2D SEISMIC INTERPRETATION AND PETROPHYSICAL ANALAYSIS OF KHAUR AREA, UPPER INDUS BASIN, PAKISTAN

A thesis submitted t Bahria University, Islamabad in partial fulfillment of the requirement for the degree of B.S Geophysics

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DEDICATION

“To our Parents and Teachers who have been continuous source of inspiration for us, otherwise we would not have the goals we have to strive and be the best to reach our dreams

ABSTRACT

The present study was conducted to identify the structure and evaluate hydrocarbon potential by using the seismic and well log data of Khaur area, Upper Indus Basin, Pakistan. Khaur area lies near Chakwal District of Punjab region in the Potwar basin region of Upper Indus Basin Pakistan. The Potwar sub-basin is situated at the northern margin of the Pakistan in the western foothills of Himalaya. It comprises of the Potwar plateau, the Jhelum plain and the Salt Range. Khaur structure is thought to be enriched by potential hydrocarbon on the basis of structural and petroleum system studies. Reservoir was marked on seismic data by time-depth chart using average velocities. Time depth and velocity contour maps of Sakesar Limestone were generated which confirmed the Pop up structures in the subsurface. It is concluded that Chorgali Formation and Sakesar Limestone are a good reservoir based on the high effective porosity and low volume of shale, but it have high water saturation so it is not economical.

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CHAPTER 1

INTRODUCTION

1.1 Introduction to study area

Seismic method is the most direct and least ambiguous geophysical method for subsurface structural analysis. Seismic method gives detail subsurface structure analysis than any other method. Pakistan also depends upon oil and gas resources to fulfill energy requirements. Indigenous resources of oil are not enough to quench energy thirst of the growing economy. As a result, Pakistan has to import large quantity of oil and oil based products from Middle East countries. Pakistan needs more oil resources to fulfill energy requirements but gas reserves in the Pakistan are enough for current gas requirements. So natural gas is playing a key role in power sector. Pakistan has high potential of hydrocarbons in its northern (like Kohat, Potwar) and southern (like Badin, Mari etc.) parts (Jaswal et al., 1997).

The geological history of the "Indus Basin" dates back to Pre-Cambrian. Potwar sub-basin preserves the sediments from Precambrian to Quaternary in the subsurface and all of these are exposed in Salt Range. In Gujar Khan exploration license area OGDCL have drilled many wells, some of which are proven oil producers in Chorgali, Sakesar, and Khewra Formation. (Jaswal et al., 1997).

1.2 History

In the history before separation of India and Pakistan the first commercial success came with the drilling of Khaur OXY-1 by Attock Oil Company in 1915, on a surface anti-cline in the Potwar Basin. Oil was discovered in sands in the lower part of the Miocene Formation and a total of 396 shallow wells were drilled in the fields from 1915 to 1954. Steady exploration drilling continued in the Potwar Basin and led to the discovery of three oil fields. Interpretation model of new seismic data reveals new information that is the strata of platform sequence display a duplex geometry overlain by a passive roof complex of Siwaliks sequence as against earlier interpretation of a pop up structure. Closed area at Eocene level is 30 km^2. Structure is bounded by a main thrust fault in the strike direction. Few orthogonal faults exist which may provide lateral barriers to the flow during production. Khaur structure lies in Rawalpindi District of Punjab Province.

1.3 Location

Geographically Khaur Oil Field, is located on earth with a latitude 33°15'42"N - 33°16'06"N and longitude 72°27'19"E - 72°28'08"E. The study area (oilfield) is located in the area / province of Punjab in Pakistan.

Figure 1.1. Map location of khaur area

1.4 Base map

A base map have essential outlines and onto which additional geographical or topographical data placed for comparison or correlation. The seismic lines are PDK-111 (strike line/ control line) and rest of the lines PDK-106, PDK-107, PDK-108, PDK-110 are dip lines of Khaur area of Upper Indus Basin .The well name is Khaur OXY-1. The base map of Khaur area is below.

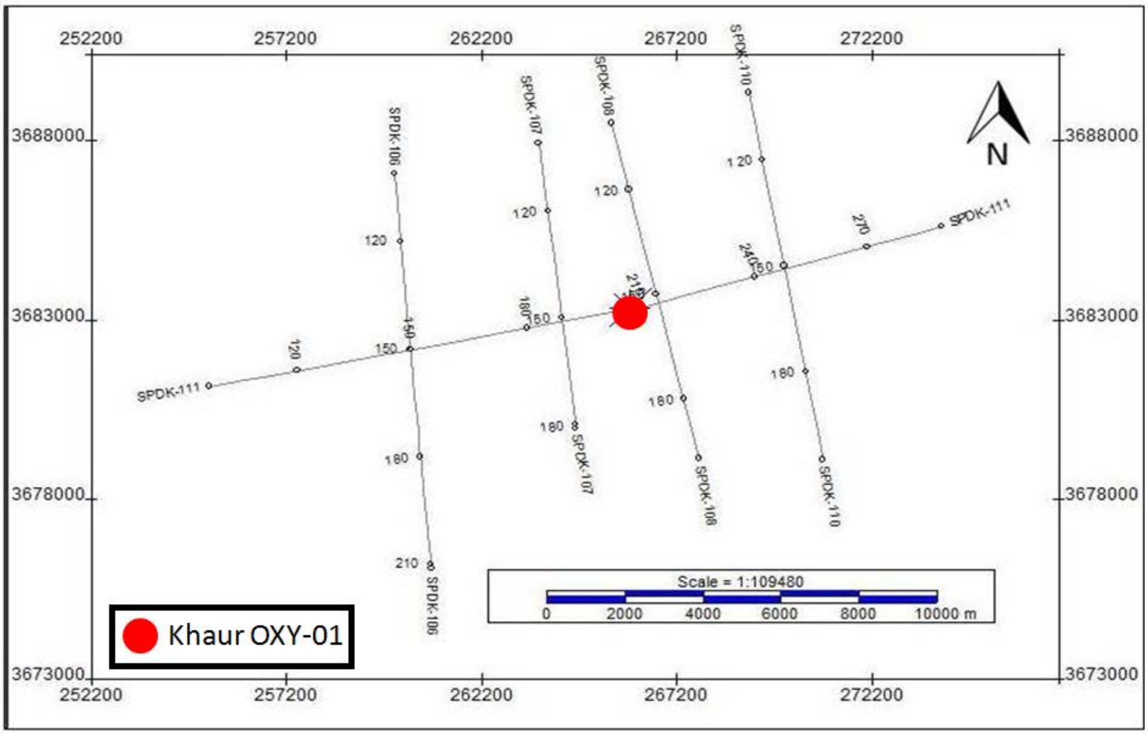

Figure 1.2. Basemap of Khaur area

1.5 Objectives of the study

The aim of the study was to interpret the subsurface structures and hydrocarbon potential in the deep reservoir of Khaur Oil and Gas field.

1. Delineate subsurface geology by interpretation steps as under:

- i. Solve velocity functions
- ii. Reflector identification
- iii. Fault identification
- iv. Calculate depth of target horizon

2. Petrophysical analysis of well data:

- i. Calculate porosity
- ii. Shale volume calculation
- iii. Water saturation calculation
- iv. Hydrocarbon saturation calculation

3. Correlation of Well Data with seismic data

4. Future prospects

CHAPTER 2

GEOLOGY OF STUDY AREA

2.1 Regional geology of Pakistan

Pakistan is a large country (79600 sq kilometers) with complex structures, which reflects its location at the boundary of Eurasian, Indo-Pakistan and Arabian plates. Pakistan is comprised of three broad geological subdivisions that, from north to south, may be referred to as the Laurasian, Tethyan and Gondwanaland domains. Their origin may be traced back to Late Paleozoic. In late Paleozoic all the continents had drifted to form a continuous landmass, the super continent of Pangaea. By Late Triassic, Pangaea had split into two super continents, Laurasia to the north and Gondwanaland to the south separated by the Tethys seaway. Pakistan is located at the junction of Gondwanian and Tethyan domains (Moghal et al, 2007).

2.2 Tectonic framework of Pakistan

Tectonics of Pakistan is characterized by two active convergent boundaries;

i. In the northeast there is an active continent-island arc-continental collision boundary, the west end of the Himalayan origin.

ii. In the southwest, there is an active boundary of oceanic lithosphere subducting arc-trench gap sediments and continental sediments, the oceanic part of the Arabian plate passing under the Makran arc-trench gap and Afghan microplate.

These two convergent boundaries are connected by a very large displacement north-south left lateral strike slip faults of Chaman-Transform Zone.

2.3 Tectonic zones of Pakistan

Tectonic zones are those zones of Pakistan which are highly unstable areas and seismically active areas. On the basis of plate tectonic features, geological structure, orogenic history (age and nature of deformation, magmatism and metamorphism) and lithofacies, Pakistan may be divided into the following broad tectonic zones.

i. Kohistan-ladakh magmatic arc

ii. Chagai magmatic arc
iii. Indus platform and foredeep
iv. East Baluchistan fold-and-thrust belt
v. Karakoram block
vi. Northwest himalayan fold-and-thrust belt
vii. Pakistan offshore
viii. Kakar khoarasan flysch basin and Makran accretionary zone

Within these broad above tectonic zones there are subtle differences in tectonic and changes in structure style to merit further subdivision into smaller subdivision. Here we are not concern about those we are going to discuss the relevant that is the Indus Platform and fore deep which is our area of interest as from all above mentioned tectonic zones our seismic line belongs to this area (Kazmi & Jan, 1997).

