the Ricker wavelet to generate the amplitudes of the synthetic seismogram.

Now the generated seismogram is used to confirm the horizon .Basically we have the limited log data only 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.

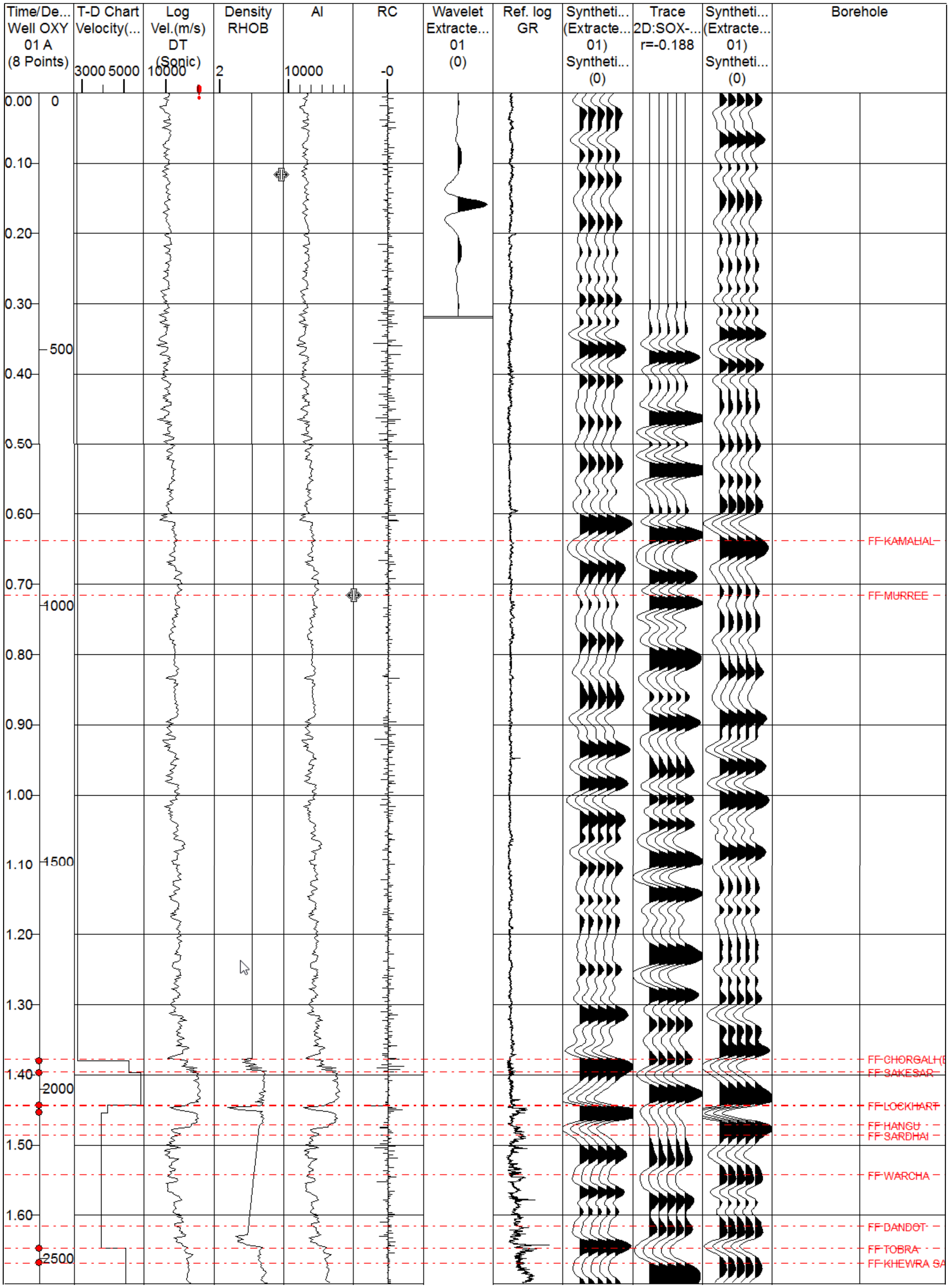


Figure 3.2: Synthetic Seismogram of Well OXY 01

3.7 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.

Table 3.1: Fault name and its type

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

F1 and F2 confine a pop up structure that may generate hydrocarbon.

3.8 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.

During interpretation process, I first generated a synthetic seismogram by the help of DT, RHOB logs and TD chart provided with the data of Well BALKASSAR_OXY_1.

Four horizons are picked on the basis of available information. The horizons are named on basis of well tops of the well BALKASSAR_OXY_1.

The following horizons were picked

- Murree Formation
- Chorgali Formation
- Sakesar Formation
- Basement

3.9 Time Section

Along X-axis we have number of traces along the location while along y-axis we have travel time and also it represents the depth of the section. It is also known as depth section. A seismic time section is actually the reproduction of actual seismic section and represents the reflectors and structures in time domain. It is generalized in two way travel time.

In this seismic section we marked four horizons and 3 reverse fault and one normal fault.

3.9.1 Interpretation of Dip line PBJ-04 and PBJ-06

Figure 3.3 shows well tie with real time domain section. We marked horizons of Murree, Chorgali, Sakesar. Top of the Murree, Chorgali, Sakesar formation on the basis of the change in the acoustic impedance also confirmed by the synthetic seismogram

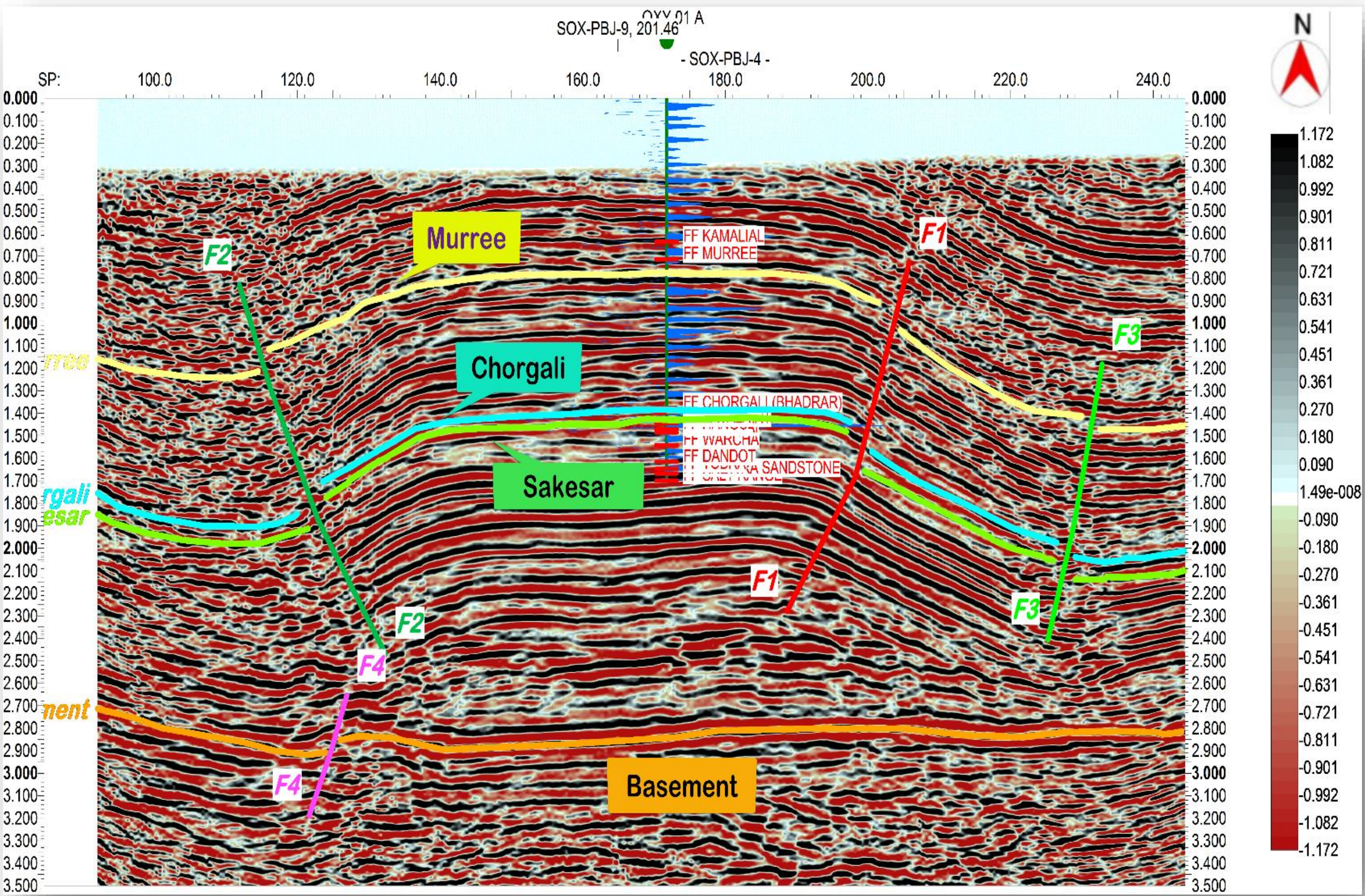


Figure 3.3: Interpretation of seismic Dip line PBJ-04

The following color scheme is used to mark the horizon.

- Murree — Light Yellow
- Chorgali — Cyan
- Sakesar — Light Green
- Basement — Gold

The interpretation shows the Pop up Anticline between Thrust faulting. The fault having almost trend of the NW-SE. The main purpose was to show the favourable structure for petroleum accumulation. The Pop up anticline structures are considered good structural trapes for the petroleum accumulation.

In the interpretation of the line PBJ-04 the thrust faulting can be seen. Due to this thrust faulting the Pop-up anticline structures are formed. These structures are considered favorable for the hydrocarbon accumulation in the compressional regime as in the Balkassar area.

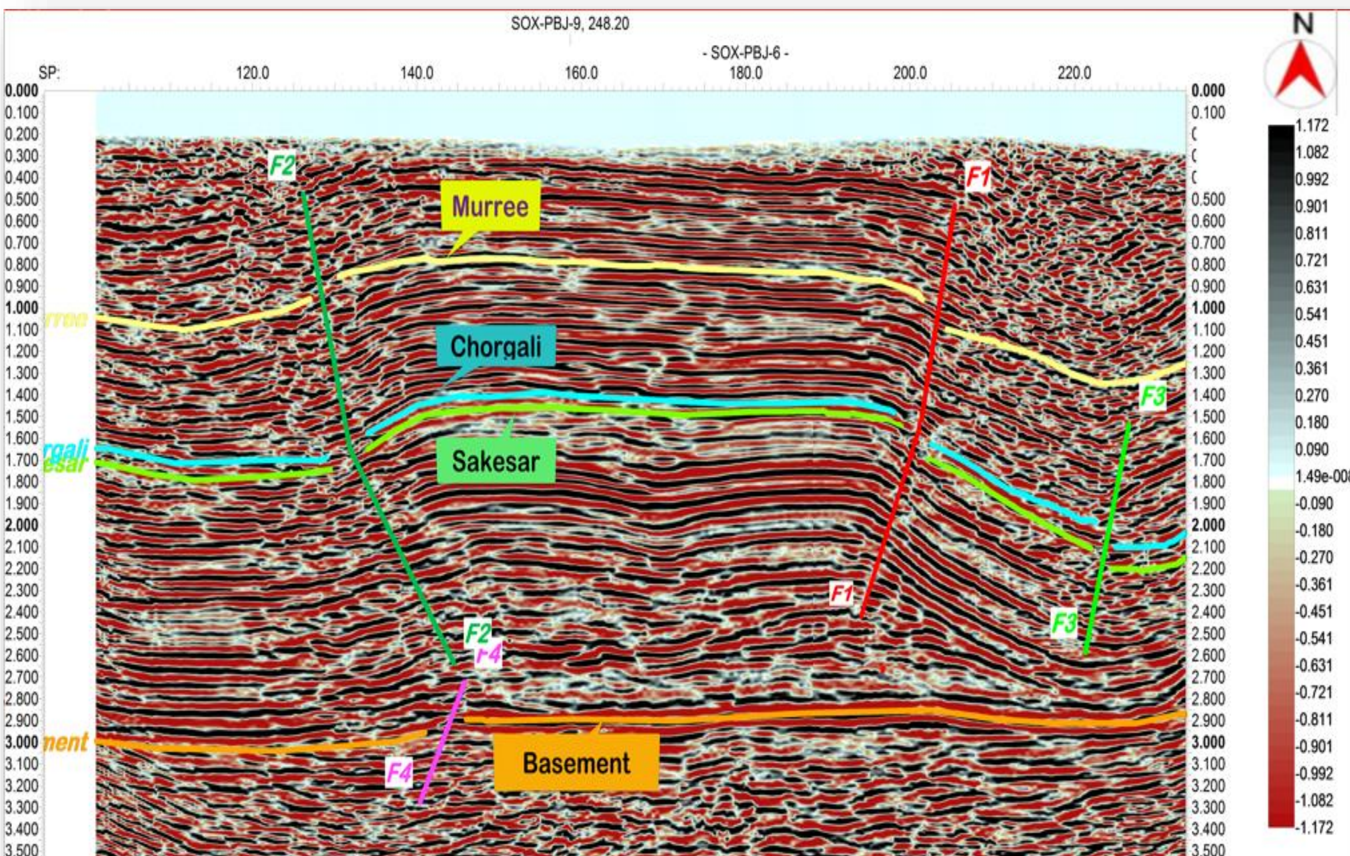


Figure 3.4: Interpretation of seismic Dip line PBJ-06

Also we have same structures in the line PBJ-06, because orientation of PBJ 04 and 06 are same only they are placed apart at some distance. In figure 3.4 also we marked 4 horizons and identified 3 reverse faults and one normal fault.

By the faults identified on these lines we form fault polygons and then make grid of time and depth and also form contours along these lines.

3.9.2 Interpretation of Strike line PBJ-09

Orientation of line PBJ-09 is SW-NE. This line can cross two dip lines which is used to tie the horizons. We marked four horizons as on other lines but here we have no fault as sownh in figure 3.5. Also we didn't identified any structure and trend of horizons is nearly straight.

