2D SEISMIC INTERPRETATION, PETROPHYSICAL ANALYSIS AND VOLUMETRIC ANALYSIS OF BALKASSAR FIELD, UPPER INDUS BASIN, PAKISTAN

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2017

ABSTRACT

The present study was conducted to reveal the subsurface geology of Balkassar area by the interpretation of seismic sections and to estimate the hydrocarbon saturation in order to find the reserves of hydrocarbon using petrophysical techniques. The horizons were marked with the help of provided well information (Balkasar OXY-1). The interpreted faults on each seismic section indicate the area belongs to compressional regime. Interpretation was performed on PBJ-03, PBJ-04, PBJ-05, PBJ06 and PBJ-09 seismic lines. Dip lines consisted of PBJ-03, PBJ-04, PBJ-05, and PBJ06 and the trend was Northwest-Southeast. PBJ-09 was the strike line along Southwest-Northeast. Information was given in time domain (milliseconds) so depth was calculated. The interpreted four horizons were correlated with formation tops of Chorgali Formation, Sakesar Limestone, Lockhart Formation and Khewra Sandstone. Contour maps were also generated which show the structure and gave the idea about tectonics of entire study area. With the help of well logs, saturation of hydrocarbon was determined in the zone of interest.

ACKNOWLEDGEMENTS

There are many people who deserve credit for seeing us through to the completion of our thesis and helping us in it. We are very grateful to our parents for their unwavering patience and support. We express our gratitude to the Head of Department of Earth and Environmental Sciences Bahria University Islamabad, Dr. Tehseen-Ullah-Bhangash for providing us this great opportunity to gain knowledge about our field and for providing us professional exposure. We would also like to show our appreciations to our supervisor, Mr. Fahad Mehmood, for his patience, co-operation, guidance and support during this time, without his help this could not have been possible. Also, Miss Urooj Shakir and Mr. Saqib Mehmood, Dr. Abid for their guidance whenever and wherever we needed it.

Finally, we would like to thank our seniors and friends for being supportive, co-operative and helping us.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Balkassar, our study area, is located in Upper Indus Basin. It lies in the central part of Potwar sub-basin that forms part of the Himalayan foreland fold and thrust belt (Kazmi and Jan 1997). It is a lease of POL (Pakistan Oilfield Limited) and was discovered by Attock Oil Company. The seismic lines used for studying were acquired by OGDCL.

Reflection Seismology is the most widely used method in the exploration of hydrocarbon. It determines the subsurface properties with the help of seismic waves which are reflected. A dynamite or vibroseis is used as a source in this method.

Petrophysics is the study of physical and chemical properties of rocks and how they interact with fluids. The interconnection of pores and accumulation and migration of hydrocarbons is investigated. Properties like porosity, water saturation and density are some of the main ones which are studied.

1.2 Location of study area

Balkassar oilfield is situated in Chakwal district which is about 105km from Islamabad in South. Oil and Gas Development Company Limited (OGDCL) has recorded the data and processed it. Balkassar area holds immense importance as it was hydrocarbon reserves among these, the Khewra Sandstone, Sakesar Limestone, and Chorgali Formation are proven reservoirs. Structures like pop up and anticlinal traps are present here. It was first discovered in 1945. In figure 1.1. shows the location Balkassar oil field.

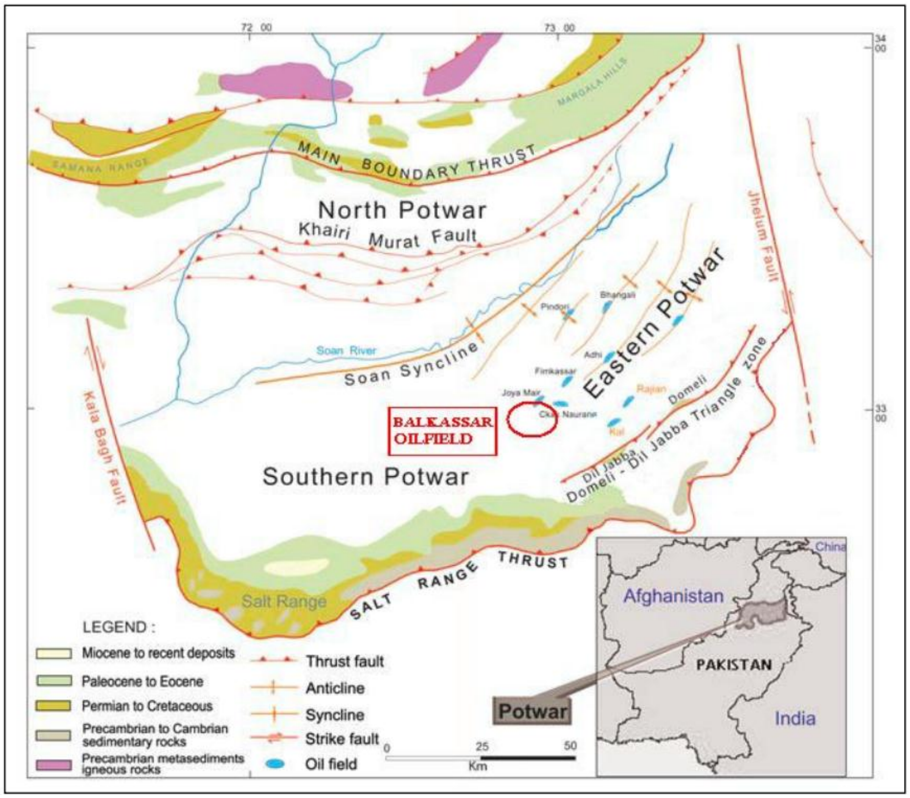

Figure 1.1. Location of Balkassar area. (Khan et al)

1.3 Objectives

1) To identify structural trend by interpreting seismic data

2) To mark the zone of interest and analyze them through petrophysical analysis

1.4 Methodology

1.4.1 Methodology for seismic data interpretation

1) Marking of horizons on seismic sections.

2) Identification of faults and their marking on the seismic section.

3) Preparation of time contour maps.

4) Preparation of depth contour maps.

1.4.2 Methodology for petrophysical analysis

1) Estimation of volume of shale

2) Porosity calculation

3) Effective porosity

4) Water saturation

5) Hydrocarbon saturation

1.5 Base map and well data detail

A base map can contain boundaries, wells, seismic survey points also buildings and roads. The basemap provides background details which are needed to align the location of the map. Figure 1.2. shows the base map of the study area along with its dip and strike lines.

Table 1.1. Available seismic lines for interpretation in Balkassar area.

Serial Number	**Line Name**	**Line Type**	**Line Orientation**
1	PBJ-9	Strike Line	NE-SW
2	PBJ-3	Dip Line	NW-SE
3	PBJ-4	Dip Line	NW-SE
4	PBJ-5	Dip Line	NW-SE
5	PBJ-6	Dip Line	NW-SE

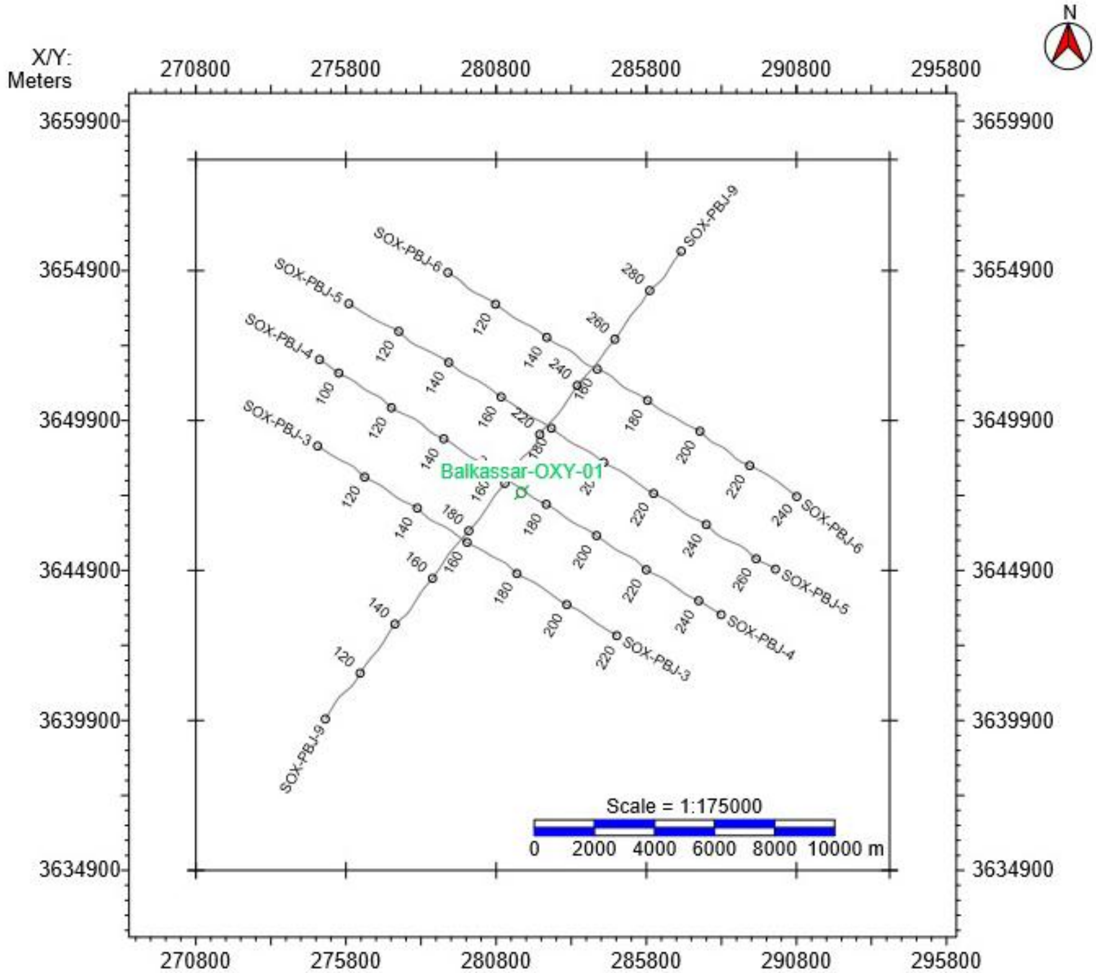

Figure 1.2. Base map of the study area.

CHAPTER 2

General Stratigraphy and Tectonics

2.1 Introduction

The data about the geology of a zone assumes an essential part for exact understanding of seismic data, since a few velocity impacts can be created from development of various lithologies and furthermore distinct velocities can be produce some lithological horizons. So as though we don't know topographical developments in range we don't perceive the diverse reflections showing up in the seismic data.

2.2 Stratigraphy

Formations from Pre-Cambrian age (Salt Range) to Pliocene-Pliestocene (Nagri Formation) are observed here in the Upper Indus Basin (Cheema, 1977). Lithologies are from shallow marine, fluvial, lacustrine to glacial environments, which can be figured out with the help of environment of depositions. In figure 2.1. stratigraphy of upper Indus basin is shown.

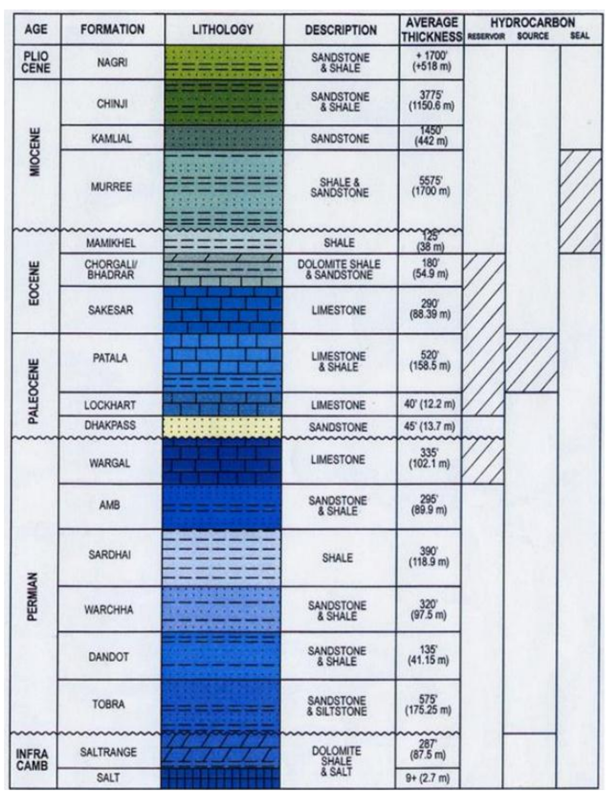

Figure 2.1. Stratigraphy of Upper Indus Basin (Shah, 1977)

2.3 Borehole Stratigraphy

Balkassar OXY-01 is drilled to the depth of 3130.6 meters. It contains formations from Pre-Cambrian to Pliocene-Pleistocene. Table shows the ages along with there formation tops.

Table 2.1. Thicknesses and ages of well data formations.

Formation	**Age**	**Thickness (m)**
Nagri	Pliocene	478.8
Chinji	Miocene	929.2
Kamlial	Miocene	105.9
Muree	Miocene	906.7
Chorgali	Eocene	45.7
Sakesar	Eocene	135.7
Patala	Paleocene	21.3
Lockhart	Paleocene	35.1
Hangu	Paleocene	27.4
Sardhai	Early Permian	109.7
Warcha	Early Permian	141.7
Dandot	Early Permian	61
Tobra	Early Permian	51.8
Khewra	Cambrian	78.3

2.3.1 Khewra Sandstone

Khewra Sandstone overlies Salt Range Formation of Pre-Cambrian age with no signs of disconformities, and above it Kussak Formation is present. It consists of purple and red sandstones, at the top massive sandstones are present while at the bottom shale is observed (Fatmi, 1973). Depositional features observed here are crossbedding, ripple marks and mud cracks. Traces of fossils like Trilobites can be spotted. The environment of deposition is deltaic.

2.3.2 Lockhart Formation

Lockhart Formation lies above Hangu and below Patala Formation without any signs of disconformities. It consists of Limestone, Shale and Marl (Fatmi, 1973). Fossils like Mollusks, Forams and Corals are spotted here and its environment of deposition is shallow marine.

2.3.3 Sakesar Limestone

Sakesar Limestone lies above Nammal and below Chorgali Formations. Lithology observed here is that of Limestone with Marl of cream light color (Fatmi, 1973). Forams and Mollusks can be seen here and the environment of deposition is shallow marine.

2.3.4 Chorgali Formation

Chorgali Formation lies above Sakesar and below Murree Formation with which it observes a major unconformity. Shale of greenish grey color, and calcareous limestone of grey color are present here. Fossils found here are Forams and Mollusks (Davies & Pinfold, 1937). Environment of deposition is shallow marine.

2.4 Tectonic Zones

Two wide geological divisions of this district the Gondowanian and the Thethyan Domains are talked about. In this situation Pakistan is exceptional in such a way as it is situated at the intersection of these two differing domains. The southeastern region of the Pakistan has a place with the Gondowanian Domain and is managed by the Indo-Pakistan crustal plate. The northern most and the western region of Pakistan fall in the Thethyan

Domain and present a convolute geological structure, orogenic history and lithofacies. Figure 2.2 is the map of Pakistan showing the regional location of the study area.

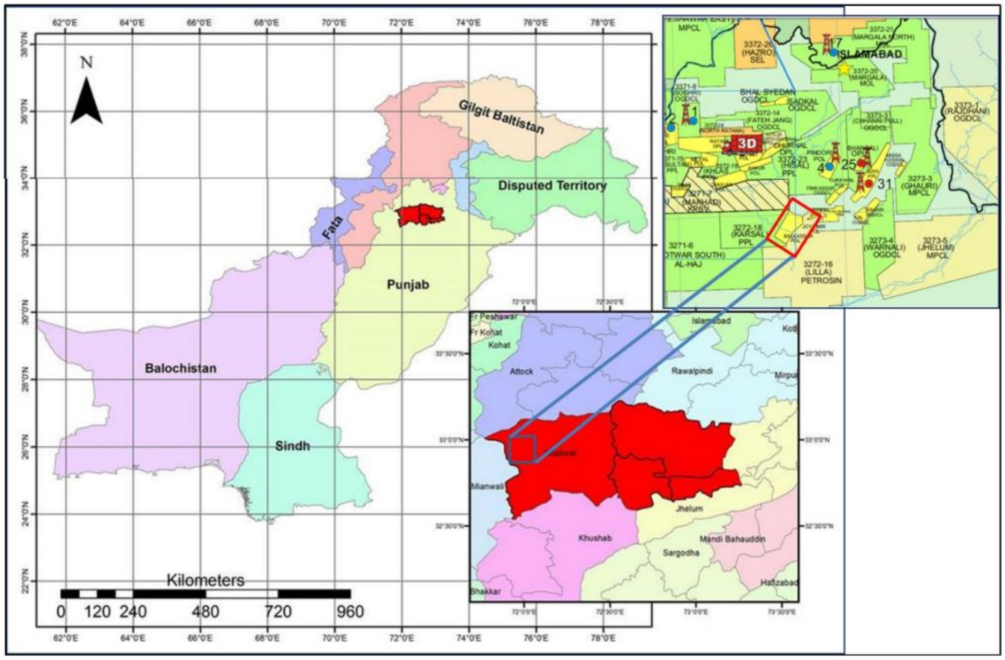

Figure 2.2. Regional Map. (Waqar, 2014)

1) Indus Platform and fore deep
2) East Baluchistan folds and thrust belt.
3) Northwest Himalayan fold and thrust belt.
4) Kohistan Ladakh magmatic arc.
5) Karakoram block Kara Khorasan Flysch basin and Makran acretionary zone.
6) Chagi magmatic arc.
7) Pakistan offshore.