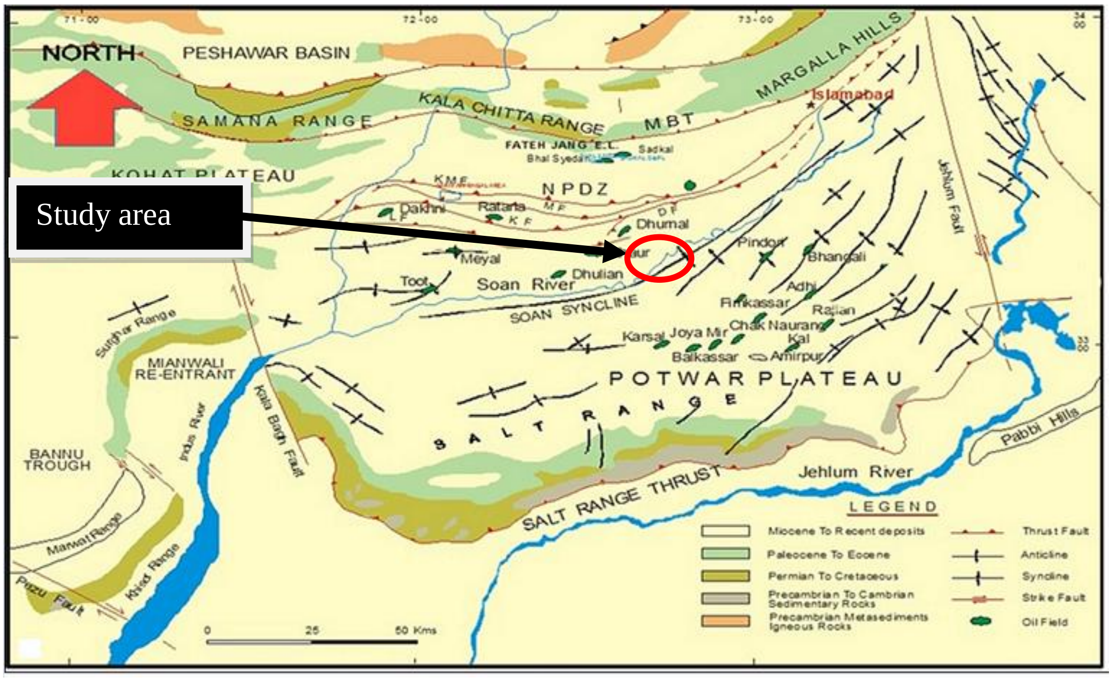

Figure 2.1. Tectonic map of khaur area (Khan et al., 1986; Gee, 1989).

2.4 Basins of Pakistan

Pakistan is comprised of following basins:

(1) Indus Basin
i. Upper Indus Basin
ii. Lower Indus Basin
iii. Central Indus Basin

iv. Southern Indus Basin

(2) Balochistan Basin

(3) Kakar Khorasan Basin

2.5 Indus basin

The geological history or the Indus Basin goes back to Precambrian age. The Paleotopographic features, shown on the gravity map of Pakistan, influenced, to a large extent, the depositional processes throughout the basin development. These features also marked the limit of the basin and its divisions. The ongoing tectonic processes further enhanced and modified the configuration and gave rise to sonic new ones creating an array of modern basins. The early Jurassic saw the first breakup of the supercontinent Pangaea which disturbed the equilibrium. Following is the classification of Indus Basin:

1) Upper Indus Basin

    i. Kohat sub-Basin
    ii. Potwar sub-Basin

2) Lower Indus Basin

    i. Central Indus Basin
    ii. Southern Indus Basin

2.6 Upper Indus basin

Upper Indus basin is located in the northern Pakistan and is separated from the Lower Indus Basin by Sargodha High. The northern and eastern boundaries coincide with the Main Boundary Thrust (MBT) the southern most of the major Himalayan thrusts. The MBT runs through the Margala Hills, Kala Chitta and Kohat Ranges. Western boundary of the basin is marked by an uplift of Pre-Eocene sediments and eastward directed thrusting to the west of Bannu. Upper Indus basin is further subdivided into Potwar, to the east and Kohat, to the west, by river Indus. Regardless of the small size of the Potwar and Kohat sub-basin they depict facies variations (Khan et al., 1986).

The Trans- Indus Ranges in South of the Kohat sub-basin expose sediments from Cambrian to Pliocene age. Potwar sub-basin preserves the sediments from

Precambrian to Quaternary age in the subsurface and all of these are exposed in the Salt Range, a southernmost thrust. Both Kohat and Potwar sub-basins are characterized by an unconformity between Cambrian and Permian. Mesozoic sediments are also exposed around the basin rim. However, this presence is governed by Pre-Paleocene erosion which progressively cut into older sequence from the Trans-Indus Ranges in the west to east Potwar through Salt Range. (Moghal et al, 2007).

In Kohat sub-basin, west of the Potwar sub-basin, Eocene through Siwaliks strata are involved in a complex fold and thrust belt in which Eocene Salt occupies the cores of many of anticlines (Khan et al., 1986).

2.6.1 Structural division

The structural divisions occur on the basis of faults and zones margins. The tectonic depression of Potwar basin is formed as a result of continent-to-continent collision at the northwestern margin of the Indian plate.

Presently, two-fold division is envisaged for the Potwar basin, on the basis of deformation style:

i. Northern Potwar Deformed Zone (NPDZ)
ii. The Platform Zone

The Northern Potwar Deformed Zone (NPDZ) is lying in south of Kalla Chitta Margalla Hills. It is structurally complex zone. In these areas tertiary rocks are exposed along a series of south verging thrust faults (Moghal et al, 2007).

The platform area is mainly covered with thick fluviatile sediments of Siwalik Group (Chinji, Nagri and DhokPathan Formations). These sediments have been folded along with underlying marine sediments of the Indian Plate as the result of the latest tertiary tectonic movements. The folded structures are generally oriented in sub-latitudinal fashion (Khan et al., 1986).

The platform zone is further subdivided into three parts

i. The eastern platform zone
ii. The central platform zone
iii. The western platform zone

2.7 Stratigraphy

The detailed stratigraphic sequence for the Potwar basin is given below

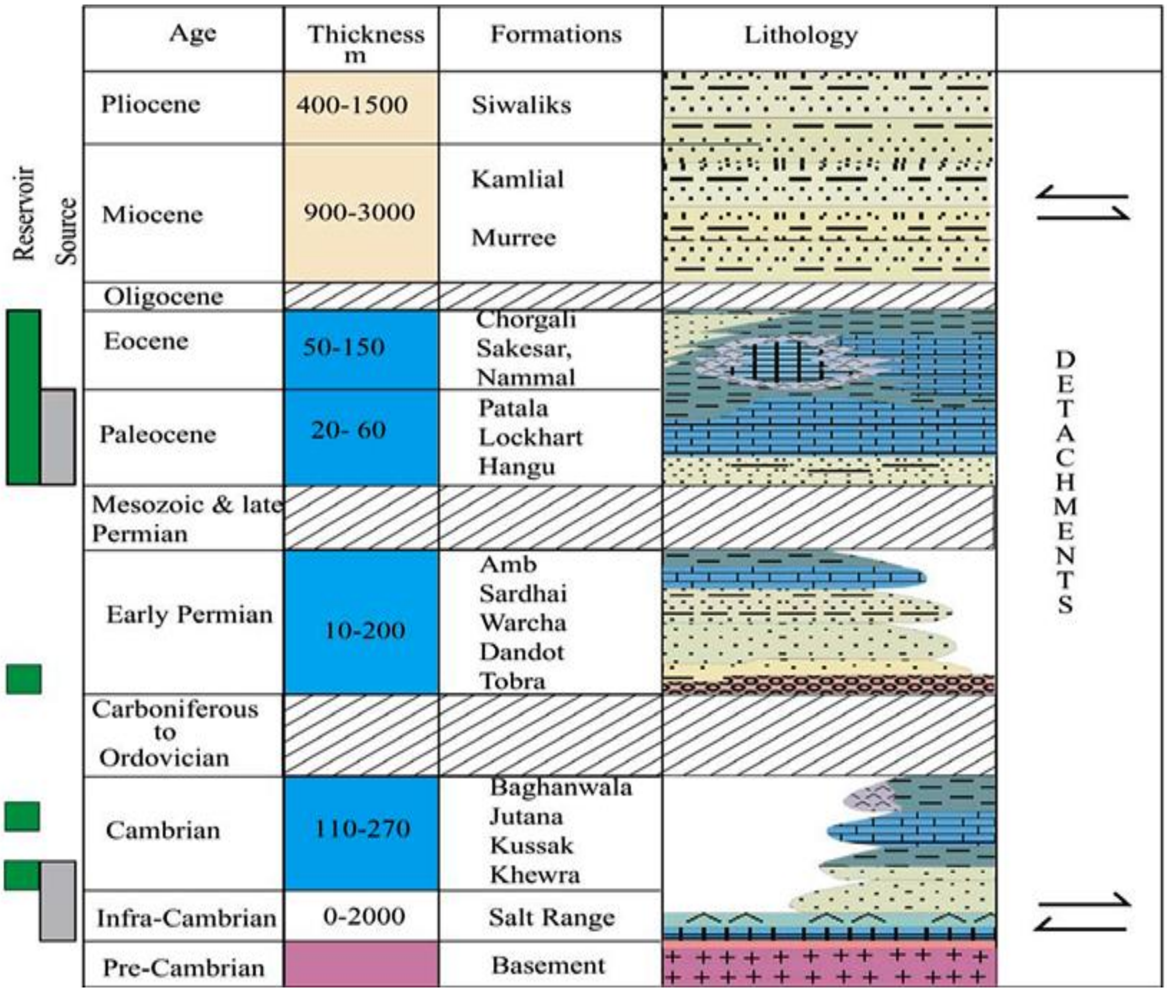

Figure 2.2. Stratigraphic column of Potwar Basin (Weandary, 1984).

2.8 Borehole stratigraphy

The stratigraphy of the well Khaur OXY-01 which is under study is given in the following table. Khaur OXY-01 has been drilled till the Tobra Formation of early Permian age. Khaur OXY-01 drilled till the total depth of 2733.3m. The main reservoir in the study area is Sakesar limestone (Ahmed et al., 2012).

Table 1.1.Borehole stratigraphy of well khaur OXY-01. (Provided by LMKR)

Formation name	Depth (m)	Thickness (m)
Murree	0	1649.8
Mami khel	1649.8	39.9
Bhadrar/Chorgali	1689.7	59.8
Sakesar	1749.5	94.5
Nammal	1844.0	25.9
Patala	1869.9	68.5
Lockhart	1938.4	72.5
Hangu	2014.9	10.7
Chhidru	2021.6	74.1
Wargal	2095.7	133.8
Amb	2229.5	75.6
Sardhai	2305.1	121
Warcha	2426.1	161.5
Dandot	2587.6	145.7
Tobra	2733.3	

2.9 Petroleum geology

The petroleum system required a source rock which capable to produce hydrocarbons, a reservoir rock which can store hydrocarbons and seal or cap on reservoir rock which stops further migration of hydrocarbons. The Kohat-Potwar depression has several features that make it a favorable site for hydrocarbon accumulations. Located on a continental margin, the depression is filled with thick deposits of sedimentary rocks, including potential source reservoir and cap rock. It contains a thick overburden (about 3000m) of fluvial sediments, which provide the burial depth and optimum geothermal gradient for seeps found in this area (Khan et al., 1986). The sedimentary rocks are deformed during thin-skinned Himalayan tectonics, forming the structural traps for hydrocarbons. (Coward and Butler, 1985).

This foreland basin is filled with thick sequence of sedimentary rocks. It contains thick overburden of 1980 m to 3050 m of fluvial sediments, which provide burial depth and optimum geothermal gradient for the Formation have oil (Shami and Baig, 2002).

