SEISMIC INTERPRETATION & PETROPHYSICAL ALYSIS OF BALKASAR AREA, UPPER INDUS BASIN, PAKISTAN

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DEDICATION

I would like to dedicate this thesis work to my sweet parents, whose love, encouragement, guidance and prays make me able to achieve such success and honour.

ACKNOWLEDGEMENT

First and foremost, all praises to **Allah Almighty**, the most beneficent and the most merciful. Secondly, my humblest gratitude to the **Holy Prophet Muhammad (Peace Be upon Him)** whose way of life has been a continuous guidance and knowledge of humanity for me. This thesis appears in its current form due to the assistance and guidance of several people.

I express my profound sense of reverence to **Prof Dr. Mona Lisa** who gave me the opportunity to work under her supervision. Her continuous support, motivation and untiring guidance have made this thesis possible. Her vast knowledge, calm nature and positive criticism motivated me to starve for pleasant results. Thanks to her for bearing my mistakes and whenever I could not meet the deadlines.

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To me, there is nothing better than having good friends, so great pride is with me while thanking my friends Rafeh, Asmad, Umer, Usama, Tayyab, Farman, Ramish, Moiz, Hamza and all other fellows. Words are lacking to express my humble obligation for their helping attitude, and kind corporation. The time spent with them will remain unforgettable for me.

Last but not least, I would like to acknowledge my family for their constant support, unceasing prayers and best wishes. They uplifted my moral whenever I needed. I do thank all those who have helped me directly or indirectly in the successful completion of my thesis. Anyone missed in this acknowledgement are also thanked.

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BS GEOPHYSICS

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ABSTRACT

The dissertation work includes seismic data interpretation, Petro physical analysis using well logs data; identification of possible resource plays and performed facies analysis for reservoir properties. Seismic and well log interpretation used for study of structural style, physical properties of rocks and identification of possible petroleum system of Balkassar area (Upper Indus Basin) Pakistan. Well locations are proposed by constructing time and a depth contour map which shows pop-up anticline in study area, shown on Time and depth contours. These contours are developed on Sakesar and Patala Formations. Petro physical analysis of wells Balkasar OXY--01 is carried out for Sakessar and Patala Formations in order to depict the probable hydrocarbon producing reservoir. The results suggest that Sakesssar Formation is more producing.

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Chapter No.1
Introduction

1.1 Introduction

Worldwide hydrocarbon industry playing an vital and indispensable part in development and economic growth of a country especially developing countries like Pakistan, and acting as a important pillar in the future economic of the country. As energy demand is increasing day by day exploration industry determine to discover more and more hydrocarbon reserves to enhance the production to fulfill demands through the utilization of the best accessible innovations and ability. The energy utilized normally originates from three significant sources of hydrocarbons: Coal, Oil and Gas.The exploration of hydrocarbon in Pakistan started in 1868 when the main spud was made at Kundal close to Mianwalli, that proceed till present day. Geophysicists have been working for hydrocarbon exploration since a long time ago and created numerous methods in such manner. Seismic reflection technique is utilized for hydrocarbon exploration in petroleum geology. Petroleum geology refers to the specific set of geological disciplines that are used for hydrocarbons exploration.

1.2 Study Area

The study area belongs to the Kohat-Potwar fold Belt. The Kohat-Potwar Fold Belt covers an area of 36000 km^2. Kohat-Potwar region, located in the sub-Himalayas, contains a significant amount of hydrocarbons trapped in compresional/transpressional subterranean structures related to the post-Himalayan orogeny .The location of Balkassar is in the Central portion of Potwar sub-basin .This structure is situated on the southern appendage of Soan Syncline. Balkassar is an important hydrocarbon producing area of the Potwar Plateau, Pakistan.The Potwar Plateau is one of the oldest oil provinces of the world, where the first commercial discovery was made in 1914 at Khaur. Since then, many hydrocarbon fields have been discovered in different parts of the plateau (Khan et al., 1986).The fractured carbonates of the Sakesar and Chorgali formations of the Eocene age are the main producing reservoirs of Balkassar. Minor oil production comes from Paleocene Lockhart Formation.

1.3 Location &Geographical Boundaries

The study area is situated in Potwar basin. The study area is situated about 105 km southwest of Islamabad in Chakwal District. The study area is situated at a part of the Potwar basin, which lies in the northern part of upper Indus basin.Geographically Balkassar shares borders with Kalar Kahar to the south and east with the town of Chakwal and to the west lies the town of Talagang.The area lies in UTM (Universal Transverse Mercator) Zone42N in the world Geodetic System as shown in figure 1.1.

Longitude: 32.51^0 -33.02^0 N

Latitude: 72.32^0 -72.47^0 E

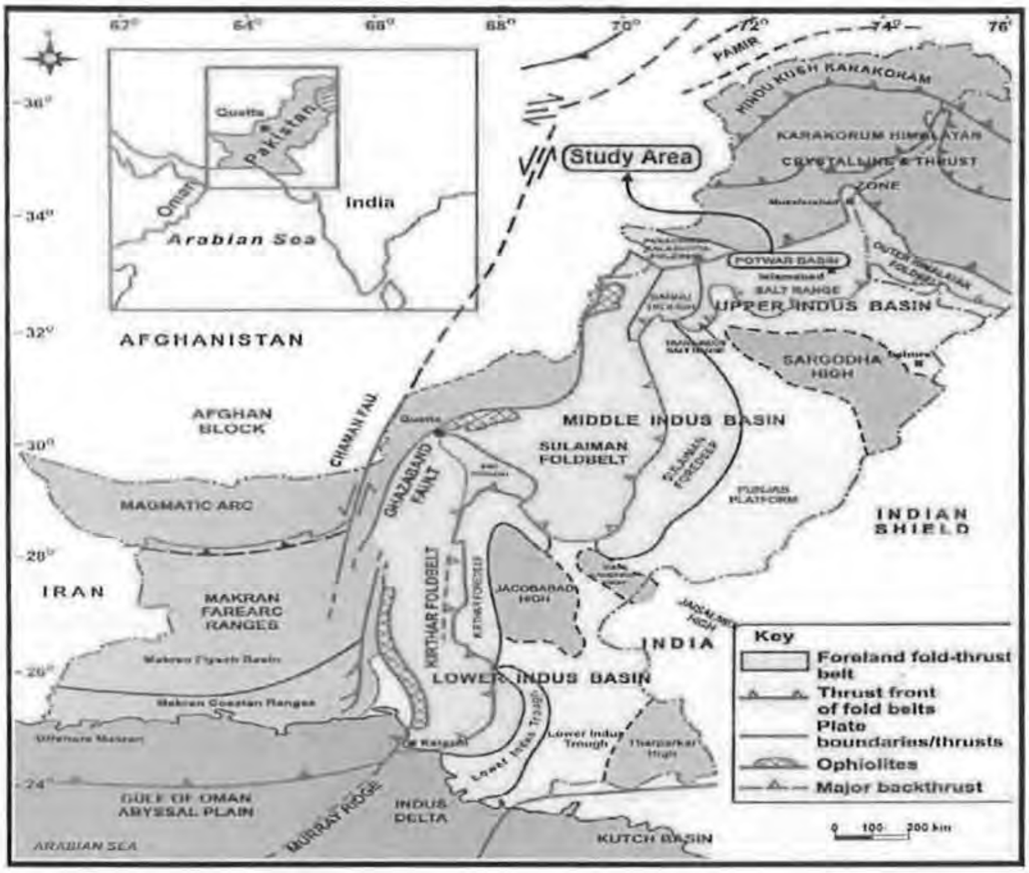

Figure: (1.1) [Location map of the study area (Highlighted)]

1.4 Data Description

To carry out this thesis, seismic reflection data, which consists of ten 2D seismic reflection sections, was provided by the permission of Directorate General of Petroleum Concessions

Government of Pakistan (DGPC). The seismic reflection data was acquired and processed by OGDCL. The Data for subsurface interpretation of the study area was obtained from LMKR. This data contain well (Balkassar OXY -01) and seismic lines (PBJ-01 to PBJ-11 except PBJ-07).

1.5 Seismic Data.

Sr. No.	SEG-Y	S.P Range	Direction	Nature/Trend
1.	SOX-PBJ-01	88 – 213	NW-SE	Dip
2.	SOX-PBJ-02	109 – 213	NW-SE	Dip
3.	SOX-PBJ-03	112 - 214	NW-SE	Dip
4.	SOX-PBJ-04	97 – 243	NW-SE	Dip
5.	SOX-PBJ-05	127 – 243	NW-SE	Dip
6.	SOX-PBJ-06	103 – 236	NW-SE	Dip
7.	SOX-PBJ-08	108 – 287	NE-SW	Strike
8.	SOX-PBJ-09	104 – 295	NE-SW	Strike
9.	SOX-PBJ-10	103 – 287	NE-SW	Strike
10.	SOX-PBJ-11	96 – 224	N-S	Oblique

Table 1.1 Description of the seismic lines

1.6 Well Data

Well information is given in the Table 1.2

Operator	OXY	**Province**	Punjab
Type	Exploratory	**Status**	ABANDONED
Well Bore Name	BALKASSAR-(OXY)-01	**Concession**	Balkassar
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 KB	**Total Depth(m)**	3130.60
List of Well Tops			
Formations	**Formation Age**	**Top (m)**	**Thickness(m)**
NAGRI	Pliocene	0.00	478.82
CHINJI	Miocene	478.82	929.29
KAMALIAL	Miocene	1408.11	106.68
MURREE	Miocene	1514.78	906.74
CHORGALI (BHADRAR)	Lower Eocene	2421.52	45.72
SAKESAR	Eocene	2467.24	135.63
PATALA	Paleocene	2602.87	21.34
LOCKHART	Paleocene	2624.20	35.05
HANGU	Paleocene	2659.25	27.43
SARDHAI	Early Permian	2686.68	109.72
WARCHA	Early Permian	2796.40	141.73
DANDOT	Early Permian	2938.13	60.96
TOBRA	Early Permian	2999.09	51.81
KHEWRA SANDSTONE	Early Cambrian	3050.90	78.33
SALT RANGE FORMATION	Pre-Cambrian	3129.229	0.77

Table 1.2: Description of well (BALKASSAR-OXY-01)

1.7 Base Map

The base map given in figure shows the orientation of the lines and position of well used for study area.A base map is the map on which data can be plotted. The base map is important for interpretation point of view because it depicts the spatial location of seismic section. A base map typically includes location of lease and concession boundaries, wells, and seismic survey points. The base map of the area is generated by loading data in Universal Transverse Mercator (UTM, Zone 43) geodetic reference system in IHS kingdom.

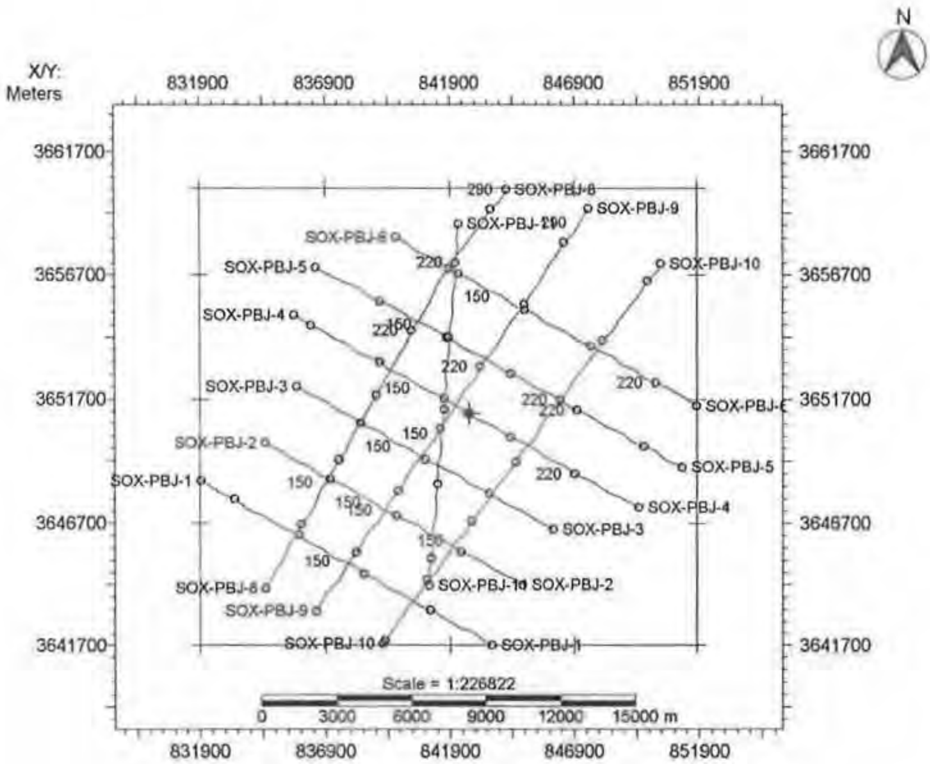

Figure 1.2: Base Map

1.8 Methodology

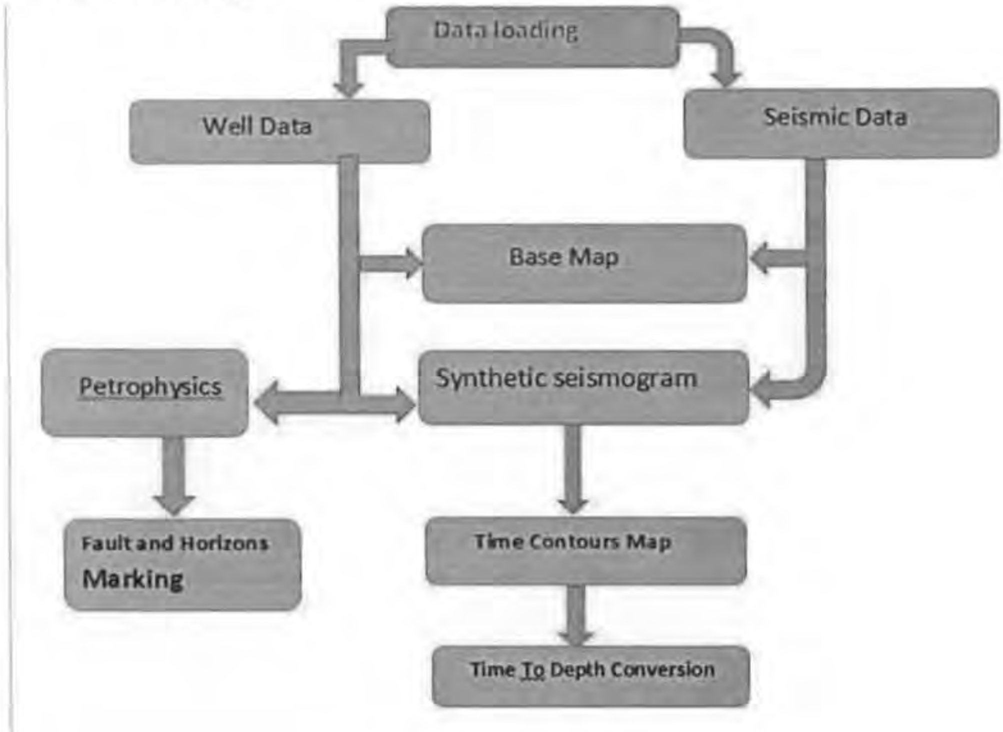

Fig 1.3 Dissertation Workflow

1.9 Objectives

The following are the objectives of this study:

- To understand the geology of the study area.
- This dissertation is primarily focused on seismic interpretation of the study area, which includes marking of horizons, fault picking and construction of time and depth contour maps.
- To find the petrophysical properties of reservoir zone.

Chapter No.2
Geology, Stratigraphy & Tectonics

2.1 Introduction

The information about geology of an area assumes an essential part in processing and interpretation of the 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. Geological and structural knowledge of the area is a key for interpreter to perform precise interpretation of seismic data. The main reason behind that, in many cases similar signature is obtained from different lithologies 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 can't recognize the different reflections appearing in the seismic section.