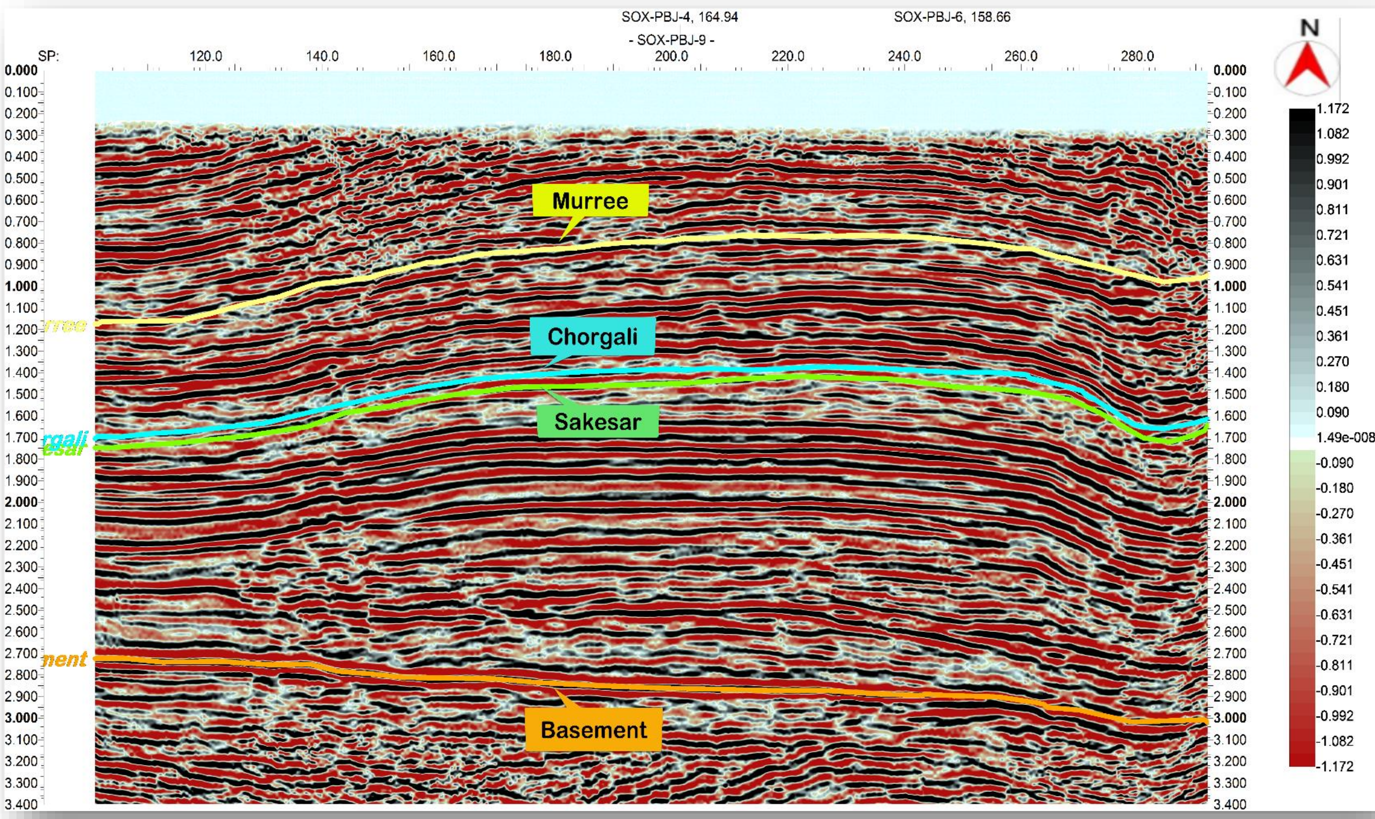


Figure 3.5: Interpretation of seismic Strike line PBJ-09

3.10 Fault polygon construction

We pick the fault on seismic section & find it at the other seismic lines. The fault in seismic section is called Fault Segment and the fault on map view is called Fault Polygon (Sroor, 2010).

In any software for mapping an area total fault should be converted into fault polygon before the contouring. The reason is that if we will not convert them into fault polygon then the software will not recognize it as a barrier due to which a wrong picture of the earth will be generated.

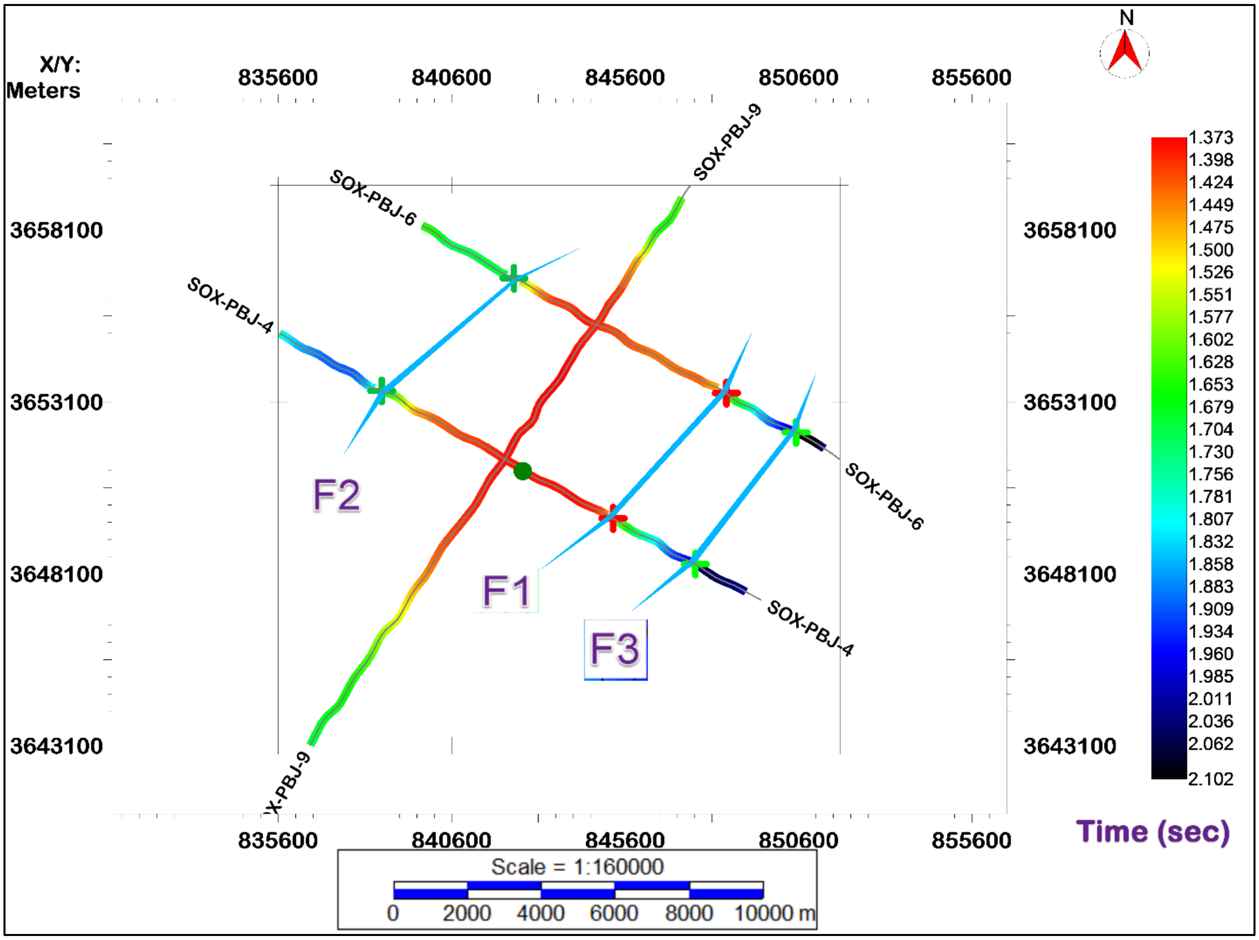


Figure 3.6: Fault Polygon of Murree formation

3.11 Contour Maps

The final products of all the seismic exploration are the contour maps, time or depth. The mapping is one of the most important part of the data interpretation on which entire operations depends upon. The contours are generally the lines which join the point of the equal depth and time (Coffeen, 1986). Contours represent the three dimensional earth surface into the two dimensional earth surface. These contour maps represent the structural relief of the formation, any faulting and folding including dip of the strata.

3.11.1 Time and Depth based contour models

As the seismic section is originally a time section and reflection time values in milliseconds by plotting the values at an appropriate CDP interval and plot these values on the map. Also 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 are not altered (Onajite, 2014).

Conversion from time to Depth contour is by using the average velocity of the area. Actually we have to use the interval velocity but due to limitation of data we can't use it so we use the average velocity to convert from time to depth by using formula. (s=vt). Contour interval for each time model and depth model is different. Below are the models for Murree formation acting as a seal rock, Chorgali and Sakesar formation acting as reservoirs in study area.

3.11.2 Time and depth contour maps of Murree:

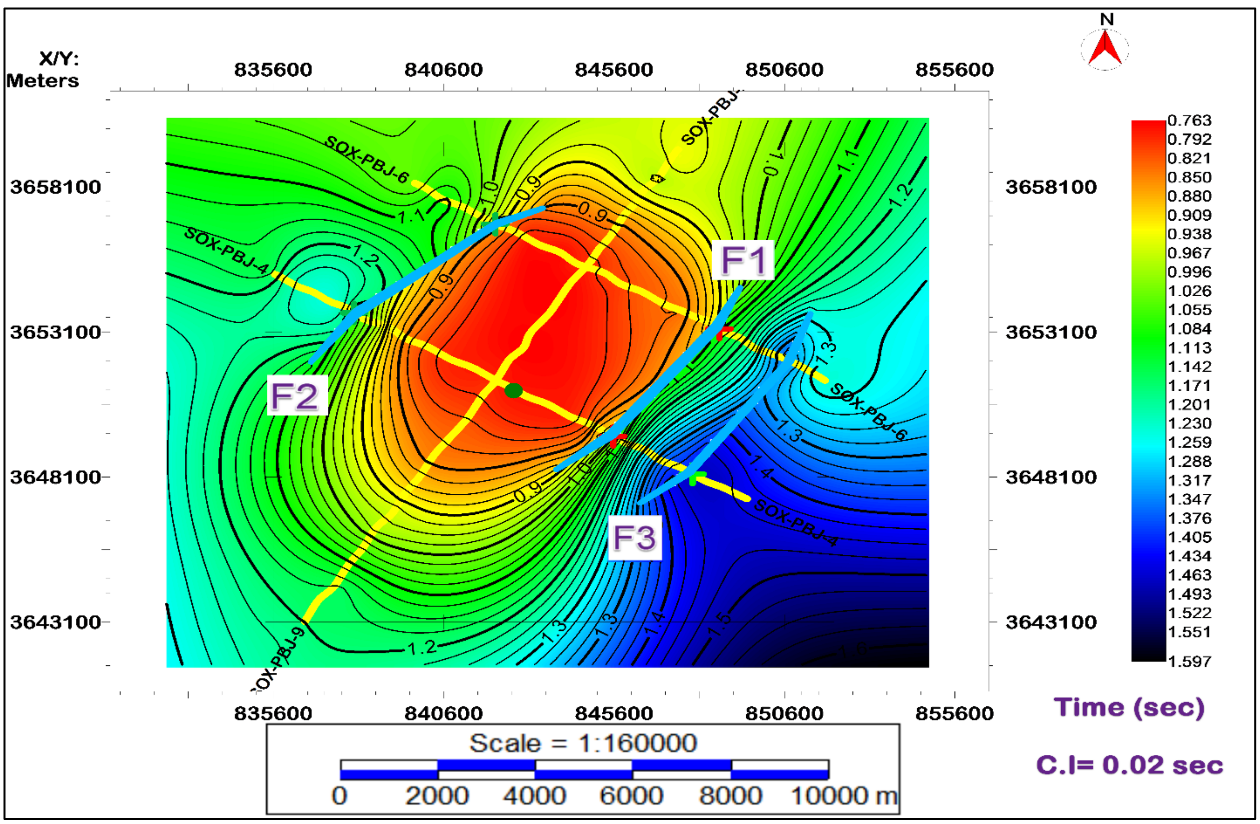


Figure 3.7: Time Contour map of the Murree Formation

Time and depth contour map of Murree formation is shown in figure 3.7 and 3.8. Time and Depth variation is given through color bar.

Orange portion is showing the lowest values i.e shallowest part while the dark blue color is showing deeper parts. It is clear that 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 orange color is showing low time values and it is a good indicator for hydrocarbon.

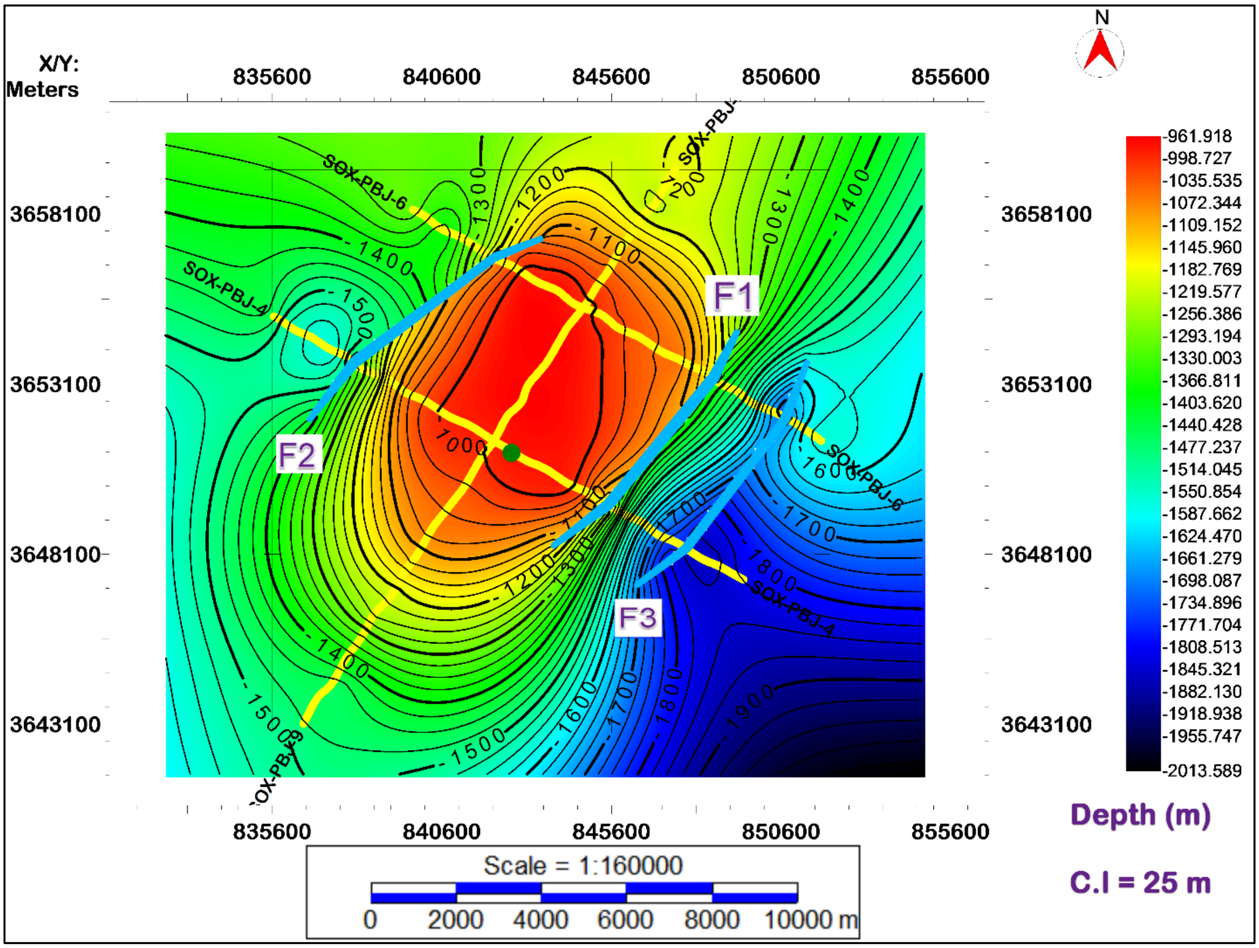


Figure 3.8: Depth Contour map of the Murree Formation

Contour interval for time section is 0.02 sec while depth contour interval is 25m.