2.5 Sedimentary Basins

Basin is an area described by provincial subsidence and in which sediments are protected for longer periods of time. In a basin a receptacle or holder which is basins substratum is called Basement. The container fill, which is the accumulation of sediments lying on the floor, is known as the Sedimentary cover. The slow setting of the basin is called Subsidence. The place of most extreme sedimentary gathering is called Depocenter. The Depocenter may not correlate to the zone of extreme subsidence. Pakistan has three sedimentary basins.

1) Indus basin
2) Baluchistan basin
3) Pishin basin

2.5.1 Indus Basin

Indus Basin incorporates 25000 square Km of South-East Pakistan. It incorporates the Thar-Cholistan leave and Indus Fields. It has 80% of the Pakistan populace. Structurally it is much stable when contrasted with other structural zones of Pakistan. It contains covered edges, stage slope, zone of up wrap and down wrap (Kazmi and Jan, 1977). Structurally Indus Basin is separated into two principle parts:

1) Upper Indus Basin
2) Lower Indus Basin

Upper Indus Basin is further classified into two basins:

1) Potwar Basin
2) Kohat Basin

Lower Indus Basin is also classified into two basins:

1) Central Indus Basin
2) Southern Indus Basin

2.5.2 Upper Indus Basin

It is situated in the Northern Pakistan and is separated from the lower Indus Basin by the Sargodah Hills in the north MBT, while in the east and west is the strike slip faults of Jehlum and Kalabagh are found. Upper Indus Basin is subdivided into Potwar and Koahat Basins along the Indus River (Kazmi and Jan, 1977). In the Upper Indus Basin the sediment deposition began Pre-Cambrian time. It is just on the basin in Pakistan which receive the sediment deposition from Pre-Cambrian time. The general stratigraphy of the Upper Indus Basin has appeared in figure 2.1.

2.5.3 Potwar Basin

2.5.3.1 Geological Boundaries

Potwar is a Fore-land fold and Thrust belt of Himalaya Orogeny that is limited by Kala-Chita and Margalla Hills toward the north, Indus River and Kohat Plateau in the west, Jehlum River and Hazara Kashmir Syntaxis in the east and Salt Range in the south. Potwar basin has wavy topography it is characterized by a progression of parallel ridges and valleys, by and large slanting in the E-W course. It is a part of the NW Himalayan Fold and Thrust Belt (Monaliza & Azam, 2004).

Structurally Potwar Basin is separated into North Potwar Deformed Zone in the north and Soan Syncline and Southern Potwar Deformed Zone in the south. Potwar Basin is secured by the molasses residue going in age from Miocene to Pleistocene. Precambrian to Quaternary succession is uncovered along the reaches in the south (Shami & Baig, 2002).

Potwar Sub Basin is portrayed by an unconformity amongst Cambrian and Permian. Mesozoic sediments are uncovered around the Basin edge.

Balkasssar is situated in the northern Punjab. In its north is the Potwar Plateau and Soan Syncline are available, in the south Salt Range Thrust , in the east Jehlum Fault, while in the left is the Kalabagh Fault. In the Balkassar area we generally get the anticline and the thrust regime, this indicates the compression regime is available in the zone.

2.6 Hydrocarbon Production in Potwar Region

2.6.1 Hydrocarbon Presence

The Potwar is one of the most oil rich region. The primary commercial discovery was made in1914 at Balkassar. The eastern Potwar district is a dominant oil and gas producing region. The oil and gas discoveries in the eastern region of the Potwar Plateau are situated in the sotheast of the Soan Syncline are for the most part from NE-SW extend anticlines. The Eocene to Cambrian plate formed deposits are around 40m thick in the eastern Potwar region. All through the eastern Potwar region, oil creation has been established by Eocene-Permian and Cambrian age rocks.

2.7 Petroleum in Potwar

Potwar marine facies has considerable potential for generation of hydrocarbon. Past drilling was restricted up to Eocene Carbonates. Recent revelations in Potwar brought about delineation of deep subsurface crest (Qadri, 1995).

2.7.1 Geothermal Gradient

Potwar region which is traditionally oil producing area of Pakistan has the average geo-thermal gradient of the order 2 degrees Celsius per 100m. Hence the oil window lies between 2750-5200 m (Qadri, 1995).

2.7.2 Source Rock

Hydrocarbon Development Institute of Pakistan (HDIP), in a coordinated effort with Federal Institute for Geosciences and Natural Resources (BGR) have distinguished various source rock horizons through Infra-Cambrian to Eocene in the Potwar Sub-basin and encompassing regions. These examinations recommend that the organic rich shale of the Paleocene (Patala Formation) can be assumed as the primary source for the Potwar oil fields.

In Potwar basin, Patala shales of Paleocene have demonstrated as the primary source rocks. These organic shale were somewhat deposited in anoxic conditions prevailing Paleocene because of collapsing of the basin floor. Pre-Cambrian Salt Range Formation likewise contains oil shale intervals, which indicate source rock potential. In Potwar the shale has normal estimations of TOC as 1.57 and hydrogen index as 2.68. The oil to source relationship show that the greater part of the oil formed in the Potwar Sub-basin has a source present in the Patala Formation.

Shale Khewra Formation are of lacustrine to marine origin and contain woody, coaly to abnormally amphorous kerogen, which are fit for producing paraffinic to typical crude oil and gas.

2.7.3 Reservoir Rocks

The Paleozoic-Tertiary predominantly marine sedimentary rocks from oil frameworks in Potwar and are uncovered in Salt Range Formation the Frontal Thrust. The carbonates of Sakesar and Chorgali Formations are fractured and they are the major production reservoirs in Balkassar. The limestones of the Paleocene Patala Formation additionally contain great reservoir conditions for hydrocarbons.

2.7.4 Traps and seals

Traps have been created because of sensitive tectonics in the region, which has resulted in anticlines with faults and pop-ups. above Pre-Cambrian salt. The clay and shale of the Murree Formation additionally give effective vertical and parallel seal to Eocene reservoirs at whatever point they come in contact with each other.

Chapter 3

Seismic Data Acquisition, Processing and Interpretation

3.1 Seismic Data Acquisition

Seismic data was acquired by placing a source and one or more than one receivers. These are placed at intervals. Vibration is produced through an energy source be it dynamite or vibroseis, depending on our parameters, and receivers are placed to detect the response of the Earth. Receiver records the seismic waves and converts the mechanical energy into electrical energy. This energy is then sent to recorder where it is stored and can be investigated (Yilmaz, 2001).

Sources are mainly dynamite or a vibroseis as mentioned before and receivers are generally geophones. As the wave is generated from the source it travels into the Earth subsurface and interacts with the underlying rock layers. The wave is reflected back from these rock layers to the surface which is due to the contrast in the density. These waves which are reflected are recorded by geophones. Through this information like the velocity of the wave as it travels through different rock layers can be obtained.

Depending upon the conditions like the geological features and the surroundings different configurations of receivers are used. The purpose of the layout of these receivers is to cancel or minimize the effect of noise that masks the signal. By using appropriate configurations, computer processing techniques can be applied to the data to enhance the signal to noise ratio.

3.2 Seismic data processing

In seismic data processing the main focus is on enhancing the signal to noise ratio. Data processing depends on how good the data acquisition is. If the data acquisition is good, not much processing would be required. The goal is to transform the data into image of the sub-surface that can be interpreted and it is to be kept in mind that the data is not to modified so much that it's originality suffers. Other than enhancing the signal to noise ratio it increases the resolution of data.

There are different steps involved in the processing but broadly they can be put under the following categories:

1) Data reduction

2) Geometric correction
3) Data analysis and parameter optimization
4) Data refinement
5) Data presentation and storage

In data reduction multiplexing and demultiplexing are performed. Static and dynamic corrections are applied in geometric corrections. Velocity analysis, deconvolution and gains are included in data analysis and parameter optimization, and Filtering and migration is done to refine the data.

3.3 Seismic data interpretation

After acquisition and processing, the last step is to interpret the data. There are different structures in the sub-surface which are studied through the seismic sections. Seismic section interpretation relies on the interpreter to select the reflecting horizons, the generation of time-depth chart is also dependent upon this. Seismic method is widely used and is important is the oil and gas industry to study the subsurface, as it provides good structural images.

Following steps are taken into consideration when interpreting the seismic data;

3.3.1 Time depth chart

Time and velocity was picked from the velocity column nearest to the well and depth was calculated, by using the values of time and depth time depth was generated, by taking depth on the vertical axis and time on the horizontal axis and best fit line was passed from the points taken from the velocity column. Time-depth chart is shown in figure. 3.1.

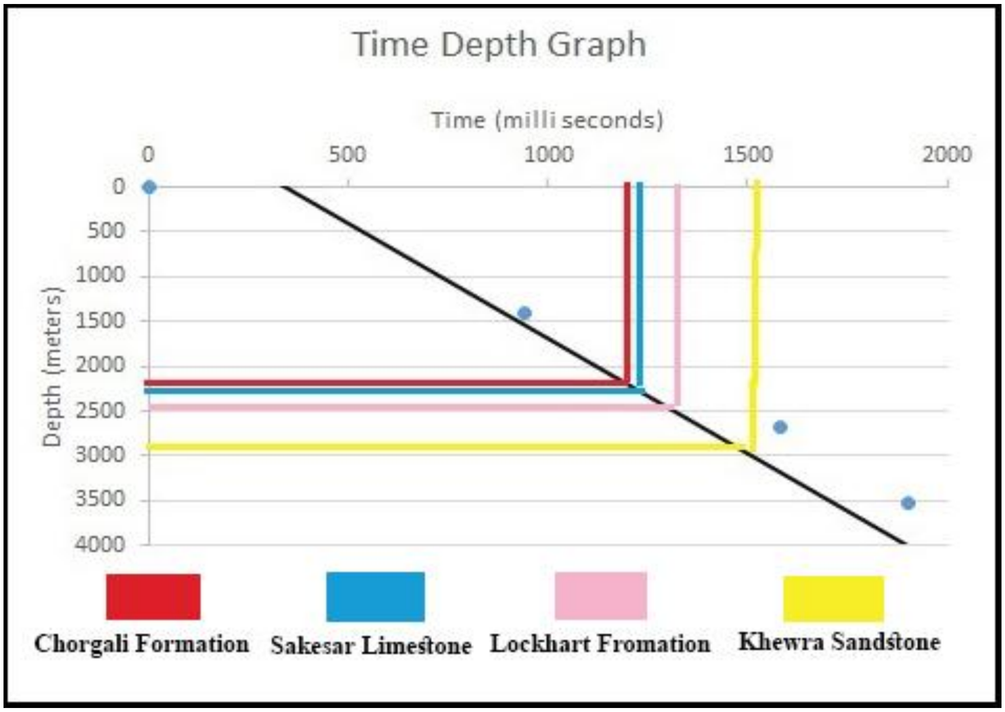

Figure 3.1. Time-Depth Chart of Balkassar Oxy-1.

3.3.2 Marking of horizons

Horizons are marked on the time section by picking continuous wavelets. As the wavelets can appear mixed up so confusion can arise or due to any geological changes. Noises are the most common type of problem that is faced and they cause distortion. So, self-judgment of the interpreter along with knowledge and experience helps a lot in marking these horizons.

Four horizons were marked on all seismic lines of Balkassar area which are.

1) Chorgali Formation
2) Sakesar Limestone
3) Lockhart Formation
4) Khewra Sandstone

By following similar steps all these horizons were marked and no problem was faced.

Table 3.1. Time and depth of marked horizons.

Formation	Depth (m)	Time (sec)
Chorgali Formation	2235.97	1.354
Sakesar Limestone	2281.67	1.377
Lockhart Formation	2438.67	1.455
Khewra Sandstone	2865.37	1.649

3.3.3 Identification and correlation of horizons

First and foremost reflections and unconformities are judged, as to if they are present on the seismic lines. Reflectors which show good continuity are selected. Interpretation is done based on acoustic impedance or broadening or narrowing down of the formations.

Depths were given in Kelly bushing (KB) so they were to be converted into Seismic Reference Datum (SRD). With the help of the base map it was known that the well lay at PBJ-4. And the horizons were marked firstly on it and then the data was transferred onto PBJ-9 which is the strike line and after that horizons were marked on rest of the lines.

3.3.4 Identification of faults

As the break appears in the continuity of the train of wavelets, fault is marked. Some faults which are prominent can be easily identified and marked.

3.3.5 Interpretation of seismic line PBJ-4

PBJ-4 is the control line as the well is located on it. PBJ-4 is a dip line and well is marked at shot point of 170 approximately

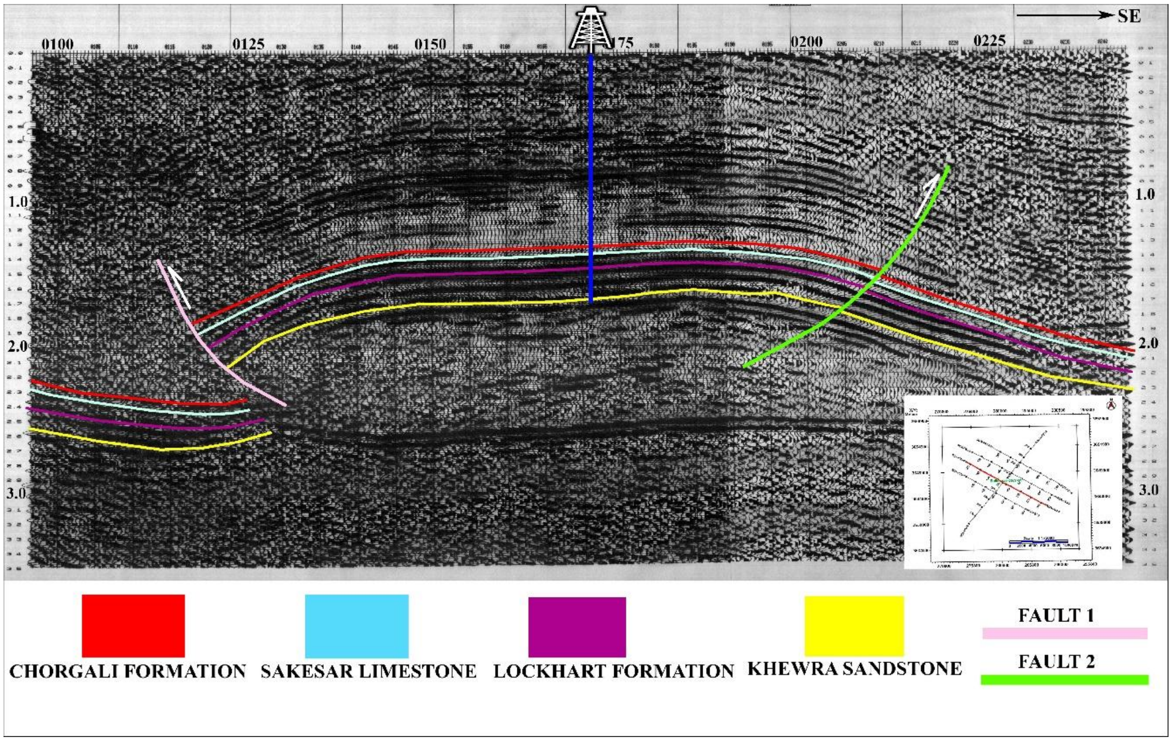

Figure 3.2. Interpreted seismic line PBJ-4.

Two thrust faults F1 and F2 can be observed here. F1 is back thrust fault which is South- east dipping and F2 is fore thrust which is North-west dipping. Presence of both of them makes a popup structure, which can be observed here in the figure 3.2.

3.3.6 Interpretation of seismic line PBJ-9

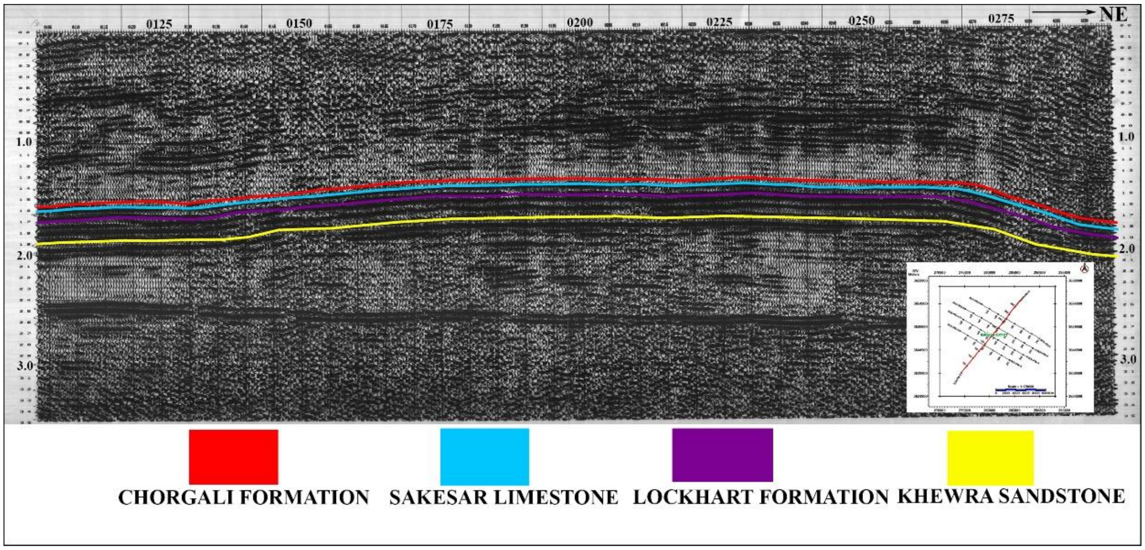

Figure 3.3. Interpreted seismic line PBJ-9.

Figure 3.3, shows the strike line PBJ-9. Control is transferred to it from PBJ-4. No major structure was found and simple straight horizons were marked because the strike line was parallel to the faults and no fault cut the strike line.