2.2 Regional Tectonic Setting

The building of Himalayan mountain process in Eocene triggered compressional system. Northward movement of Indian plate is about 40mm/year (1.6 inches/year) and is colliding with Eurasian plate. 55 million years ago Indian plate collided with the Eurasian plate and building of Himalayan mountain belt 30-40 million years was formed in the North Western Pakistan and mountain ranges moved in the east west direction (Kazmi and Jan., 1997). Being one of the most active collision zones in the world foreland thrusting is taking place on continental scale. It has created variety of active folds and thrust wedges with in Pakistan passing from Kashmir fold and thrust belt in North East, South West through the Salt Range-Potwar plateau fold belt, the Suleiman fold belt and the Makran accretionary wedge of Pakistan. As far as the Indian plate is concerned which is subducting under the Eurasian plate at its Northern edge, a sequence of north dipping south thrusts is being produced. The shortening of crust caused a large amount of folds and thrust belt. The youngest basins in the Western Himalayan Foreland Thrust Belt are Kohat Plateau, Bannu Basin and Potwar Plateau which have compressive stresses and convergent tectonics. Pakistan isolated at in the two domains Gondwanian and the Tethyan Domains (Kazmi& Jan., 1997). The south eastern part of Pakistan belongs to Gondwanian Domain and is supported by the Indo-

Pakistan crustal plate whereas then or then-most and western areas of Pakistan fall in Tethyan.

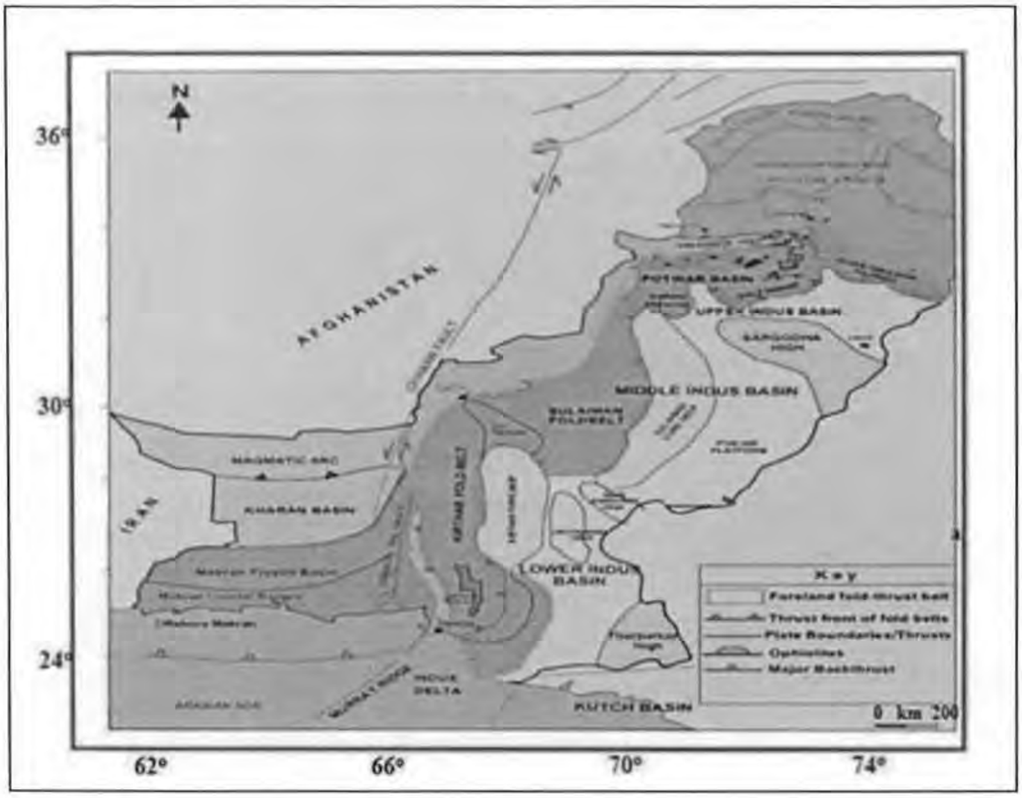

Figure 2.1: Tectonic framework & major sedimentary basins of Pakistan

2.3 Sedimentary Basins of Pakistan

Basin is an area characterized by regional subsidence and in which sediments are preserved for longer period of time. Pakistan comprises of following basins:

- **Indus basin**
- **Baluchistan basin**

2.3.1 Indus Basin

The Indus basin belongs to the type extra continental down wrap. The basin has elongated shape and is oriented in Northeast and Southwest direction. The main tectonic features of Indus basin are the platform, the fordeep comprising depressions, inner folded zone and outer folded zone (Kazmi & Jan., 1997). Indus basin is divided into Compression regime in upper Indus basin, Basement uplift in central Indus basin and Extensional regime in lower Indus basin. On the basis of structure Indus basin is subdivided into two parts

- Upper Indus Basin (North)
- Lower Indus Basin (South)

Upper Indus basin is located in Northern Pakistan and separated from lower Indus basin by the Sargodha High. In its North MBT, while in the east and west strike slip faults Jhelum and Kalabagh is located respectively. Upper Indus basin is subdivided into two parts (Kazmi & Jan., 1997).

- Potwar basin
- Kohat basin

2.3.1.1 Structure of Potwar

The overall structural trend in study area is east to west or northeast to southwest. Anticlines are separated by synclines in East Potwar salt core. Due to strike slip movement these structures are formed. These structures (Anticlines, Synclines) are mostly bounded by hinterland and foreland verging faults, popup zones. The northern part is more intensively deformed called North Potwar Deformed Zone (NPDZ). NPDZ is followed to the south by soan syncline which is gently northward dipping southern flank along the salt range and steeply dipping northern limb along NPDZ. Several eastwest broad and gentle folds are present in its Western part. Strike abruptly changes to North-East in its Eastern part and tightly folded anticline and broad syncline structures are present.

Axial zone of most anticline dip steeply or overturned (Pennock et al., 1989). Thrust wedge has been transported southward as a coherent slab with little internal deformation in the western and central Potwar, and less than 1 Km shortening between NPDZ and salt range (Baker et al, 1988). Deformation has been reduce in size due to increase basal traction and fault cut up section in Eastern Potwar, in contrast, the, producing different structural style characterized by fault-folds, triangles and pop-up zone in this region 24 Km of shortening has occurred (Pennock et al., 1989). Without significant involvement of basement tectonic in the Potwar is thin skinned tectonic (Kazmi & Jan, 1997).

2.4 Structural Features

The following structural features are found in study area (Pennock et al., 1989)

- Tanwin Anticline
- Domeli Thrust
- Adhi-Gungril Anticline
- Chak-Naurang Anticline
- Soan Syncline
- Jhelum fault
- The Salt Range Thrust

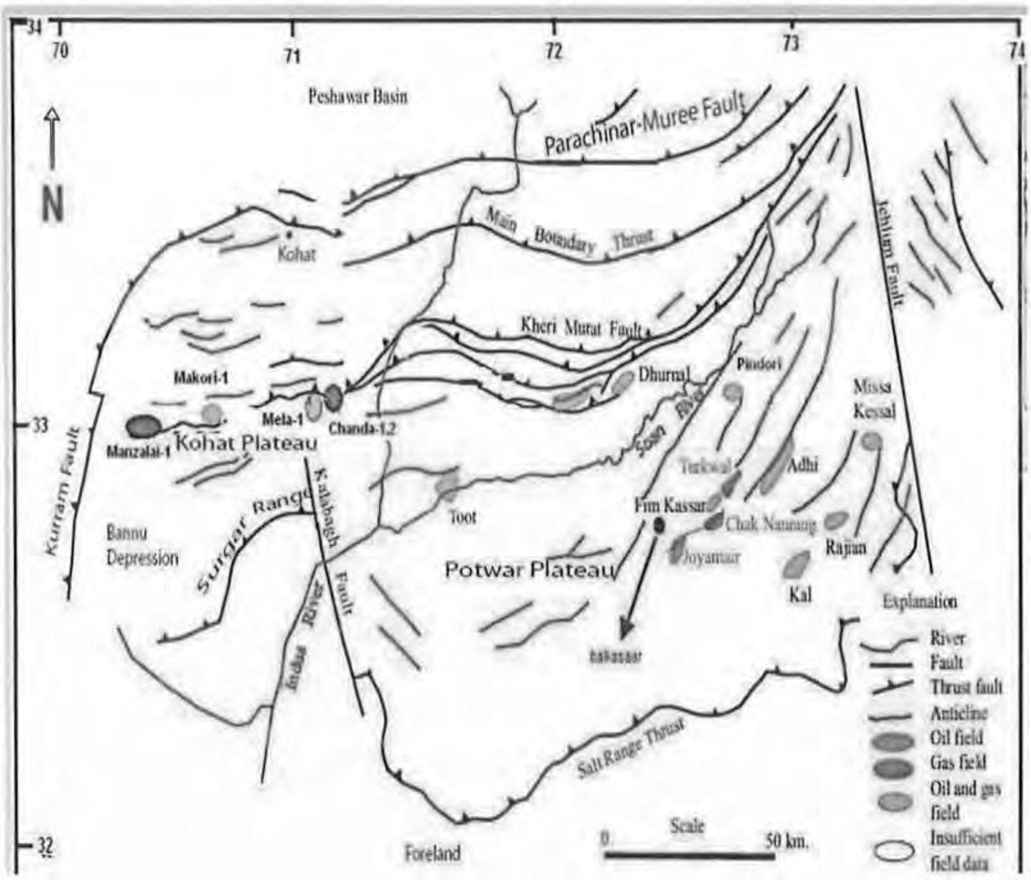

Figure 2.2 Major Structures in Potwar Basin

2.5 Straitigraphy

In Potwar basin deposition of sediments ranges from Precambrian to Pleistocene. The deposition was however interrupted several times. From top to bottom the stratigraphic section can be divided into four groups. Table 2.1 is showing the division of stratigraphic section their ages and rock types.

Sr No.	Group	Age Range	Rocks
1	Basement complex	Precambrian	Metamorphic and Volcanic rocks of Indian shield
2	Salt range formation	Eocambrian	Sedimentary, (Evaporates)
3	Platform section	Cambrian to Eocene	Sedimentary
4	Molassic section	Miocene to Pliocene	Molasses deposits

Table 2.1 General Stratigraphic of Potwar basin

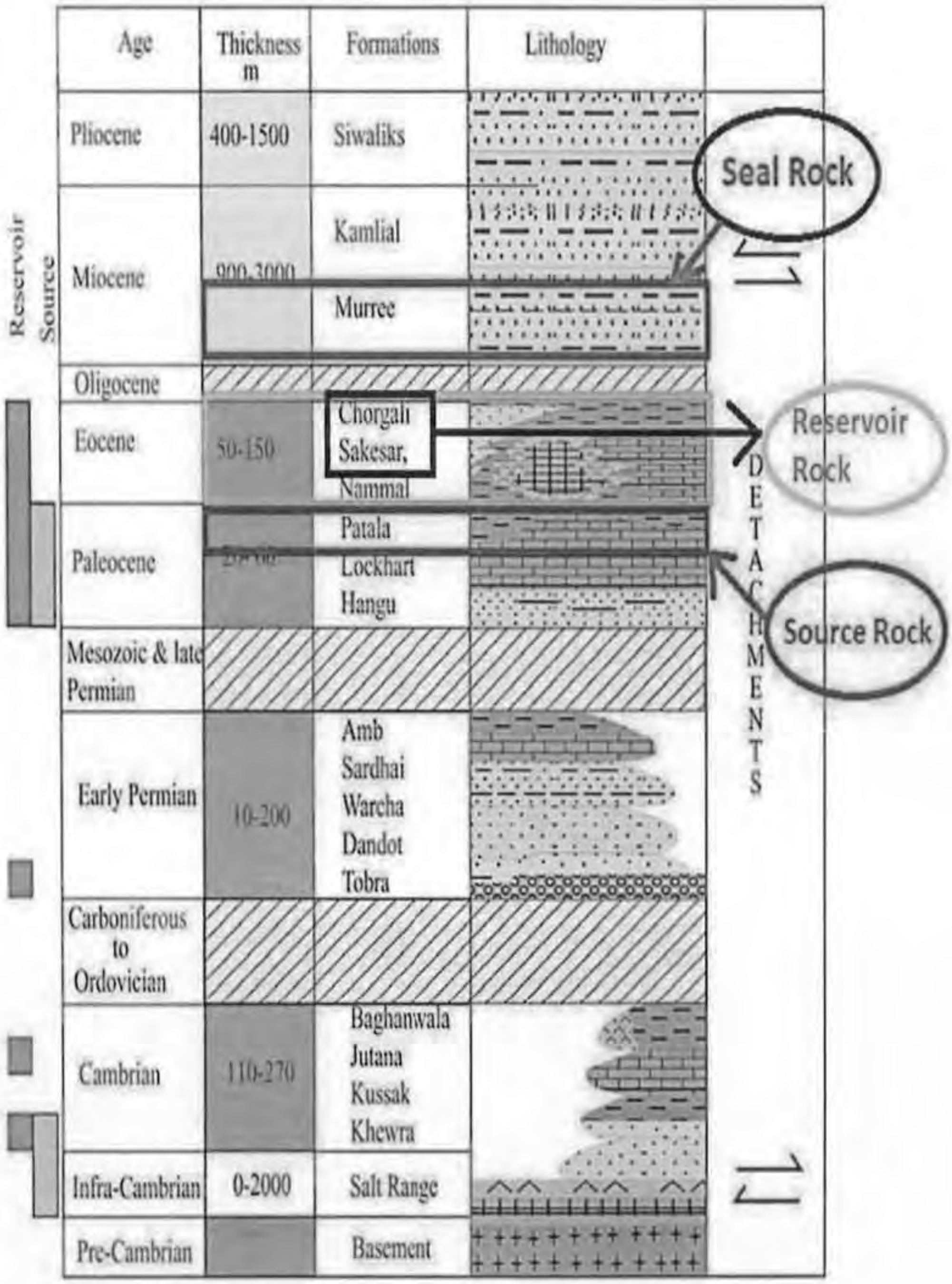

Figure 2.3: Stratigraphic chart of the area. (Aamir and Siddiqui., 2006).

2.6 Hydrocarbon Potential

A system comprising of source rock, reservoir rock and cap rock makes petroleum play of that particular area. It includes all the elements that are essential for hydrocarbons to exist. A petroleum system consists of the following elements

2.6.1 Source rock

The source rock correlation study has not been carried out in this area which indicates the source rock but 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 InfraCambrian to Eocene in the Potwar Sub-basin and surrounding areas.

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. . A basin profile indicates maturities equivalent to vitrinite reflectance of 0.62 to 1.0 percent for tertiary rocks in the productive part of the Potwar Basin.

2.6.2 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.

2.6.3 Seal Rocks

The following formations act as seal rocks.

- ☐ Shales of Chorgali formation.
- ☐ Shales or Claystone of Murree formation, it provides efficient vertical and lateral seal to Eocene reservoirs in Salt Range Potwar- Foreland Basin where ever it is in contact (Shami & Baig, 2003).

2.6.4 Trap

In Potwar basin both structural and stratigraphic traps are available. In study area the associated structures are pop up anticlines and snaked head structures. The seal is provided by Murree Formation additionally, give effective vertical and horizontal seal to Eocene reservoirs wherever it is in contact. The Murree Formation consists of clay and shale both of these lithologies act as a good seal rock

Chapter No.3
Seismic Survey Parameters

3.1 Introduction

The seismic survey is one form of geophysical surveys that aims at measuring the earth's geophysical properties by means of physical principles such as magnetic, electric, gravitational, thermal, and elastic theories. It is based on the theory of elasticity and therefore tries to deduce elastic properties of materials by measuring their response to elastic disturbances called seismic (or elastic) waves.