In time and depth contour maps orange color ranges for time section from (0.763sec-0.909sec) while for depth it ranges from (961m-1109m) showing the shallowest parts.

While dark blue color for time section ranges from (1.40sec-1.59sec) while for depth it ranges from (1735m-2013m) showing deeper parts.

3.11.3 Time and depth contour maps of Chorgali

Time and depth contour map of Chorgali formation is shown in figure 3.9 and 3.10. Time variation is given through color bar. Orange portion is showing the lowest values i.e shallowest part while the dark blue color is showing deeper parts. It is clear that Murree is deepening NW-SE direction as the time is increasing and Chorgali formation is shallowing towards NE-SW direction because time is decreasing. Hence the orange color is showing low time values and it is a good indicator for hydrocarbon.

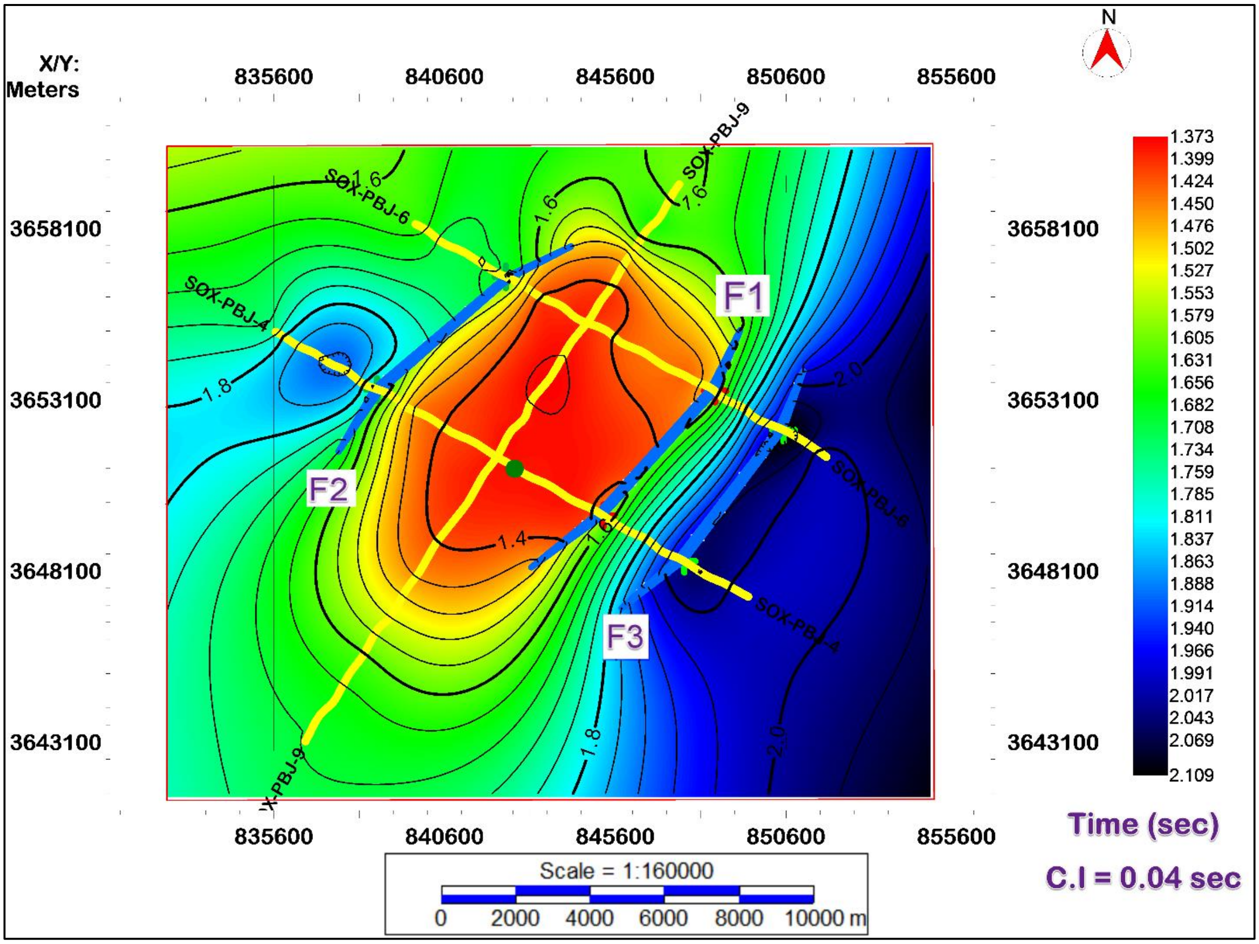


Figure 3.9: Time Contour map of the Chorgali Formation

Contour interval for time section is 0.04 sec while depth contour interval is 50m.

In time and depth contour maps orange color ranges from (1.373sec-1.476sec) for time contours while for depth it ranges from (1870.955m-2000m) showing the shallowest parts.

While dark blue color ranges from (1.966sec-2.109sec) for time contours while for depth it ranges from (2680m-2874.621m) showing deeper parts.

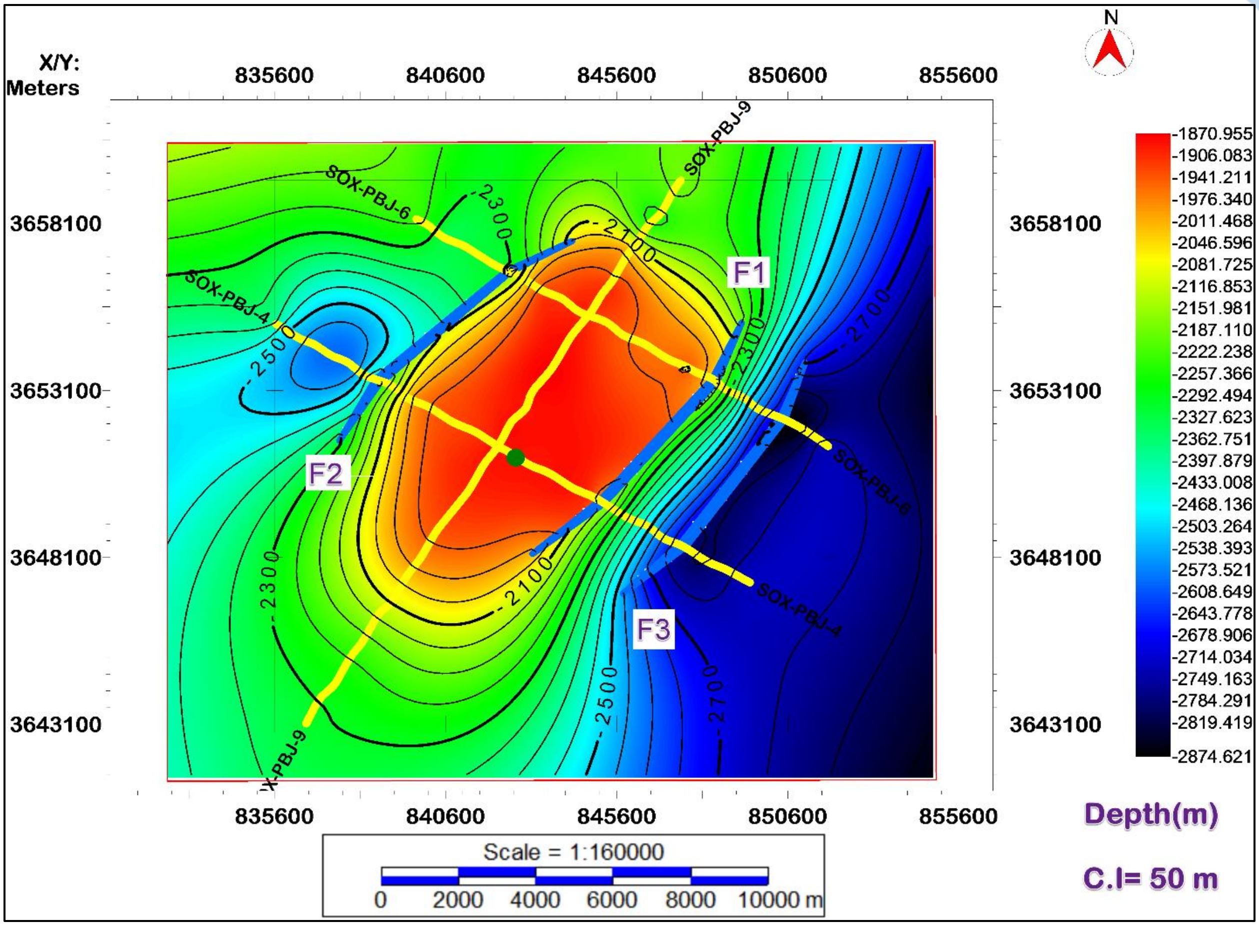


Figure 3.10: Depth Contour map of the Chorgali Formation

3.11.4 Time and depth contour maps of Sakesar:

Time and depth contour map of Sakesar formation is shown in figure 3.11 and 3.12. Time and depth variation is given through color bar. Orange portion is showing the lowest values i.e shallowest part while the dark blue color is showing deeper parts. It is clear that 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 orange color is showing low time values and it is a good indicator for hydrocarbon.

Contour interval for time section is 0.04 sec while depth contour interval is 50m.

In time and depth contour maps orange color ranges from (1.416sec-1.512sec) for time contours while for depth it ranges from (1914.362m-2028.726m) showing the shallowest parts. While dark blue color ranges from (2.092sec-2.221sec) for time contours while for depth it ranges from (2791.156m-3003.547m) showing deeper parts.

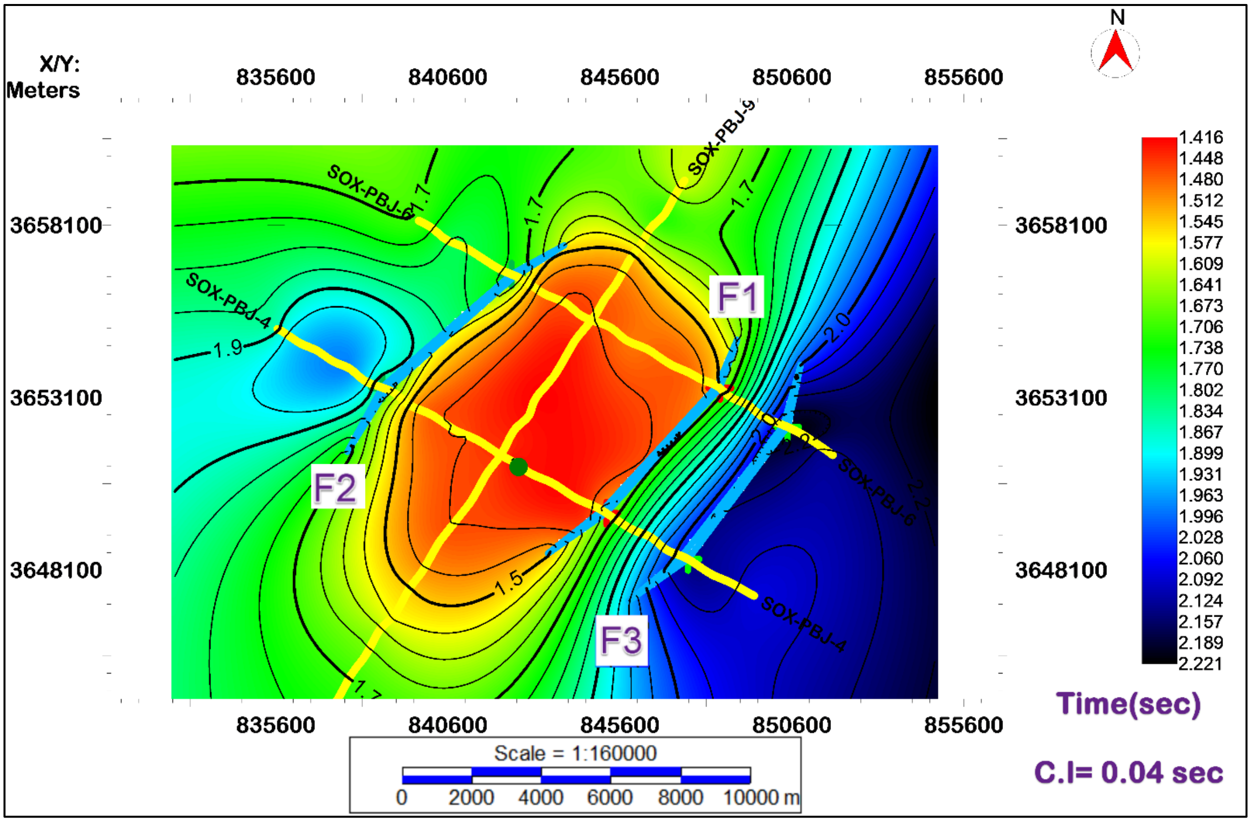


Figure 3.11: Time Contour map of the Sakesar Formation

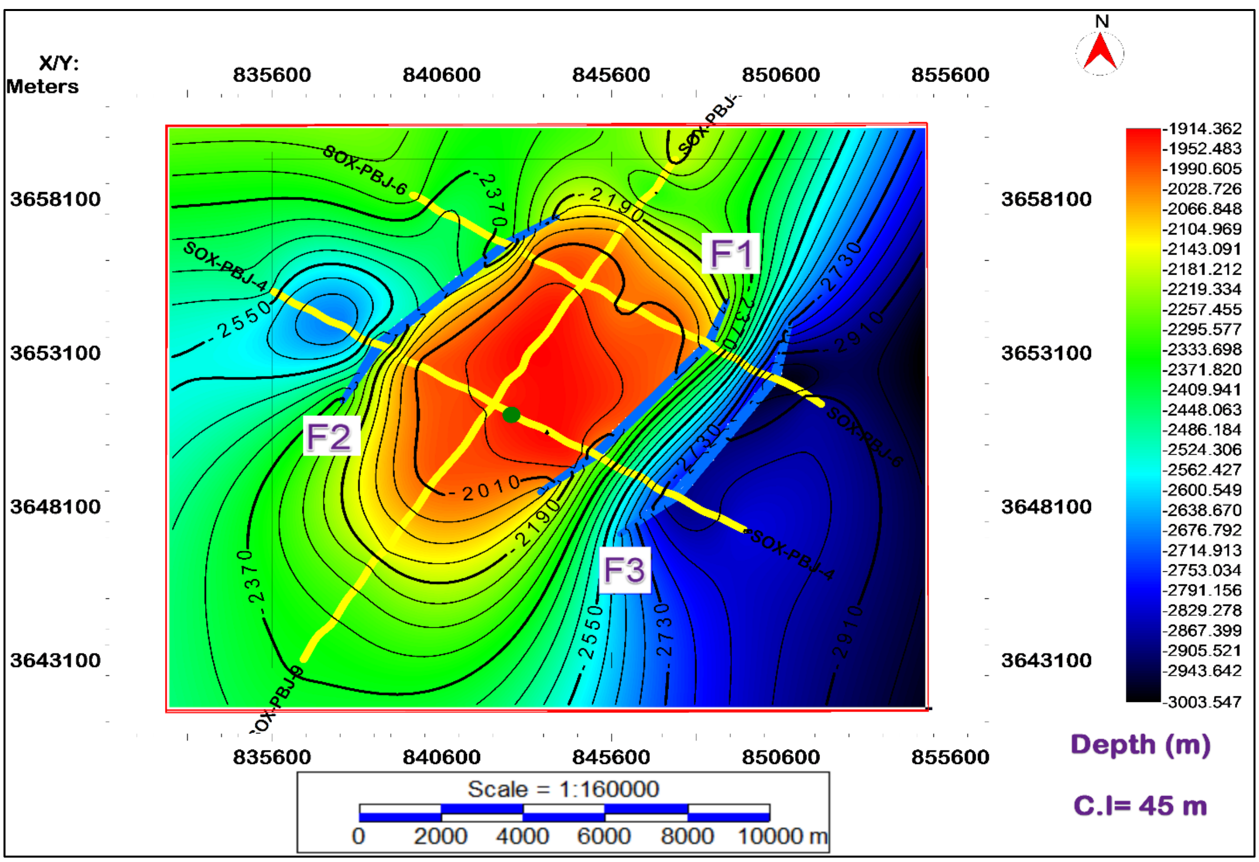


Figure 3.12: Depth Contour map of the Sakesar Formation

3.12 Conclusion

- Time and depth structure map shows a pop up anticlinal structure with faults at limbs.
- Chorgali and sakesar act as a reservoir.
- Murree and kamlial provides a lateral seal.
- Faults extend from the salt range formation to the upper horizons and provide a trap for all hydrocarbon bearing zones.
- Patala act as a source.
- The high area is promising zone for developments.