3.3.7 Interpretation of seismic line PBJ-3

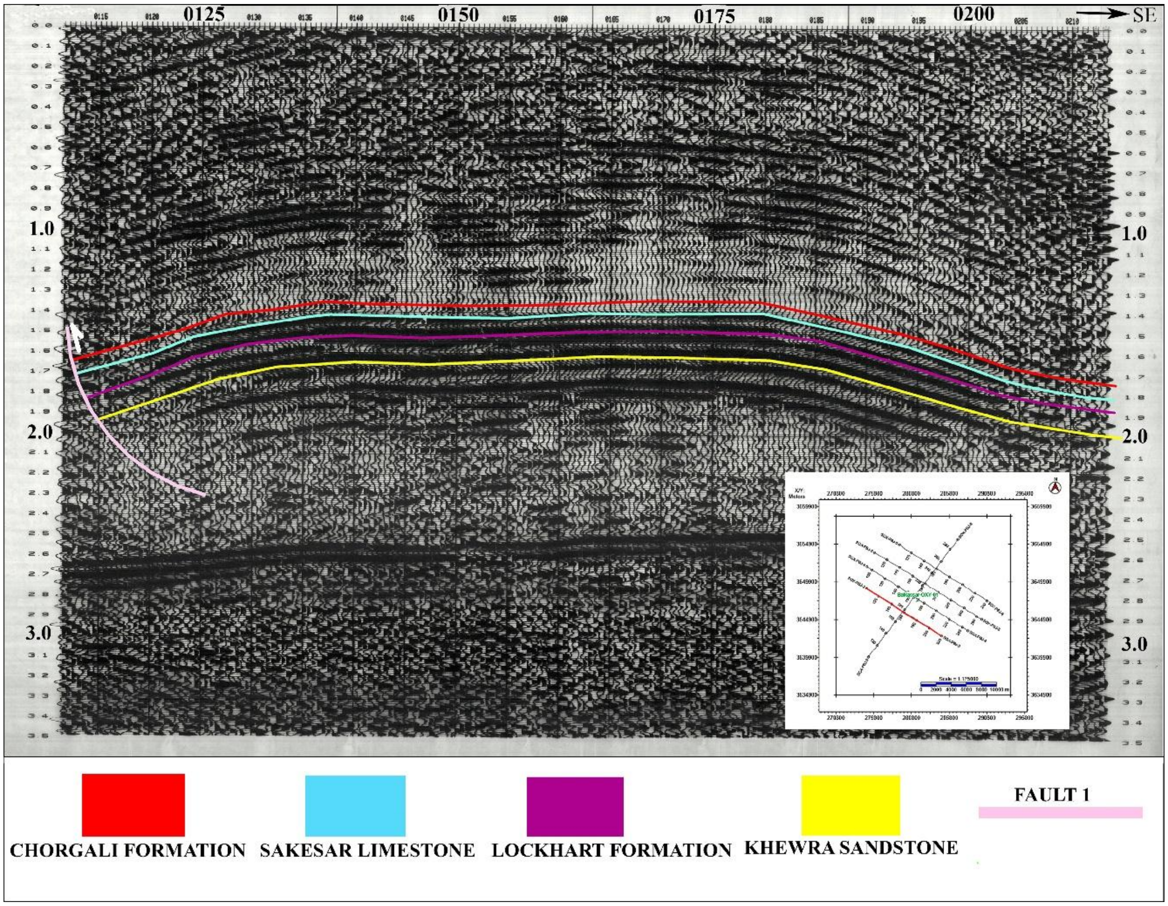

Figure 3.4. Interpreted seismic line PBJ-3.

F1 can be observed in PBJ-3, As we move towards the south the tectonic forces are less, this line is in the southern part so the fore thrust fault (F2) was not observed. Which is showed in above figure 3.4.

3.3.8 Interpretation of seismic line PBJ-5

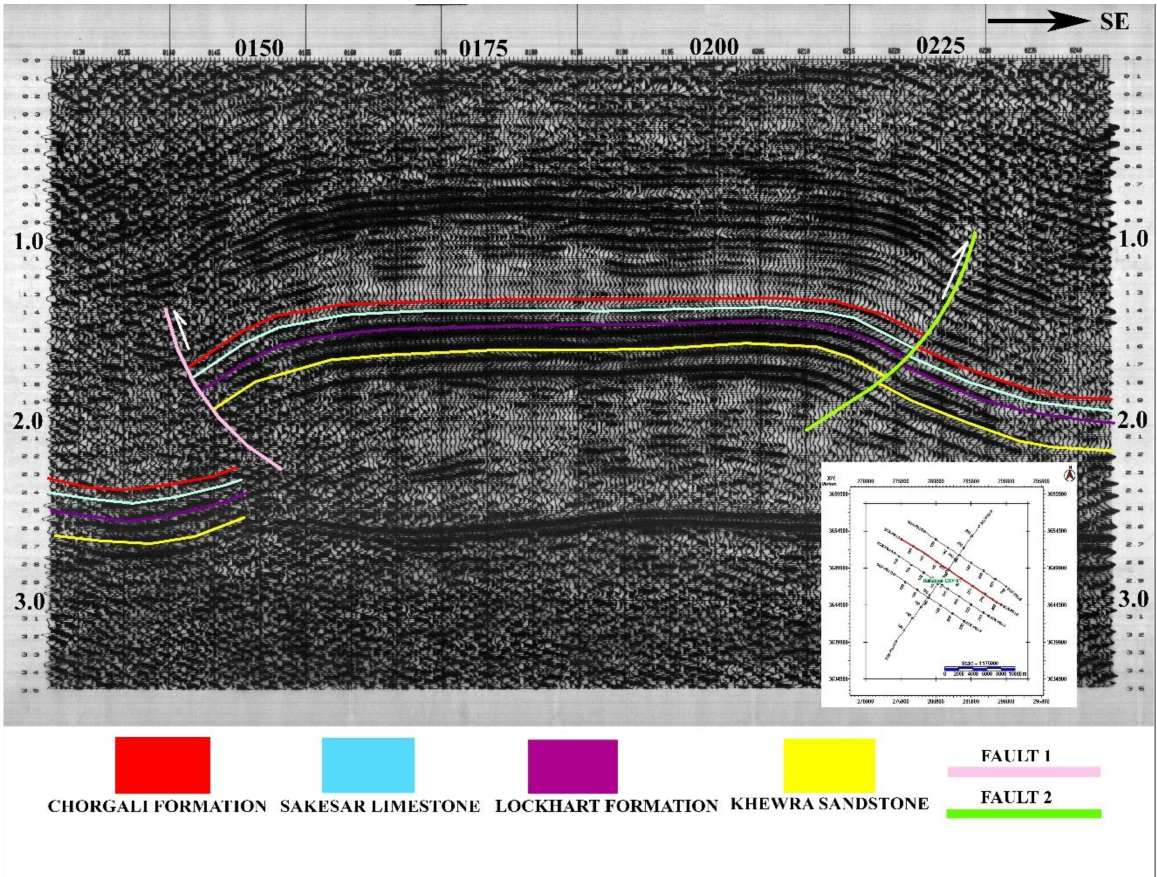

Figure 3.5. Interpreted seismic line PBJ-5.

As we move towards north the tectonic forces increases so, both faults back thrust (F1) and fore thrust (F20 can be observed, in this area the throw of the F2 slightly increase as compared to PBJ-04 and PBJ-03 due to the occurrence of fore thrust and back thrust faults simultaneously the pop up structure can be observed. Which is showed in above figure 3.5.

3.3.9 Interpretation of seismic line PBJ-6

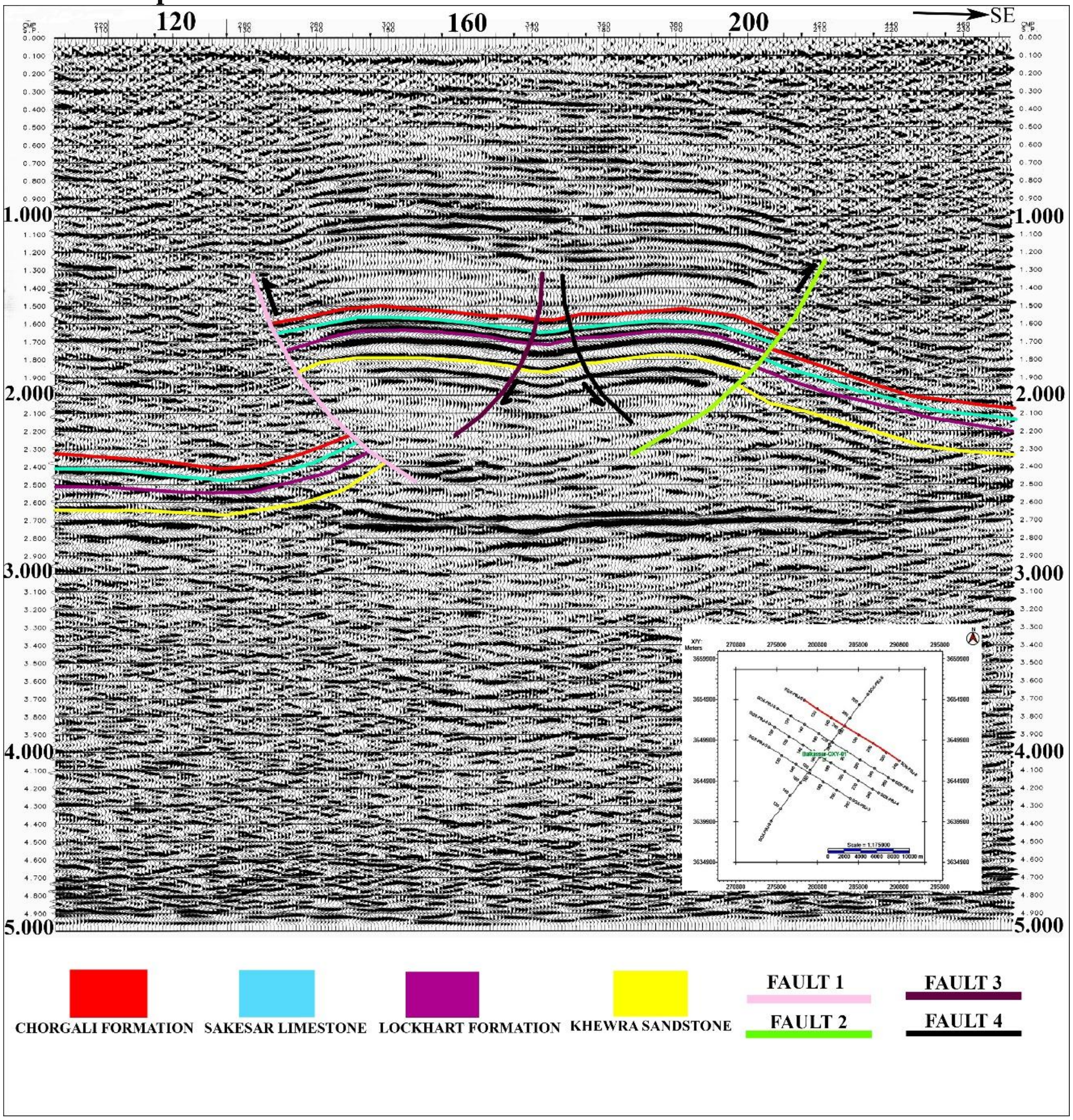

Figure 3.6. Interpreted seismic line PBJ-6.

PBJ-6 lies to the north most out of these lines so in this region the tectonic forces are much intense due to which the structure narrow down and fault bounded syncline plunge appear in the middle of the anti-cline which results in compartmentalization the eastern compartment and the western compartment. Which is showed in above figure 3.6.

3.4 Contouring

Contours were developed after picking two way time (TWT) and calculating the depth at every shot point. Contouring represents a 3-D information on 2-D and the lines having equal values are connected which are called contour lines. The map which is produced with the help of these lines is called contour map. From the given data the time, depth and velocity contour maps were generated of Chorgali Formation, Sakesar Limestone, Lockhart Formation and Khewra Sandstone Formation, which gives us an idea about the sub-surface. Faults are marked prior to plotting time and depth for time and depth contour mapping, with respect to the shot points.

3.4.1 Time contour maps

Time contour maps are made by using the two way time that was picked against the shot points and to do so the basemap of seismic lines is important on which latitude, longitude and shot point number are given. Same time values are connected and contour map is constructed.

3.4.1.1 Time contour of Chorgali Formation

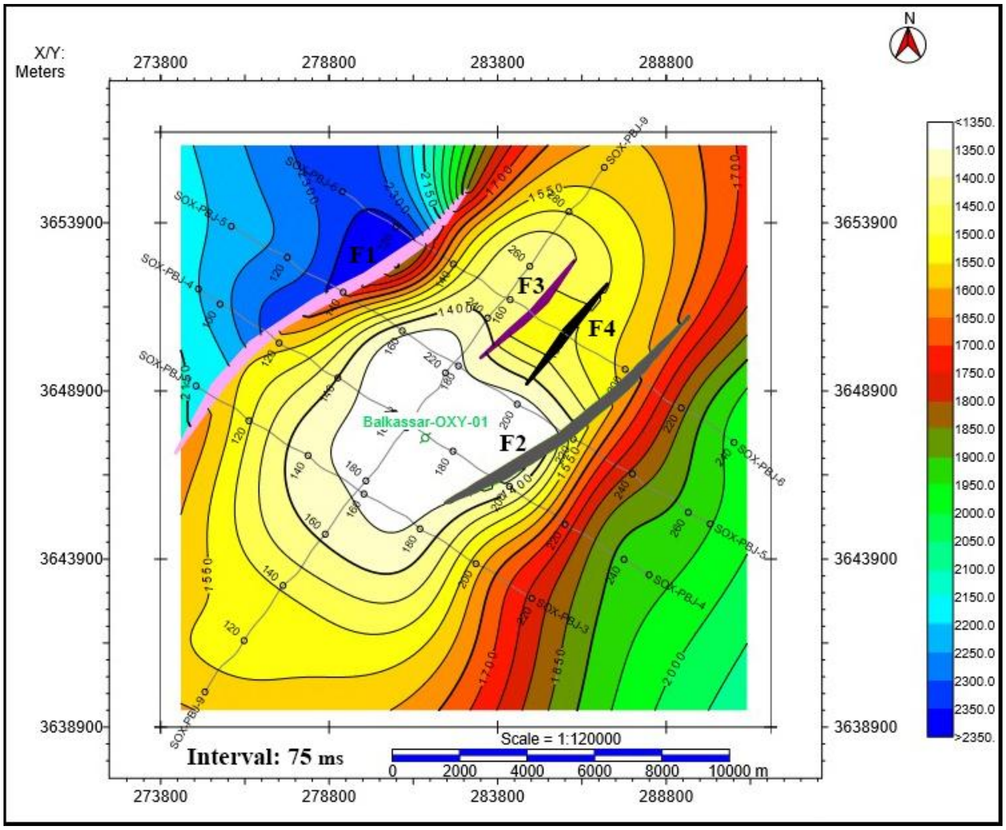

Figure 3.7. Two way time counter map of Chorgali Formation.

The above figure 3.7, shows time contour map of Chorgali Formation and light color to dark ones show expansion in time as we move from shallow to deeper surface. The contours show that the tectonic forces are less in the southern part as compared to the northern part. The area was bounded with the two thrust faults, the back thrust and the fore thrust fault, which results in the flat topped pop structure. In this area the throw of the back thrust fault as more as compared to the fore thrust fault and in the northern part where the tectonic forces are more the fault bounded syncline plunge appear which results in compartmentalization the eastern compartment and the western compartment.

3.4.1.2 Time contour of Sakesar Formation

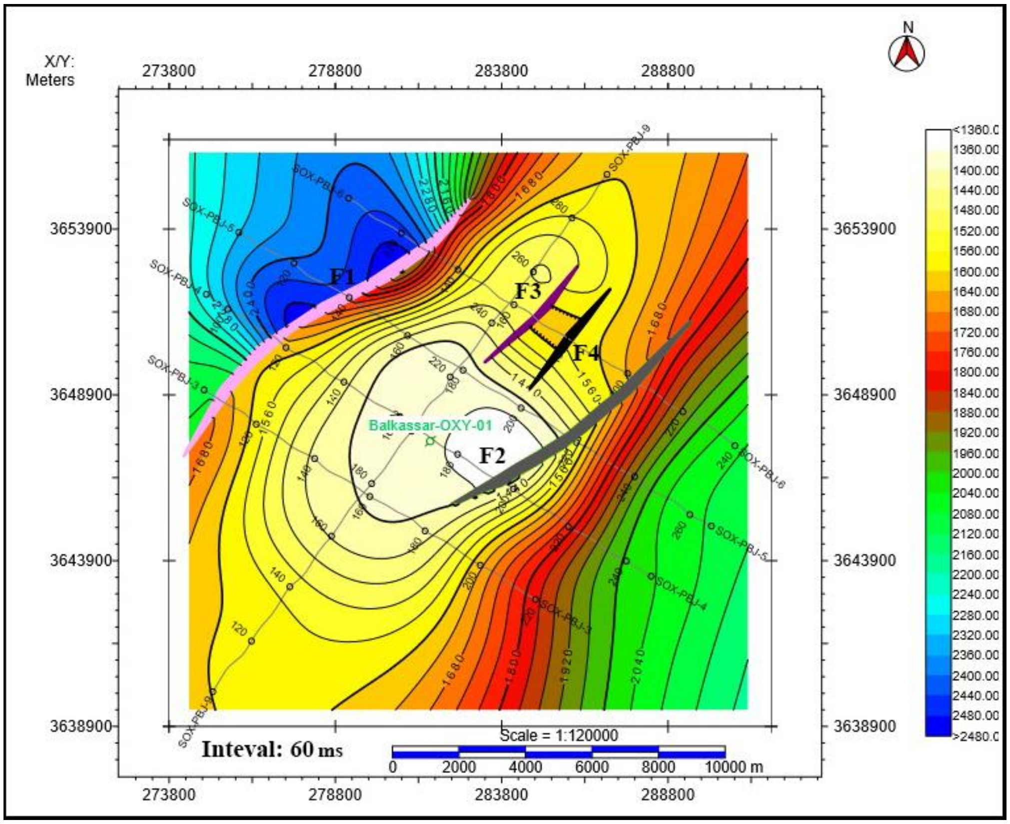

Figure 3.8. Two way time counter map of Sakesar Formation.