Seismic surveys are used to locate and estimate the size of underground oil and gas reserves. Seismic images are produced by generating, recording and analyzing sound waves that travel through the Earth. These sound waves are also called seismic waves. The oil and gas exploration industry has deployed this evolving technology for decades to determine the best places to explore for oil and gas.

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. 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.

3.3 Seismic Data Acquisition

Seismic investigation starts in the field with the acquisition of data. The purpose of seismic data acquisition is to record the effects produced by mechanical disturbance at the surface of earth, and its effects are observed at number of locations along the surface in a way that its relation with initial disturbance can be interpreted.It includes all those steps which yield final output to be processed and interpreted. The instruments so adopted to acquire seismic data today differ from those used in past, but essential principle for all instruments is same.

The seismic data acquisition starts with, field by few organization divided as if it is land organization or marine organization. Then the whole work starts with field equipment and methods to be adopted for the acquisition of seismic data. Seismic acquisition system consists of three basic subsystems:

- Energy sources (Explosives)
- Energy receiving units (Geophones)
- Recording system

Explosives or vibrating plates generate the waves and a line or grid of geophones records them. Density changes between rock or soil layers reflect the waves back to the surface and the speed and strength that the waves are reflected back indicates what geological features lie below.

3.4 Seismic Data Processing

The process of data processing includes the sequence of operations. According to predefined program these operations are carried out to convert set of raw data into useful information. Advancement of technology/electronic computers in last two decades brought the digital revolution in seismic prospecting for oil and gas. After the introduction of computers seismic data processing attained new shape. The rationale behind the seismic data processing is to convert the recorded information of field into a form that allows geological interpretation, the reflections presentation with maximum possible resolution on the seismic section and the reduction or elimination of different noises.

The main objectives of the seismic data processing are summarized as below.

- Improving Signal to Noise ratio.
- Representation of geology in seismic cross-section ☐ To acquire the target provided by client.

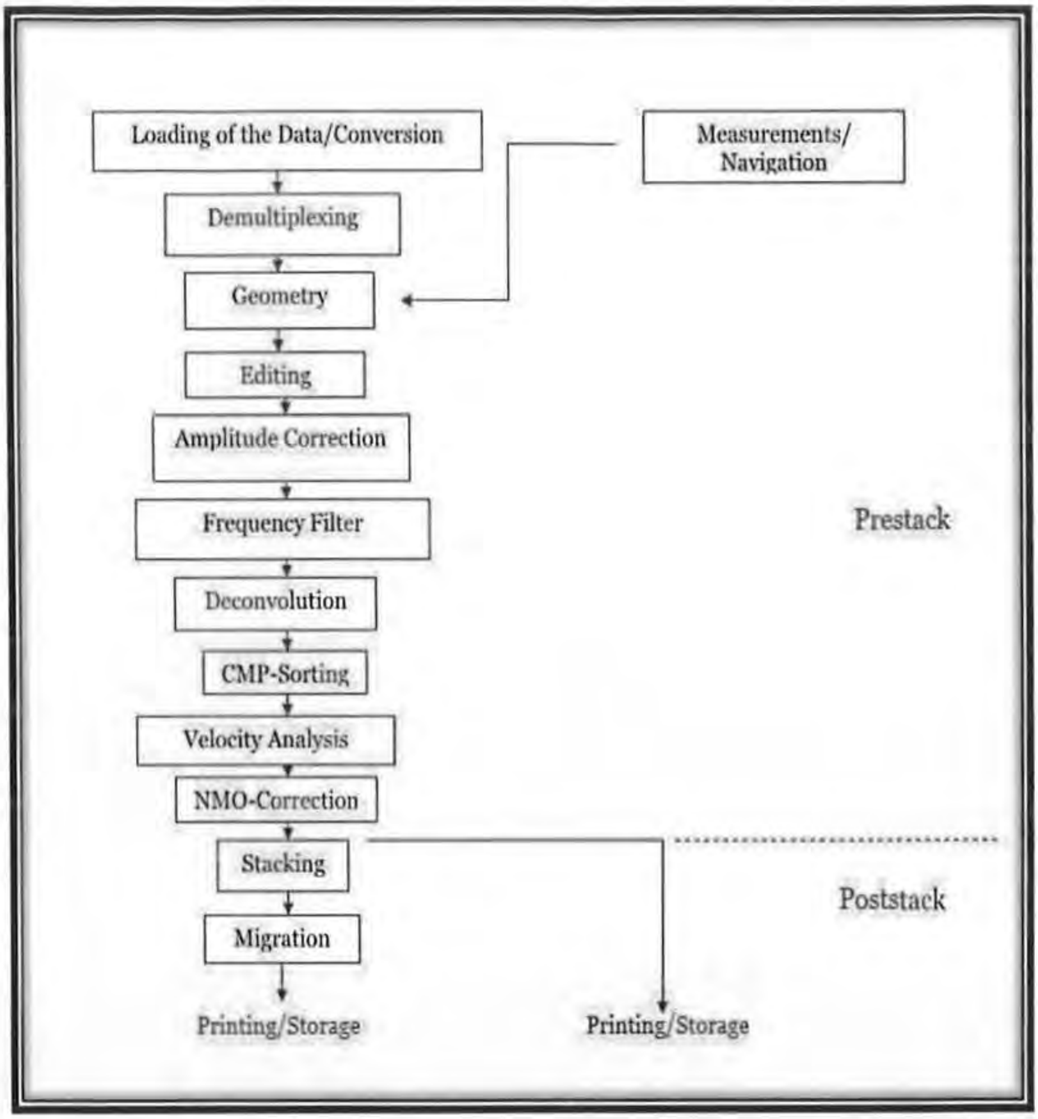

Figure 3.1 Generalized Seismic data Processing Flowchart

3.5 Survey Parameters of Study Area

In this section survey parameters, acquisition parameters and processing parameters, are displayed.

3.5.1 Acquisition Parameters

Acquisition parameters of study area are enlisted in Table 3.1

Source	Number of Vibrators	2 to 3
	Number of Sweeps per VP	42
	Source Pattern	Inline
	Type of Vibrator	Mertz Model SHV-100
	Vibration length	100m
	Sweep frequency	7-42Hz
	Sweep Duration	20000ms
Geophones	No of Geophones	48
	Group interval	100 m
	Group length	159 m
	Number of channels	62

Table 3.1 Acquisition Parameters of study lines

3.5.2 Processing Parameters

Instruments, filters and processing parameters used in the processing of the data of study area are enlisted in Table 3.2

Instrument	Summing computer	CDBA-11
Filter	Low cut filter	Out
	Notch filter	Out
	High Cut filter	62HZ @78DB/OCT
	Pre Amplifier Gain	2
	Main Amplifier Gain	I.F.P
	Summing	Diversity Average
	Density Notch filter	1600 BPI
	Record length	25000ms
	Processing Sample rate	4ms
Processing	Edit- demultiplexed	WGC code-4 format
Parameters	Vibrosies correlation	
	Preprocessor	CDP sorted
	Replacement velocity	2300m/s
	Datum plane elevation	350m
	Mute	

Type	Early mute
Mute velocity	2200m/s
Constant start time	350ms
Min Distance for start time	550m
Deconvoulution	
Type	Predictive Decon
No of windows	One
Auto corr stop time	3500ms
Auto corr delay	200ms
Min prediction distance	Time of 2nd zero crossing
Operator length	140ms
Pre filter	10-40 Hz
Trace blance	
Datum statics	
Normal moveout	
Automatic residual statics	
Final velocity analysis	
Normal move out stack	
Finite diff migration filter	10-40 Hz
RMS Scaling	
Display Scale	
Horizontal scale	8 Traces/inch
Vertical Scale	5Inchs/sec
Gain	15 dB

Table 3.2 Processing parameters of study area

Chapter No.4
Interpretation of Seismic Data

4.1 Introduction

Seismic method is one of the most significant geophysical methods among all geophysical techniques because of its great penetration, high resolution and high accuracy. This technique works by generating seismic waves and their travel time is measured from source to receiver (Badley., 1985).

Geophysicist use to practice this analysis to find out the most probable structure for hydrocarbon accumulation. For subsurface structural analysis Seismic interpretation is performed .In this dissertation seismic interpretation technique for subsurface structural analysis has been used. Seismic interpretation has been done with the help of IHS Kingdom 8.8.

4.2 Methods of Interpretation

There are two main approaches for the interpretation of the seismic reflection data.

- Qualitative Interpretation
- Quantitative Interpretation

4.2.1 Qualitative Interpretation

Mapping the subsurface geology is the primary objective of the qualitative interpretation of the seismic data. Qualitative interpretation is seismic technique that includes the marking of horizontally consistent reflectors and discontinues and their mapping on different scales (space and travel time). The geometry on the seismic section is accurately interpreted according to geological concept to find out hydrocarbons accumulation.

The structure and stratigraphic structure of the petroleum is determined and on base of the geometric features the location of the well is established. Stratigraphy analysis is used to delineating the seismic sequences, which tell us about different depositional units, find out the seismic facies characteristic with gave us information about depositional environment and analysis the reflection feature variation to locate the stratigraphy changes and hydrocarbon depositional environment (Sheriff, 1999).

In structural analysis main focus is on the structural traps. Tectonic plays an important role in traps. Tectonic setting usually tell us, which types of the structure are present and how the structural features are correlated with each other's, so tectonic setting of the area is helpful for locating the traps. Structural traps include the faults, folds anticline, pop up, duplex, horsts and grabben structures, etc. (Sheriff, 1999)

4.2.2 Quantitative Interpretation

Seismic quantitative interpretation technique as compared to the traditional seismic interpretation technique is more useful. One advantage of these unconventional techniques is that they make prospect generation easier by widening the exploration area. Various alterations in these techniques have contributed to the better prospects evaluation and reservoir characterization. The most important of these techniques include post-stack amplitude analysis (bright-spot and dim-spot analysis), off-set dependent amplitude analysis (AVO analysis), Acoustic impedance inversion, and forward seismic modeling. Base map is prepared by loading navigation data and seismic data (seg Y). Horizons are marked in zone of interest 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.

4.3 Seismic Interpretation

Initially 2D seismic surveys were carried out in which strike and dip lines were used to interpret the structural and stratigraphic variations (Yilmaz., 2001). But with the passage of time 2D surveys were replaced by 3D surveys that are more advanced techniques used for detailed analysis of the structural and stratigraphic variations in the study area (Badley., 1985). Seismic data interpretation leads to interpret subsurface features such as stratigraphy, folds, faults etc. Main objective of such interpretation is to locate and quantify groundwater reserves, hydrocarbon reserves and mineral deposits (McQuillin et al.,1984). Parameter that leads to interpretation are following:

- Travel times are used to generate depth maps of particular horizon.
- Travel time difference are used to calculate velocity.
- Discontinuities in the reflectors are used to predict faults and stratigraphic changes.

Figure 4.1 Work flow for seismic data interpretation

4.4 Well To Seismic Tie

Tying well and seismic data is very necessary step in seismic interpretation to begin because it helps to establish a relationship between seismic reflectors and stratigraphy. The aim of well to seismic tie is to compare the seismic data which is obtain in time domain and with the well data which is in depth domain. This relationship can be achieved in different ways:

4.4.1 Well Tops

Another way to establish relationship between seismic reflectors and stratigraphy is to relate them by using drilling data i.e. well tops. Well tops represent the tops of different formations in a well.In this process, we get the depths of well tops while drilling.

4.4.2 Synthetic Seismogram

With the help of Balkassar (OXY-01) A the synthetic seismogram was constructed in order to mark the horizons. It is a powerful tool to relate the seismic reflectors with stratigraphy. The objective is to use well log data to generate a synthetic trace that can be compared to real seismic data collected at well location. Acoustic impedance (product of seismic velocity & rock density) is very important property to be discussed here. As seismic reflection comes at every that point where acoustic impedance changes (McQuillin et al., 1984). So, we can use well log data to calculate acoustic impedance. One thing should be considered that well log data is measured in depth while seismic section is measured in time so conversion is required for tying. Sonic log provides the seismic wave velocity in the subsurface while density log provides rock's density. Both the logs are multiplied to get acoustic impedance log. The equation for this conversion is (Asquith et al., 2004).

$$T = \frac{S}{V} .$$

Here,

T = One-way travel time of seismic wave,

S = Depth of interface provided during drilling,

V = Velocity of seismic wave from sonic log or checkshot survey.

As it is required to know that how much reflection would have occurred from interfaces so we will calculate reflection coefficient log from acoustic impedance log from the equation below (Asquith et al., 2004).

$$R.C = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1} .$$

ρ_2 and ρ_1 = Acoustic impedance of deeper/second reflector and shallower/first reflector,

Next step is to define a pulse for convolution. The pulse can either be extracted from seismic data at well location or it may be estimated by defining a standard pulse of user defined parameters i.e. polarity and central frequency. Once the pulse is defined, convolve it with the reflection coefficient log/reflectivity series. The synthetic seismogram prepared is shown in the Figure 4.2.

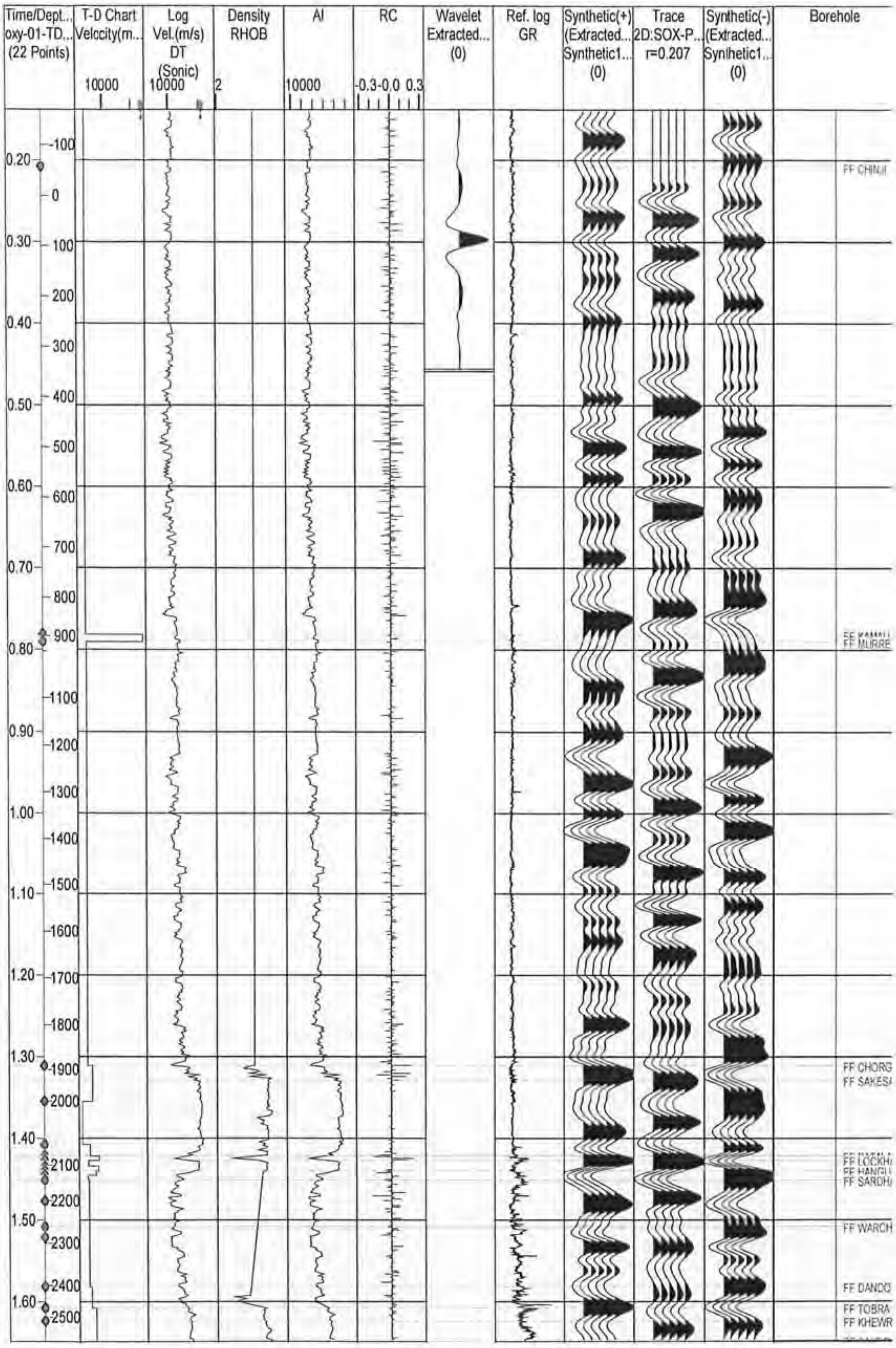

Figure 4.2 Synthetic seismogram on Seismic line (SOX_PBJ- 04)