CHAPTER 04
PETROPHYSICAL ANALYSIS

4.1 Introduction

Petrophysics (petro is Latin for "rock" and physics is the study of nature) 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 sometimes seismic measurements, and combining them with geology and geophysics.

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 three major parts namely

- Rock mechanical properties
- Ore quality
- Conventional Petrophysical properties

These properties provide complete description about the rock, for instance, they provide information about the size of the grains present, composition of the rock and the texture of the rock.

4.2 Reservoir Petrophysical Properties

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

4.2.1 Lithology

What type of rock is it? When combined with local geology and core study, geoscientists can use log measurements such as natural gamma, neutron, density, Photoelectric, resistivity or their combination to determine the lithology downhole.

4.2.2 Porosity ϕ

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 measured to derive rock porosity.

Nuclear magnetic resonance (NMR) logging, including porosity, saturation, hydrocarbon identification, facies prediction, and permeability.

4.2.3 Water saturation (SW)

The fraction of the pore space occupied by water. This is typically measured using an instrument that measures the resistivity of the rock.

4.2.4 Hydrocarbon saturation (H.C.S)

The fraction of the pore space occupied by hydrocarbon. This is typically measured by subtracting the water saturation from one (1).

4.2.5 Net Pay

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

4.3 Given Data

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

4.4 Logs Available

Table 4.1: Logs available of Balkassar OXY 01 well

	Name	Type
1	CALI	Other
2	CALIPER	Other
3	DRHO	Other
4	DT	Sonic
5	GR	Other
6	ILD	Resistivity
7	LLD	Other
8	LLS	Other
9	MSFL	Other
10	NPHI	Other
11	PE	Other
12	PHIE	Other
13	RHOB	Density
14	Rt	Resistivity
15	Rxo	Other
16	SFLU	Other
17	SMTPERM	Other
18	SMTPHIE	Other
19	SMTPHISW	Other
20	SMTPHISXO	Other
21	SMTPHIX	Other
22	SMTSW	Other
23	SMTSWAR	Other
24	SMTSXO	Other
25	SMTSXOAR	Other
26	SMTVSH	Other
27	SP	Other

4.5 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.

4.6 Lithology Track

4.6.1 GR log

GR logging tool detect the natural Gamma radiations across the formation. These radiations comes 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) have 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.

4.6.2 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.

4.6.3 Caliper log

Caliper log tell us about bore hole diameter. Bore hole 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 hole 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.

4.7 Resistivity Track

4.7.1 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).

4.8 Porosity Track

4.8.1 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 a indicator of Gas/hydrocarbons called Gas Effect,. The overlapping curves indicate the presence of water.

4.8.2 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

4.8.3 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.

4.8.4 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.

4.9 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

4.10 Volume of Shale

We have two methods:

4.10.1 Linear Method

In linear method we compute IGR by following formula.

$$IGR = \frac{\text{GR log} - \text{GR min}}{GR\,\text{max} - GR\,min}$$

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

4.10.2 Non Linear Method

In non linear 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)

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

Where, IGR= Index Gamma Ray

- **Larinov:** (Used for Older rocks)

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

- **Clavier:**

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

4.11 Porosity

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

- **Density Porosity**
- **Sonic porosity**
- **Effective Porosity**
- **Neutron porosity** (Given)

4.11.1 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.

$$RHOB\ \Phi = \frac{(RHOB\ mat - RHOB\ log)}{(RHOB\ mat - RHOB\ fluid)}$$

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 $1gm/cm^3$.

4.11.2 Sonic porosity

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

$$\Phi s = \frac{\Delta T\ \log - \Delta T\ mat}{\Delta T\ fluid - \Delta T\ mat}$$

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.

4.11.3 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:

$$\Phi_e = (1-V_{sh})*\Phi_{avg}$$

4.11.4 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.

4.11.5 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

φT=Average porosity

4.12 Water Saturation

Water saturation is the percentage of pore volume in rock that is occupied by water of formation. If it is not confirmed that pores in the formation are filled by hydrocarbons, it is assumed that these are filled with water. To determine the water and hydrocarbon saturation is one of the basic goals of well logging. 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 by Spontaneous potential log.

The steps are discussed below

1. Pick SSP from S-P log by using formula given by (Rider, 1996).

$$SSP = SP_{Clean} - SP_{Shale}$$

SSP = Static spontaneous potential.

SP_{Clean}= Spontaneous potential for sand.

SP_{Shale}= Spontaneous potential for shale.

The value of SSP in OXY-01 is calculated to be -19 mv.

2. Determine the Formation temperature TF against the depth (d) using formula shown in equation given by (Rider, 1996).

$$T_f = \frac{d(BHT - T_S)}{T_D + T_S}$$

D =Depth of Formation (3250m).

BHT = Borehole temperature (820F).

T_S = Temperature at surface (260F).

T_D = Temperature at depth.

3. Resistivity of the mud filtrate is calculated 0.48Ωm at surface temperature by using this relation.

$$R_{mf} = R_{mfe}\left(\frac{T_s + 6.77}{f_t + 6.77}\right)$$

T_s = Surface temperature

R_{mfe} = Resistivity of mud filtrate equivalent.

f_t = Formation temperature.

4. Now resistivity of the mud equivalent (Rmfeq) is calculated by using Schlumberger chart shown in figure (4.1).

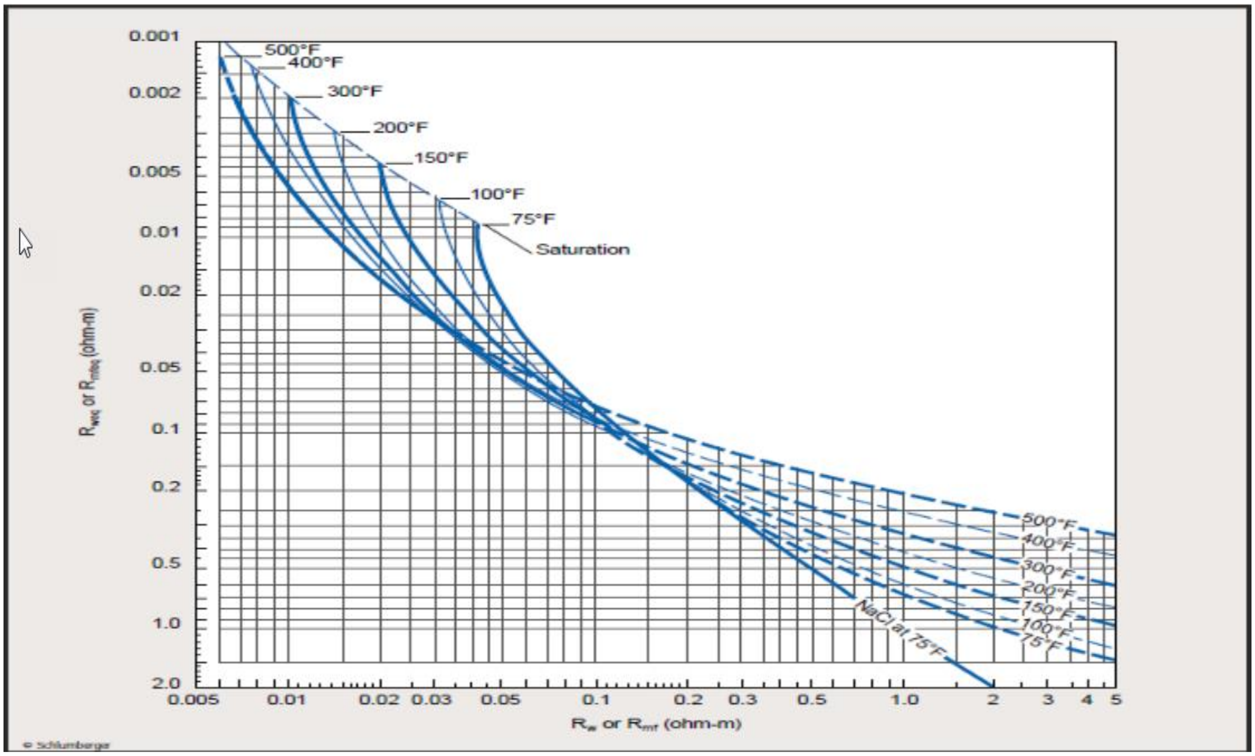


Figure 4.1: Determination of Rweq from SP chart (Schlumberger, 1989).

5. Rweq (Water equivalent resistivity) is determined from the Essp (Static spontaneous potential).
6. This is the last step in this step the value of the resistivity of the water (Rw) is obtained against the value of the Rweq (Resistivity of the water equivalent) and Formation temperature.

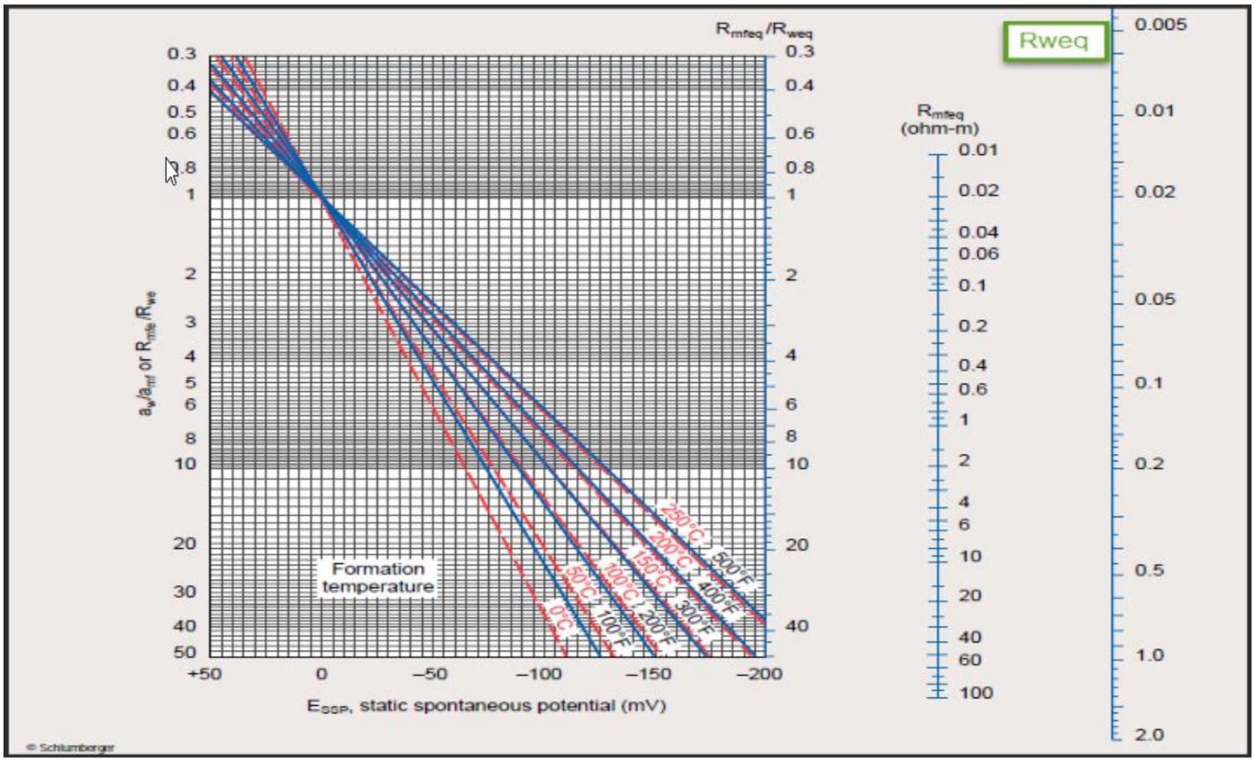


Figure 4.2: Determination of Rw from SP chart (Schlumberger, 1989)

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.

$$Sw = (\frac{Rw * F}{Rt})^{\frac{1}{n}}$$

Table 4.2: Calculated values for Chorgali and Sakeasar formation

Zones	R_w **(Ωm)**	S_W
Chorgali	0.049	60-70%
Sakesar	0.042	70-80%

4.13 Hydrocarbon Saturation:

The fraction of pore spaces containing hydrocarbons is known as hydrocarbon saturation. The simple relation used for this purpose is given below.

$$S_w + S_H = 1$$

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

$$S_H = 1 - S_w$$

Where, S_H= Hydrocarbon saturation

S_w= Water saturation

4.14 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 (2421m-2467m) while Sakesar Formation is encountered at the depth ranges from (2467m-2602m). The Chorgali and Sakesar Formation is confirmed as a reservoir by different results obtained from well log. The Chorgali and Sakesar Formation is 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.

4.14.1 Interpretation of Chorgali Formation

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

4.14.2 Petrophysical Analysis of Chorgali Zone

Only one main zone of interest is marked. Depth range of Zone of interest varies from 2445m-2452m 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 67%. And water saturation is 33%. This is only one pay zone in which high net pay is expected. This zones bear low value of the GR, high porosity and the greater value of the resistivity.