The above figure 3.8, shows the time contour map of Sakesar Formation, which is the formation in which zone of interest is present. Indicates that time values increase with the increase in depth on the fault surroundings. The structure of the formation remains the same, like area was bounded with the two thrust faults, the back thrust and the fore thrust fault, which results in the flat topped pop structure and the throw of the back thrust fault as more as compared to the fore thrust fault and in the northern part where the tectonic forces are more the fault bounded syncline plunge appear which results in compartmentalization the eastern compartment and the western compartment.

3.4.1.3 Time contour of Lockhart Formation

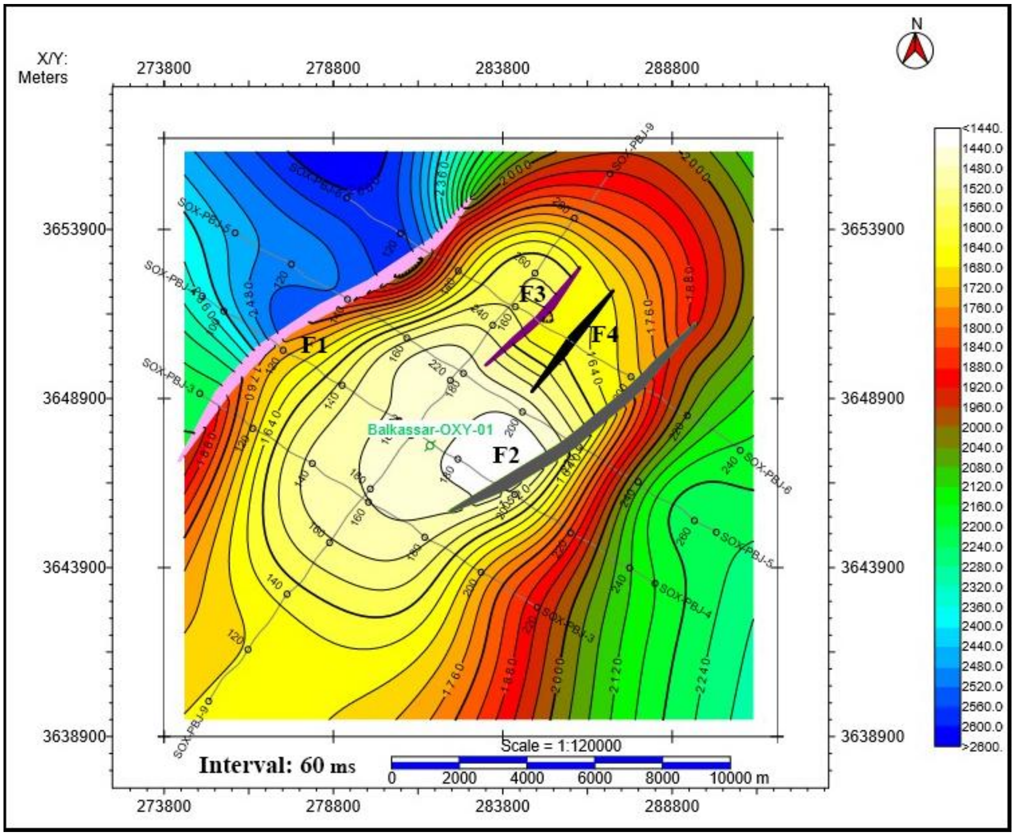

Figure 3.9. Two way time counter map of Lockhart Formation.

Above figure 3.9, shows time contour map of Lockhart formation and pop-up structure can be seen. The dark colors represent the increase in time as we move from shallower surface to deeper surface. The structure of this formation also shows the same trend. The southern part has less tectonic forces whereas northern part where the tectonic forces are more the fault bounded syncline plunge appear which results in compartmentalization the eastern compartment and the western compartment.

3.4.1.4 Time contour of Khewra Sandstone

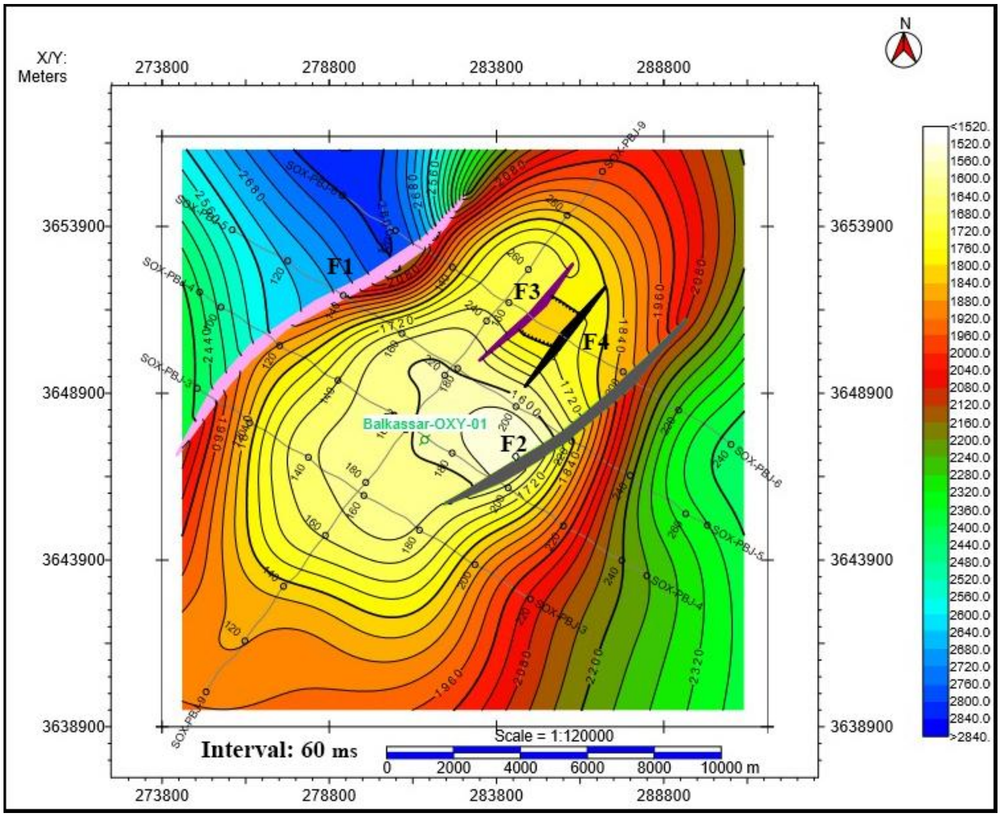

Figure 3.10. Two way time counter map of Khewra Sandstone.

The above figure 3.10. shows time contour map of Khewra Sandstone. It indicates that time values increase with the increase in depth on the fault surroundings. The structure in all the formations remain the same like contours show the same trend that the tectonic forces are less in the southern part as compared to the northern part. The area was bounded with the two thrust faults, the back thrust and the fore thrust fault, which results in the flat topped pop structure.

3.4.2 Velocity contour maps

Velocity contour maps are generated by plotting the average velocities against the respected shot points. Velocity analysis was run, vertical velocities and horizontal velocities was calculated to find the velocity trend in whole the region the velocity countour maps were generated.

3.4.2.1 Velocity contour map for Chorgali Formation

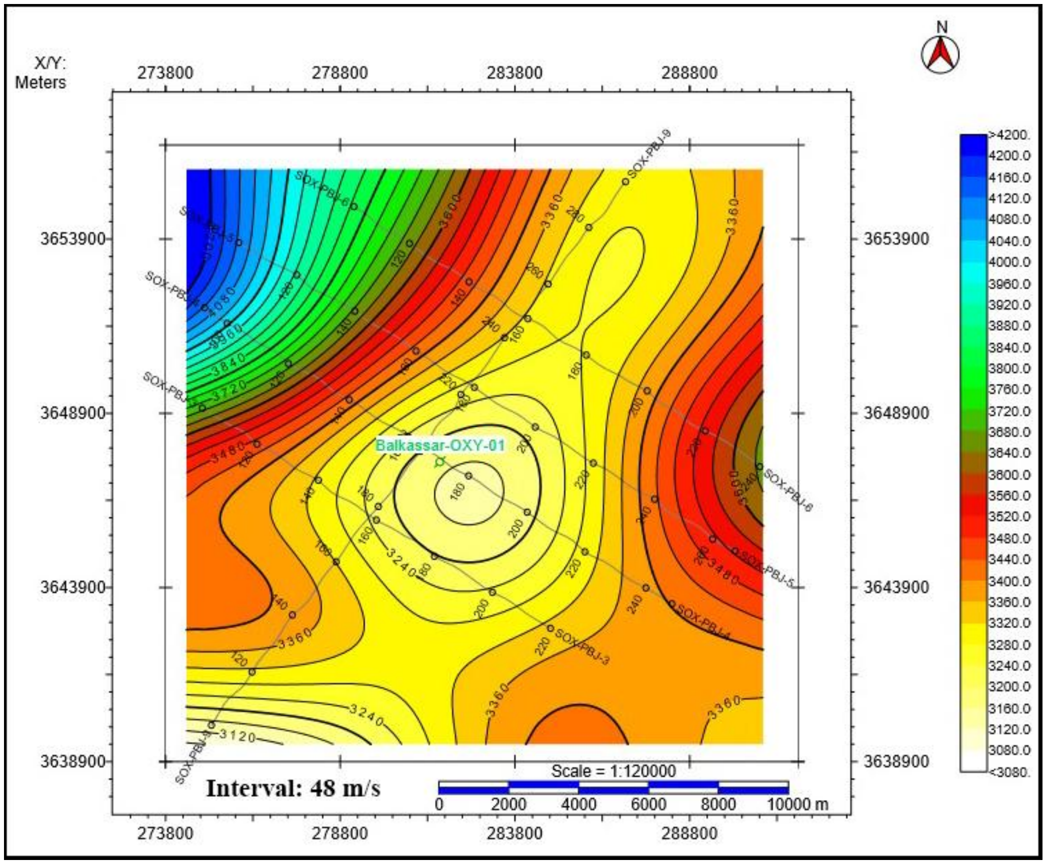

Figure 3.11. Velocity contour map of Chorgali Formation.

Above figure 3.11, shows velocity contour map of Chorgali formation. High velocities show anomalous behavior. In the middle the values are less as compared to the surroundings. The velocities in the surrounding have the high values because after the faults the formation are deeper and as we move deeper the overburden pressure increases due to which compaction increases and velocity increases.

3.4.2.2 Velocity contour map for Sakesar Formation

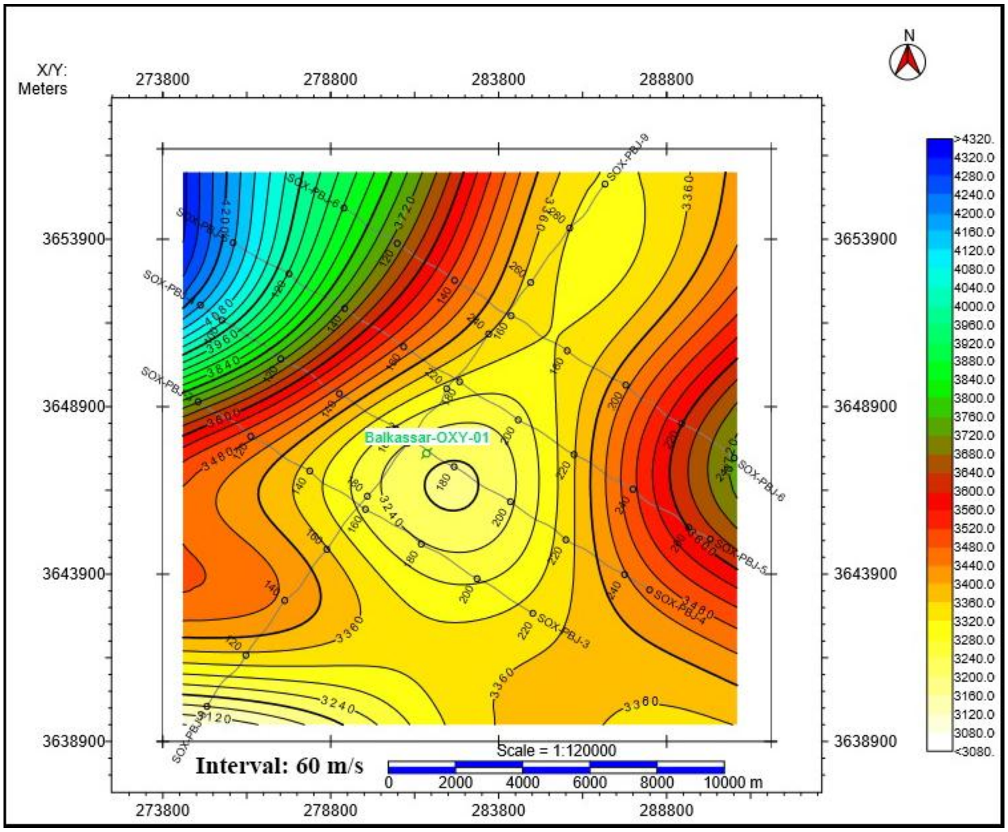

Figure 3.12. Velocity contour map of Sakesar Formation.

Above figure 3.12, shows velocity contour map of Sakesar Limestone. As the depth increases velocity is increasing. This velocity contour map shows the same trend, in the middle the values are less as compared to the surroundings. The velocities in the surrounding have the high values because after the faults the formation are deeper and as we move deeper the overburden pressure increases due to which compaction increases and velocity increases.

3.4.2.3 Velocity contour map for Lockhart Formation

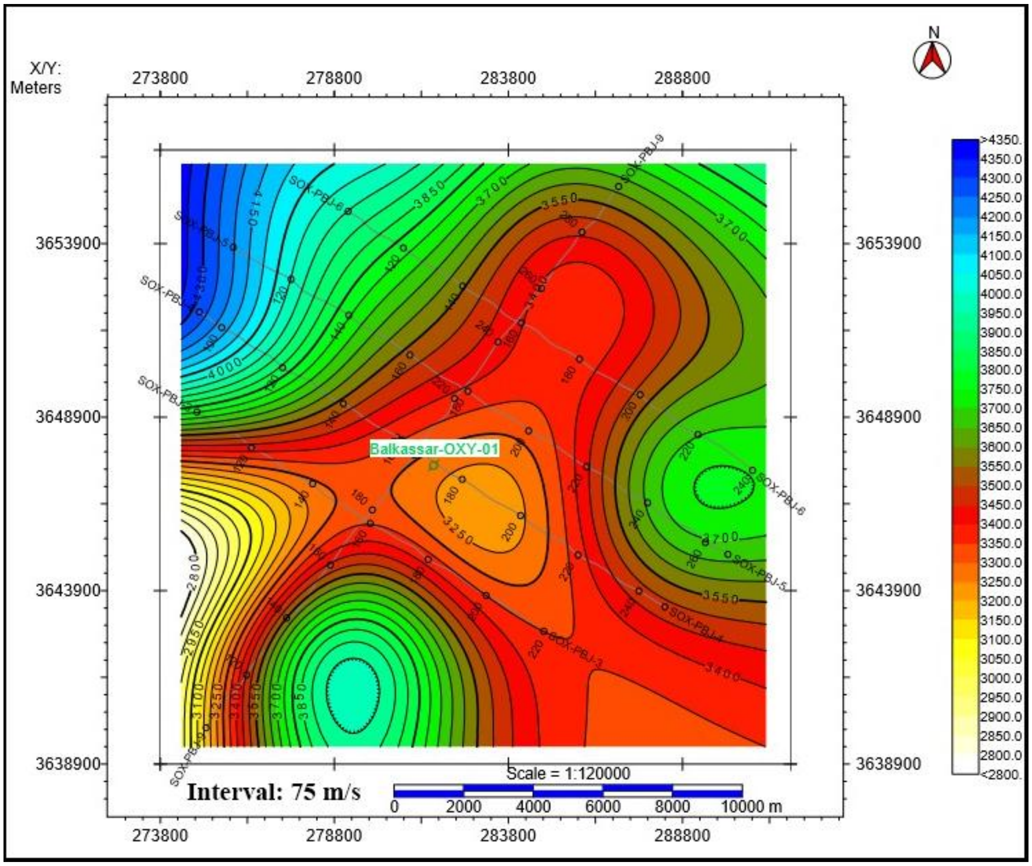

Figure 3.13. Velocity contour map of Lockhart Formation.

Above figure 3.13, shows velocity contour map of Lockhart formation. As the fault in encountered velocity increases. This velocity contour map also shows the same trend, just contour interval is different. In the middle the values are less as compared to the surroundings. The velocities in the surrounding have the high values because after the faults the formation are deeper and as we move deeper the overburden pressure increases due to which compaction increases and velocity increases.