4.5 Base Map

A map on which primary data and interpretations can be plotted. The base map is important for interpretation point of view because it depicts the spatial location of seismic section and also shows how seismic section are interconnected. A base map typically includes locations of lease or concession boundaries, wells, seismic survey points and other relevant data sets, with a geographic reference such as latitud and longitude or Universal Transverse Mercator (UTM) grid information. Base map is a map which shows orientation and location of the seismic lines and wells. Well of Balkassar (OXY01) is shown below.The map consists of dip and strike lines as shown in Figure 4.3

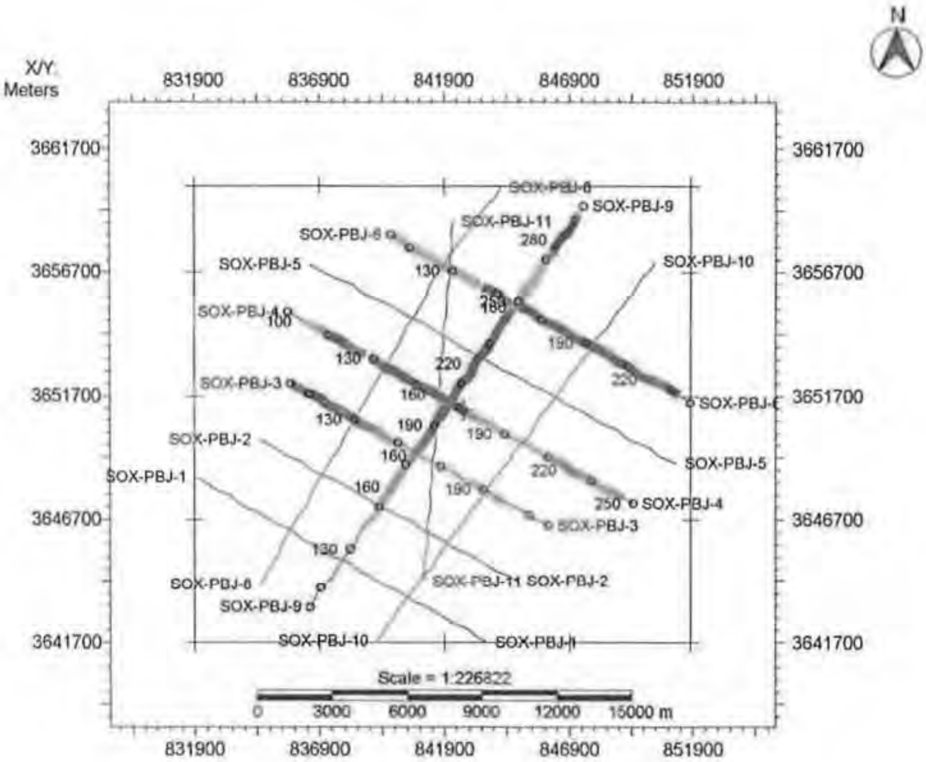

Figure 4.3 Base Map

4.6 Interpretation of Seismic Lines (Dip And Strike)

Seismic survey is conducted to acquire data for subsurface analysis, for information about stratigraphic patterns in depositional basins. Seismic Interpretation of Balkassar area involves 10 Seismic Lines. These lines have been interpreted on the basis of Seismic Interpretation criteria. When I interpret these seismic lines, I observed structural changes on seismic section.

4.6.1 Fault Marking

Fault marking on real time domain seismic section is quite a hard work to do without knowing tectonic history of area (Sroor., 2010). Faults are marked on the basis of breaks in the continuity of reflection. This discontinuity of the reflector shows that the strata is disturbed here due to the passing of the faults

Over all four faults are marked on the seismic section which indicates the complexity of study area. Three prominent reverse faults are present in the sedimentary cover sequence, following prominent broken reflectors. These reverse faults are bounding an anticline where one reverse fault is on the NW limb of the anticline, while two are on its SE limb. Normal faulting is present in basement. The basement normal faults indicate Jurassic rifting and splitting of Pangaea.

FAULT NAME	NATURE
F1	Reverse
F2	Reverse
F3	Reverse
F4	Normal

Table 3.1: Marked faults

4.6.2 Interpretation of dip line PBJ-04

In figure 4.4, well is located and synthetic is displayed. Horizons are marked and on this line three faults are marked. Two are major and third is minor. First horizon is top of sakessar and second is bottom of sakessar or top of patala. Sakessar is reservoir and Patala is our sourse rock.

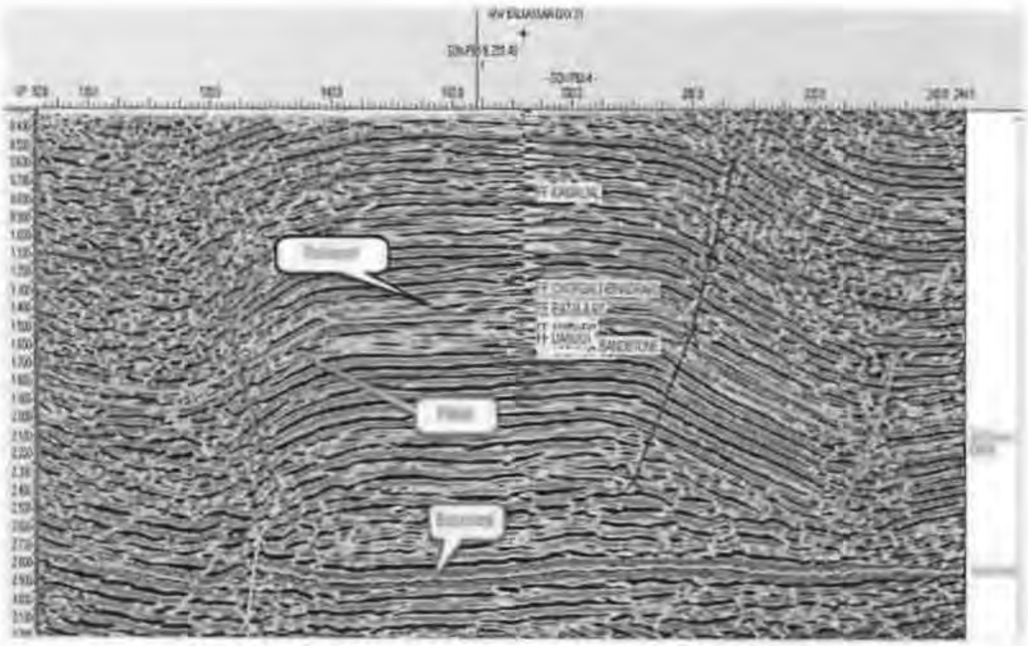

Figure 4.4 Horizons and Faults marking on SOX_PBJ-04 (Balkassar OXY-01)

4.6.3 Interpretation Of Dip Line SOX-PBJ-06

In figure 4.5, horizons are marked and on this line 3 faults are marked. Two faults are major and third one is minor fault. Here also two horizons are marked. These horizons show top and bottom of reservoir zone, which is Sakessar.

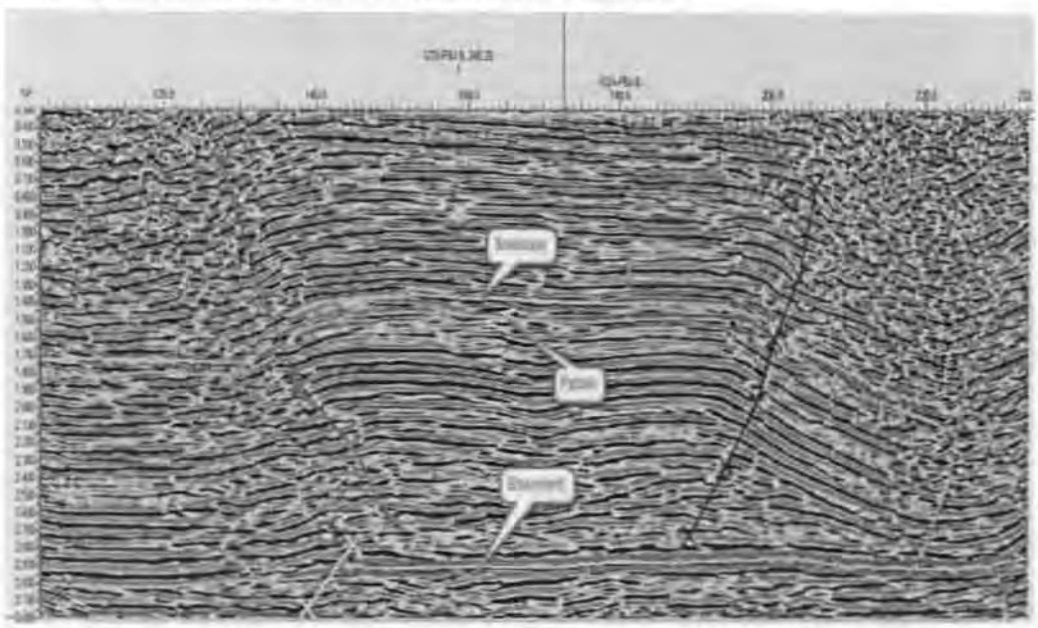

Figure 4.5 Horizons and Faults marking on SOX_PBJ-06 (Balkassar OXY-01)

4.6.4 Interpretation Of Dip Line SOX-PBJ-03

In figure 4.6, horizons are marked and on this line 2 faults are marked.Here two faults are major . Here also two horizons are marked. These horizons show top and bottom of reservoir zone, which is Sakessar.

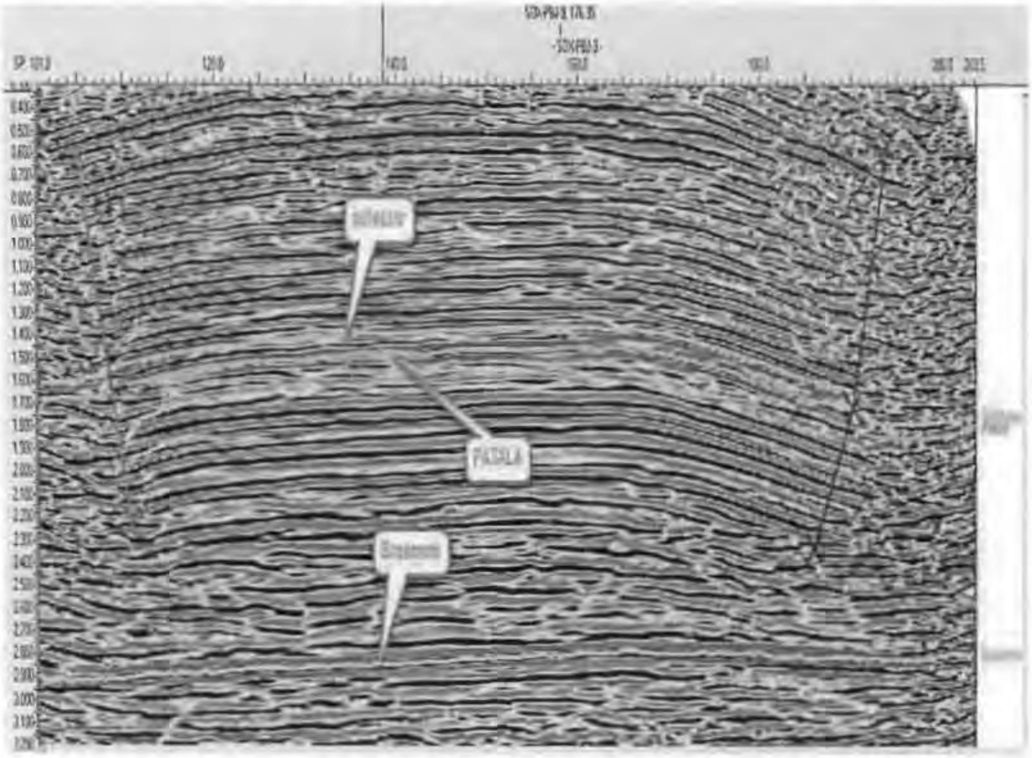

Figure 4.6 Horizons and Faults marking on SOX_PBJ-03 (Balkassar OXY-01)

4.6.5 Interpretation of Strike Line SOX-PBJ-09

Line SOX-PBJ-09 is a strike line whose orientation is SW-NE. Also the horizons of interest are also marked on this strike line. Seismic line PBJ-09 passes through the crest of the Balkassar anticline, and no fault exits on this line as faults are on the limbs. In Figure 4.7 strike line is shown with marked horizon of interest.

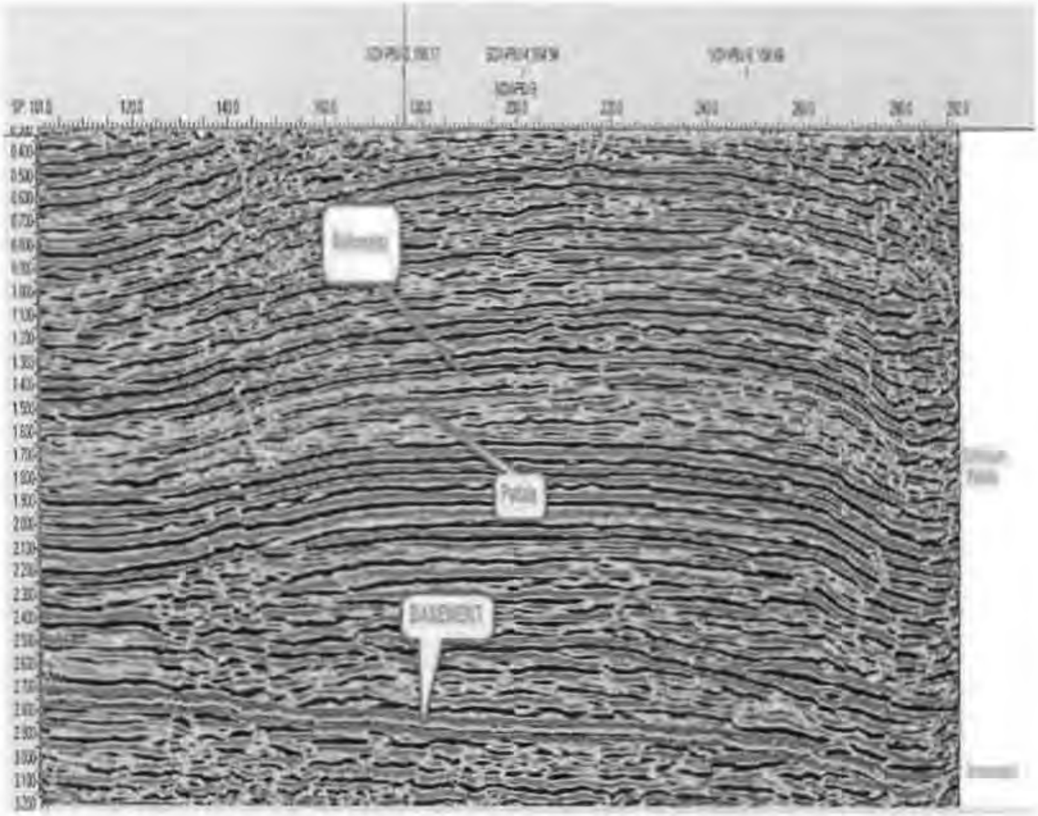

Figure 4.7 Horizon marking on SOX_PBJ-09 (Balkassar OXY-01)

4.7 Fault Polygon

After marking faults, next step is to generate fault polygon which involves a fault model made by connecting points based on fault attitude over base map. Before generation of fault polygon, it is necessary to identify the faults and their lateral extent by looking at the available seismic data and assign proper name to all these faults. If one finds that the same fault is present on all the dip lines, then all points (represented by a "+" or "x" sign by Kingdom software) can be manually joined to make a polygon. Construction of fault polygons are very important as far as time and depth contouring of a particular horizon is concerned.