Table 4.3: Calculated values for Zone of interest in Chorgali Formation

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

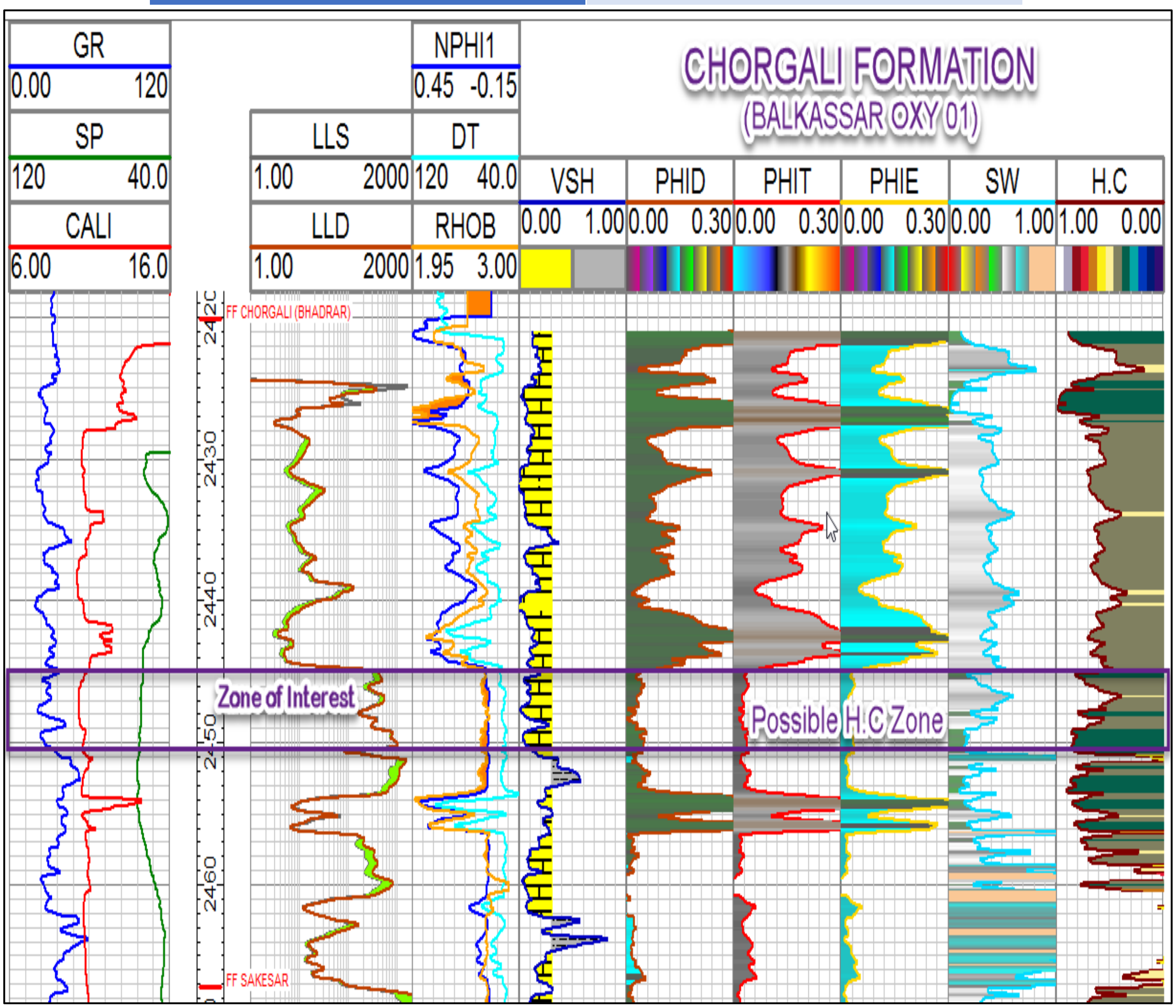


Figure 4.3: Petrophysical Graph of Chorgali Formation of Balkassar OXY-01 well

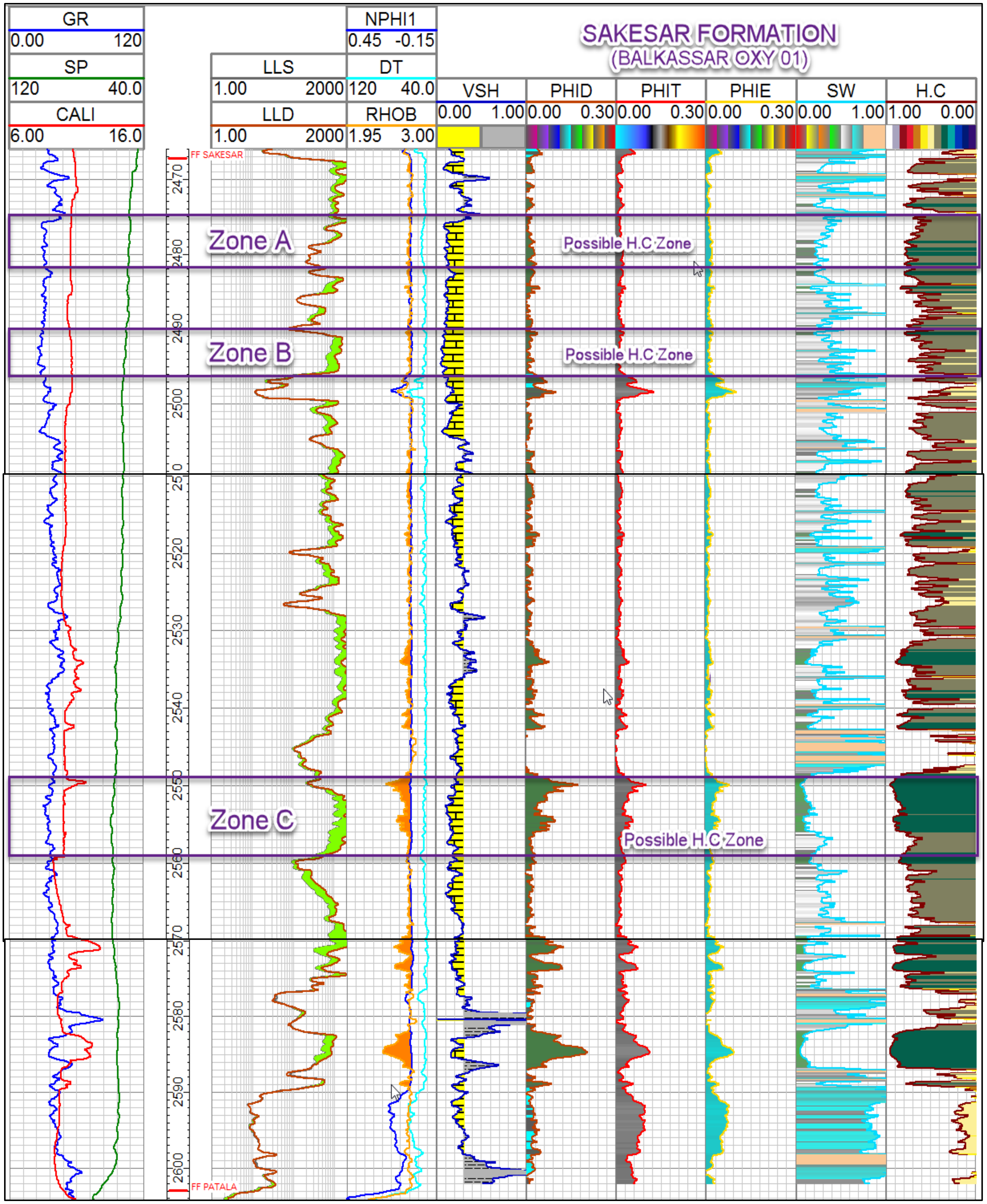


Figure 4.4: Petrophysical Graph of Sakesar Formation of Balkassar OXY-01 well

4.14.3 Interpretation of Sakesar Formation

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

4.14.4 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 4.4: Calculated values for Zone of interest in Sakesar Formation

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

4.15 Conclusion

We have concluded that Chorgali and sakesar formation have reservoir potential as all the Petrophysical parameters support what we concluded. On the basis of results of the whole formations it is clear that there is 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 that sakesar formation and it is a tight reservoir. Over all there is a problem with calliper log response specially 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-2440m. 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 P-Wave Velocity and S-Wave Velocity

Sonic travel time of compressional wave is generally used as porosity tool for given lithology. VP-VS 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.

$$V_P = \frac{1 \times 1000000}{Sonic \log(DT) \times 3.28} (\frac{m}{s})$$

$$V_S = (0.58321 \times V_P) - (0.07775$$

5.3 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.

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

5.4 Bulk Modulus

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.

$$K = \left(\rho \times {V_P}^2\right) - \frac{4}{3}\left(\rho \times {V_S}^2\right)$$

5.5 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.

$$E = \frac{9 \times K \times \mu}{3K + \mu}$$

5.6 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.

$$\mu = \left(\rho \times {V_s}^2\right)$$

5.7 Poisson's Ratio

Poisson's ratio (σ) is the ratio of transverse strain (normal to the applied load) to longitudinal strain (in the direction of the applied load).

$$\sigma = \frac{\frac{1}{2} \times (\frac{V_P}{V_S})^2 - 1}{(\frac{V_P}{V_S})^2 - 1}$$

5.8 Vp/Vs Ratio

Lower values of P-wave and S-wave velocity ratio show the shaly material and higher values stiffer material.

5.9 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:

$$Z = \rho \times Vp$$

5.10 Shear Impedance

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

$$Shear\ Imp = \rho \times Vs$$

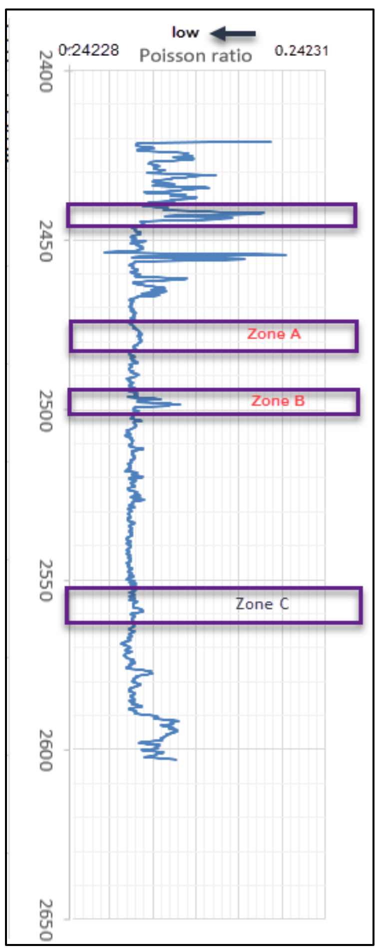


Figure 5.1: Poisson’s Ratio

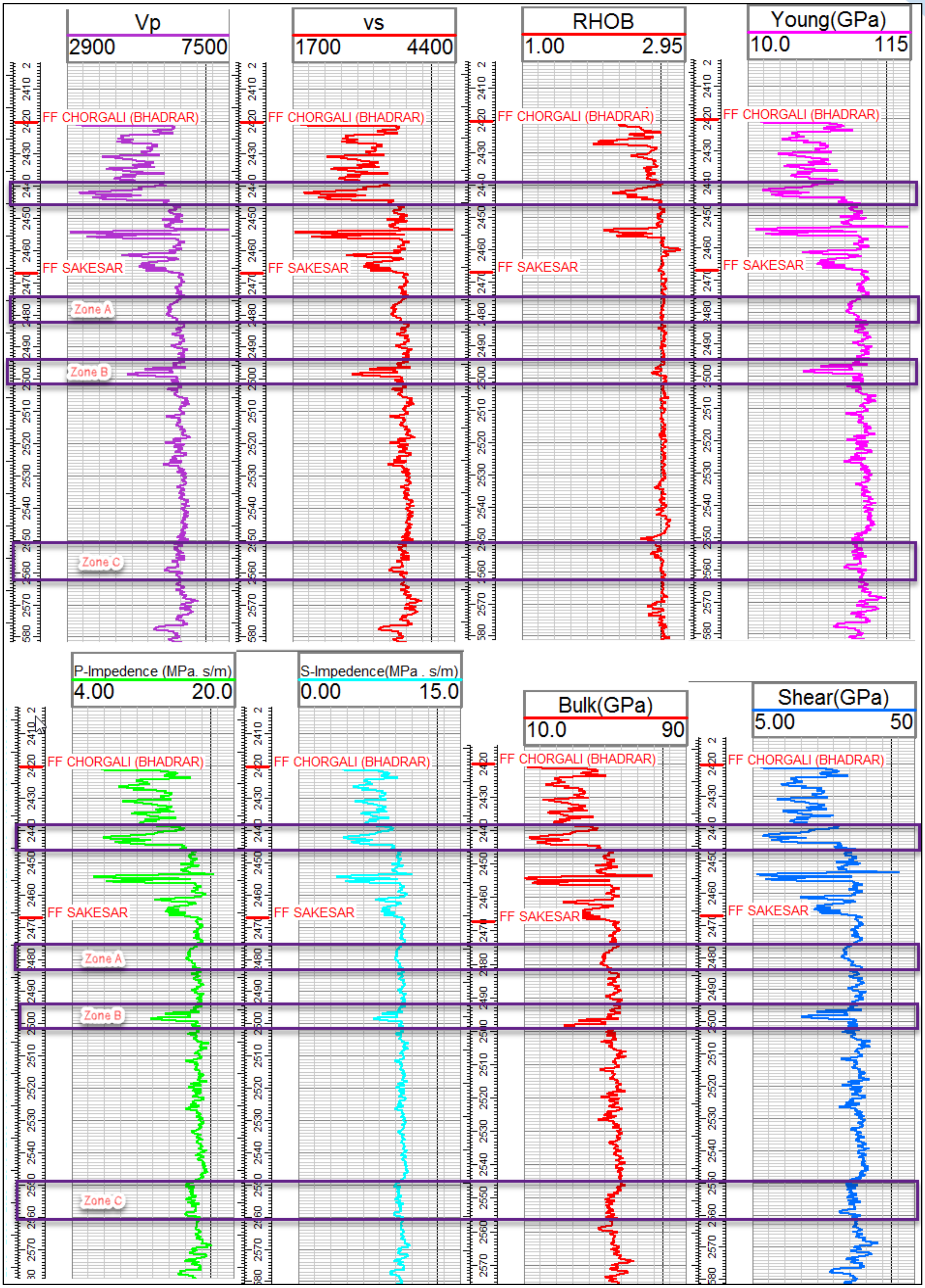


Figure 5.2: Combine figure of Rock physics

5.11 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 bot decrease in our area of interest hence indicating that hydrocarbons present there.