3.4.2.4 Velocity contour map for Khewra Sandstone

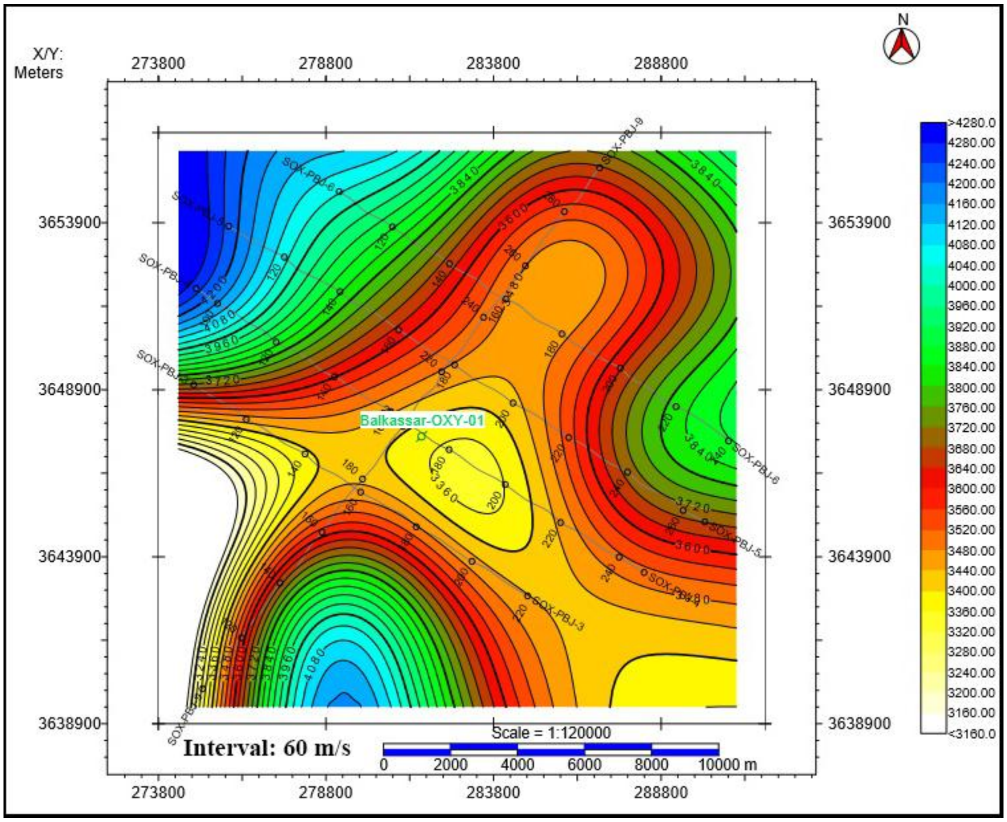

Figure 3.14. Velocity contour map of Khewra Sandstone.

Above figure 3.14, shows velocity contour map of Khewra Sandstone. The same trend was observed in all the formations. Large values of velocity are due to pop-up structure. In the middle the values are less as compared to the surroundings. The velocities in the surrounding have the high values because after the faults the formation are deeper and as we move deeper the overburden pressure increases due to which compaction increases and velocity increases.

3.4.3 Depth contour maps

Depth contour maps are generated with the help of velocities and time by the depth formula which is:

S=V*T/2000

As the velocities were in millisecond so we divided the formula with 2000. After the depth for each shot point is calculated the depth is plotted against their respective shot points. The similar depths are connected to generate the contour maps for depth.

3.4.3.1 Depth contour map for Chorgali Formation

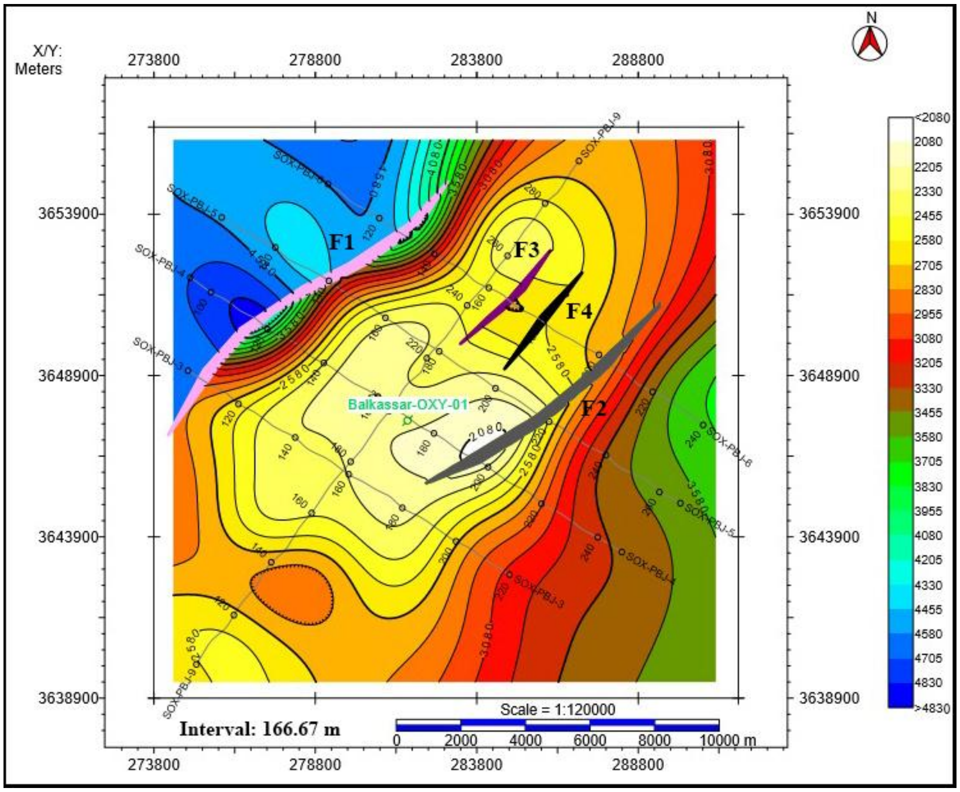

Figure 3.15. Depth contour map of Chorgali Formation.

Above figure 3.15, shows depth contour map of Chorgali formation. Dull hues tells us about shallow depth and dark color shows deeper formation. It is the flat topped anticlinal pop-up structure bounded by two thrust faults, the back thrust and the fore thrust fault. The back thrust dip towards the south-east and fore thrust move towards the north-west. In the southern part the tectonic forces are less and in the northern part tectonic forces are more due to which fault bounded syncline plunge appear which results in the compartmentalization the eastern and the western compartment. The western compartment is structurally less deep as compared to the eastern compartment.

3.4.3.2 Depth contour map for Sakesar Limestone.

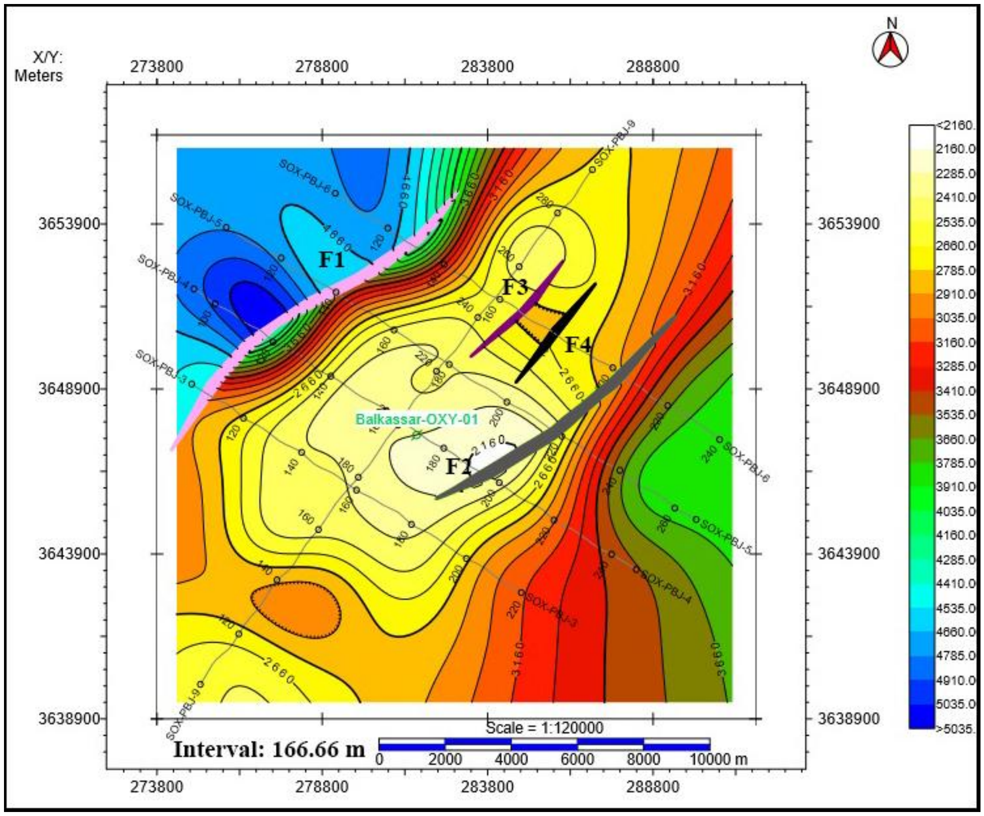

Figure 3.16. Depth contour map of Sakesar Limestone.

Above figure 3.16, shows depth contour map of Sakesar Limestone. The structure remain the same, the flat topped anticlinal pop-up structure bounded by two thrust faults, the back thrust and the fore thrust fault. The back thrust dip towards the south-east and fore thrust move towards the north-west. In the southern part the tectonic forces are less and in the northern part tectonic forces are more due to which fault bounded syncline plunge appear which results in the compartmentalization the eastern and the western compartment. The western compartment is structurally less deep as compared to the eastern compartment.

3.4.3.3 Depth contour map for Lockhart Formation

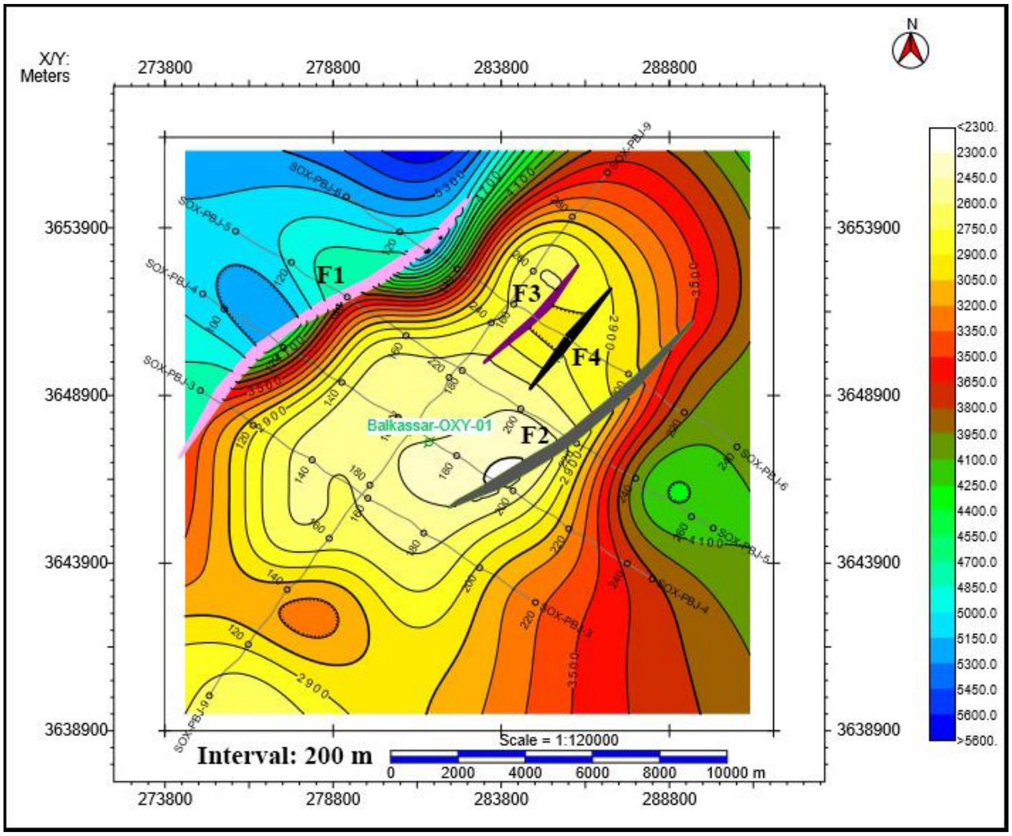

Figure 3.17. Depth contour map of Lockhart Formation.

Above figure 3.17, shows depth contour map of Lockhart formation. At the center the values are less which shows that the formation is shallow as compared to the surrounding. In this formation the structure also remain the same which is the flat topped anticlinal pop-up structure bounded by two thrust faults, the back thrust and the fore thrust fault. The back thrust dip towards the south-east and fore thrust move towards the north-west. In the southern part the tectonic forces are less and in the northern part tectonic forces are more due to which fault bounded syncline plunge appear which results in the compartmentalization the eastern and the western compartment. The western compartment is structurally less deep as compared to the eastern compartment.

3.4.3.4 Depth contour map for Khewra Sandstone

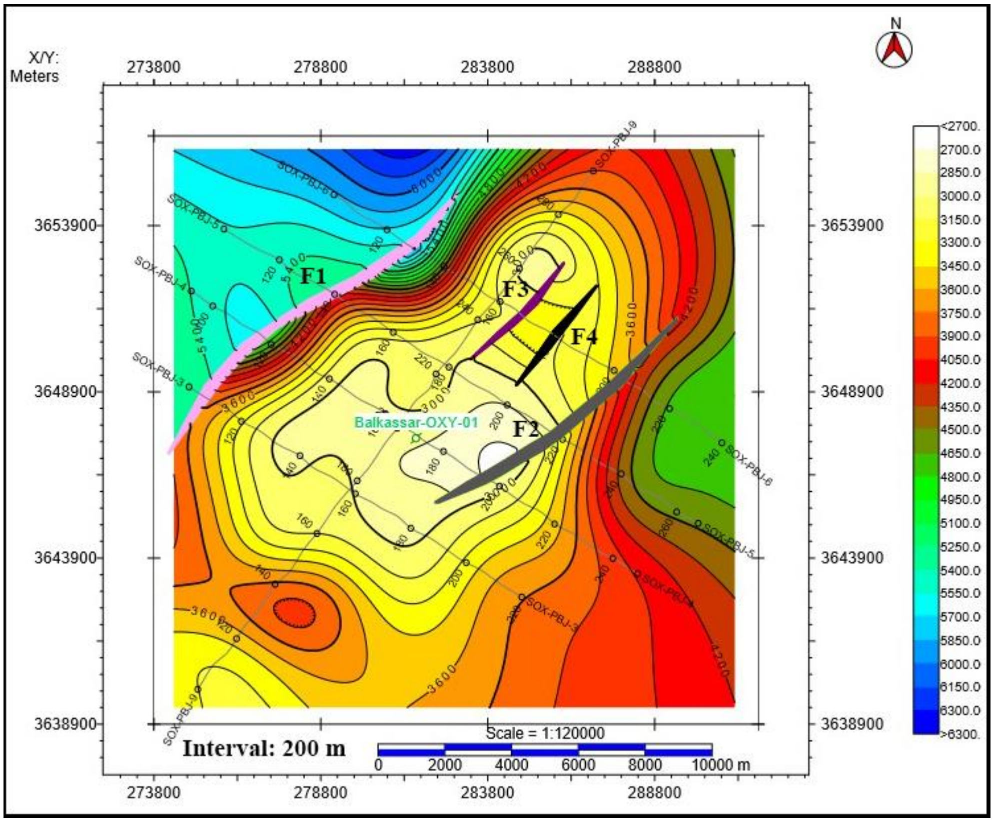

Figure 3.18. Depth contour map of Khewra Sandstone.

Above figure 3.18, shows depth contour map of Khewra sandstone. The dark color represents the increase in depth. The structure remain same in all the formation. Which is the flat topped anticlinal pop-up structure bounded by two thrust faults, the back thrust and the fore thrust fault. The back thrust dip towards the south-east and fore thrust move towards the north-west. In the southern part the tectonic forces are less and in the northern part tectonic forces are more due to which fault bounded syncline plunge appear which results in the compartmentalization the eastern and theh western compartment. The western compartment is structurally less deep as compared to the eastern compartment.

CHAPTER 4

PETROPHYSICAL ANALYSIS

4.1 Petrophysics

The physical characteristics of the rock samples are studied in petrophysics, with reference to the data obtained through the wireline logs. Then the petrophysical analysis is carried out.

The main reason for well logging is to obtain data for the assessment of reservoirs and to assist in testing and completion of the well.

4.2 Steps for petrophysical analysis

1) Volume of shale
2) Porosity (Neutron, density, average and effective)
3) Resistivity of water
4) Saturation of water
5) Saturation of hydrocarbon
6) Summation

4.3 Volume of Shale

The Gamma Ray log evaluates the naturally occurring radioactivity of the formation under observation. It basically detects the shale content in the formation. The formation that don't possess shale are not radioactive and are called clean formations. Formation with a high shale content are termed dirty formation as they have a high radioactivity value. Following formula is used (Schlumberger, 1974).

$$IGR = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

Where.

GR_{log}=Gamma ray log

GR_{min}=Minimum value of Gamma ray

GR_{max}=Maximum value of Gamma ray

4.4 Calculation of Porosity

The density of pore spaces is measured against the bulk volume. Porosity of a rock is its capability to store fluids. This is calculated by an instrument that monitors the link between the rock to the bombardment of either gamma rays or neutron on its surface. Different types of porosities are measured.

1) Neutron porosity
2) Density porosity
3) Sonic porosity
4) Effective porosity
5) Total porosity

4.4.1 Density logs

This log is used for observation of porosity. Other things that this log can be used for are.

1) Identification of minerals in evaporite deposits
2) Detection of Hydrocarbons
3) Evaluation of complex lithologies.