The reason is that if a fault is not converted into a polygon, the software doesn't recognize it as a barrier or discontinuities, thus making any possible closures against faults represent a false picture of the subsurface. After construction of fault polygons, the high and low areas on a particular horizon become obvious. Fault polygons are constructed for all marked horizons and these are oriented in NE-SW 'direction. Well of Balkassar (OXY01) is shown below.

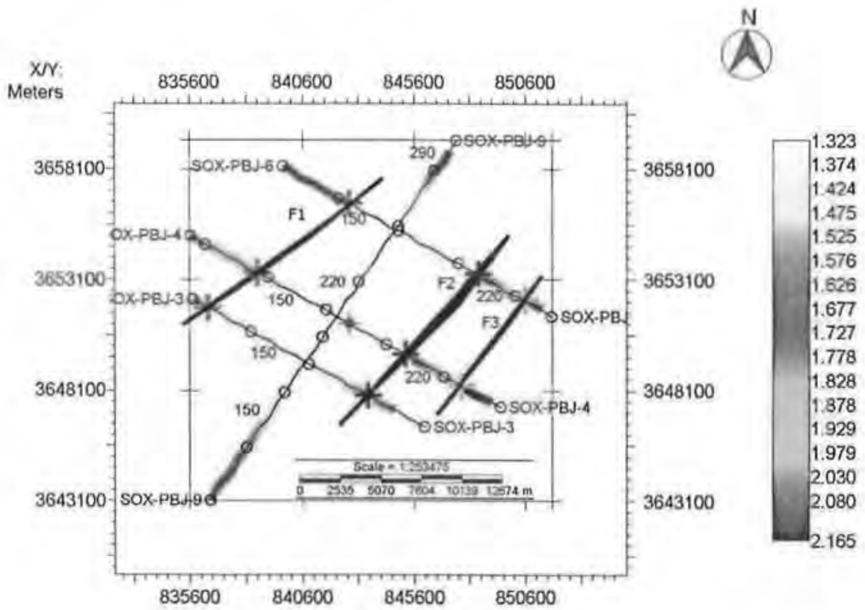

Figure 4.8 Fault Polygon of Sakessar

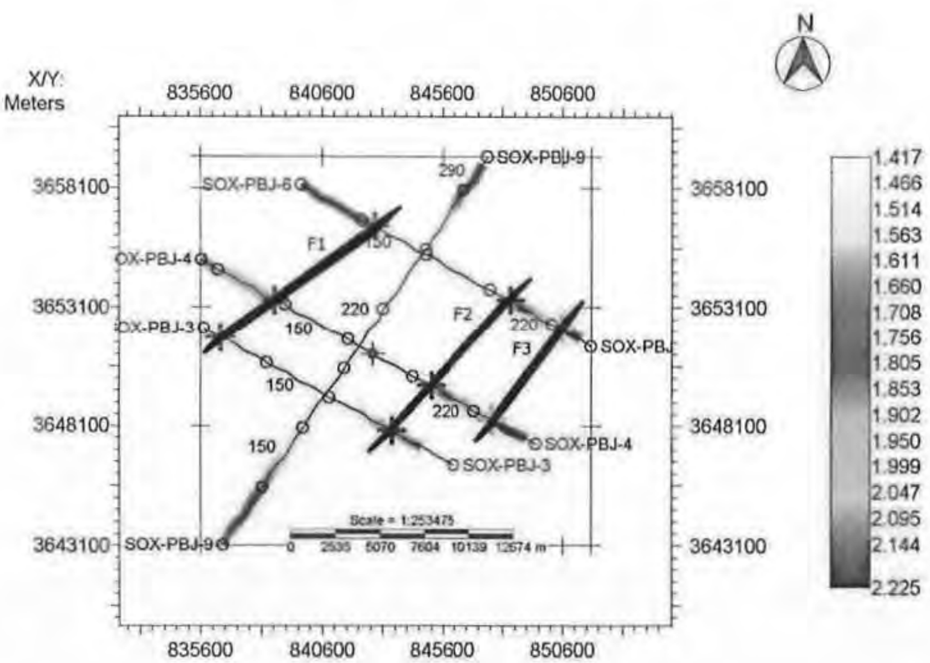

Figure 4.9 Fault Polygon of Patala

4.8 Grids

4.8.1 Time Grid

In figure 4.10, Time grid map of Sakessae is displayed. First I mark horizon on seismic lines and then I develop grids (Time and Depth), after that contour maps are developed . Well of Balkassar (OXY01) is shown below. In figure 4.11, Time grid map of Patala is presented.

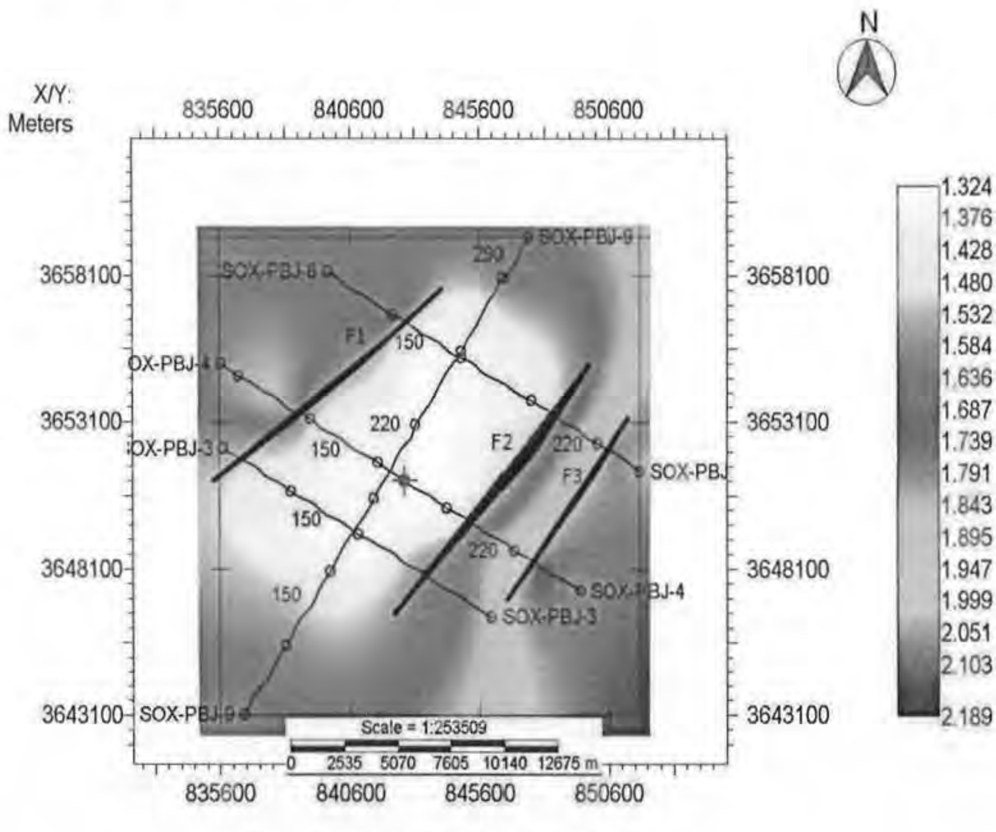

Figure 4.10 Time grid map of Sakessar

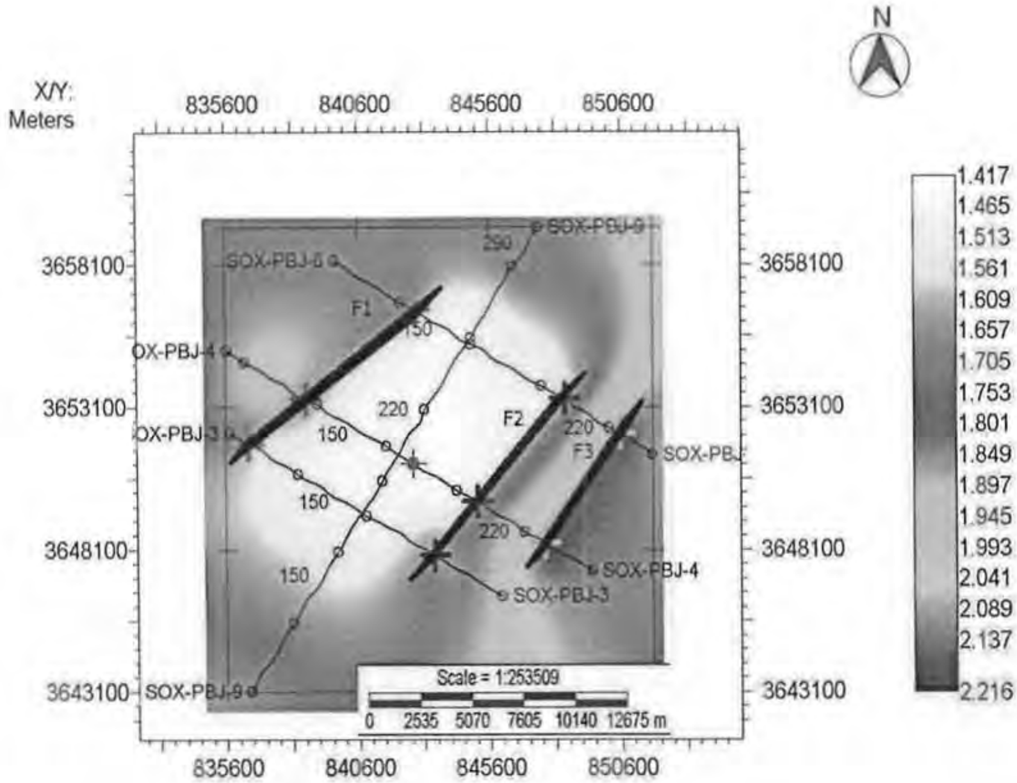

Figure 4.11 Time Grid Map of Patala

4.8.2 Depth Grid

In figure 4.12, Depth grid map of Sakessar is displayed. First I mark horizon on seismic lines and then I develop grids (Time and Depth), after that contour maps are developed Well of Balkassar (OXY01) is shown below. In figure 4.13, depth grid map of patala is presented

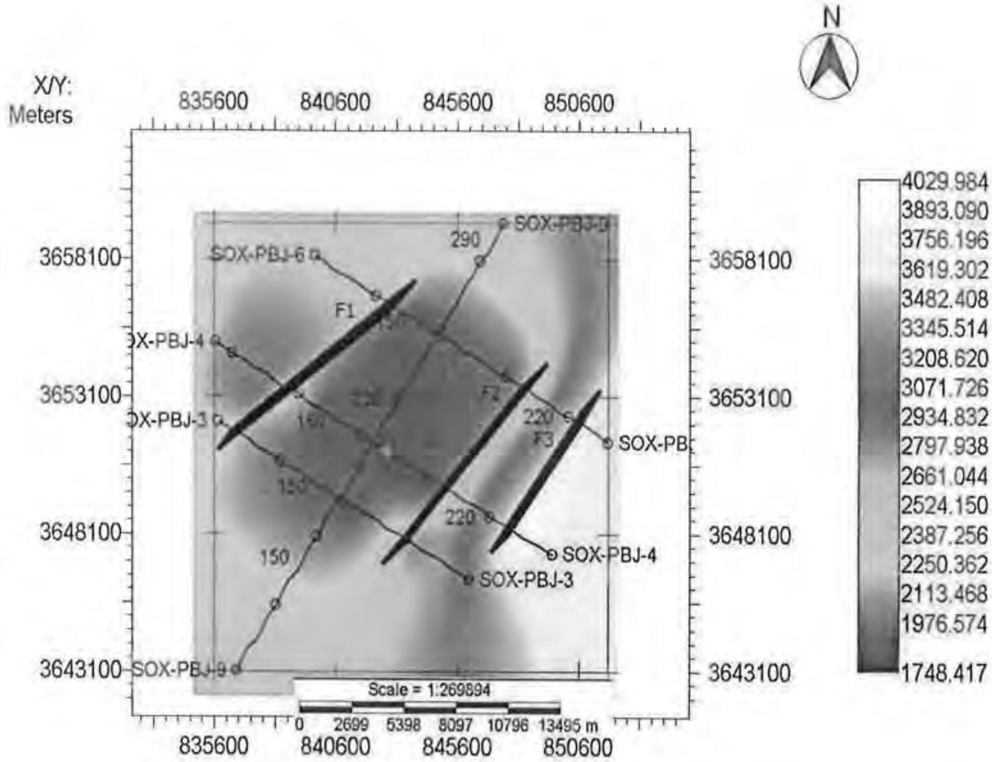

Figure 4.12 Depth grid map of Sakessar

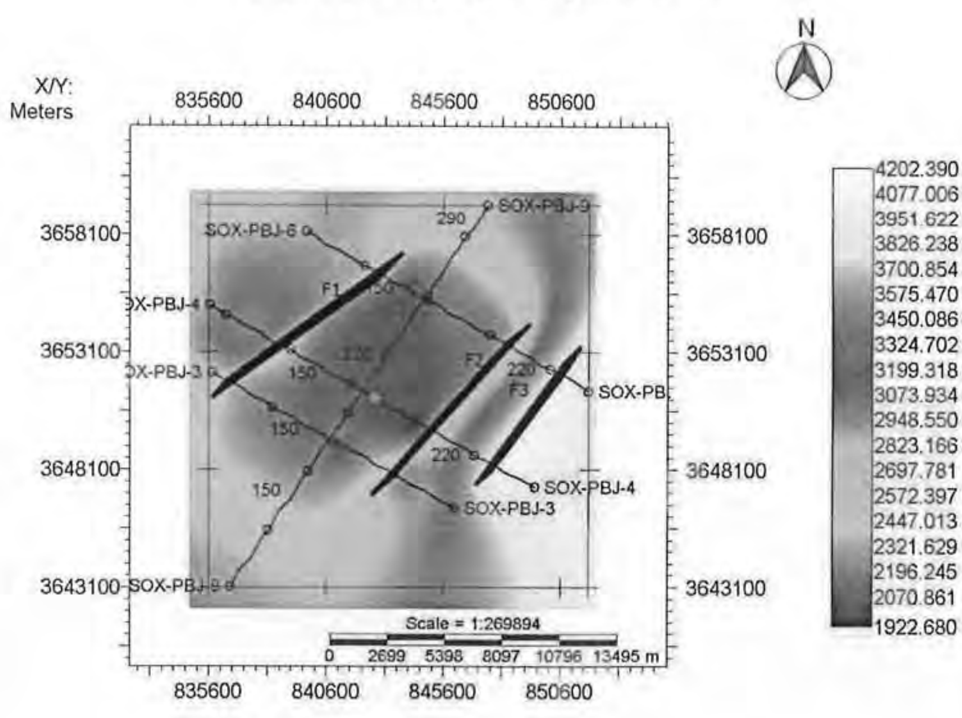

Figure 4.13 Depth Grid Map of Patala

4.9 Contour Maps

The last step in seismic interpretation is generation of contour maps (time contour maps and depth contour maps). Mapping is necessary part of the interpretation of the data, on which the entire operation depends. The contours are the lines of equal time or depth wandering around the map as dictated by the data (Coffeen, 1986). Contouring represents three-dimensional earth on a two dimensional surface. These contour maps gave us different type of information, for example, the slope of the formation, structural relief of the formation, its dip and faulting and folding.