2.9.1 Hydrocarbon potential

The SRPFB belongs to the category of extra continental down warp basins, these accounts for 48% of the world known petroleum. The thick overburden of 3047 m of molasse provides burial depth and optimum geothermal gradient for oil Formation. The SRPFB with an average geothermal gradient of 2 °C/100 m is producing oil from the depth of 2750-5200 m (Shami and Baig, 2002). The presence of an optimal combination of source, reservoir and trap within the oil window resulted oil and gas accumulation in Joya Mair, Toot, Meyal and Dhulian oilfields (Kozary et al., 1968).

2.9.2 Source rocks

Shales of the Patala Formation are the source rocks. These are well developed in this area.

2.9.3 Reservoir rocks

Limestone of the Sakesar Limestone of Eocene age was secondary objective in this well. It is proved being producers at Chak naurang, Ahdi, and Rajian Oil Fields. The reservoir rock found in this area is Chorgali Formation.

2.9.4 Cap rocks

The shale of the Chorgali Formation and Patala Formation serve as a cap rocks for underlying Sakesar Limestone.

CHAPTER 3

SEISMIC DATA INTERPRETATION

3.1 Introduction to seismic data interpretation

Seismic interpretation is the method to study and analysis the subsurface seismic data that was acquired and processed to reach the final picture of subsurface. Seismic interpretation is the transformation of seismic reflection into a structural picture by processing issue, contouring of subsurface horizons and further depth conversion by applying some suitable velocities. In seismic data interpretation subsurface model is prepared and correlate with previous models and studies. The seismic reflection interpretation usually consists of calculating the positions, and identifying geologically, concealed interfaces or sharp transition zones from seismic pulses returned to ground surface by reflection. The influence of varying geological conditions is eliminated along the profile to transform the irregular travel times into acceptable subsurface model. This is very important for confident estimation of depth and geometry of the bed rock or target horizon (Dobrin and Savit, 1988). The methodology adopted for interpretation consists of following points:

i. Making of prominent reflector
ii. Determination of velocities of selected reflector
iii. Time to depth conversion
iv. Restoration of depth section
v. Time contouring mapping
vi. There are two main approaches of interpretation of seismic reflection data.

There are two main approaches for the interpretation of the seismic section.

i. Structural analysis
ii. Stratigraphic analysis

3.2 Structural analysis

It is the study of reflector geometry on the basis of reflection time. The main purpose of structural analysis of seismic section is search of structural traps having hydrocarbon. The reflector geometry shows the subsurface structural variations which helps to mark structures, traps, horizons. Most structural interpretation using two-way reflection times rather depth and time structure maps are constructed to display the geometry of selected reflection events. The structural maps can produce from time structure maps by conversion of times in to depth using reasonable velocity.

3.3 Interpretation of given seismic sections

In my thesis work we interpreted the following lines as given below:

i. PDK-106 (Dip Line)
ii. PDK-107 (Dip Line)
iii. PDK-108 (Dip Line)
iv. PDK-110 (Dip Line)
v. PDK-111 (Strike Line)

These lines are located at Khaur area in Punjab province. The orientation of strike line was from West to East and orientation of dip lines was from north to south. Overall interpretation of the seismic section and the complete detail is given in the graphs below.

3.3.1 Identification of horizon

The first and the most important step in interpretation of a processed seismic section are to pick up the best seismic reflections from the seismic section. Reflectors are marked on the basis of prominent coherence of reflections visible, which appeal us most on the seismic section from the above subsurface interface. Two reflectors were marked in the seismic sections of the study area, which were designated as R1 and R2then this information is shifted to other lines by tying the seismic sections.

3.3.2 Identification of faults

After picking the best seismic reflection from the seismic section as horizon the next step in the seismic interpretation is identification of faults. The study is the part of the compressional regime. Therefore major thrust faults with some minor reverse faults.