CHAPTER 06

FACIES MODELING

6.1 Introduction

In geology, a 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 effect the reservoir properties. This gives the main indication about the productive zone in the reservoir (Kurniawan, 3005).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

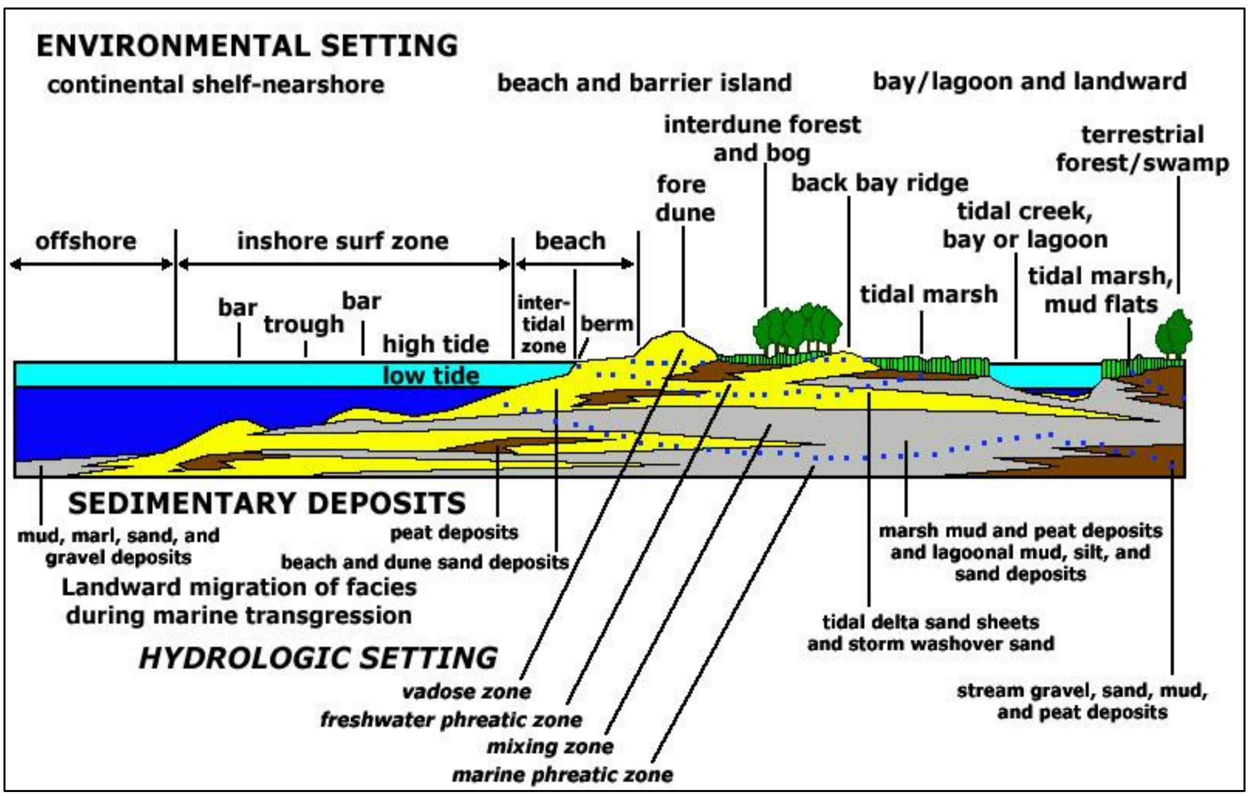


Figure 6.1: Different types of the environment

environment is specific type of place where the facies are deposited. Such as the Glaciers. Lakes, Abyssal plain, Sea bottom. Stream, Delta etc. The different types of the environment are shown in the below figure 6.1.

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 on the basis of their lithology. Similarly, biofacies 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.

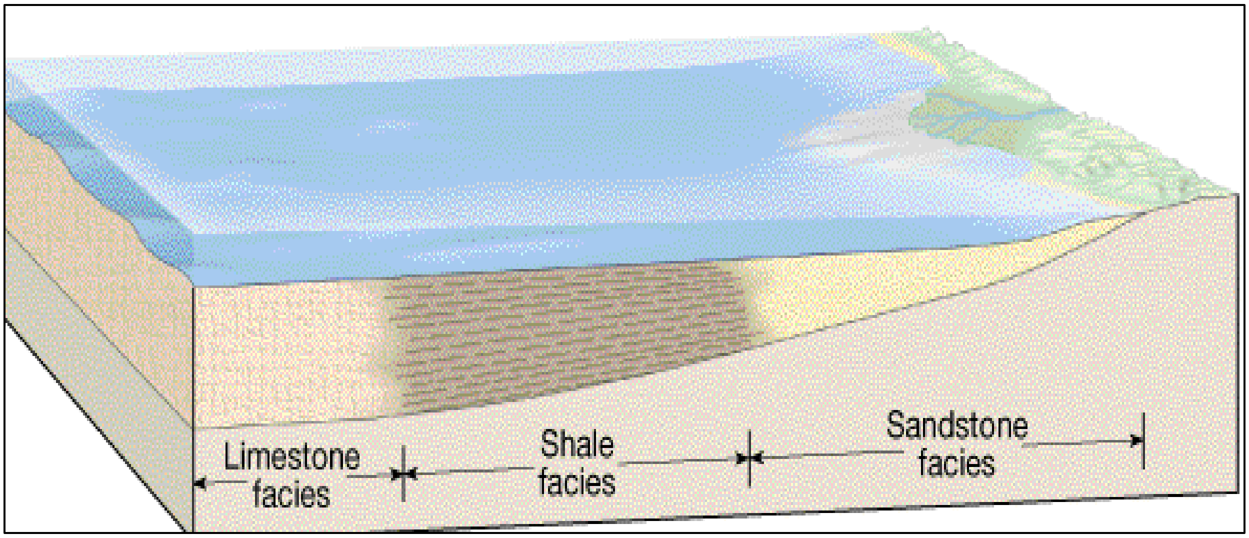


Figure 6.2 Sediment deposited in a different depositional environment.

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 particular challenging interplay between capturing enough information for environmental interpretation. A good understanding of paleoecology always strengthen the interpretation and such studies should be included as part of all depositional facies studies. Depositional textures in turn effect 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 Crossplot

A crossplot 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 lies between depth range 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.

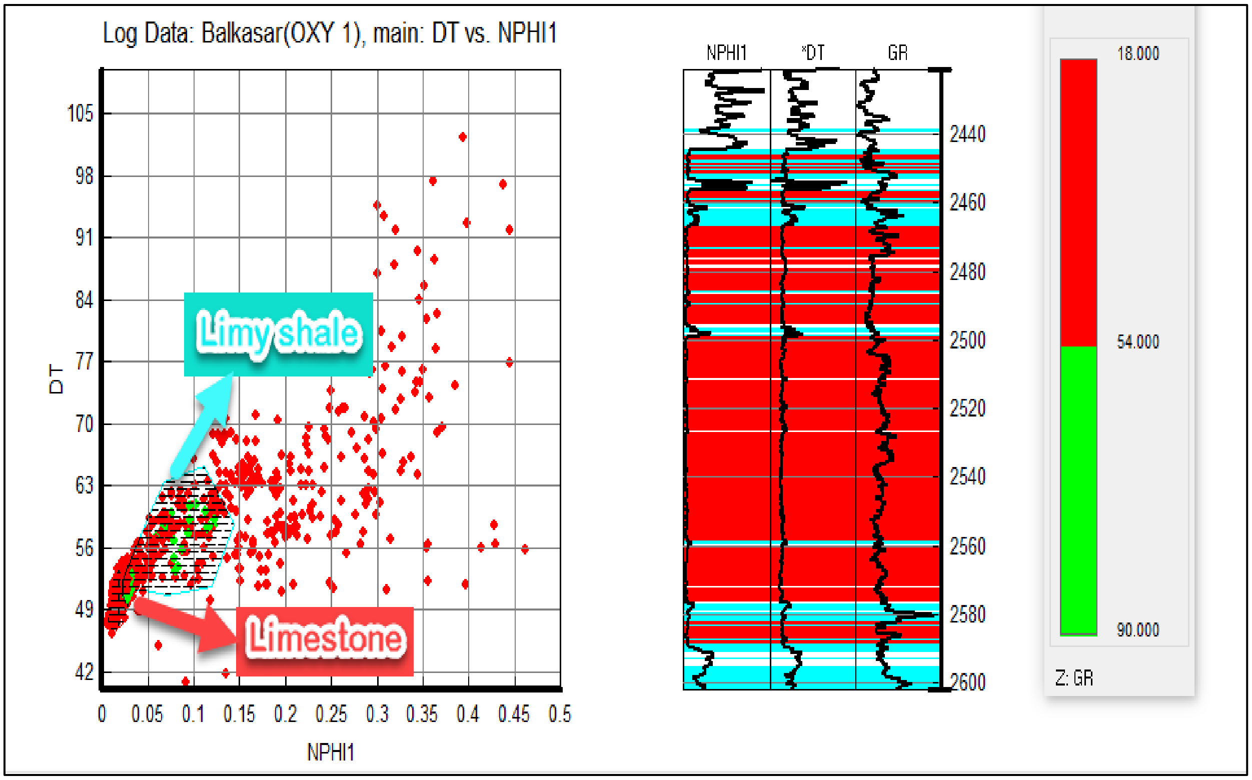


Figure 6.3: Cross plot between **DT vs NPHI**

Cluster of dots indicate the pure lithology here in our reservoir only limestone have cluster of dots. So we concluded that the reservoir is mainly comprises of 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 range 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 5.4. Since density of shale is highly variable in case 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.

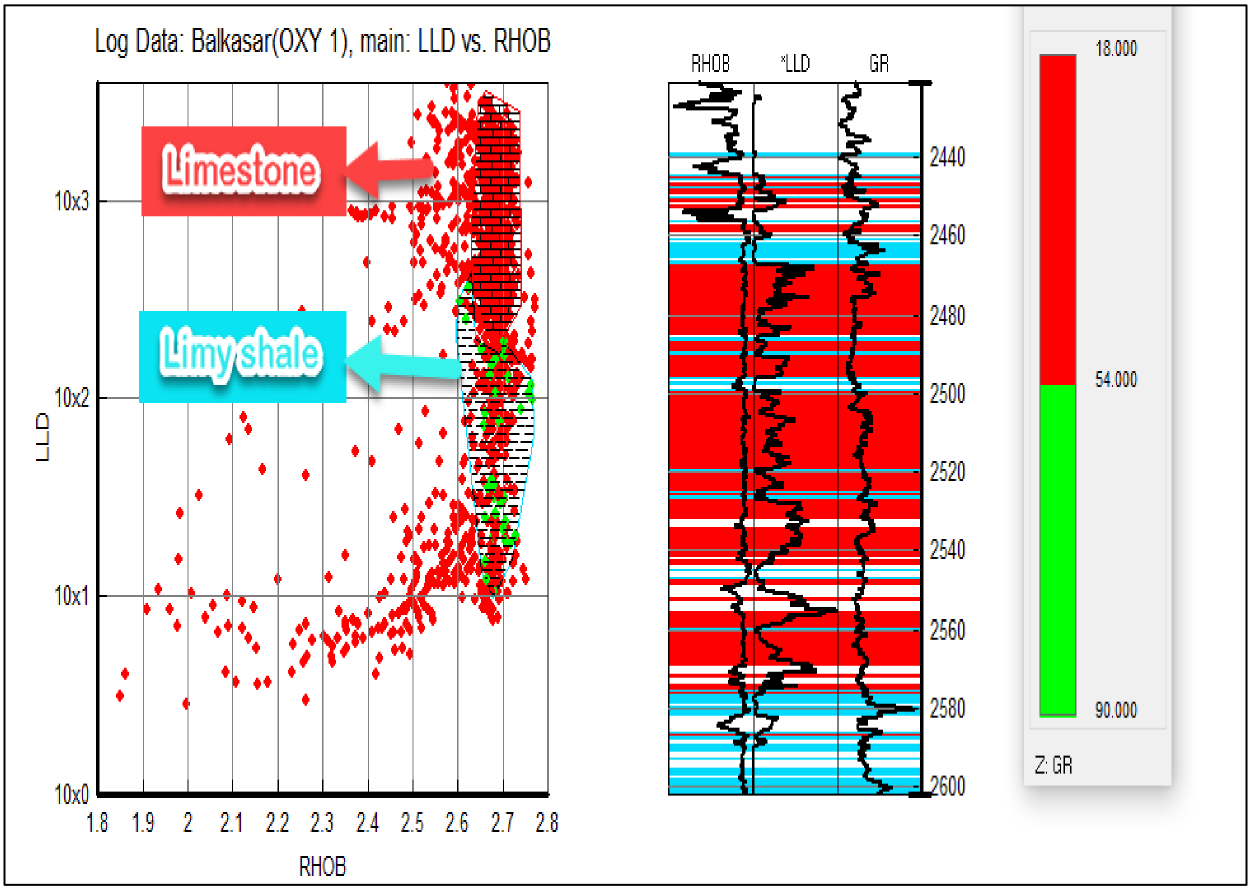


Figure 6.4: Cross plot between **LLD vs RHOB**

High resistivity values associated with higher gamma ray values are indicative of limestone. Finally, high gamma ray values associated with low resistivity values indicate shales but in our reservoir zone we have calcareous shale instead of pure shale. It is also evident from the fact that LLD values decreased in the second polygon which we have designated as calcareous shale.

CHAPTER 07
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 publicised 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 include 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 broad-band zero-phase dataset is obtained which forms the input to colored inversion (Lancaster and Whitcombe, 2000).

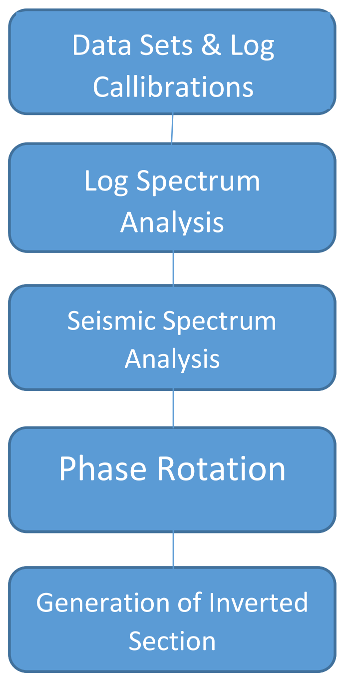
Colored inversion converts the seismic data to a relative impedance data set. The advantages of colored inversion are the speed of calculation and avoidance of artefacts that may be introduced by a model. Colored inversion, whether acoustic or elastic impedance (Connolly, 1999), is an excellent qualitative interpretation tool.

A method was developed by Lancaster and Whitcombe (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.

Coloured 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 Work Flow

We followed the following work flow 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 -90^{o} 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

Coloured 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.

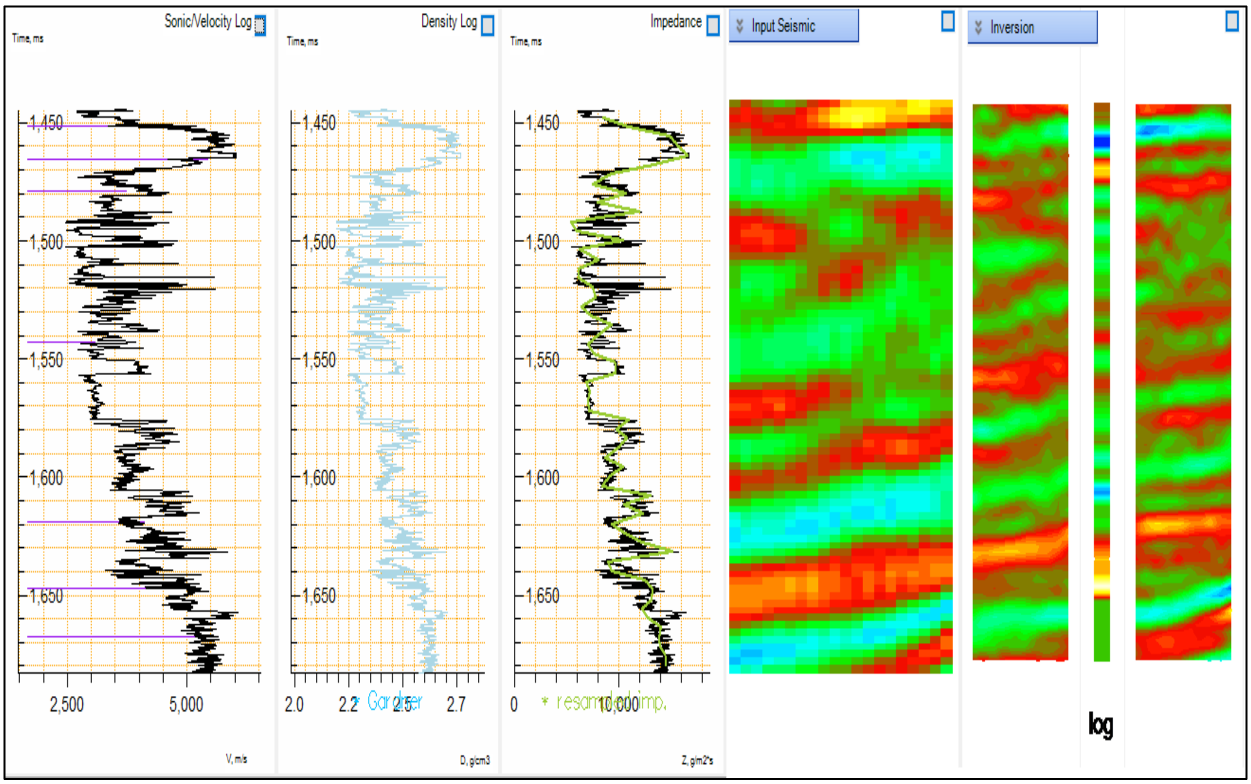


Figure 7.1: Generation of Acoustic Impedance and Inverted section

7.4 Log Spectrum Analysis

Here the impedance spectrum of the log is generated on the log 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 rises with frequency the impedance logs tends to decay with frequency – having effectively undergone the process of integration relative to the reflectivity data.