After interpretation of seismic data contour maps are developed. These maps are time and depth contour maps. These time and depth contour maps are developed with the help of IHS Kingdom.

4.9.1 Time Contour Maps Of Marked Horizons

Time contour map of sakessar at the level of marked horizon is presented in figure 4.14. In this time contour map, the central part of the map, in the NE-SW direction represented by light colors, according to scale, is indicating shallow area, and forming flat shaped crustal part of the anticline. Both the limbs are dipping steeply and terminated by reverse and back thrusts/faults respectively. These contour maps (Time, Depth) clearly gave us indication about the back thrusting in the study area. The closed contour part can be considered as structural trap. Well of Balkassar (OXY01) is shown below.

Time contour map of Patala is develop and presented in figure 4.15 It also shows that central part is flat and both limbs are steeply dipping and show pop-up anticline.

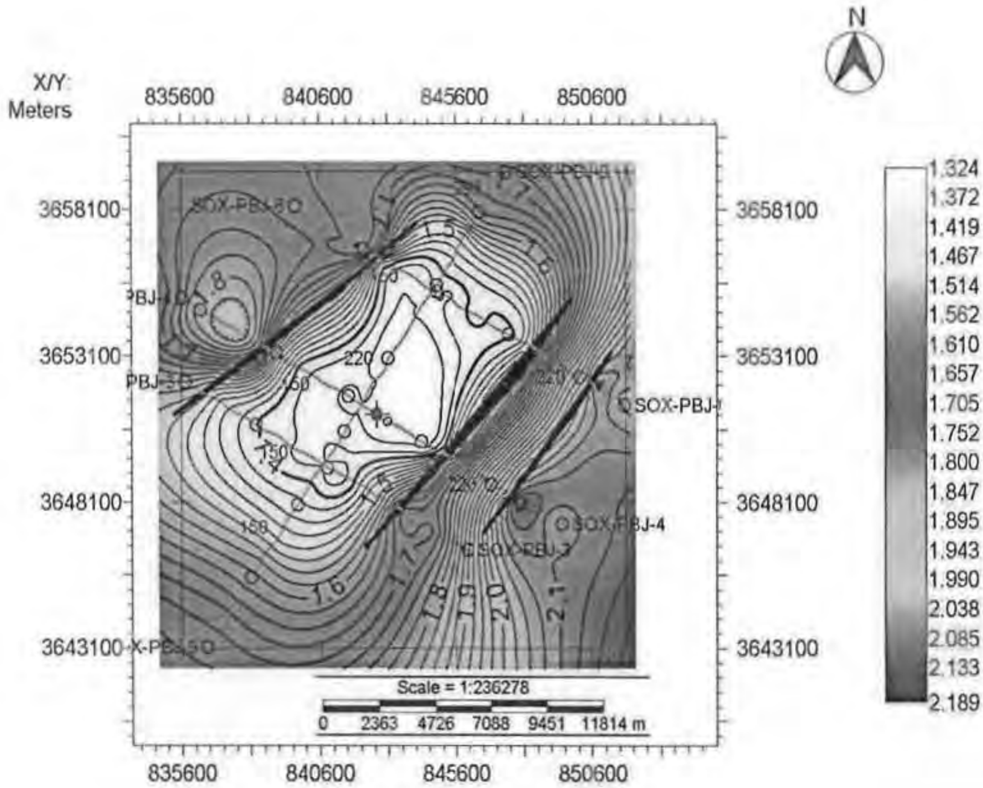

Figure 4.14 Time Contour Map of Sakessar

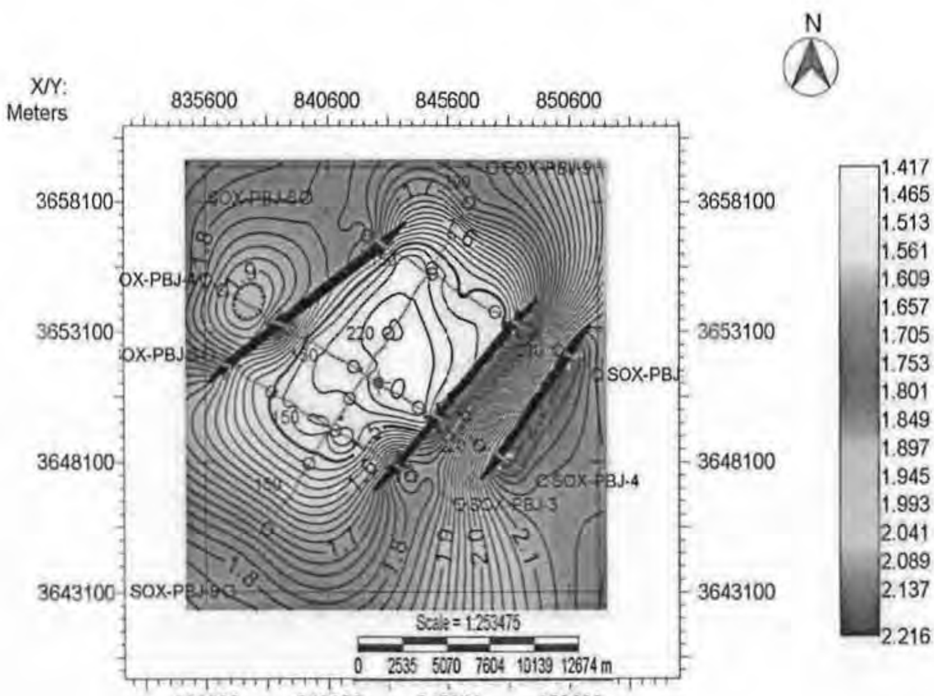

Figure 4.15 Time Contour Map of Patala

4.9.2 Depth Contour Maps of Marked Horizons

The depth contour maps of Sakesar and Patala show the horizos depth variation. It can easily be interpreted that horizon is forming an anticline structure, as from the scale the central portion between fault polygons is shallower in depth than the surrounding area. Figure 4.16 shows depth contour map of Sakessar and figure 4.17 shows depth contour map of Patala.

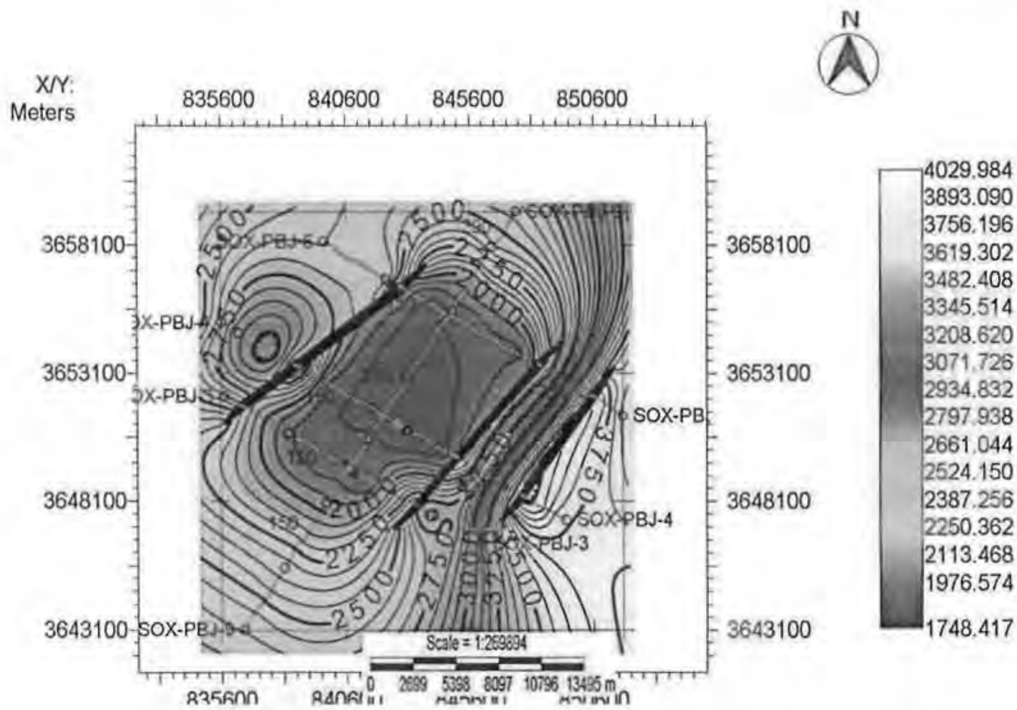

Figure 4.16 Depth Contour Map of Sakessar

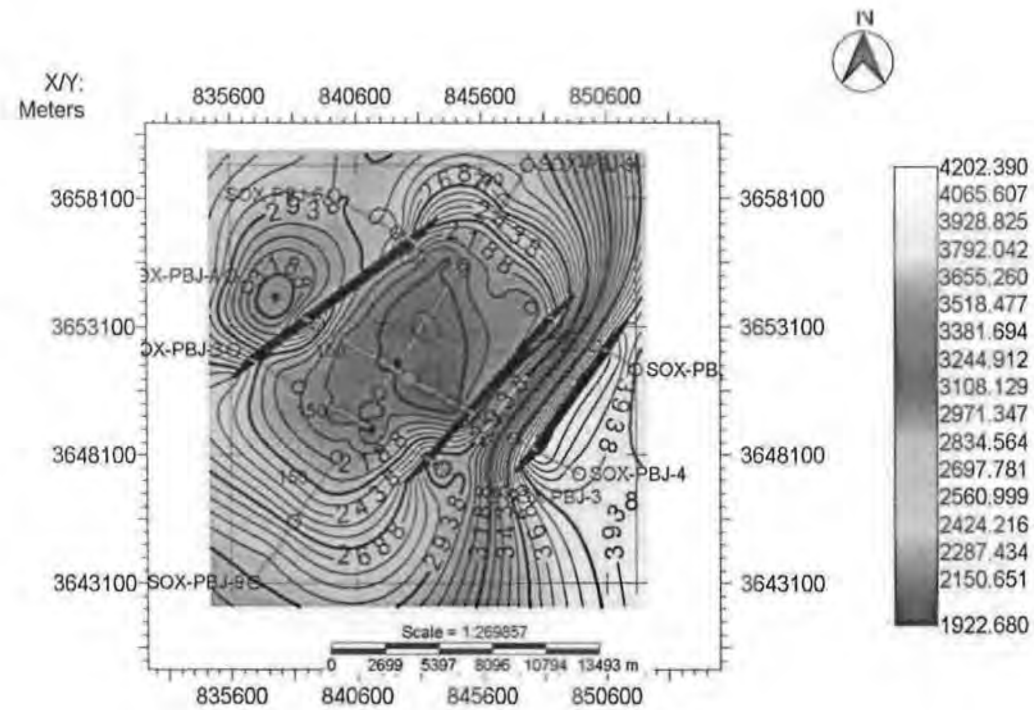

Figure 4.17 Depth Contour Map of Patala

4.10 Discussions

Following deductions are made from the interpretation done above.

- A pop up structure is identified
- This provides an ideal structural trap
- The normal fault present in the basement has been significantly important in the tectonic nature of the area.
- . The hydrocarbons accumulate in anticlinal structure is bounded by faults planes. This anticlinal structure acts as a trap in the area, which is best for hydrocarbon accumulation.

Chapter No.5
Petrophysics

5.1 Introduction

Well logging is the method of making a complete record of the geologic formations in a borehole (Asquith and Gibson., 2004). Such well logs may be based on visual assessment of samples taken out on the surface known as geological logs or they may be based on physical measurements performed by instruments pull down into the well known as geophysical logs. This study facilitates in identification and quantification of fluid in a reservoir .Knowledge of reservoir physical properties like volume of shale, porosity, and water and hydrocarbon saturation is needed to define accurately probable zones of hydrocarbons. The combination of petrophysics with rock physics enables the geophysicists to understand the physical properties of rocks in the study area. Petrophysics is apprehensive with using well measurements to subsidize reservoir depiction.

In petroleum industry, logs are used to examine fluid and rock properties and also identify hydrocarbon bearing zones in the geological formations. The procedure of logging includes lowering an instrument into a well bore hole, attached at the end of a wireline to measure the fluid and rock properties (Asquith and Gibson., 2004). Well logging can be done during any phase of a well's history; drilling; producing and abandoning. Once the measurements are made, their interpretations in terms of logging are done to locate and quantify hydrocarbon bearing zones. The properties measured by logging tools are acoustic, electromagnetic, electrical, radioactive, nuclear magnetic resonance and several other properties

The results obtained from well logs help to define the characteristics of rock;

Lithology/mineralogy; Water saturation; Porosity (φ); Permeability (k); Hydrocarbon saturation etc. Logging data helps to determine the depth & thickness of zones; Identify production zones; Distinguish between oil/gas and water; Evaluation of hydrocarbon reserves.

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

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

Schlumberger charts (Appendix-A & B) and several mathematical equations (Figure 5.2) are used for calculation of resistivity of water (Schlumberger., 1989). Different zones are defined as Chorgali and Sakesar are considered as main reservoir to be studied. Its workflow is given in the Figure 5.1 and practically performed afterwards. Lithology logs used in Petrophysical analysis are Gamma Ray (GR) log, Caliper log and Spontaneous Potential (SP) log. While resistivity logs used in the analysis are Laterolog Deep (LLD) and Laterolog Shallow (LLS). Similarly, porosity logs used in the Petrophysical analysis are Sonic log (DT), Neutron log (NPHI) and Density log (RHOB) (Asquith and Gibson., 2004). Raw log curves are loaded in Kingdom software for performing reservoir characterization. Whiles

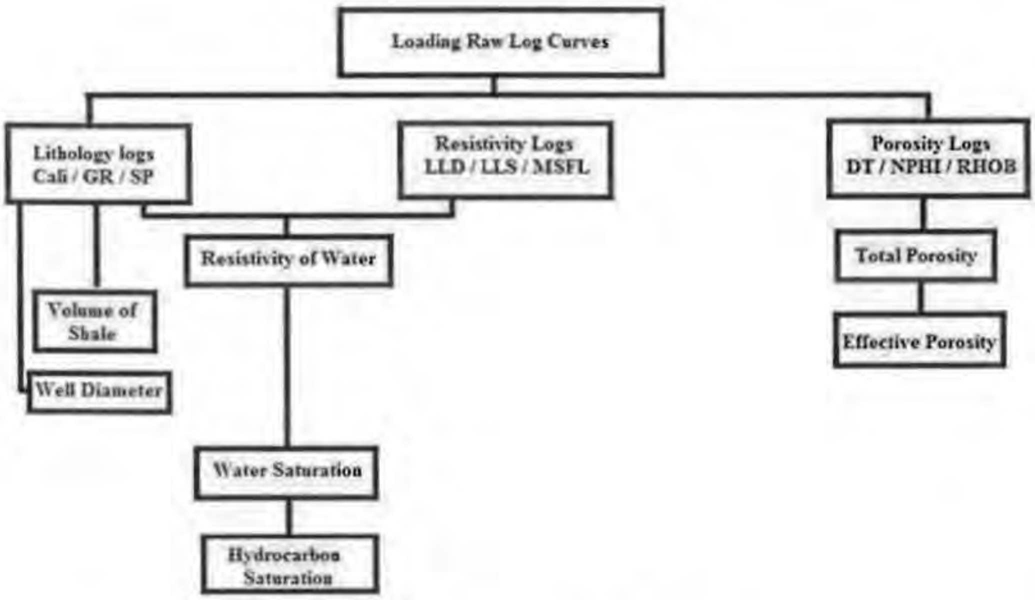

Figure 5.1: Petrophysics Workflow

Volume of Shale

$$I_{gr} = \frac{(GR_{log} - GR_{min})}{GR_{max} - GR_{min}}$$

Sonic Porosity

$$\emptyset_s = \frac{(\Delta t - \Delta t_{mat})}{(\Delta t_f - \Delta t_{mat})}$$

Density Porosity

$$\emptyset_D = \frac{(\rho_{mat} - \rho_b)}{(\rho_{mat} - \rho_f)}$$

Average Porosity

$$\emptyset_{AVG} = \frac{(\emptyset_N + \emptyset_D)}{2}$$

Static Spontaneous Potential

$$SSP = SP(clean) - SP(shale)$$

Formation Temperature

$$FT = ST + \frac{(BHT - ST)}{(TD \times FD)}$$

Resistivity of Mud Filtrate

$$R_{mf2} = R_{mf1} \times \left(\frac{ST + 6.77}{FT + 6.77}\right)$$

Water & Hydrocarbon Saturation

$$Sw(\%) = (A \times Rw/RT \times \emptyset^M)^{\frac{1}{N}}$$

$$S_h(\%) = 100 - S_w(\%)$$

Figure 5.2: Formulae used in Petrophysics (Asquith and Gibson, 2004)

5.2 Volume Of Shale

Shale contains radioactive minerals that emit natural gamma radiations and they can be recorded easily with the help of gamma ray logs. This type of log acts as a lithology indicator that distinguish between sand and shale. V_{sh} (Volume of shale) is the parameter which represents the percentage of clays (Radioactive minerals) existing in a specific formation. The first step is to find Gamma-ray index symbolized by "I_{gr}" (Asquith and Gibson., 2004).

$$I_{gr} = \frac{(GR_{log} - GR_{min})}{GR_{max} - GR_{min}} .$$

Here,

I_{gr} = Gamma ray index,

GR_{log} = Gamma ray reading of formation,

GR_{min} = Minimum gamma ray value,

GR_{max} = Maximum gamma ray value.