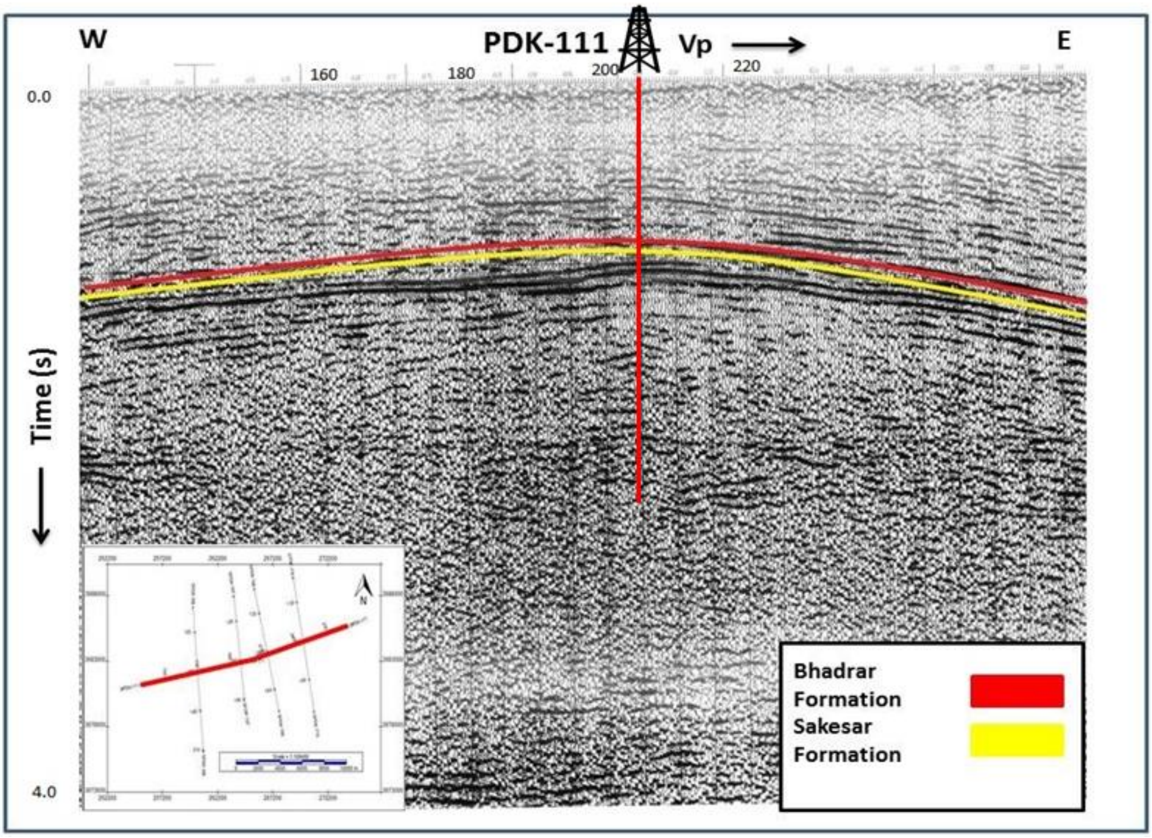

Figure 3.1. Interpretation of line PDK-111

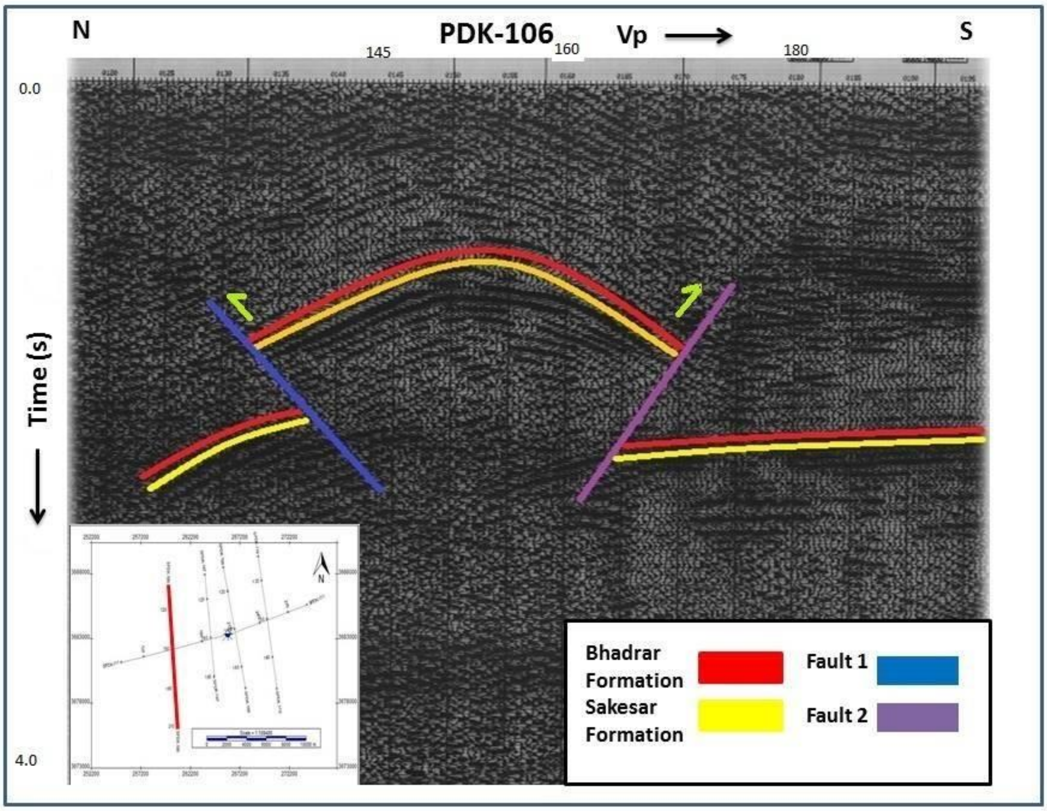

Figure 3.2. Interpretation of line PDK-106

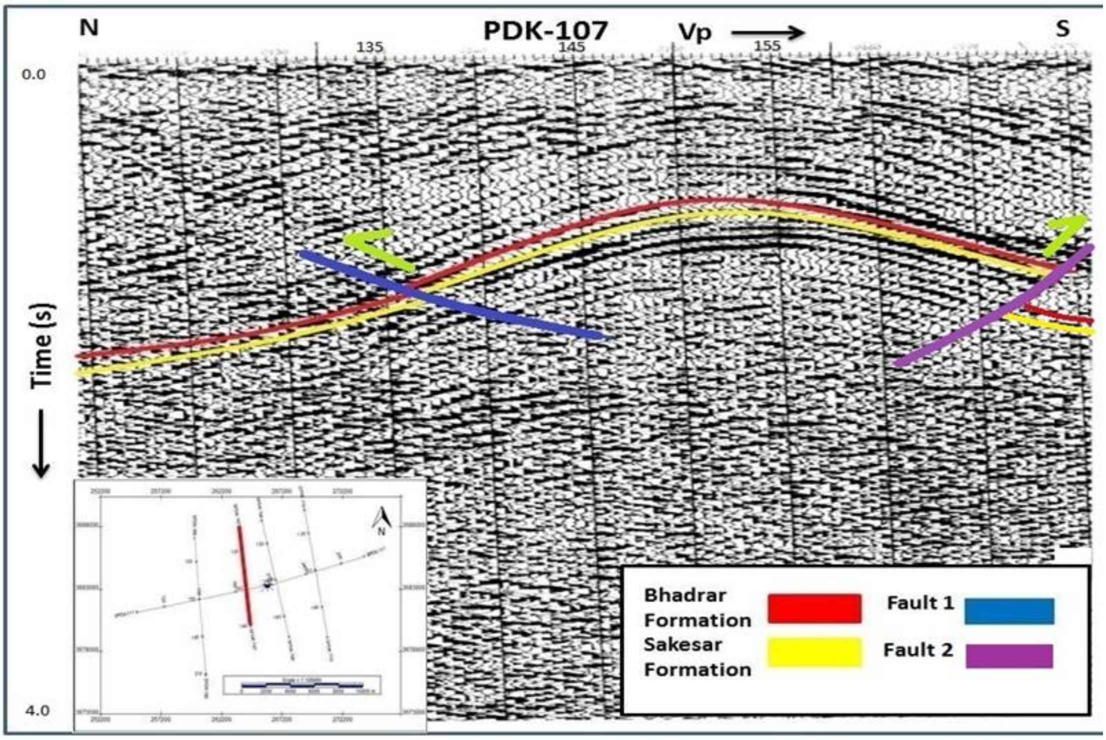

Figure 3.3.Interpretation of Line PDK-107

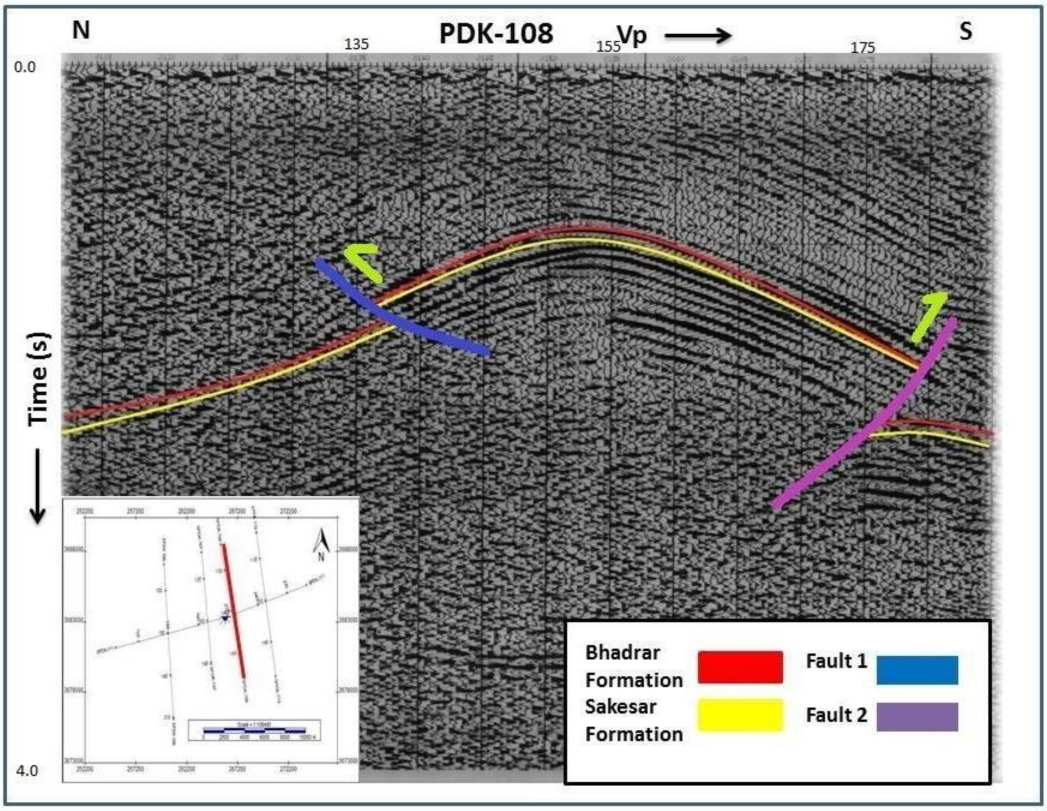

Figure 3.4. Interpretation of Line PDK-108

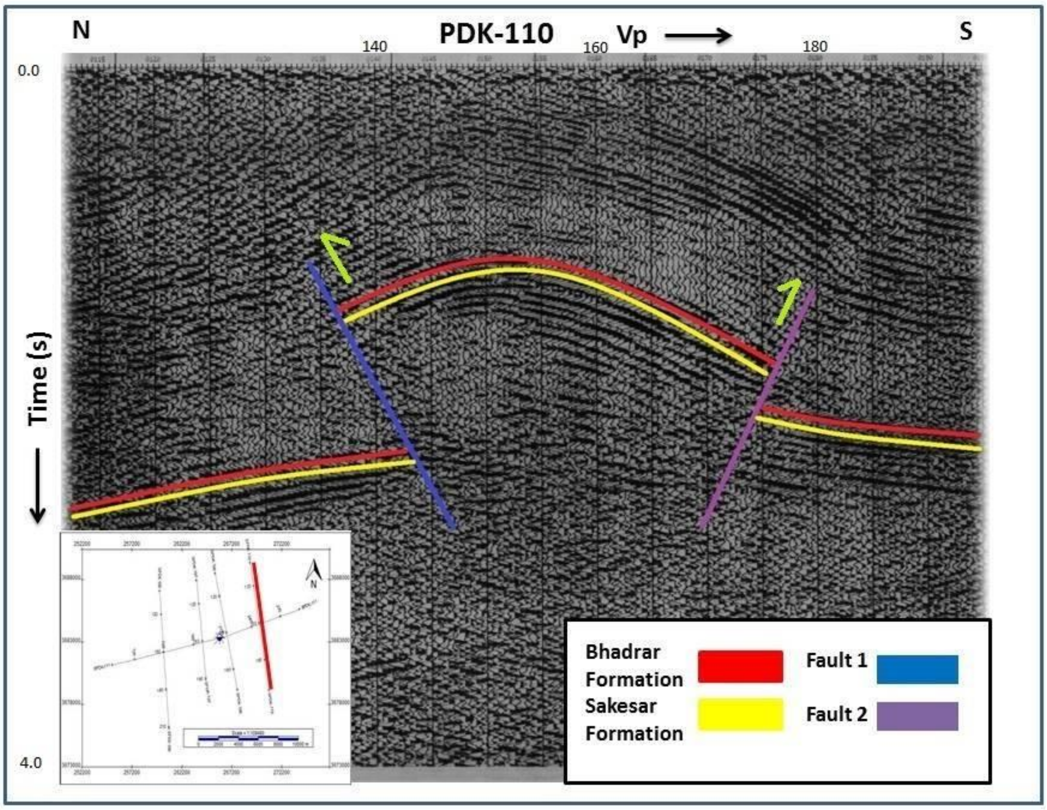

Figure 3.5. Interpretation of Line PDK-110

3.4 Seismic depth section

The depth section provides the configuration of reflectors in similar way as it is in the time section. To determine the depth, the initial step is to read times of each reflector from seismic section. Using the appropriate velocity values and time, the depth of each reflector is calculated as follows

$$Depth = (V \times T)/2$$

Where,

V= The velocity of respective reflector (m/s)

T= The two way travel time of each reflector (sec)

3.5 Estimation of seismic velocities

An accurate measurement of the seismic velocities is an important step in the seismic interpretation and processing. Two different methods were adopted in order to construct the depth section:

i. Mean Average Velocity Line Method

ii. Dix Average Contour Map Method

3.6 Time contour map

To make a time contour map it is necessary that more than one seismic sections of the same area must be interpreted. Along with seismic line PDK-106there are four other seismic lines (PDK-107, PDK-108, PDK-110 and PDK-111) which are interpreted and the time contour maps is made.

The time contour map is made by the following procedure

i. Transfer the time reading from seismic time section to their respective seismic lines on the base map after specific interval.

ii. Join the points of equal values on the seismic lines to construct iso-contour lines.

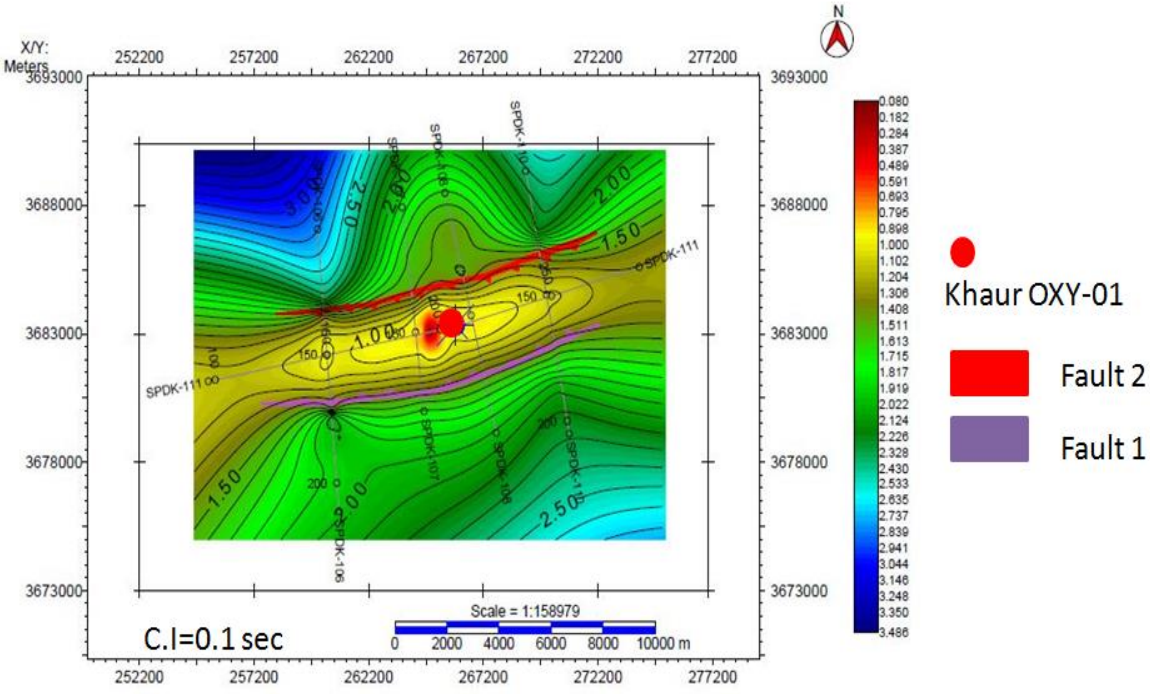

Figure 3.6.Time Contour Map of Reflector 1 (R1)

The above figure shows the time contour map of Reflector 1 (Badrar). The area between fault F1 and F2 is shown in light color representing minimum time and clearly indicate the pop-up structure made by these two thurst faults. Contour interval is 0.1 sec. Area bounded by fault F1 and F2 clearly indicate an anticlinal structure also Contours which are in dark color representing the area of maximum time. Well Khaur OXY-1 is drilled just beside the peak of the anticline. Time range of this contour map is from 800 to 3000 msec.