Form this log values were interpreted at the depth of Sakesar Limestone. The following relation is used for calculation of density porosity (Schlumberger, 1974):

$$\Phi_D = \frac{\rho ma - \rho b}{\rho ma - \rho f}$$

Average porosity is the combination of Density and Neutron probity. Its calculated by the following relation:

$$\Phi_A = \frac{\Phi_D + \Phi_N}{2}$$

Effective porosity is used to deal with interconnected pores. These pores are what leads to permeability. Effective porosity is used to study the spaces containing water and hydrocarbons, the following relation is used:

$$\Phi_E = \Phi_A * (1 - V_s)$$

4.4.2 Neutron logs

This log is used to monitor the porous formation and determine porosity. This log takes into account the hydrogen present in the formation. In this case if the formation is clean i.e. it has water or hydrocarbons in it, the hydrogen atom will reflect back to the detector. Gas zones are determined by the differentiation of neutron log with some other porosity log. From this log values are observed form at depth of Sakesar Limestone.

4.4.3 Resistivity log

In this log if resistivity is observed than it is an indicator of hydrocarbons. This log tells us about the type of fluid present in the pore spaces of the lithology, this is done by calculating the resistivity these lithologies provide against the flow of electricity.

4.5 Zone of interest

With the results of the Density and Neutron logs the zone of interest is established. If there is a crossover between these two logs then there is a chance that hydrocarbons are present in the reservoir. In figure 4.1 and 4.10, zone of interest is shown.

Table 4.1. Zone of Interest

Zone of interest	**Formation**	**Starting depth (feet)**	**Ending depth (feet)**	**Total thickness (feet)**
Zone 1	Sakesar Limestone	8098	8098	82
Zone 2	Sakesar Limestone	8210	8308	98

4.5.1 Zone of interset 1

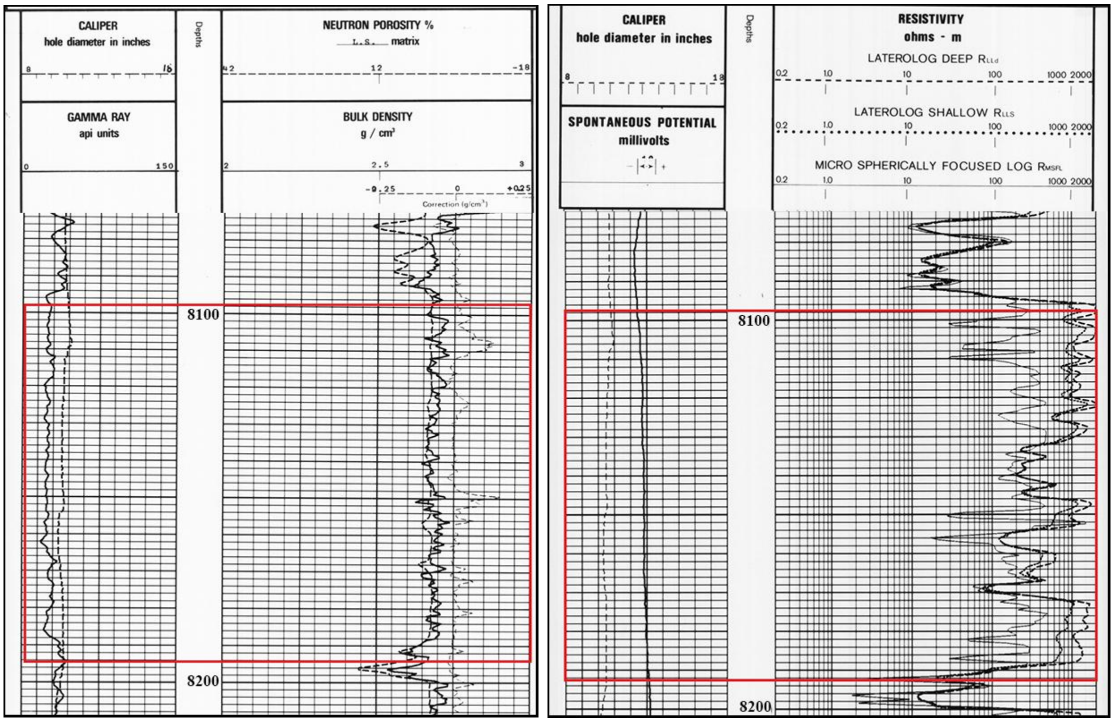

Figure 4.1. Log trends of Balkassar Oxy-01 (zone 1)

4.5.2 Graphs of Zone 1

4.5.2.1 Graph of Volume of Shale

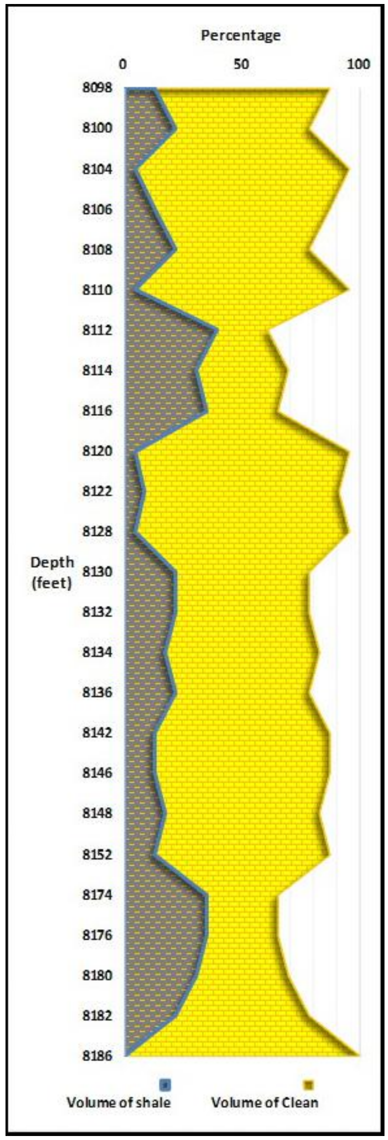

Figure 4.2. Relationship of volume of shale and volume of clean with respect to depth within Sakesar limestone of Oxy-01 well (zone 1).

In figure 4.2., variation can be seen in the volume of shale and volume of clean in accordance with depth. Where the value of shale is more it indicates high radioactivity and the formation is considered as dirty and the zone is labeled as poor reservoir zone due to the high shale content. Where the volume of shale is low the zone is considered as clean and a good reservoir, radioactivity is also low. The volume of shale varies from 8090 feet to 8188 feet. Maximum value of volume of shale can be observed at the depth of 8112, feet and minimum at 8186 feet. Maximum value of clean lithology is at 8186 feet and minimum is at 8112 feet. Average value of volume of shale is 18.43% and volume of clean is 81.56%.

4.5.2.2 Graphs of Density and Neutron Porosties

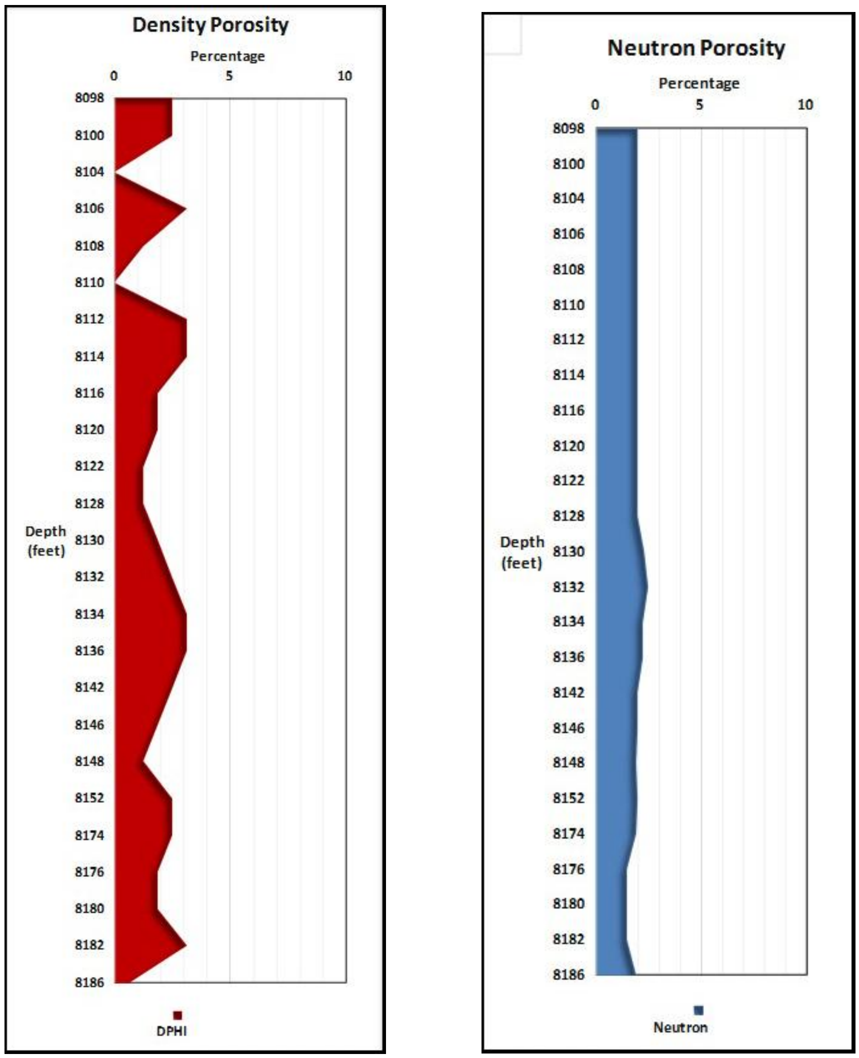

Figure 4.3. Relationship of density porosity and neutron porosity with respect to depth within Sakesar limestone of Oxy-01 well (zone 1).

In figure 4.3., variation in density porosity and neutron porosity can be seen with respective depths. Values vary from 8098 feet to 8180 feet. Maximum value for density porosity is 3.1% , where as minimum is 0%. Average value for density porosity is 2.01%. Neutron porosity has highest value of 2.5% and lowest of 1.5%. Average value of neutron porosity is 1.97% in this zone of interest. Low value of neutron porosity shows that fluid is present and that the lithology has high porosity.

4.5.2.3 Graphs of Average and Effective Porosities

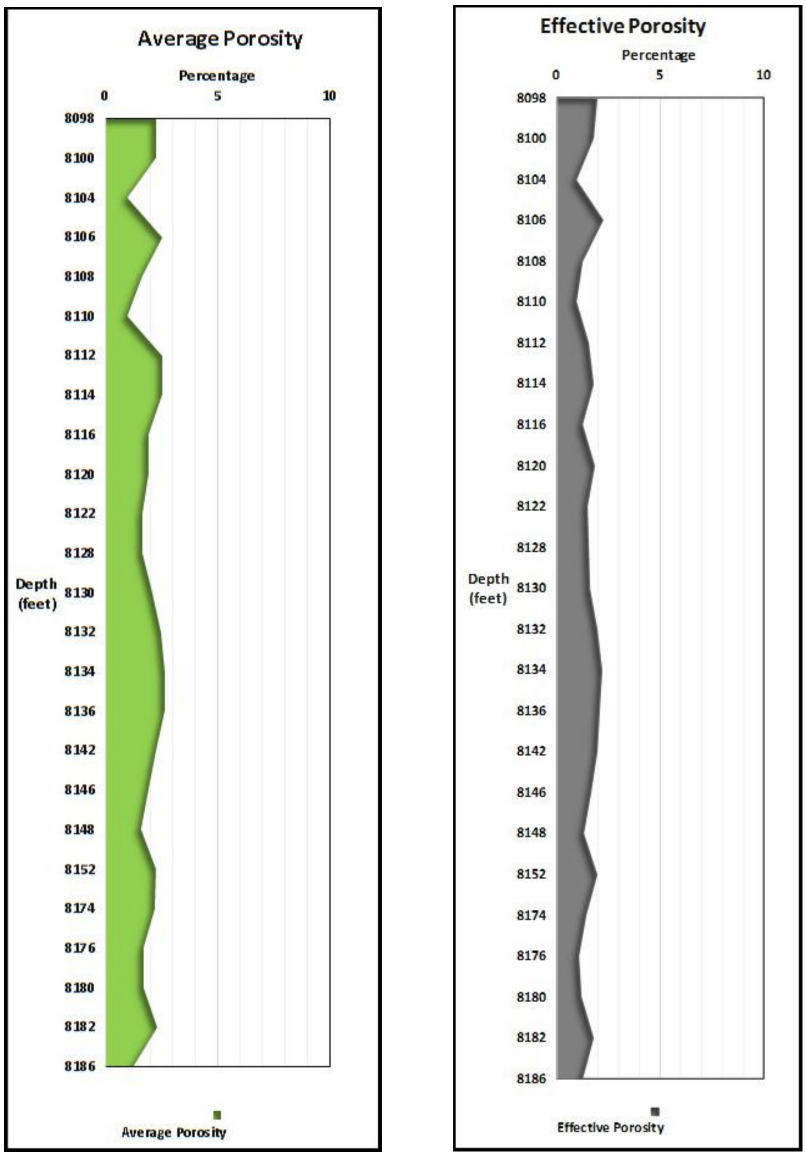

Figure 4.4. Relationship of average porosity and effective porosity with respect to depth within Sakesar limestone of Oxy-01 well (zone 1).

In figure 4.4., variation in average porosity and effective porosity can be seen with respect to depth. Average value of total porosity is 1.99% and average value of effective porosity is 1.60%. Effective porosity is telling about amount of interconnected pore spaces.

4.5.3 Determination of resistivity of water (Rw)

Following steps were taken to find the resistivity of water:

1) By using the following formula formation temperature (Tf) was calculated:

$$\text{Temperature Gradient} = \frac{\text{BHT} - \text{Surface Temperature}}{\text{T. D}}$$

$$\text{Temperature Gradient} = \frac{180 - 72}{2715.8} = 0.03977$$

$$\text{Formation temperature} = (\text{Formation Top x Temp. Gradient}) + \text{Surface Temperature}$$

= (2467.2*0.03977) +72 = 170.12°F

Where, BHT= Bottom hole temperature,

T.D = Total depth

Calculation of Resistivity of mud fluid (Rmf) at formation temperature as shown below in the figure 4.5.

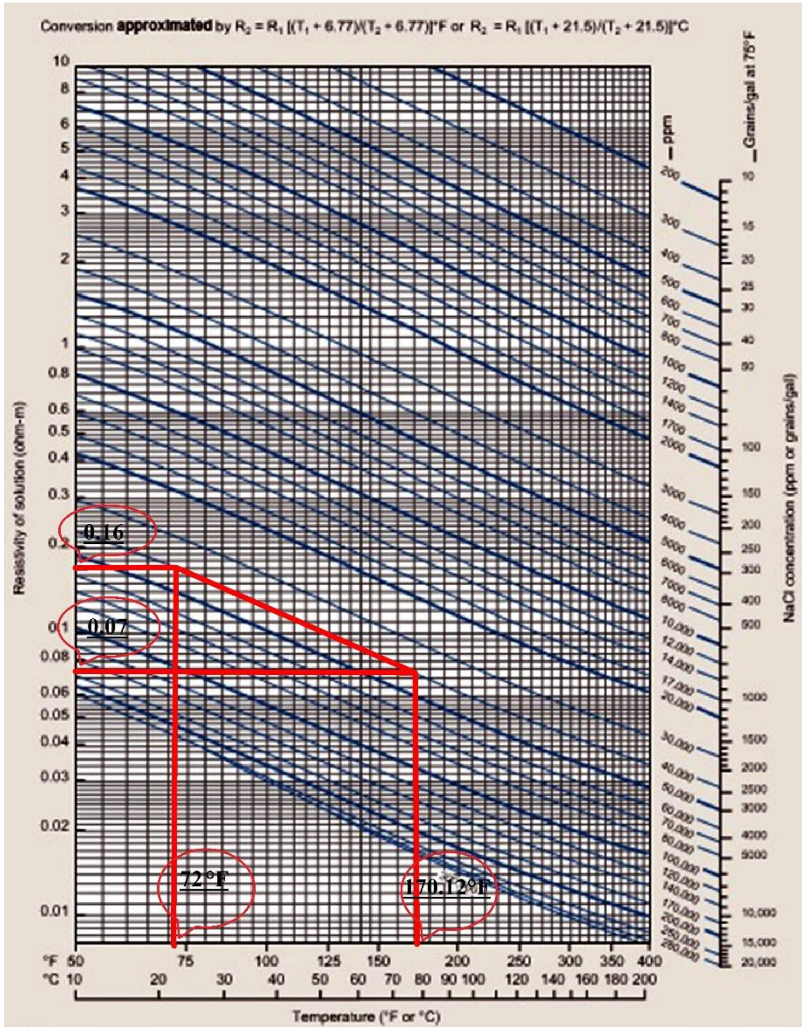

Figure 4.5. Graph GEN-9 elaborating interpreted value of Rmf at surface temperature. (Schlumberger)

2) Spontaneous potential which was calculated that is -13mV from the shale baseline.

3) By using SP-2 chart Resistivity of mud fluid equivalent (Rmfeq) was calculated which was 0.06. As shown in the figure 4.6.