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

We have different GR models to calculate volume of shale:

Stieber formula (1970):

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

Lorionov Formula (1969):

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

Clavier formula (1971):

$$V_{sh} = 1.7\sqrt{3.38 - (IGR + 0.7)^2}$$

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

5.3 Estimation of Porosity

Porosity is the ratio of volume of voids to total volume of rock. Porosity is calculated for different zones of interest by using sonic log, neutron log, density log.

$$\text{Porosity} = \frac{\textit{PORE VOLUME}}{\textit{TOTAL BULK VOLUME}}$$

There are different type of porosity such as primary porosity, secondary porosity, total porosity and effective porosity. For reservoir characterization we must find out the effective porosity.

5.3.1 Sonic Porosity (ØS)

Sonic log measures the transit travel-time of "P wave" in the formation. The rate of transmission of P waves through a formation depends on the elastic properties of matrix and contained fluids within a rock. The velocity of P-wave in the rock is then calculated using this information This type of log can be used to identify porosity, fractures and lithology of the rock (Daniel., 2003). Sonic log is also used for generating synthetic seismograms, formation mechanical properties, detection of abnormal formation pressure, permeability and size of borehole. "Wyllie's Time Average" equation is used to calculate porosity using sonic log (Asquith and Gibson., 2004).

$$\emptyset_s = \frac{(\Delta t - \Delta t_{mat})}{(\Delta t_f - \Delta t_{mat})}\,.$$

Here,

$\emptyset_s$ = Sonic porosity,

Δt = transit time of formation,

Δt_{mat} = transit time of matrix,

Δt_f = transit time of pore fluids

Material	Δt (μs / ft)
Sandstone	51.3-55.6
Limestone	43.5-47.6
Shale	60-170
Dolomite	38.5-43
Oil	238
Water	180-192
Methane	625

Table 5.1: Transit time through different medium (Asquith and Gibson., 2004)

5.3.2 Density Porosity (ØD)

The density log is used to record deviation in the density of lithological column within borehole. Overall density of a unit volume of rock includes grain density and fluid density in the pore spaces. Gamma rays emitted by logging device collide with the formation and undergo Compton Scattering. Thus scattered gamma rays are detected and counted as formation density. As counting rate increases, it shows that bulk density of the formation decreases (Tittman and Wahal., 1965). The sum of fluid density times its relative volume plus matrix density and its relative volume is considered to be bulk density. Hence bulk density of the rock is calculated by following formula (Asquith and Gibson., 2004):

$$\emptyset_D = \frac{(\rho_{mat} - \rho_b)}{(\rho_{mat} - \rho_f)} \quad .$$

Here,

ρ_{mat} = Density of matrix,

ρ_b = Bulk density,

ρ_f = Density of fluid.

Type of material	Density
Oil	0.8-0.9
Salt water	1.1-1.2
Fresh water	1
Sandstone	2.65

Limestone	2.7
Shale	2.2-2.7
Dolomite	2.85

Table 5.2: Density of different medium (Asquith and Gibson., 2004).

5.3.3 Neutron Porosity (ΦN)

The neutron log measures hydrogen ions concentration in the rock. The neutrons are emitted from logging device and collide with nuclei of the rock. As a result of this collision, some of their energy is lost. Mass of hydrogen atom is same as that of neutron so when they collide with hydrogen, maximum energy is lost. Now hydrogen is indication of fluids in pore spaces. Therefore, energy loss is indication of rock porosity (Asquith and Gibson., 2004). Neutron log shows higher response when run through clean sands where there are water or oil present. But in oil and gas filled reservoirs, the response of neutron log is lower because of less hydrogen ion concentration in gas.

5.3.4 Average Porosity

Average porosity is the sum of neutron porosity and density porosity divided by 2. As there were two porosity logs used for calculation of average porosity. It can be calculated with the help of following formula (Schlumberger., 1989):

$$\emptyset_{AVG} = \frac{(\emptyset_N + \emptyset_D)}{2}$$

Here,

$\emptyset_{AVG}$ = Average porosity,

$\emptyset_N$ = Neutron porosity,

$\emptyset_D$ = Density porosity.

5.3.5 Effective Porosity ($\emptyset e$)

Effective porosity is usually indicator of shale free or shale rich zones because it is the measurement of interconnected pores and there is no effective porosity in shaly zones. This is further used for calculating water saturation. Effective porosity is calculated by following formula (Asquith and Gibson., 2004).

$$\emptyset_e = \emptyset_t \times (1 - V_{sh})$$

Here,

$\emptyset_e$ = Effective porosity,

$\emptyset_t$ = Total porosity,

V_{sh} = Volume of shale.

5.4 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. There are different models of determination of water saturation but we use Archie's model for the calculation of water saturation. We have a well (OXY-01) with many logs data. Archie equation is used to determine the water saturation from well logs.

$$Sw = (\frac{ARw}{\varphi^M Rt})^{\frac{1}{N}}$$

Gus Archie gives this equation in 1942 which relates the water saturation with the porosity and resistivity of formation.

Where

S_w=Water saturation

Rw= Formation Water Resistivity

A = tortuosity factor

R_t = resistivity for reservoir rock= ILD (KAMGANG., 2013)

M= cementation exponent

N=saturation exponent

5.4.1 Calculation of Rw

Resistivity of water (Rw) is calculated after performing a series of calculations (Asquith and Gibson., 2004):

1) Note down values of surface temperature (ST), resistivity of mud filtrate (Rmfl) and maximum temperature (BHT).
2) Calculate Static Spontaneous Potential (SSP) using SP log from the relation (Rider., 1996). $SSP = SP(clean) - SP(shale)$
3) Calculate Formation Temperature from the relation (Rider., 1996).

$$FT = ST + \frac{(BHT - ST)}{(TD \times FD)}$$

4) Calculate resistivity of mud filtrate from the relation

$$R_{mf2} = R_{mf1} \times \left(\frac{ST+6.77}{FT+6.77}\right)$$

5) Calculate resistivity of mud equivalent (Rmfeq) from the relation or from schlumberger charts

$$R_{mfeq} = 0.85 \times R_{mf2}$$

Once the value of Rmfeq is derived, now calculate resistivity of water equivalent Rweq against Rmfeq at SSP value and BHT from S.P chart (Schlumberger chart) shown in Appendix A. Now the resistivity of water (Rw) is calculated against Rweq and FT by

SP chart method (Appendix B).The value of Rw for chorgali formation is 0.049Ωm and for sakesar formation the value of Rw is 0.042Ωm.

6) Calculate water saturation using Archie Water Saturation equation (Archie., 1942),

$$Sw(\%) = (A \times Rw/RT \times \emptyset^{M})^{\frac{1}{N}}$$

Now calculate hydrocarbon saturation using the relation,

$$S_h(\%) = 100 - Sw\ (\%)$$

5.5 Hydrocarbon Saturation

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

$$S_w(\%) + S_h(\%) = 100$$

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

$$S_h(\%) = 100 - S_w\ (\%)$$

S_h= Hydrocarbon saturation

S_w= Water saturation

5.6 Interpretation of Well Logs

In this section there are interpreted well logs of BALKASSAR-OXY-01: Here our reservoirs is Sakesar Formation mainly consists of limestone and have some intercalations of limy shale. Sakesar Formation is encountered at the depth ranges from (2467m2602m). The Sakesar Formation is confirmed as a reservoir by different results obtained from well log. The 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 sakesar act as a reservoir. Petrophysical analysis was carried out for both the reservoirs using different well log curves.

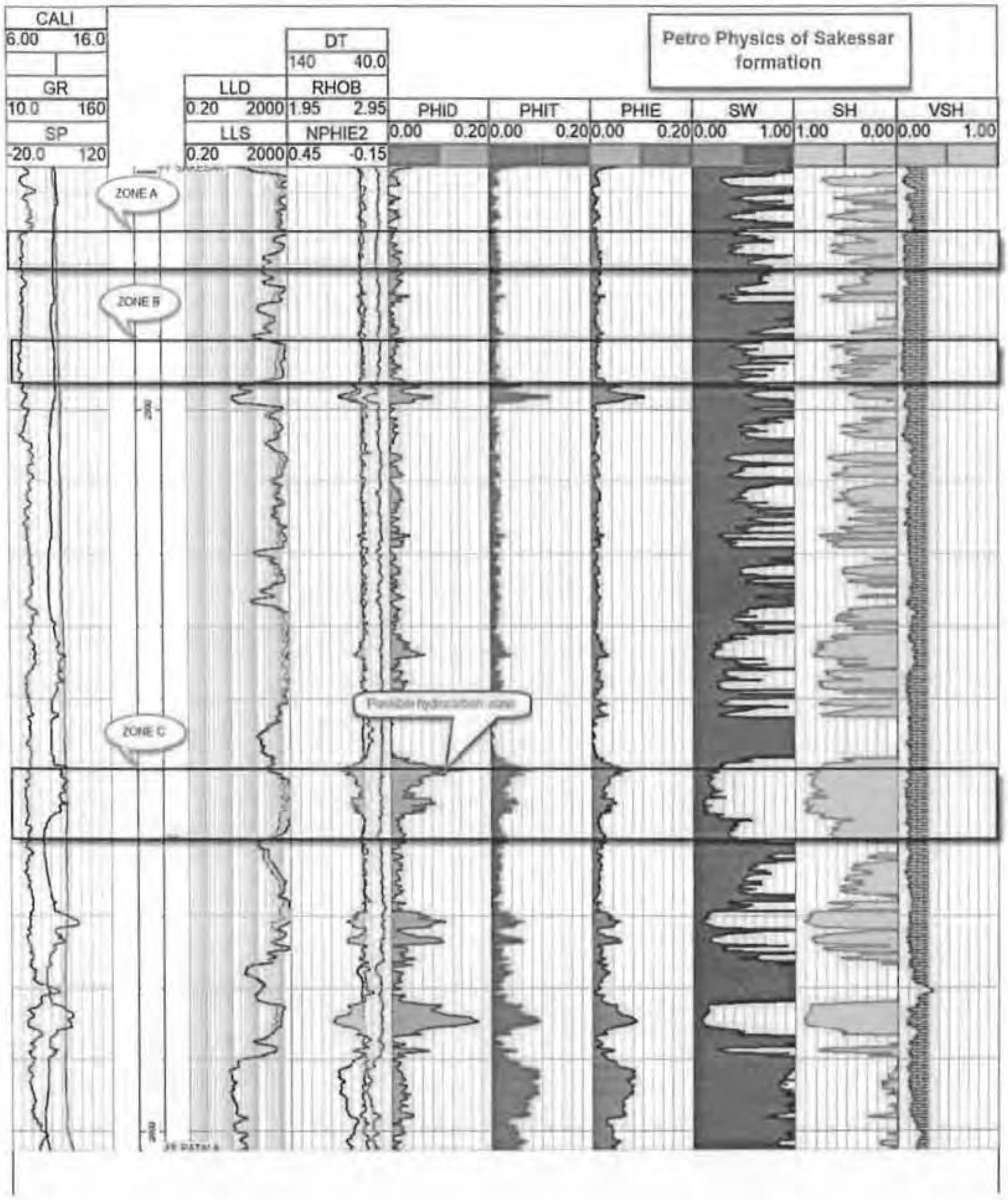

Figure 5.3 show petro physical logs (2467m-2514m) Sakesar

5.6.1 Interpretation of Sakesar Formation

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

5.6.2. 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.

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

Table 5.3 Calculated values for Zone of interest in Sakesar Formation

5.7 Conclusion

We have concluded that 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 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. Identified zones in 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 No.6
Seismic Attributes

6.1 Seismic Attributes

Seismic attribute is defined by as a measurement derived from seismic data. Such a broad definition allows for many uses and abuses of the term. Countless attributes have been introduced in the practice of seismic exploration (Brown, 1996 and Chen et al, 1997) which led Eastwood 2002 to talk about attribute explosion. Many of these attributes play an exceptionally important role in interpreting and analyzing seismic data (Chopra et al, 2005). Some particular attribute applications are considered i.e. Amplitude, Frequency, Energy, etc. A seismic attribute is any quantity derived from seismic data using measured time, amplitude, frequency, attenuation or any combination of these. It intends to output a subset of the data that quantifies rock and fluid properties and/or allows the recognition of geologic patterns and features. Almost all seismic attributes are post-stack but there are few pre-stack ones. They can be measured along a single seismic trace or throughout various seismic trace.

The first attributes developed were related to the 1D complex seismic trace and included: envelope amplitude, instantaneous phase, instantaneous frequency, and apparent polarity. Acoustic impedance obtained from seismic inversion can also be considered an attribute and was among the first developed.

6.2 Classification of Seismic Attributes

The Seismic Attributes are classified basically into two categories.

- Physical Attributes
- Geometric attributes

6.2.1 Physical Attributes

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

6.2.2 Geometrical Attributes

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

6.3 Attributes Analysis

The following attributes were applied to line SOX-PJB-4 and the results are interpreted.

6.3.1 Acoustic Impedance

Relative Acoustic Impedance is computed by continuous integration of the original seismic trace with the subsequent application of low cut filter. Assume that the seismic data has been processed to have minimum noise and multiple contaminations and it contains zero phase, wide band wavelet illumination. Based on this assumption the seismic trace represents the band limited reflectivity series. Therefore, integrating the zero phase trace results in the band limited estimate of the natural log of the acoustic impedance. Since it is band limited, the impedance will not have absolute magnitudes and the stack section is usually the estimate of zero offset reflectivity; hence it is called relative acoustic impedance. In practice, however, due to noise and imperfect spectral content of the seismic data, relative acoustic impedance computed by integration will develop arbitrary long wavelength trends. It reflects physical property contrast, hence it is a physical attribute effectively utilized in many calibration procedures. It is used in:

- Band limited apparent acoustic impedance contrast.
- It relates to porosity.
- High contrast indicates possible sequence boundaries.
- Indicates unconformity surfaces.
- Indicates discontinuities.

In line SOX-PJB-4, Figure 6.1 it can be observed that breakage of the relative acoustic impedance confirms the faulting in the area and its lateral extension confirms the horizon marking. Also the reservoir shows high thickness of acoustic impedance which confirms its reservoir property.