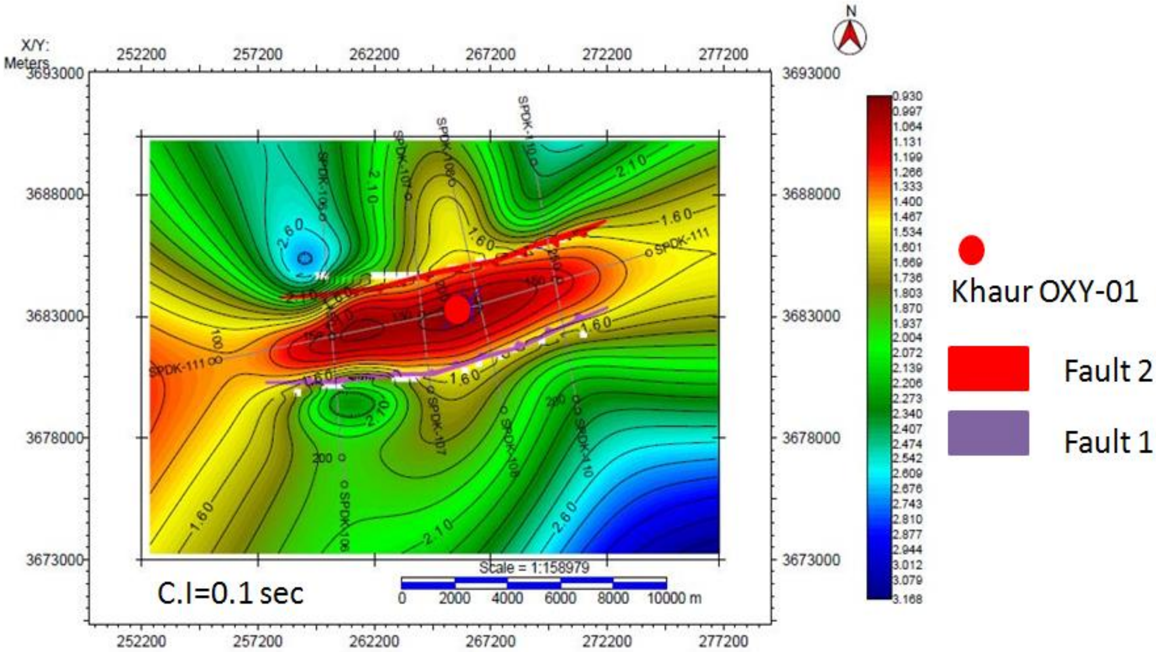

Figure 3.7. Time Contour Map of Reflector 2 (R2)

The above figure 3.8 shows the time contour map of Reflector 2 (Sakesar). Contour interval is 0.1 sec. The area bounded by fault F1 and F2 is showing the contour lines of less time which shows an anticlinal structure or a pop-up structure. The anticlinal structure is also verified by the closeness of contour lines near the faults. Both faults are thurst faults and they are dipping towards each other. Light colored contours are showing minimum time and dark colored contours are showing maximum time. Time range is from 800 to 3000 msec.

3.7 Velocity contour map

In this method, the velocities used for the determination of the depth of every reflector are estimated with the help of Average velocity contour map (Iso-velocity map). The different average velocities under the shot points are plotted along their respective times. Velocity maps are generated by using constant velocities against the respective Vibroseis point. Figures (3.6and 3.7) are showing Iso-Velocity maps of reflectors 1 and 2 respectively.

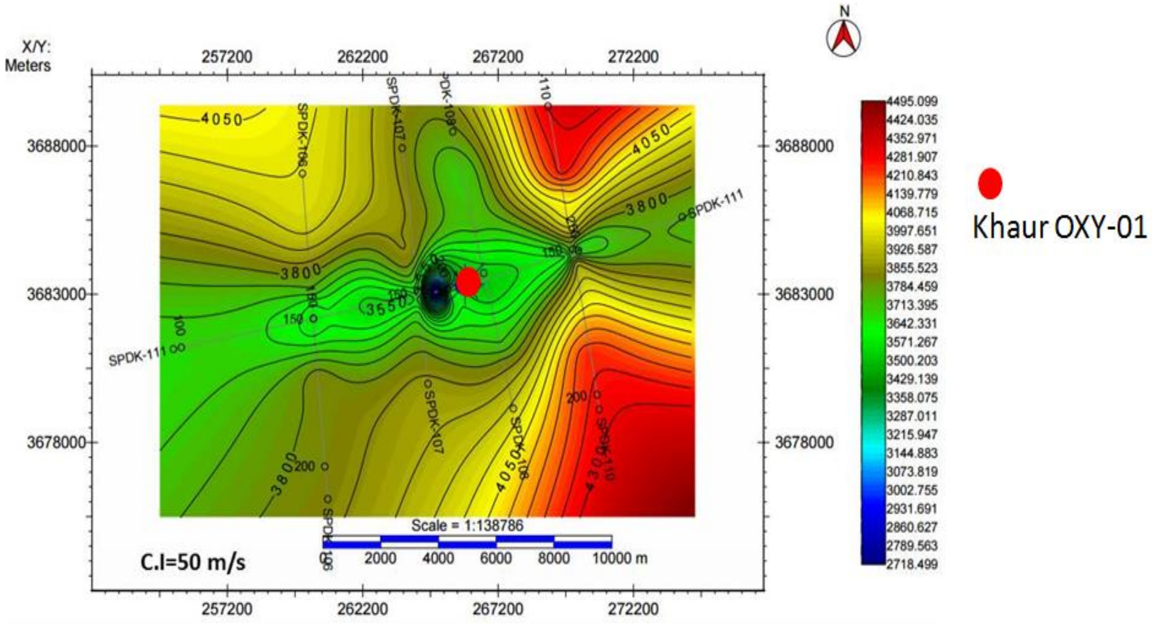

Figure 3.8.Velocity Contour Map of Reflector 1 (R1)

The above figure is showing the velocity contour map of Reflector 1 (Badrar). The contour interval is 50 m/s. Dark color is representing the zones of high velocity and light color is representing the zones of low velocity. Velocity is low where our structure (anticline) lies because of less compaction. Velocity range in the above map is from 3400m/s to 4350m/s.

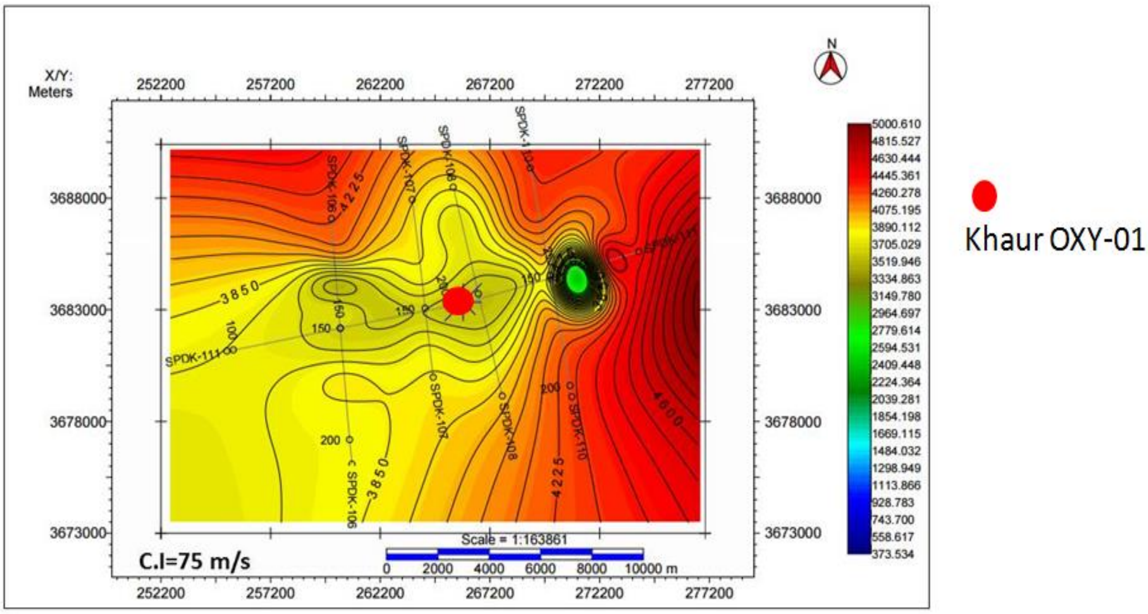

Figure 3.9. Velocity Contour Map of Reflector 2 (R2)

The above figure is showing the velocity contour map of Reflector 2 (Sakesar). The contour interval is 75 m/s. Dark color is representing the zones of high velocity and light color is representing the zones of low velocity. Velocity is low where our structure (anticline) lies because of less compaction.

3.8 Depth contour map

The depth of the Reflector 1 and 2 on the base map are contoured to make a depth contour map are showing in figures below. The contours show the exact locations of the structures present in the area.