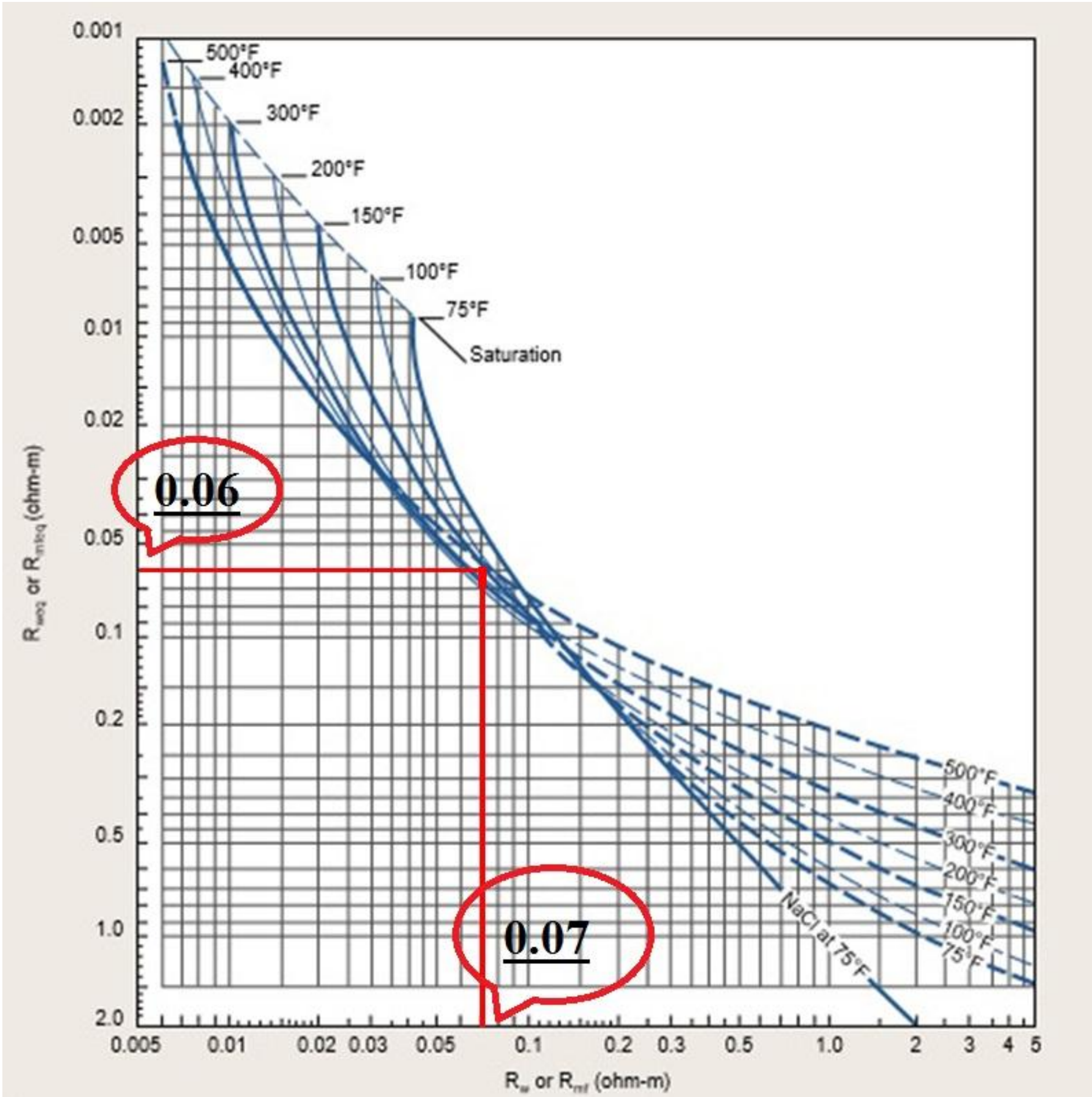

Figure 4.6. Graph SP-02 elaborating the interpreted value of Rmfeq. (Schlumberger)

4) Resistivity of water equivalent (Rweq) was calculated by using SP-1 chart by using spontaneous potential (-13 mV) which is 0.055. As shown in figure 4.7.

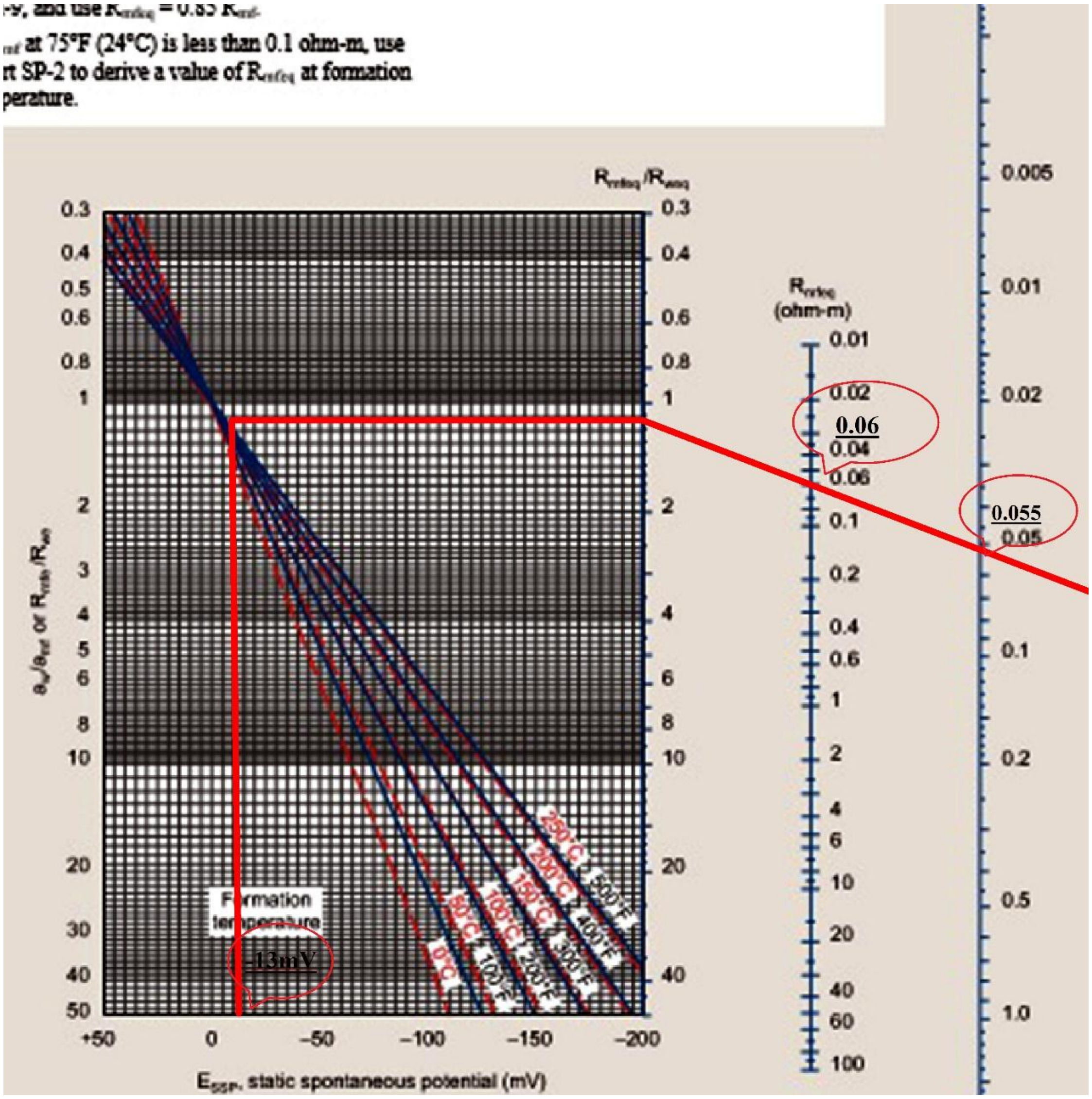

Figure 4.7. Graph SP-01 elaborating interpreted value of Rweq. (Schlumberger)

5) With the help of Rweq Rw was found to be 0.055. As shown in figure 4.8.

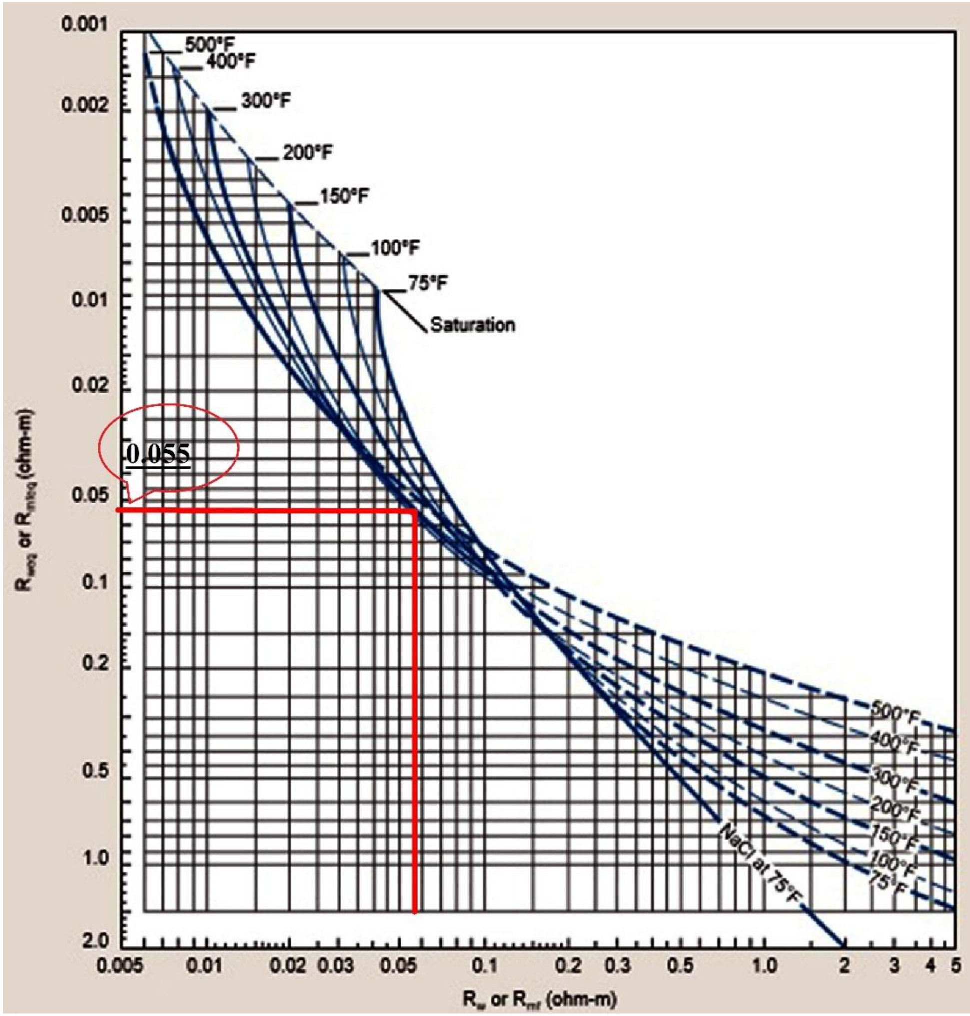

Figure 4.8. Graph SP-02 elaborating the interpreted value of Rw. (Schlumberger)

4.5.3.1 Graph of Hydrocabon Saturation and Water Saturation

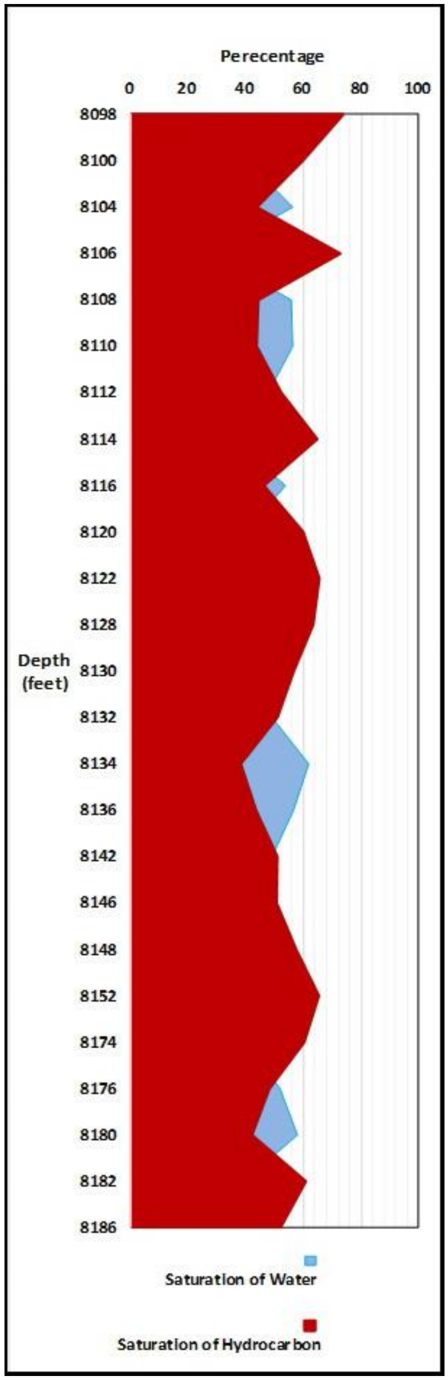

Figure 4.9. Relationship of saturation of water and saturation of hydrocarbon with respect to depth within Sakesar limestone of Oxy-01 well (zone 1).

In figure 4.9., variation of saturation of water and saturation of hydrocarbon according to depth. Saturation of hydrocarbon is dominant. The average value of saturation of hydrocarbon in this zone is 54.65% and average value of saturation of water is 45.35%.

4.5.4 Zone of interest 2

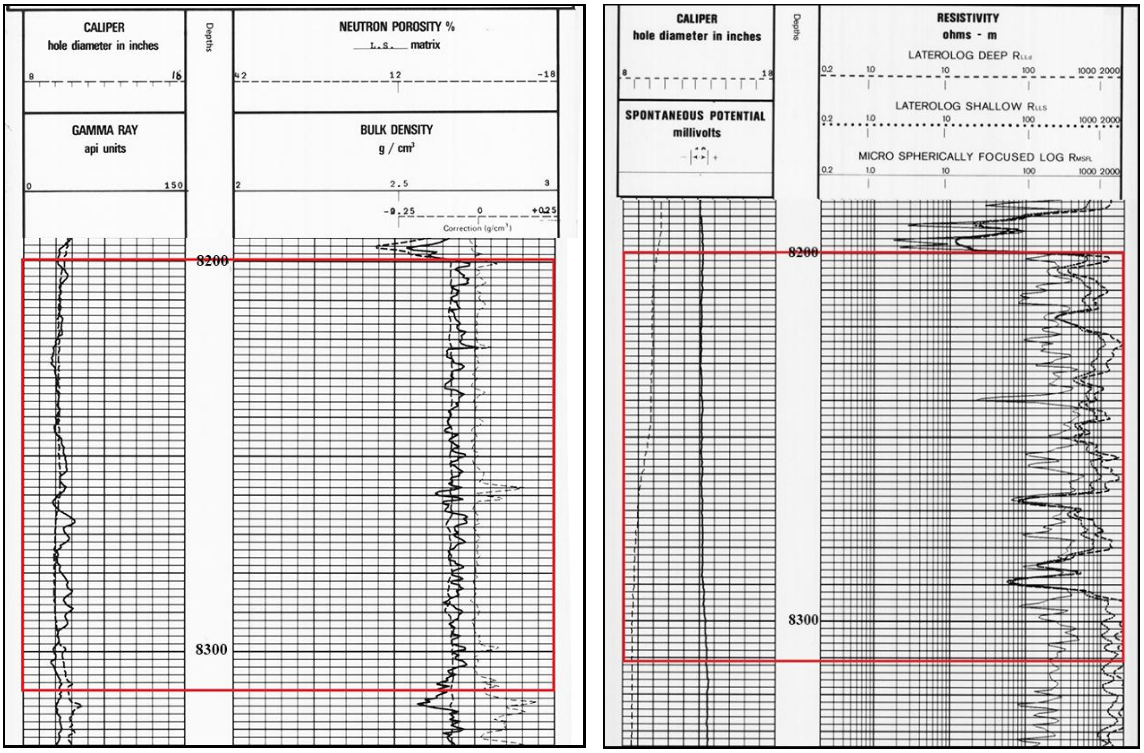

Figure 4.10. Log trends of Balkassar (zone 2)

4.5.4.1 Graph of Volume of Shale

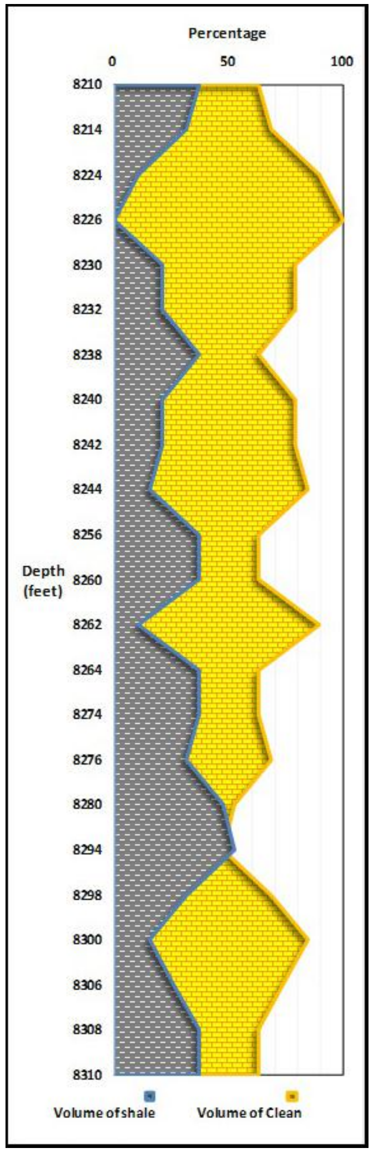

Figure 4.11. Relationship of volume of shale and volume of clean with respect to depth within Sakesar limestone of Oxy-01 well (zone 2).

In figure 4.11., variation can be seen in the volume of shale and volume of clean in accordance with depth. Where the value of shale is more it indicates high radioactivity and the formation is considered as dirty and the zone is labeled as poor reservoir zone due to the high shale content. Where the volume of shale is low the zone is considered as clean and a good reservoir, radioactivity is also low. The volume of shale varies from 8210 feet to 8308 feet. Maximum value of volume of shale can be observed at the depth of 8280 feet and minimum at 8226 feet. Maximum value of clean lithology is at 8226 feet and minimum is at 8280 feet. Average value of volume of shale is 28.37% and volume of clean is 71.62%.