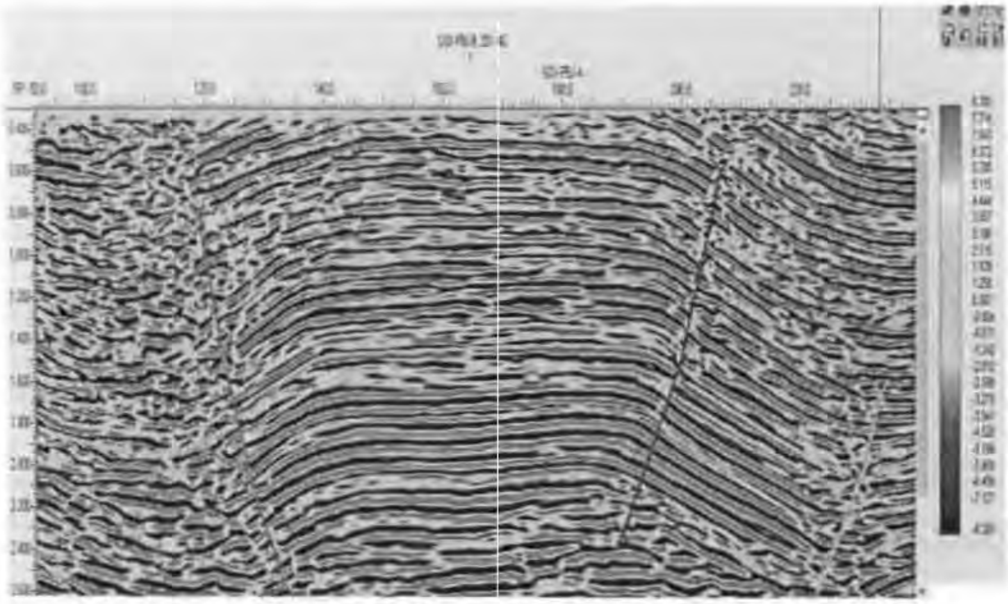

Figure 6.1 Relative acoustic impedance attribute applied SOX-PBJ-04

6.3.2 Event Continuity

Event Continuity is designed in order to emphasize continuous events. The program outputs values of +1 at the location of each peak's maximum, and –1 at the location of each trough's minimum. The rest of the trace samples are set to 0. The display therefore will show only the peaks and troughs, all with same magnitude. It used in

- Conjunction with the similarity and dip of maximum similarity attributes will be used to form spatially continuous pick-strings and surfaces.
- They will also be used to identify event terminations for use in stratigraphic interpretation. In line SOX-PJB-4, Figure 6.2 horizon lateral extension is confirmed and also it confirmed that the reflector has been marked correctly. Because of the fact the study area lie in the Upper Indus Basin so there is no major stratigraphic event can be observed but breakage at faults can be observed clearly.

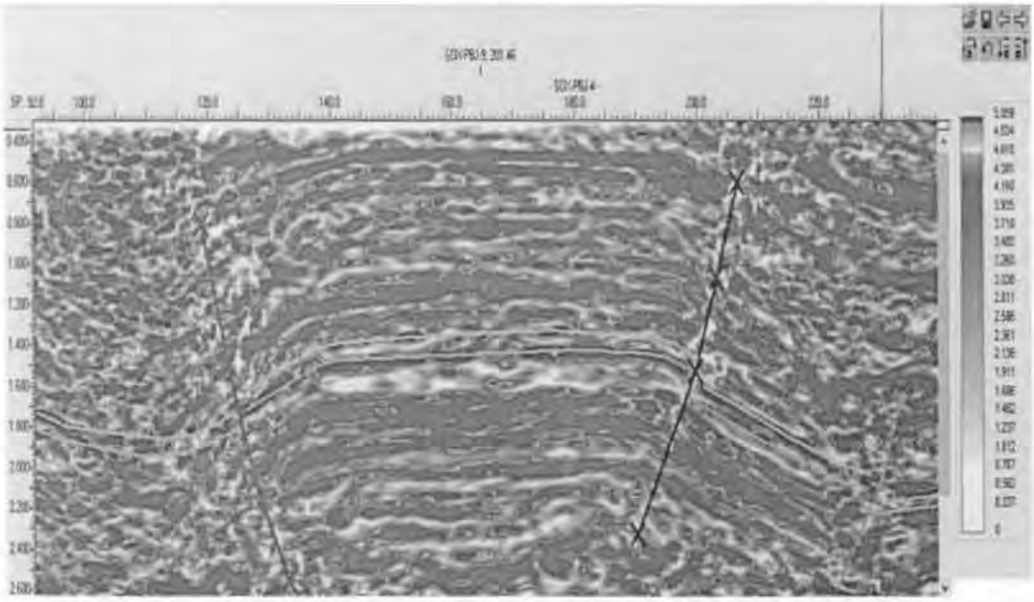

Figure 6.2 Event Continuity attribute calculated for SOX-PBJ-04

6.3.3 Dip Varience

Dip variance attribute is designed to mark discontinuity in seismic data. So it is placed in the category of discontinuity attributes. Basically it uses statistical variance (squared differences) of "adjacent" seismic amplitudes. The following are the advantages of discontinuity attributes

Automated fault delineation

- Assistance in manual fault picking
- Delineation of directional fault sets
- Seismic geomorphology (turbidite fan terminations (thrust faults)
- Auto tracking of seismic horizons in time slices without fault picks.

In line SOX-PJB-4 dip variance attribute is applied. Figure 6.3, white portion clearly delineate the faults and their direction. Figure 6.4 shows that faults and horizons are picked correctly.

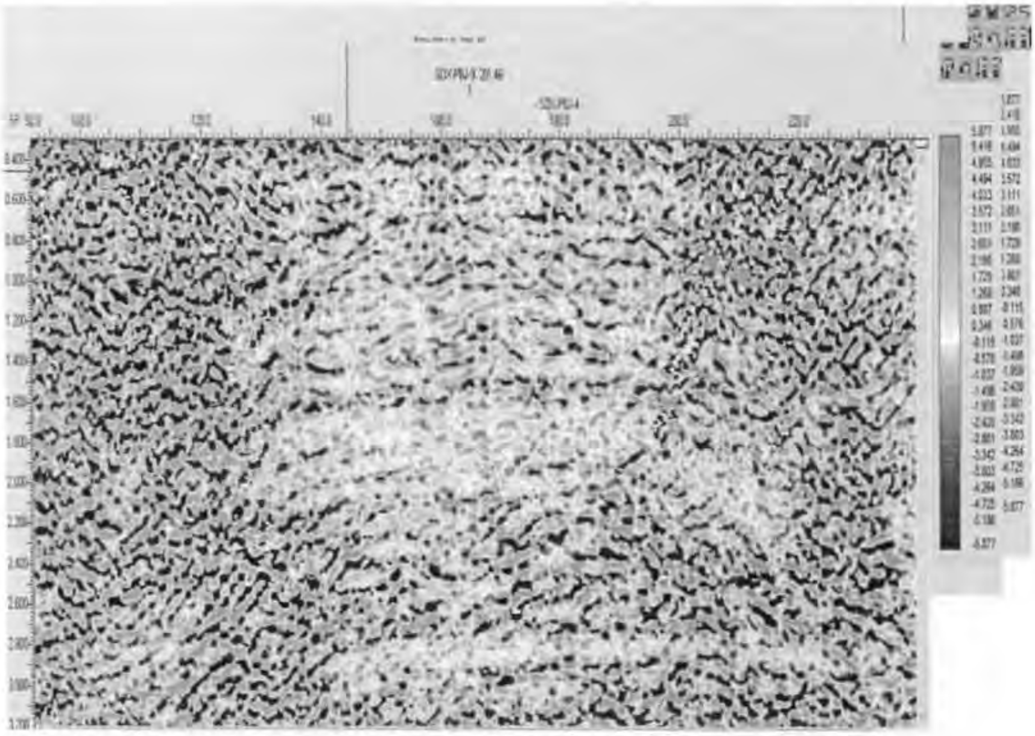

Figure 6.3 Dip Variance attribute applied on SOX-PBJ-04

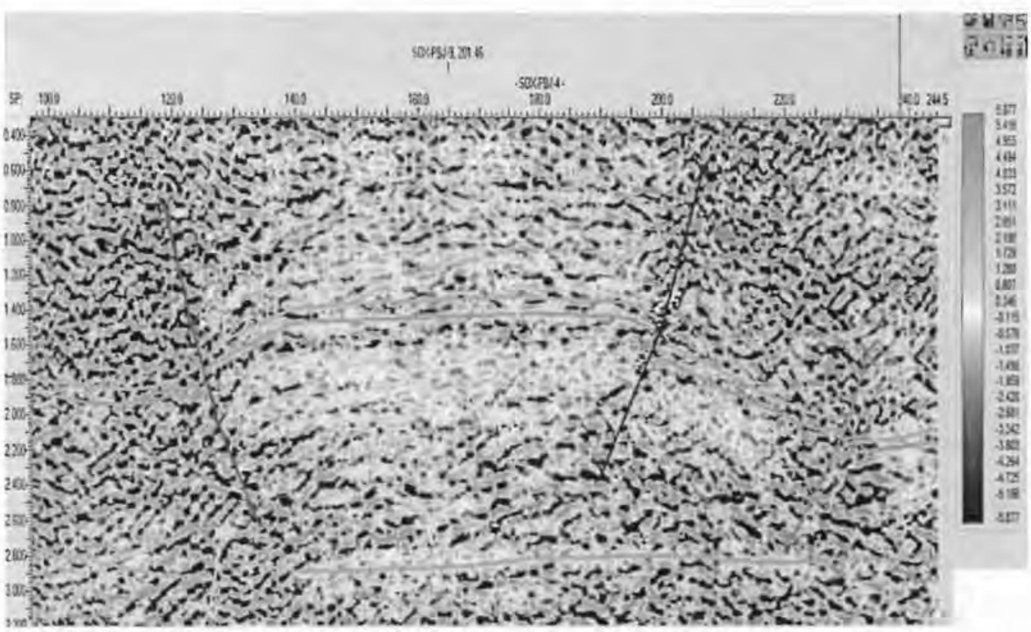

Figure 6.4 Dip Variance attribute applied on SOX-PBJ-04

6.3.4 Instantaneous frequency

Instantaneous Frequency (Hz) is the rate of change of phase over time (Sheriff, 2002):

$$\text{Freq }(x,t) = \frac{\partial \arctan[\frac{g(x,t)}{f(x,t)}]}{\partial(t)} = \frac{[f(x,t).\frac{dg}{dt} - g(x,t).\frac{df}{dt}]}{[f^2(x,t) + g^2(x,t)]}$$

Since the phase function is multi-valued with jumps, the instantaneous frequency is actually computed as the derivative of the arctangent function, which avoids the discontinuities. Instantaneous frequencies relate the wave propagation and depositional environment, hence they are physical attributes and they can be used as effective

discriminators, Instantaneous frequency can indicate bed thickness and also lithology parameters.

- Indicates the edges of low impedance thin beds.
- Hydrocarbon indicator by low frequency anomaly. This effect is sometimes accentuated by the unconsolidated sands due to the oil content of the pores.
- Fracture zone indicator, appear as lower frequency zones.
- Bed thickness indicator. Higher frequencies indicate sharp interfaces or thin shale bedding, lower frequencies indicate sand rich bedding.

In this research Instantaneous frequency shows a complete continuity in entire reservoir with breakage at some point, showing low frequency, confirms the faults which clearly prove that reflectors and faults has been marked are correctly, Figure 6.5.If we study seismic section with scale it shows that at places where wells have been drilled shows high frequency which indicates hydrocarbon are not present and well is abondant.

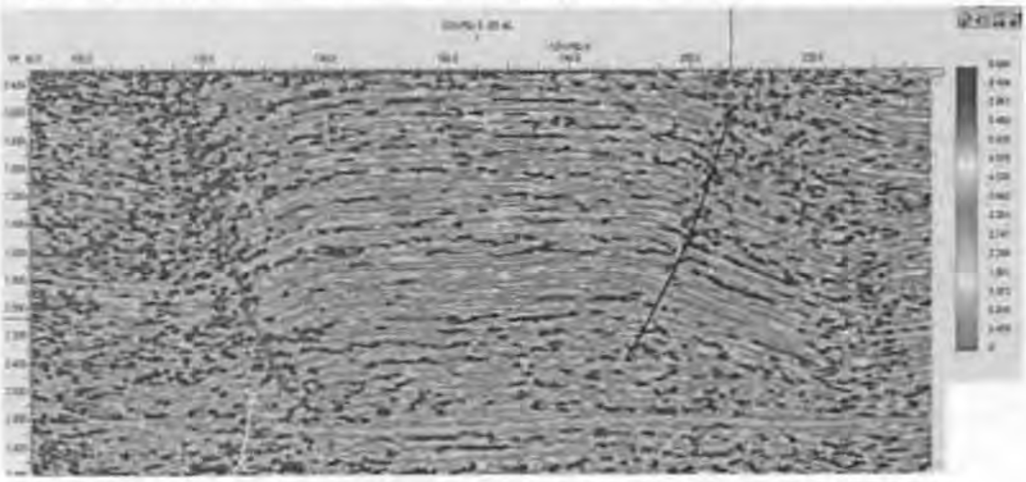

Figure 6.5 Instantaneous frequency attribute applied on SOX-PBJ-04

References

- Asquith, G.B., D. Krygowski, and C.R. Gibson (2004), Basic well log analysis.
- SAmerican Association of Petroleum Geologists.
- Badley, M. E. (1985). Practical seismic interpretation.
- Brown, A.R., (1996), Seismic attribute and their classification, The Leading Edge, V.15, P.10-90.
- Chopra, S.K.J.Marfurt, (2005), Seismic attribute-A historic perspective: Geophysics
- D.Subrahmanyam, P.H.Rao, (2008), Seiesmic attributes – a Review, 7th International conference ans exposition of Geo physics, Hyderabad, India.
- Hasany, S. T., & Saleem, U. (2012). An integrated subsurface geological and engineering study of, Potwar plateau, Pakistan. Search and Discovery Article, 20151, 1 41.
- Khan, M.A., Ahmed, R., Raza, H.A, and Kemal, A., 1986, Geology of Petroleum in Kohat-Potwar depression, Pakistan: American Association of Petroleum Geologists Bulletin, V.70, no.4, P. 396414.
- Kazmi, A. H., & Jan, M. Q. (1997). Geology and tectonics of Pakistan.
- McQuillin, R., Bacon, M., and Barcaly, W., 1984 An introduction to seismic interpretation, Graham & Trotman Limited Sterling House, 66 Wilton Road London SW1V 1DE
- MonaLisa and Azam A. Khwaja, (2004). Structural trends and focal mechanism studies in the Potwar area with special emphasis on hydrocarbon exploration. Pakistan Journal of Hydrocarbon Research.
- Vol. 14, p. 49-60.
- Pennock, E. S., Lillie, R. J., Zaman, A. S. H., & Yousaf, M. (1989). Structural interpretation of seismic reflection data from eastern Salt Range and Potwar Plateau, Pakistan. AAPG Bulletin, 73(7), 841-857.
- Rider, M. H. (1986). The geological interpretation of well logs.
- Saggaf, M. M., & Nebrija, E. L. (2000). Estimation of lithologies and depositional facies from wire-line logs. AAPG bulletin, 84(10), 1633-1646.
- Shami B.A & Baig M.S, (2003), Geo modeling For Enhancement of
- Hydrocarbon Potential of Joya Mir oil field , POL, Rawalpindi, Pakistan, in SPE-Annual Technical Conference and Oil show 2003-Islamabad, Pakistan

- Sheriff, R.E., 1999. Encyclopedic dictionary of exploration geophysics, S.E.G., Tulsa, Oklahoma.
- Sroor, M. (2010). Geology & Geophysics in Oil Exploration. Mahmoud Ahmed Sroor.
- Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A. (1999), Applied Geophysics, Cambridge University Press, London.
- Velzeboer, C. J. (1981). The theoretical seismic reflection response of sedimentary sequences. Geophysics, 46(6), 843-853.
- Yilmaz.2001, Seismic Data Analysis and Processing, Inversion and Analysis of Seismic Data, Society of Exploration Geophysics, Tulsa