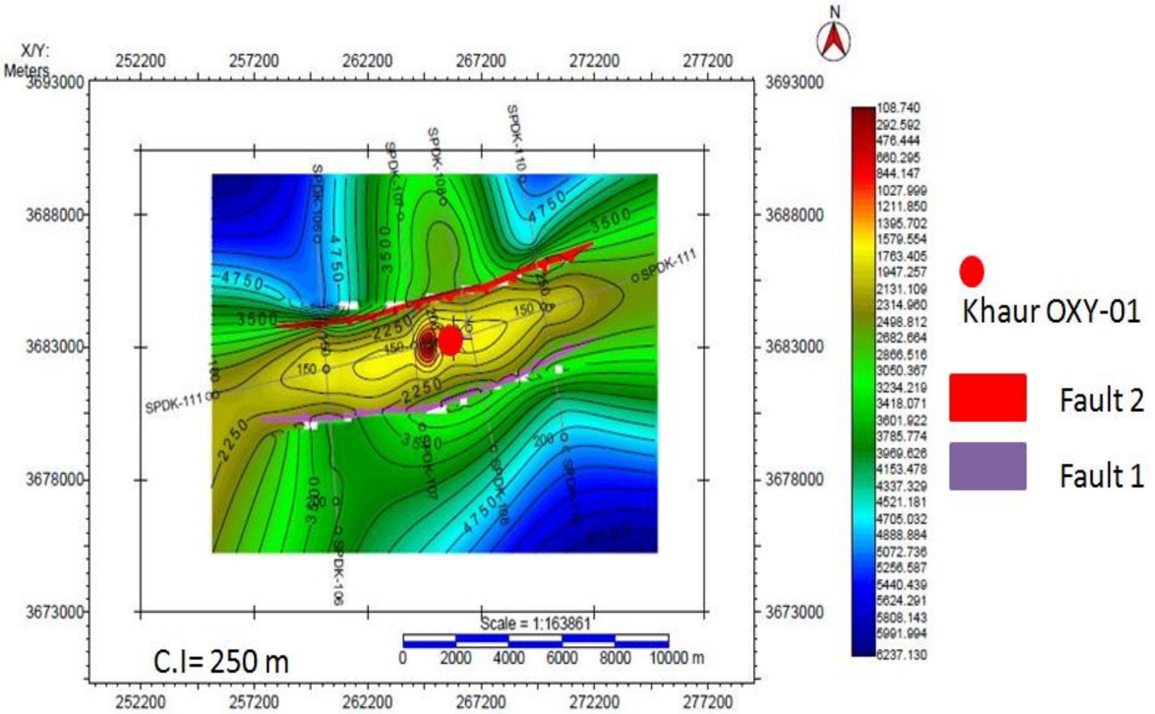

Figure 3.10. Depth Contour Map of Reflector 1 (R1)

The above figure 3.11 is showing the depth contour map of Reflector 1 (Bhadrar/Chorgali). Contour interval is 250 meters. Dark color is representing the contours of high depth and light colors are showing the contours of low depth. Two main faults i.e F1 and F2 are passing through that area and both of them are thurst faults and dipping towards each other and thus give rise to an anticline. The anticlinal structure is shown in light color between these two faults. Well khaur OXY-01 is drilled just beside the peak of anticline. Depth range of this contour map is from 1400 to 6200 meters.

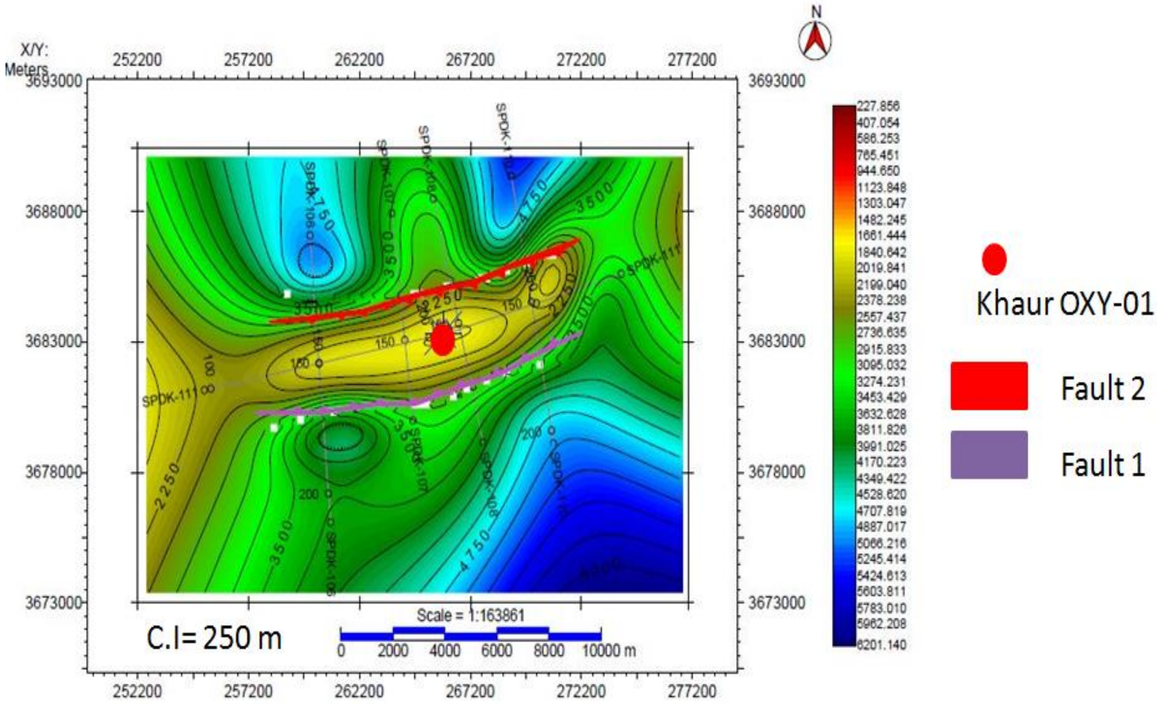

Figure 3.11. Depth Contour Map of Reflector 2 (R2)

The above figure is showing the depth contour map of Reflector 2 (Sakesar). Contour interval is 250 meters. Dark color is representing the contours of high depth and light colors are showing the contours of low depth. Two main faults i.e F1 and F2 are passing through that area and both of them are thurst faults and dipping towards each other and thus give rise to an anticline. The anticlinal structure is shown in light color between these two faults.

CHAPTER 4
PETROPHYSICAL ANALYSIS

4.1 Wireline logging

Well logs or wireline logs are continuous recordings of well depth versus different petrophysical characteristics of the rocks through which the well is drilled. There are many types of well logs, depending upon the characteristics of the rock being measured.(Mavko et al., 2003).

4.2 Logging objectives

The main purpose of well logging is:

i. To provide data for evaluating petroleum reservoirs
ii. To aid in testing, completion and repairing of the well

To calculate the oil reserve in an oil pool we need to know the following.

i. Thickness of the oil bearing Formation
ii. Porosity of the Formation
iii. Oil saturation
iv. Lateral extent of the pool

4.3 Types of well logging

Well logging is classified into three broad categories:

i. Open Hole Logging
ii. Cased Hole Logging
iii. Production Logging

4.3.1 Open hole logging

Logging surveys taken before the hole is cased are called open hole logs. The logs included in this group are:

i. Electrical surveys (induction, lateral log and microlog logs)
ii. Sonic logs

iii. Dip meter Logs
iv. Radioactive surveys (density, neutron and gamma ray logs)

4.3.2 Cased hole logging

Logging surveys taken after the casing is lowered are usually categorized as cased hole logs. The surveys included in this group are:

i. Gamma Ray
ii. Neutron
iii. Temperature
iv. Pulsed Neutron
v. Cement Bond Log
vi. Tracer Logs

4.3.3 Production logging

Well logging surveys taken to improve production or repair the well are termed as production logs.

4.4 Logs used for Khaur Oxy-1 well

Following are the logs which were used for the petrophysical analysis of well Khaur OXY-01.

i. Neutron Log
ii. Gamma Ray Log
iii. Density Log
iv. Resistivity Log
v. Sonic Log

4.4.1 Neutron log

Neutron logs are used principally for delineation of porous formations and determination of their porosity. They respond primarily to the amount of hydrogen in the formation. Thus, in clean Formations pores are filled with water or oil, the neutron log reflects the amount of liquid-filled porosity. Gas zones can often be identified by comparing the neutron log with another porosity log.

From Neutron Log NΦ (Neutron Porosity in %age) readings were noted against the each depth of Chorgali (Reservoir). These NΦ readings were used for the calculating the Porosity from Neutron-Density Cross plot. (Serra, 1984).

4.4.2 Gamma ray log

The GR Log is the measurement of natural radioactivity of the formations. In sedimentary formations the log normally reflects the Shale content of the formations. This is because the radioactive elements tend to concentrate in clays and shales. Clean formations usually have a very low level of radioactivity. The GR log can be recorded in cased wells, which makes it very useful as a correlation curve. (Serra, 1984)

4.4.3 Density log

Density Logs are primarily used as porosity logs. Other uses include identification of minerals in evaporate deposits, detection of gas, determination of hydrocarbon density, evaluation of shaly sands and complex lithologies, determination of Oil-Shale yield, calculation of overburden pressure and rock mechanical porosities.

From Density Log ρb (Bulk Density) values were noted against the each depth of Chorgali (Reservoir). These ρb values were used for the calculating the Porosity from Neutron-Density Cross plot. (Serra, 1984)

4.4.4 Resistivity log

In log evaluation the resistivity of the formation is the principal indicator of hydrocarbons; therefore emphasis has been put on the precise determination of resistivity. That is why quite a number of tools and techniques have been designed and developed to make very accurate measurements of this parameter (Mavko et al., 2003).

4.5 Types of resistivity logs

Various types of laterologs and induction logs are currently in the use, each designed to reduce adverse effects. These are given below.

4.5.1 Lateral log deep resistivity (LLD)

Lateral logs emit focusing currents to direct the path of the measured current through the mud and the invaded zone to the uninvaded formation. They reduce the effects of the borehole, adjacent formations and thin beds, but are still affected by hole diameter, mud resistivity and very thin formations with high resistivity contrast (Serra, 1984)

4.5.2 Lateral log shallow resistivity (LLS) and microspherically focused (MSFL)

The Dual Lateral log (DLL) consists of two advanced lateral log tools, which share the same electrodes on the primary Sonde. One lateral log is used for deep investigation of the undisturbed zone (Rt) and the other for shallow investigation of the transition zone (Ri).

4.6 Petrophysical analysis

During petrophysical interpretation different logs were used. The Gamma ray log is particularly useful for defining shale beds. When the SP is distorted or when the SP is featureless. The Gamma ray log can also be used for delineation of non radioactive minerals. During the log analysis of well (Khaur OXY-01), the Gamma ray log is used for the interpretation of shale volume.

4.6.1 Volume of shale by gamma ray log

In the quantitative evaluation of shale content, it is assumed that radioactive minerals other than shale are absent. The reservoir encountered in well (Khaur OXY-01) was Chorgali Formation and Sakesar Formation. Top of Chorgali Formation was at the depth of 1689.7m and its base was at the depth of 1749.5m. The base of Chorgali Formation is the top of Sakesar Formation and base depth of Sakesar Formation is 1844.0m.