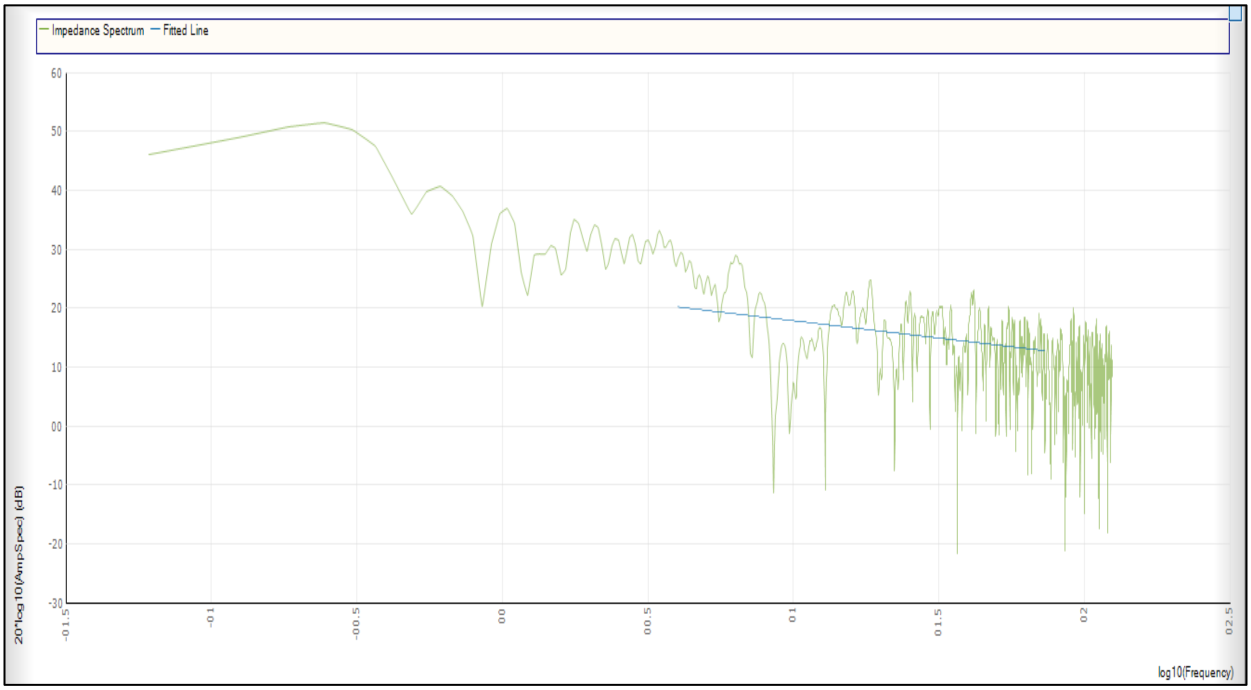


Figure 7.2: Impedance log spectrum with a best fitted line.

7.5 Butterworth Filter

Butterworth filter is used to smooth and constrain the impedence 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. The Butterworth filter is shown in figure.

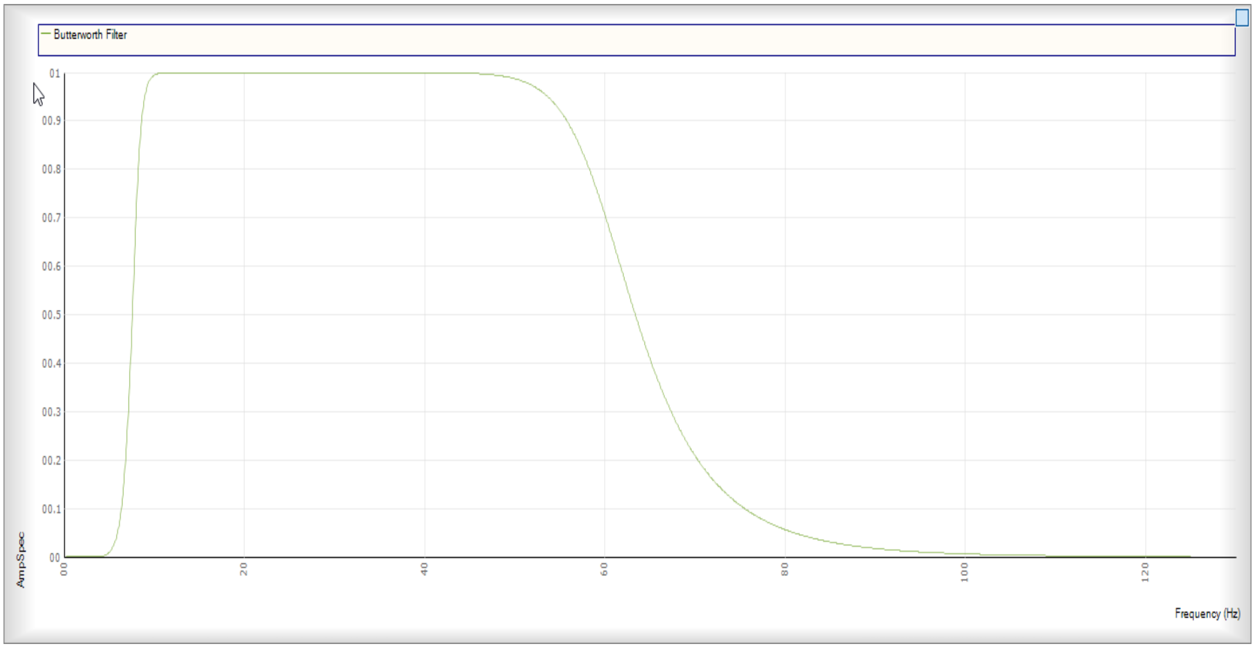


Figure 7.3: Butterworth filter

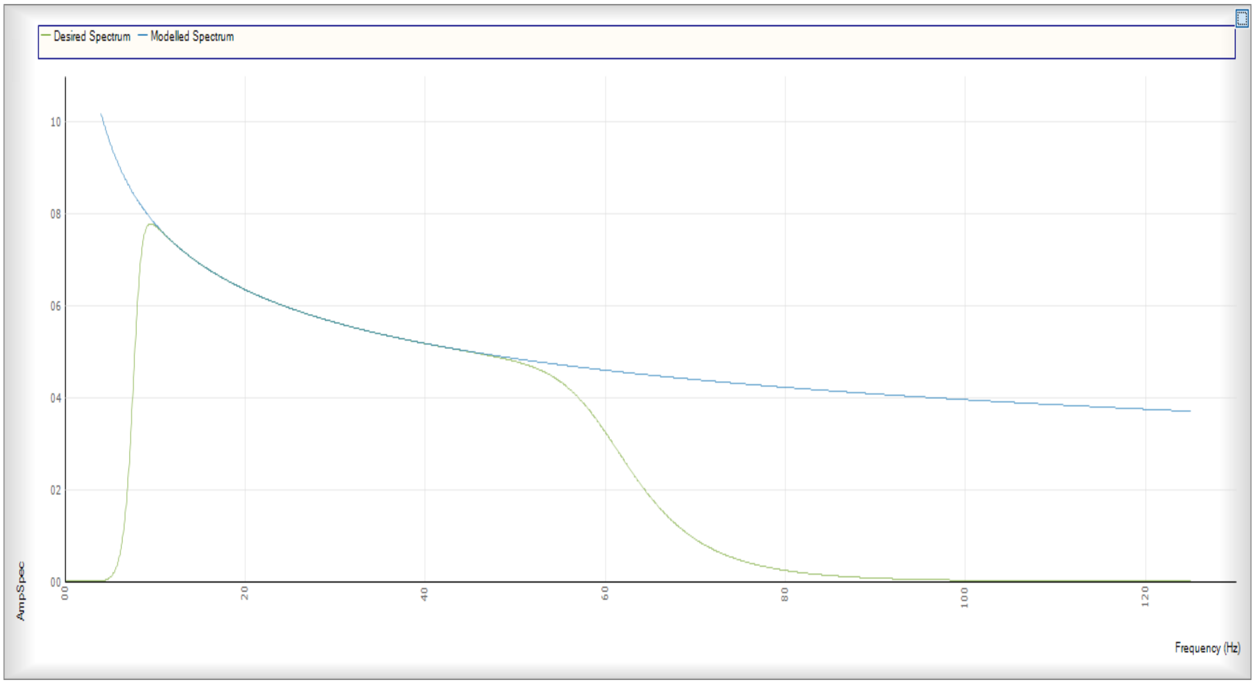


Figure 7.4: Desired impedance log spectrum constrained by the Butterworth filter

We get modelled 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 above figure.

7.6 Seismic Spectrum Analysis

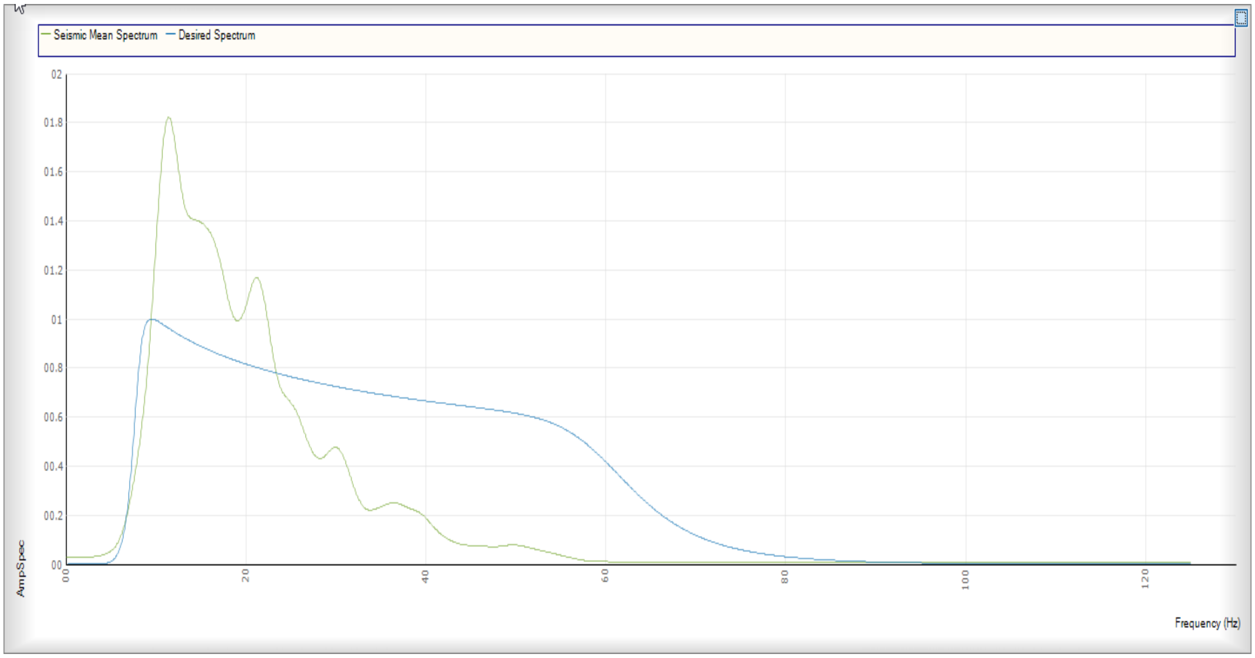


Figure 7.5: Seismic spectrum compared with desired impedance log spectrum

In the above figure we have an average spectrum of seismic data which is superimposed with the desired impedence log spectrum 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 impedence log spectrum.

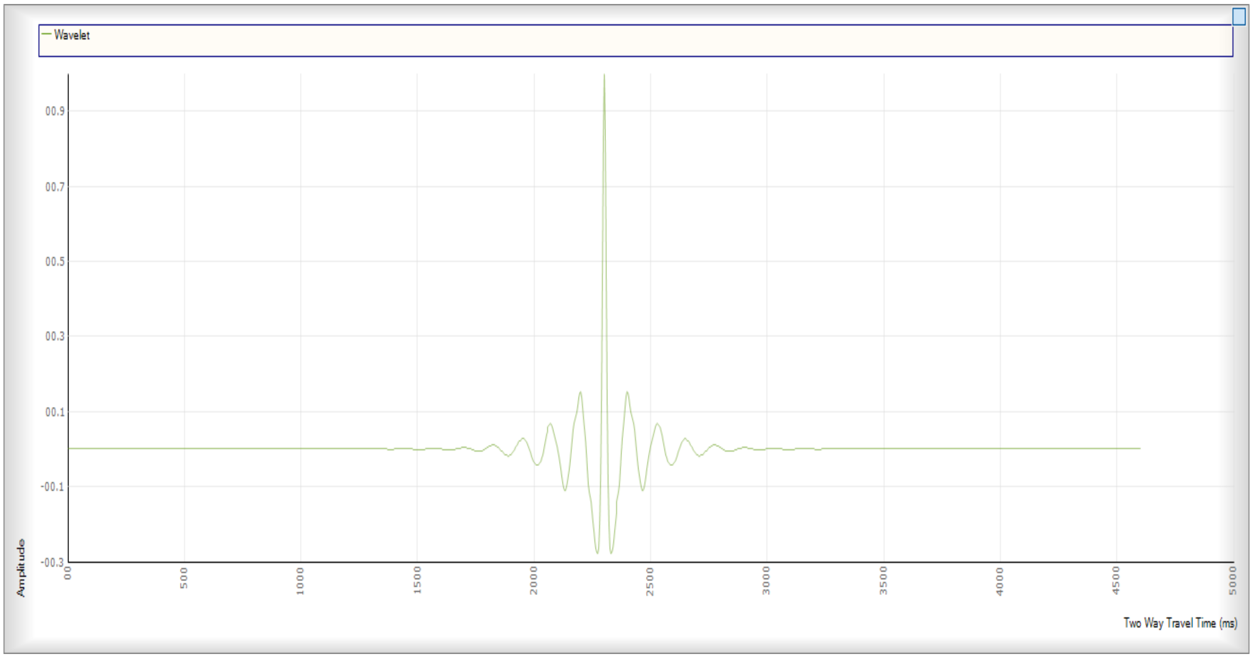


Figure 7.6: Extracted Wavelet (Operator in Time Domain)

The wavelet shown in te 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). 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).