4.5.4.2 Graphs of Neutron and Density Porosities

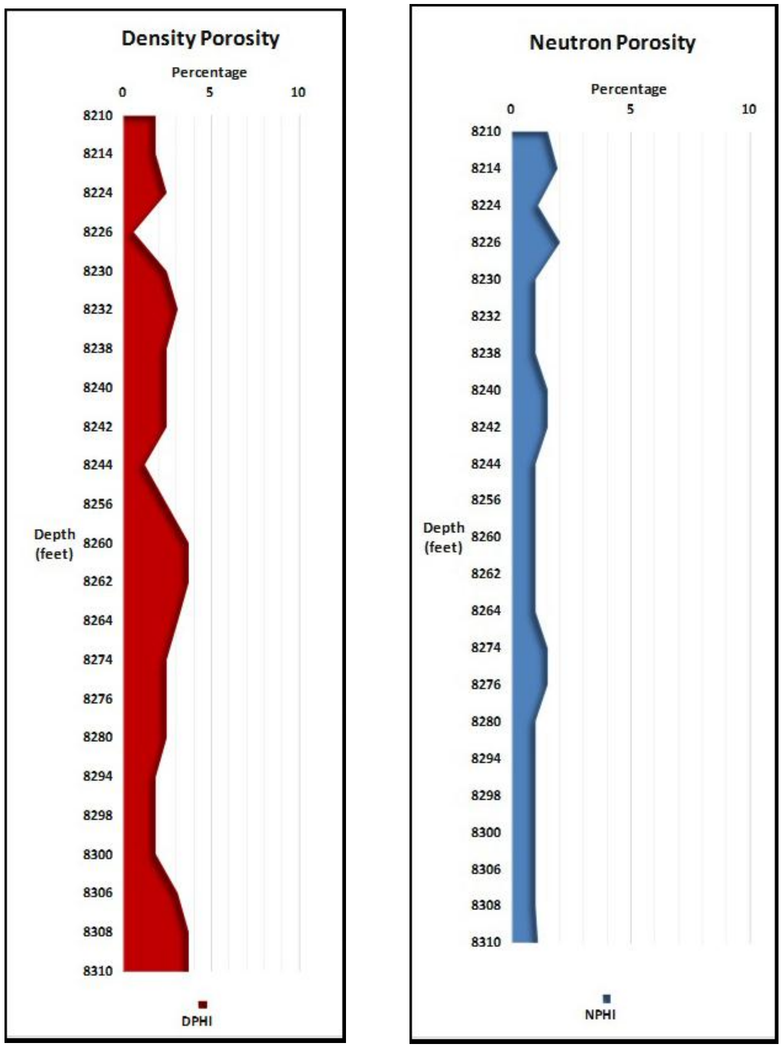

Figure 4.12. Relationship of density porosity and neutron porosity with respect to depth within Sakesar limestone of Oxy-01 well (zone 2).

In figure 4.12., variation in density porosity and neutron porosity can be seen with respective depths. Values vary from 8210 feet to 8308 feet. Maximum value for density porosity is at 8260, 8262, 8308 and 8310 feet, whereas minimum can be seen at 8226 feet. Average value for density porosity is 2.51%. Low density porosity shows that matrix is in less content so the porosity is high. Neutron porosity has highest value of 2% and lowest of 1%. Average value of neutron porosity is 1.2% in this zone of interest. Low value of neutron porosity shows that fluid is present and that the lithology has high porosity.

4.5.4.3 Graphs of Average and Effective Porosities

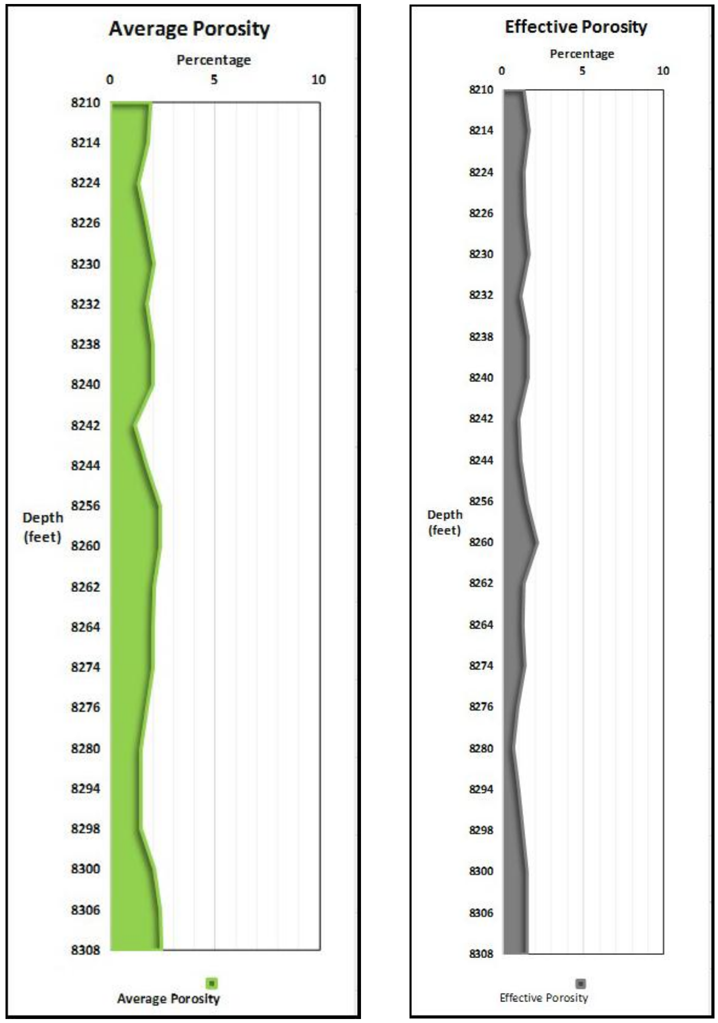

Figure 4.13. Relationship of average porosity and effective porosity with respect to depth within Sakesar limestone of Oxy-01 well (zone 2).

In figure 4.13., variation in average porosity and effective porosity can be seen with respect to depth. Average value of total porosity is 1.85% and average value of effective porosity is 1.32%. Effective porosity is telling about amount of interconnected pore spaces.

4.5.4.4 Graph Water saturation and Hydrocarbon saturation.

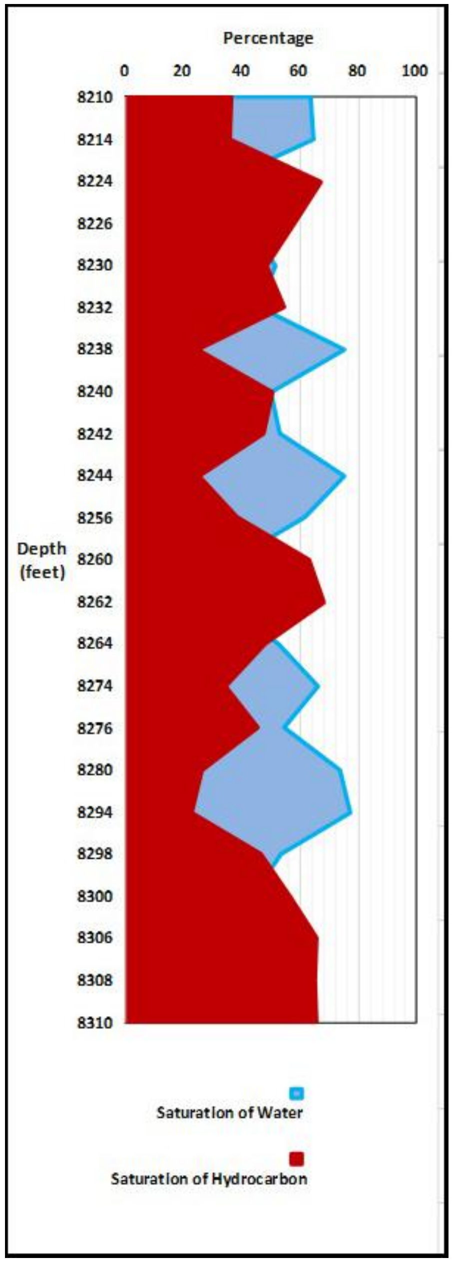

Figure 4.14. Relationship of saturation of water and saturation of hydrocarbon with respect to depth within Sakesar limestone of Oxy-01 well (zone 2).

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In figure 4.14., water is slightly more dominant in this zone. The average value of saturation of hydrocarbon in this zone is 47.46% and average value of saturation of water is 52.53%.

Chapter 5

Volumetric Estimation

5.1 Proved Reserve (P90)

- Area = 446.73 acres

OIIP = 7758 x 446.73 x 210 x 0.0146 x (1-0.485)/1.2

= 4.56 million barrels

- After recovery = 4.56 million barrels x 0.35

= 1.59 million barrels

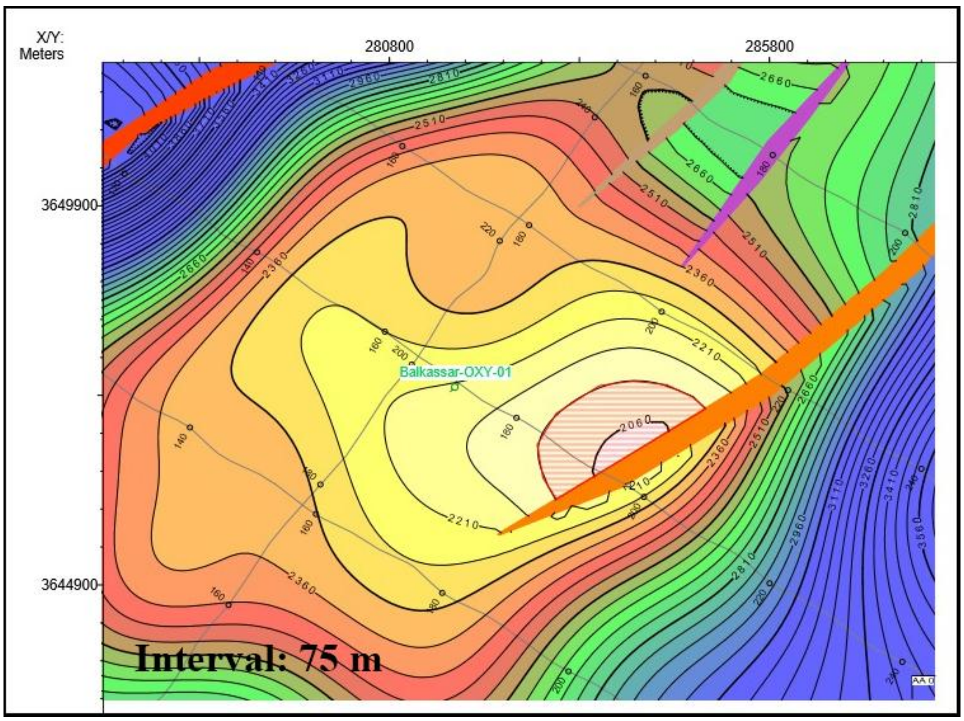

Figure 5.1. Area of proved hydrocarbon reserves.

5.2 Proved + Probable Reserves (P50)

- Area = 1015.51 acres

OOIP = 7758 x 1015.51 x 210x 0.0146 x (1-0.485)/1.2

= 10.36 million barrels

- After recovery = 10.36 million barrels x 0.35

= 3.63 million barrels

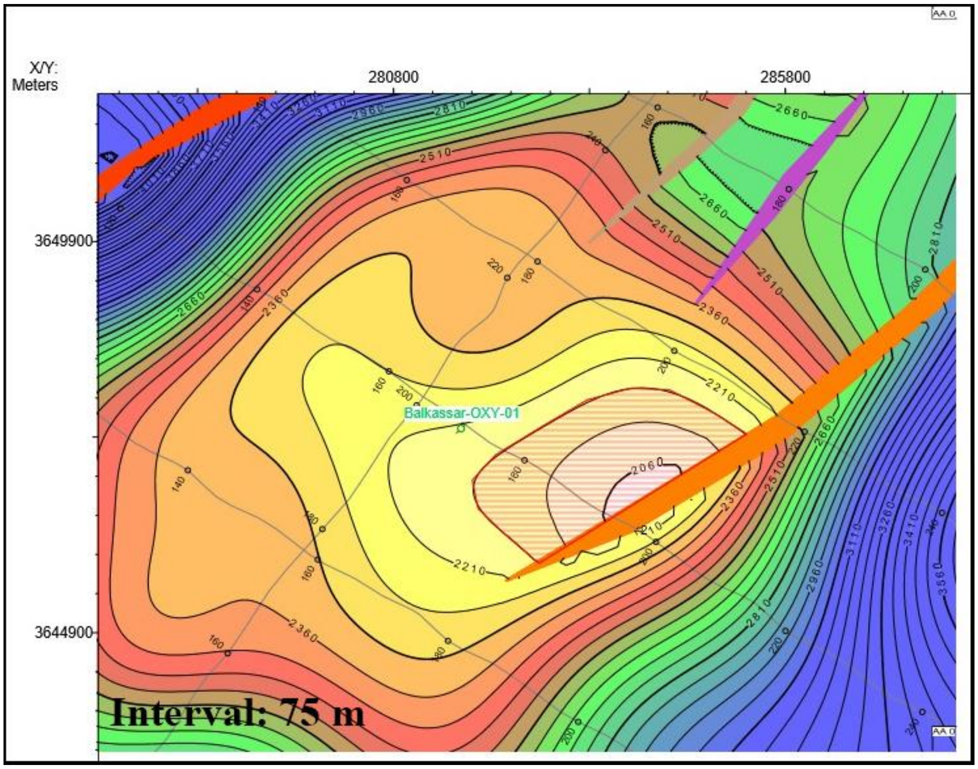

Figure 5.2. Area of probable hydrocarbon reserves

5.3 Proved + Probable + Possible Reserves (P10)

- Area = 1846.8 acres

  OOIP = 7758 x 1846.8 x 210 x 0.0146 x (1-0.485)/1.2

  = 18.85 million barrels

- After recovery = 18.85 million barrels x 0.35

  = 6.59 million barrels

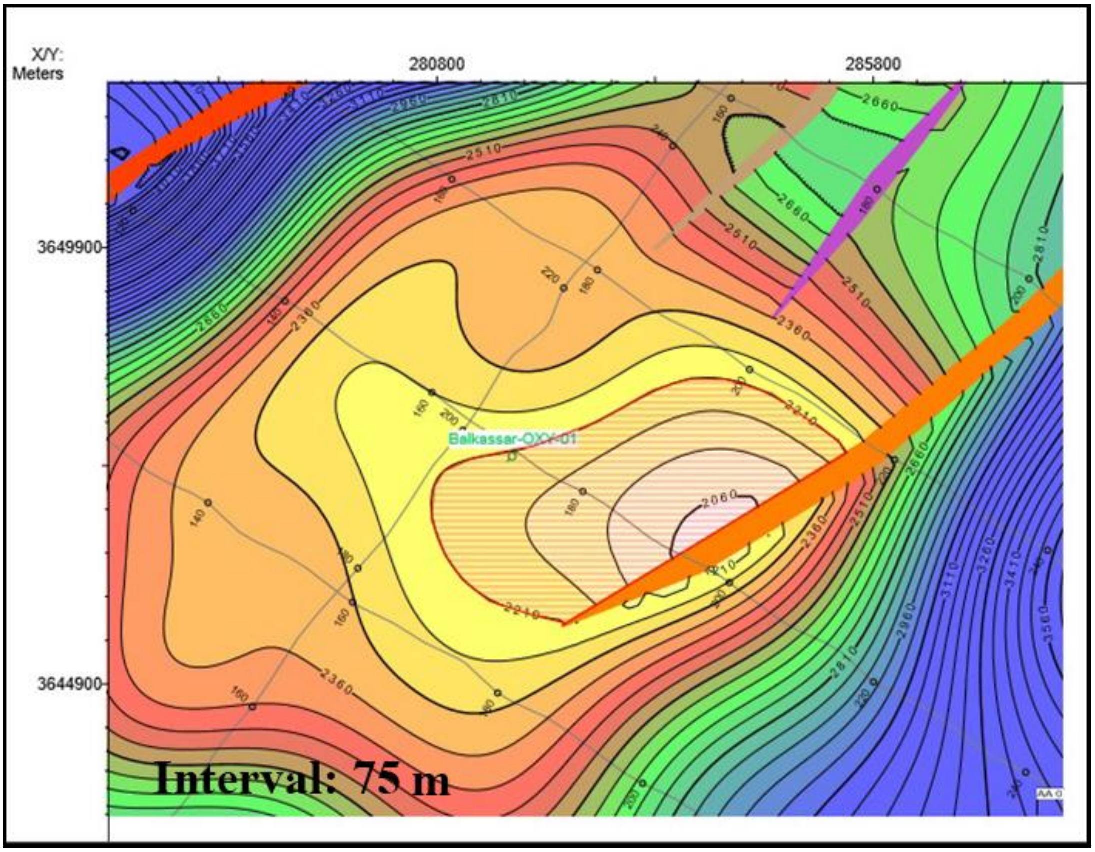

Figure 5.3. Area of possible hydrocarbon reserves.

CONCLUSION

(i). Seismic data was interpreted and thrust faults were marked, from which it was deduced that Balkassar area lies in the compressional regime.

(ii). Four reflectors were marked which are Chorgali Formation, Sakesar Limestone, Lockhart Formation and Khewra Sandstone.

(iii). The structure present here is pop-up structure.

(iv). According to previous studies the petroleum system indicates that Chorgali and Sakesar limestone are acting as reservoirs, Patala Formation is source and Murree formation shale is acting as seal.

(v). On the basis of petrophysical analysis and previous studies done on the area show that Sakesar Limestone is hydrocarbon bearing zone.

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