Zones of interest

This well (Khaur OXY-01) was divided into different zones according to clean shale content at different depths. These zones were called as clean zones where API values were minimum. Due to this reason shale volume is minimum in these zones. So finally by noting the API values volume of Shale was calculated in these zones.

A gamma ray “shale index” I_{GR}, has been defined as

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} * 100$$

Where,

GRlog = log response in the zone of interest, API units

GRmin = log response in the clean beds, API units

GRmax = log response in the shale beds, API units (Serra, 1984)

4.6.2 Porosity

The porosity for most of the wells was computed from Neutron-Density Cross plot. NΦ values were read from Gamma ray log and ρb values were calculated from Density log. Porosity is derived by plotting the NΦ and ρb values on Neutron-Density Cross plot.

The Volume of Shale (%) and Porosity (%) calculated for both zones of Chorgali Formation (Reservoir) and Sekasar Formation are shown in the figures.

4.6.3 Water saturation

During the log analysis of well (Khaur oxy 1) Water Saturation (Sw) is calculated with the help of Archie Equation.

$$(Sw)^n = \frac{a}{\phi^m} \times \frac{Rw}{Rt}$$

Where

Sw = Water Saturation

n = Saturation exponent

a = Lithological coefficient

Φ= Porosity

m = Cementation factor

Rw = Resistivity of water

Rt = True resistivity (deep resistivity) at that or depth.

The values of m, n and a come from the core analysis of the data. We assume these three values to be constant.

n = 2

m = 2

a = 1

By putting values of theses parameters and simplifying the above equation it becomes as follows.

$$Sw\ (\%) = \sqrt{\frac{1}{\phi^2} \times \frac{Rw}{Rt}} \times 100$$

Now Sw values are calculated by using above formula.

4.6.4 Hydrocarbon saturation

The values of hydrocarbon saturation are calculated with the help of formula as under:

Sh (%) = 100-Sw (%)

Where

Sh (%) = Hydrocarbon saturation percentage

Sw (%) = Water Saturation percentage

Zone A (Bhadrar/Chorgali)

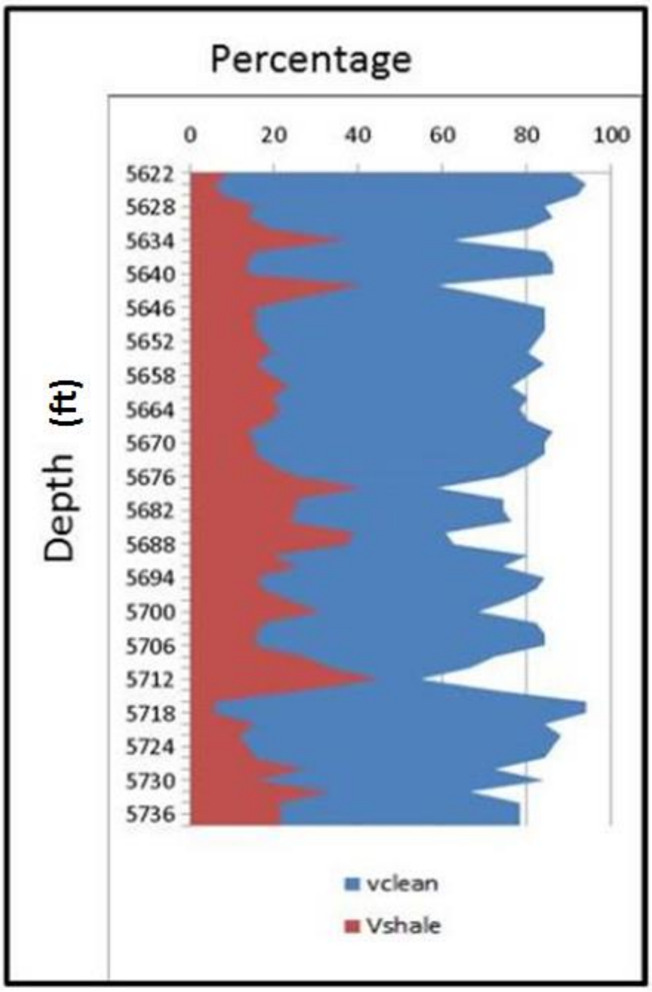

Figure 4.1. Shale Volume of Zone A (Chorgali)

The zone 'A' represents variation of volume of shale as a function of depth. The depth range in this plot is from 5622 to 5736 ft. Chorgali is our reservoir in this area. The maximum and minimum percentages of shale in this zone are 25% and minimum is 1.1% respectively.

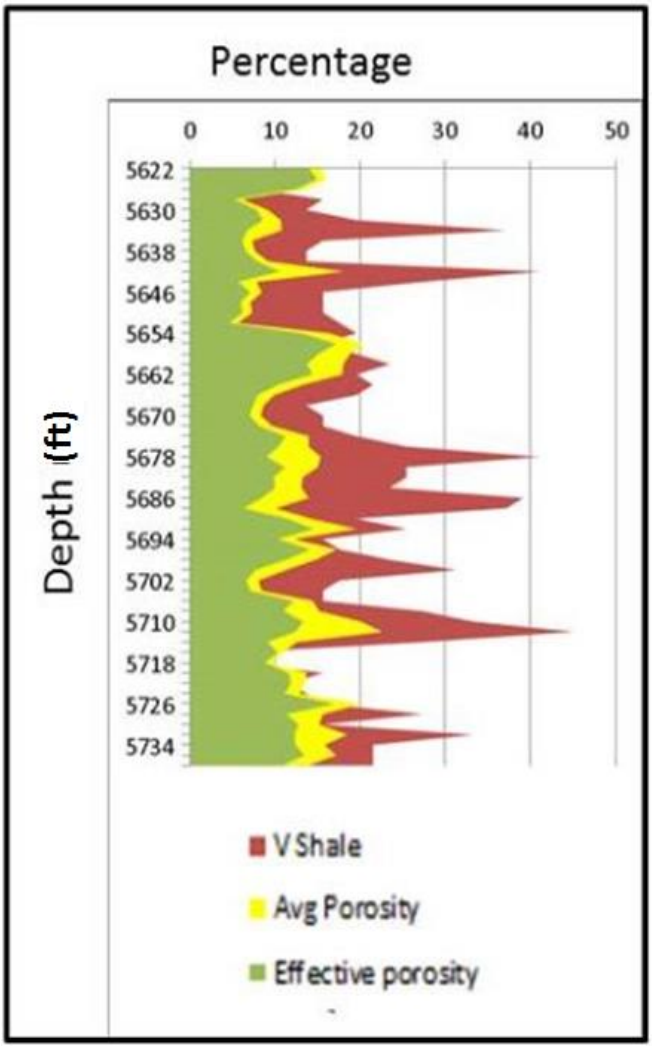

Figure 4.2. Effective Porosity of Zone A (Chorgali)

The above figure is showing the plot of depth vs effective porosity of zone A (Chorgali). The depth range in this plot is from 5622 to 5734ft. This zone is showing very good effective porosity as the maximum value of effective porosity is 22%.

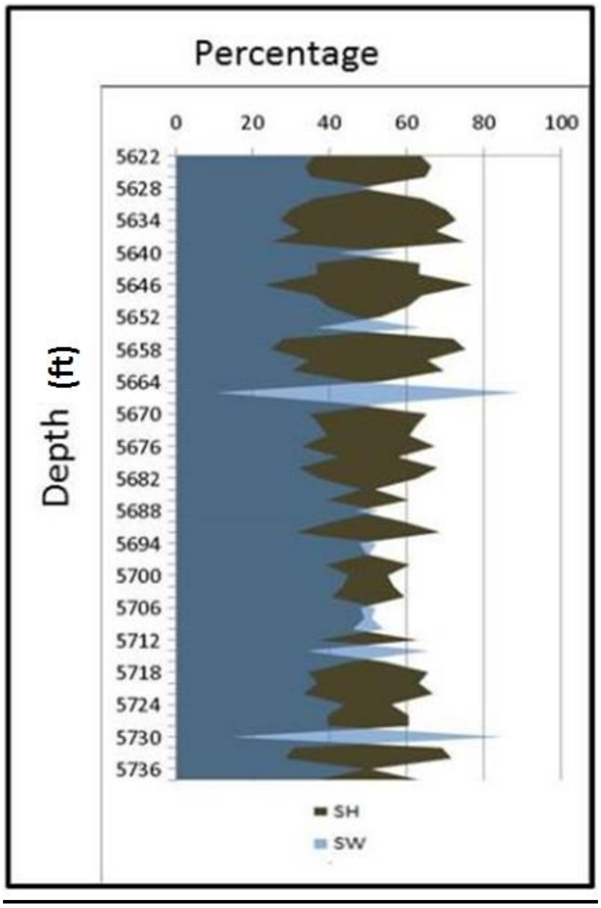

Figure 4.3. Water saturation & hydrocarbon saturation of Zone A (Chorgali)

The above figure is showing the plot of depth vs water saturation of zone A (Chorgali). The depth range in this plot is from 5622 to 5736ft. This zone is showing consistent saturation of water but from depth 5665 to 5730ft saturation of water is very low due to low volume of shale and high effective porosity and it is clearly indicating the presence of hydrocarbons within this depth range.

The above figure is showing the plot of depth vs hydrocarbon saturation of zone A (Chorgali). The depth range in this plot is from 5622 to 5736ft. Hydrocarbon saturation is very good in this zone between depth 5665 to 5730ft with highest value of 79% because of low shale volume, high effective porosity and less saturation of water. This zone has perfect hydrocarbon potential and that’s why it’s our reservoir zone.

Zone B (Sakesar)

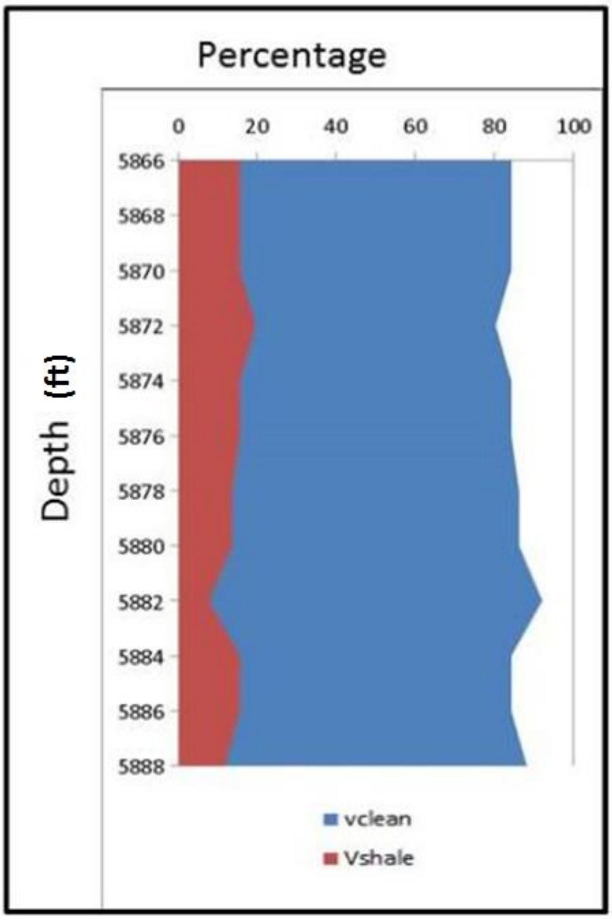

Figure 4.4. Shale Volume of Zone B (Sakesar)

The above figure is showing the plot of depth vs Shale volume of zone B (Sakesar). The depth range in this plot is from 5866 to 5888ft. The minimum values of shale are lies at depths range from 5874ft to 5882ft which is indicating the presence of hydrocarbons in this depth range.