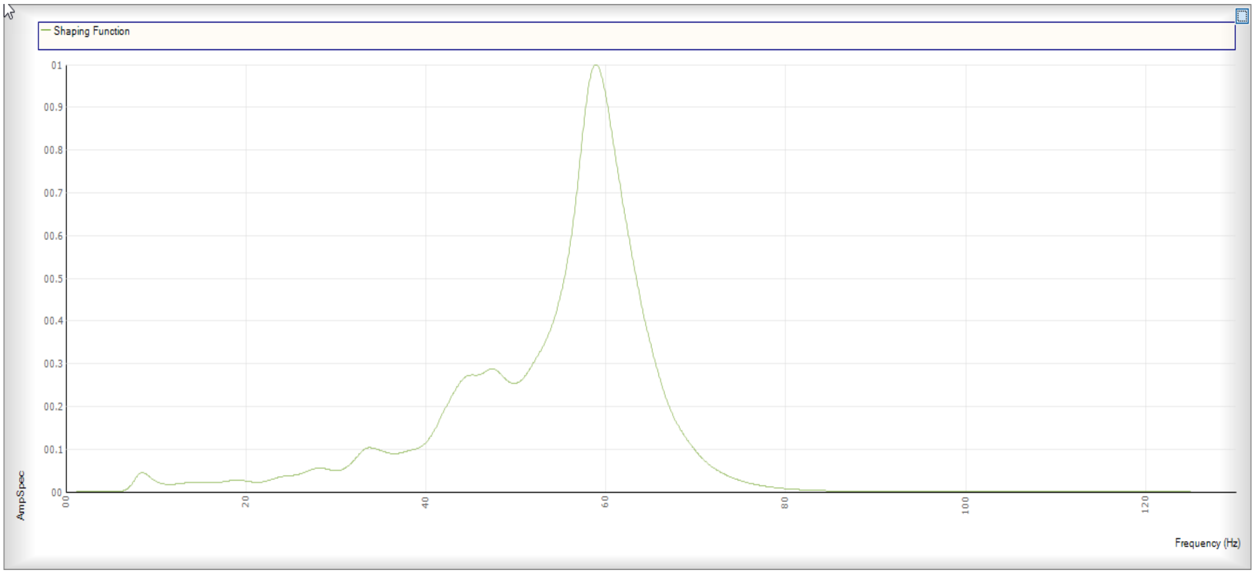


Figure 7.7: Shaping Spectrum

In the figure above we have a derived operator i.e shaping function in frequency domain which will shape and match the seismic and desired impedence log spectrum.

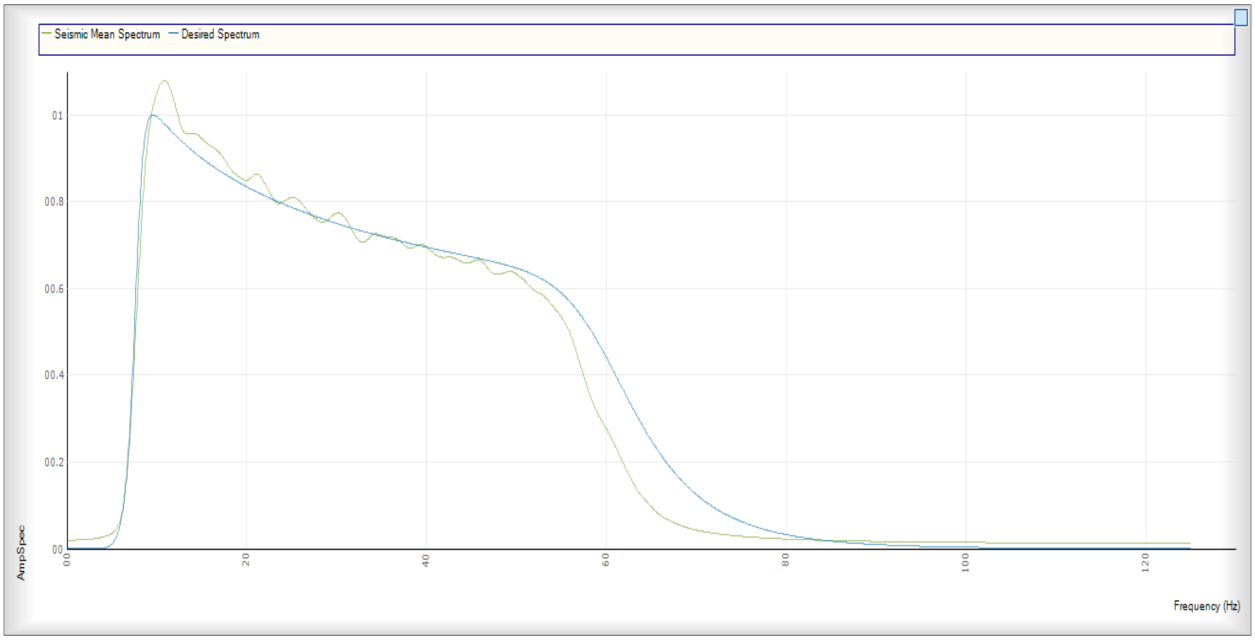


Figure 7.8: Shaped seismic spectrum compared with the desired impedance log spectrum

Now finally after the derived shaping function in the frequency domain is applied on the seismic mean spectrum, it has done some spectral shaping of the seismic data and almost matched it with the desired impedence log spectrum.

7.7 Phase Rotation

The phase of the operator is a constant -90^o 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.

7.8 Generation of Inverted Section

I had a single well data available that is why I used one well to derive operator i.e balkassar-oxy-01. 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 (white) and low (blue) acoustic impedance. The inverted section is shown in figure 7.9.

7.9 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.

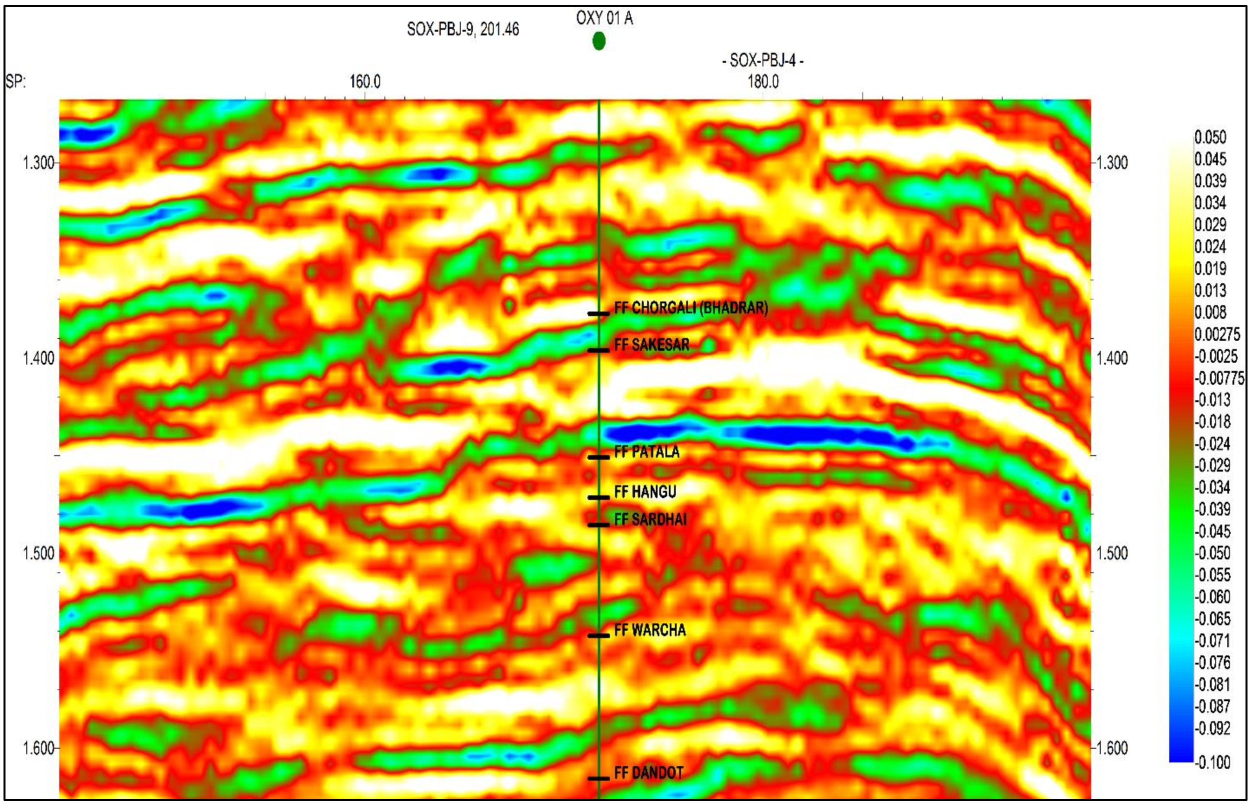


Figure 7.9: Inverted seismic section.

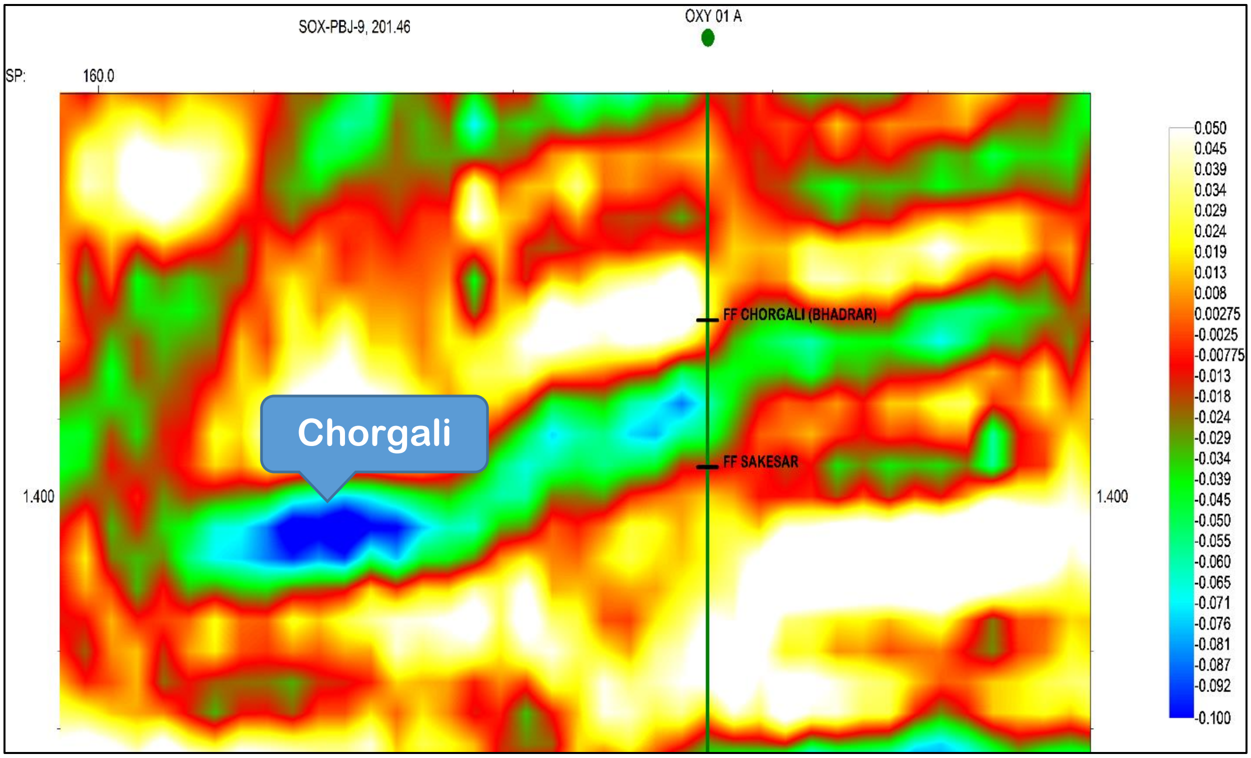


Figure 7.10: Zoomed view of Chorgali inverted section

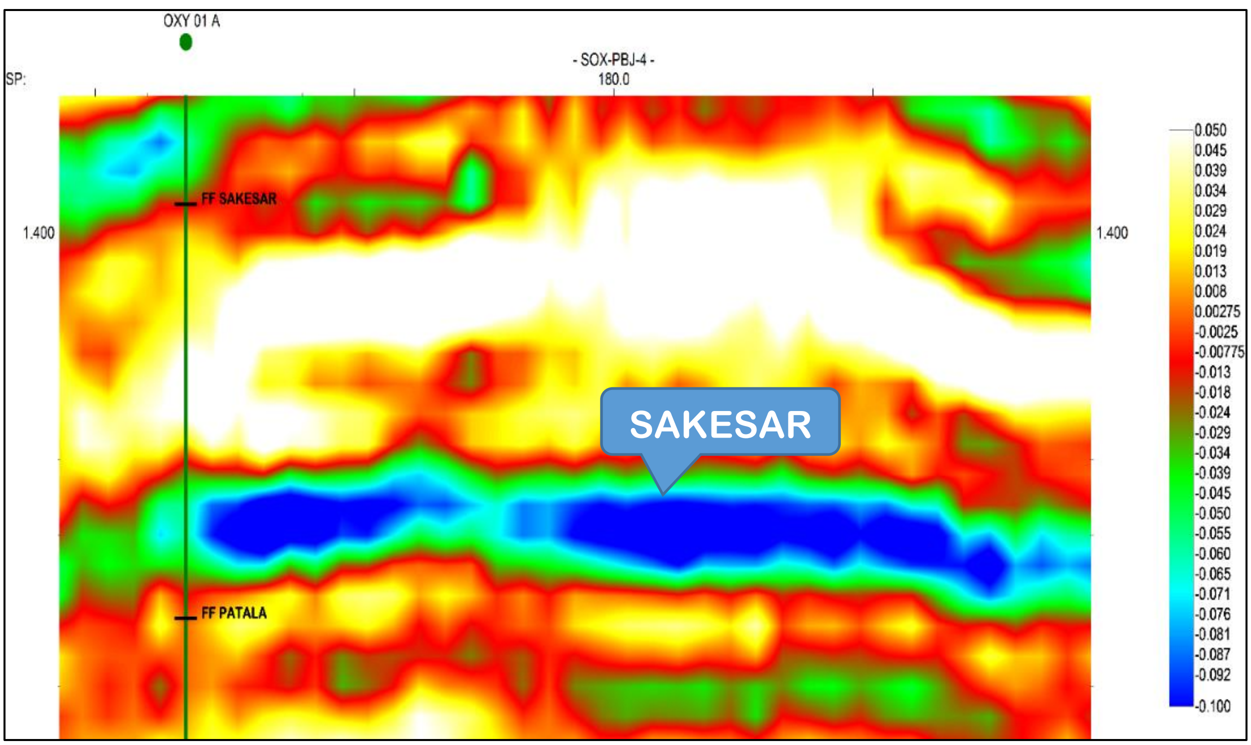


Figure 7.11: Zoomed view of Sakesar inverted section

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