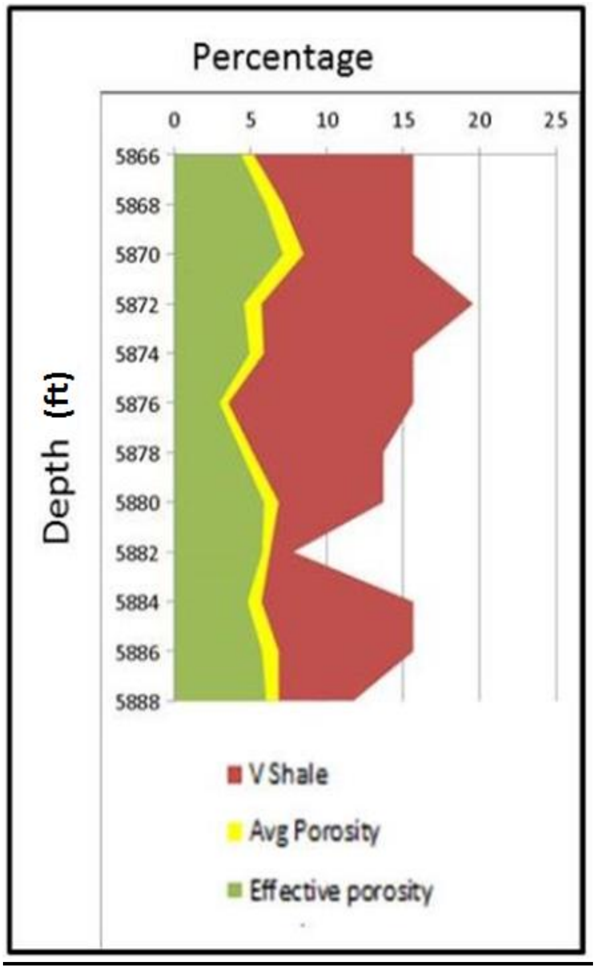

Figure 4.5. Effective Porosity of Zone B (Sakesar)

The above figure is showing the plot of depth vs effective porosity of zone B (Sakesar). The depth range in this plot is from 5866 to 5888ft. This zone is showing very good effective porosity from depth 5760 to 5850ft this is because of low volume of shale in the previous plot within the same depth. It shows that from depth 5760 to 5850ft our promising zone for hydrocarbons lies.

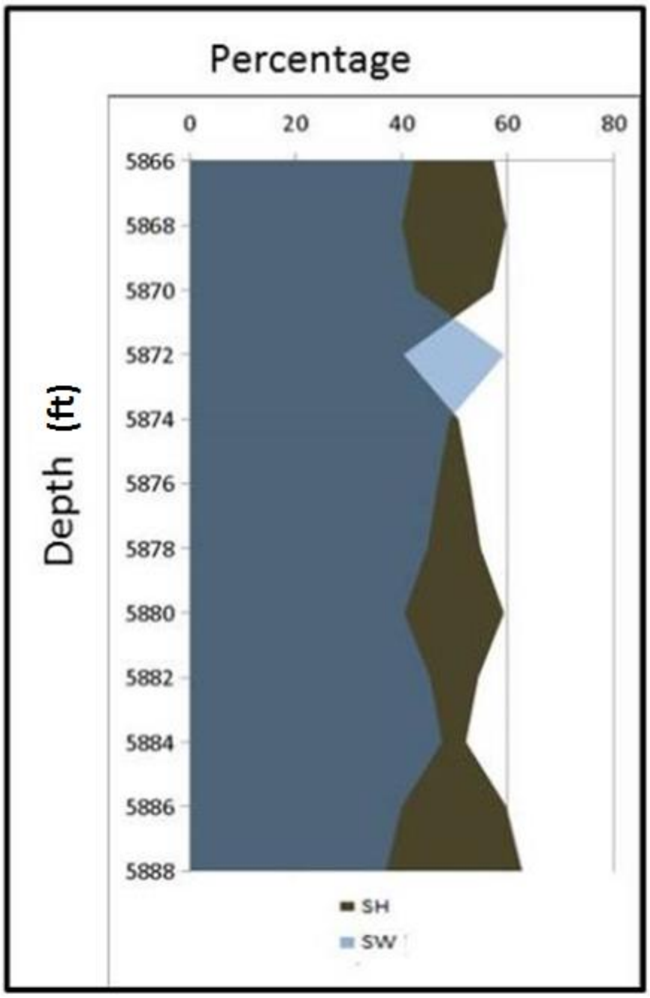

Figure 4.6. Water saturation & hydrocarbon saturation of Zone B (Sakesar)

The above figure is showing the plot of depth vs water saturation and hydrocarbon saturation of zone B (Sakesar). The depth range in this plot is from 5866 to 5888ft. Saturation of water is very low due to low volume of shale and high effective porosity and it is clearly indicating the presence of hydrocarbons within this depth range. Hydrocarbon saturation is very good in this zone between depth because of low Shale volume, high effective porosity and less saturation of water. This zone has perfect hydrocarbon potential and that’s why it is our reservoir zone.

RESULTS

i. In our Area Khaur two prominent reflectors are marked R1, R2, i.e. Bhadrar/Chorgali Formation (Limestone), Sakesar Limestone.
ii. The fractured Carbonates of the Sakesar and Chorgali Formation are the producing reservoirs.
iii. The faults bounding anticline are thrust faults (F1 and F2) dipping towards each other.
iv. The structure is an anticline.
v. The well is divided into two Zones i.e. Chorgali and Sakesar.
vi. Zone A which is Chorgali (Limestone) acting as a reservoir in this area because of low concentration of volume of shale. And also low saturation of water makes this formation a favorable reservoir for hydrocarbons but this hydrocarbon saturation is not economical in this well and water saturation exceeds so it get dry.
vii. Zone B Sakesar (Limestone) which is a also fair reservoir in this area but the hydrocarbon saturation does not show it as good as Bhadrar/Chorgali Formation.
viii. In anticlinal structure we observed has low seismic velocities because of less compaction. As the zone of interest is at depth 1690ft to 1749ft. The values we observed are quite low.

CONCLUSIONS

1. Seismic interpretation depicts that Himalayan orogeny related compressional forces in Khaur area generated pop-up structure.
2. The Khaur structure is an elongated, northeast southwest trending four way closure anticline and may be a structural trap for the accumulation of hydrocarbons.
3. Petrophysical analysis shows that Bhadrar and Sakesar Formation are not economically viable because of high water saturation.

RECOMMENDATIONS

i. High resolution seismic and wire line logs should be acquired in future operations.
ii. 3D seismic survey should be acquired in future to obtain the maximum information of subsurface.
iii. Advance seismic interpretation techniques such as AVO (Amplitude variation with offset), should be utilized to understand the reservoir characteristics more efficiently.
iv. For research work core samples should be taken from reservoir and source rock for lab analysis like geochemical analysis for source rock identification.

REFERENCES

Al-Sadi, H.N., 1980. Seismic Exploration Technique and Processing, 1st Ed, Birkhauser Verlag publications, Basel, Switzerland, 215p.

Badley, M.E., 1985. Practical Seismic Interpretation, IHRDC Publishers, Boston, 260p.

Coward and Butler, 1985. Deformation of Continental Crust, published by The Geological Society Publishing House UK, 155-186p.

Dobrin, M.B. and Savit, C.H., 1988. Introduction To Geophysical Prospecting, 4th Ed, McGraw-Hill, 867p.

Kazmi, A.H. and Jan, M.Q, 1997. Geology and Tectonics of Pakistan. Graphic publishers Karachi, Pakistan 1-27p.

Khan, A.M., Riaz Ahmed, Raza H.A., 1986. Geology of Petroleum in Kohat-Potwar Basin Pakistan, AAPG Bulletin, 396-414p.

Kozary, M.T., Edward S., Robert J., 1968. Structural Interpretation of Seismic Reflection Data from Eastern Salt Range and Potwar Plateau, Pakistan. AAPG Bulletin, 841- 857p.

Mujtaba, M., 2006. Pertroleum Prospects of Punjab Platform, Middle Indus Basin, Pakistan, through personnel communication.

Noetling, F., 1894. On the Cambrian Formation of the Eastern Salt Range 23-41. In: Shah. 1977. eds. Stratigraphy of Pakistan, Geological Survey of Pakistan, Quetta. 12p.

Qadri I.B., 1995. Petroluem Geology of Pakistan, Published by Pakistan Petroleum Limited, Karachi, 26-38p.

Raza H.A., Ahmed.R, Alam.S, and Ali S.M, 1989. Petroleum zones of Pakistan: Pakistan Journal of Hydrocarbon Research, vol 1, 1-19 p.

Robinson and Coruh, 1988. Basic Exploration Geophysics. Published by John Wiley & Sons. 25-70p.

Robert G. H. Reynolds Douglas W. Burbank, 1988. Stratigraphic Keys to the Timing of Thrusting in Terrestrial Foreland Basins, Applications to the Northwestern Himalaya Springer-Verlag, New York. 5p.

Schlumberger, 1974. Log interpretation, manual/applications vol II. Schlumberger well series Inc., Ridgefield. In: Asquith GB, Gibson C.R., 1982. Basic well log analysis for geologists, Tulsa, Oklahoma. 143p.

Shami B.A. and Baig M.S., 2002. Geomodelling for the Enhancement of Hydrocarbon Potential, Potwar , Pakistan. Proceeding of SPE-PAPG Annual Technical Conference 2002, 124-145p.

Thomas J. Ahrens, 1995. Rock Physics & Phase Relations: A Handbook of Physical Constants, American Geophysical Union, AGU Reference Shelf Series, Volume 3, Washington. 57-102p.