INTEGRATED RESERVOIRS SIMULATION STUDY AND SUBSURFACE FRACTURE NETWORKING ANALYSIS IN CARBONATE RESERVOIRS: POTWAR PLATEAU, PAKISTAN

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ABSTRACT

The Balkassar field is located in southern Potwar Basin which is a sub basin of Upper Indus Basin, Pakistan. Tectonically, the study area lies in a compressional regime where reverse faults are observed which make pop up structures. To reduce the risk and problems during drilling a well, the evaluation of reservoir properties is very important 3D seismic cube were interpreted by correlating with well data of Balkassar OXY-01. It appears probable the early Eocene age Chorgali Formation could offer commercial production with lower water cuts from the eastern lobe (yet untapped) of the structure that may have at least 30 million barrels of unrecovered oil. Four horizons in 3D seismic data were marked and pointed out. Two prominent faults were identified and interpreted on the seismic sections. The contours of the horizons (Chorgali, Sakesar and Patala and Khewra formations) are trending north-east to south-west. The contours in the region of the faults illustrate reverse faults forming pop-up structure i.e. north-west and south-east dips and north-east and south-west strike. 3D depth surface models were generated which indicates that the major structure has lower pull out in the course of north-east to south-west with sinking along south-east and north-west directions.

The Chorgali Formation (2425m-2490m) were marked and encountered lithologies are composed of limestone and dolomite. The values of GR-log (Gamma Ray Log) shows high values which indicate that the Patala Formation (2605m-2625m) is mostly consist of shale. The Khewra Formation (3050m-3125m) values were relatively ~50% sandstone, ~10% sandy limestone while rest of the formation is shale (high GR-Log values). The targeted reservoirs in Balkassar oil field are Chorgali and Sakesar Formations in well BLK-OXY-01. The overall depth range of the reservoirs zone were marked is in between 2420m to 3100. The reservoir area has a seismic reversal, where the low impedance area indicates the presence of limestone opposite the shale. Now, using an impedance graph model from the well data, an initial map is developed in the time interval between 1300 ms and 1450 ms in which interest is generated.

The seismic interpretation and modeling alongside the petrophysical analysis were then quality checked via qualitative rock physics analysis. From the Kdry/Porosity plot, the limestones were generally observed to lie within the 2420-2580m which indicates a high level of compaction. From high impedance values can be observed on a seismic cube of 2600 m, and these values decrease slightly as you go up. This shows that we have Patala shale at 2,600m and as we go up we are approaching the reservoir area at 2,400-2,580m.

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LIST OF ABBREVATIONS

BOPD	Barrel oil per day
MMT	Main Mantle Thrust
MBT	Main Boundary Thrust
MCT	Main Central Thrust
AI	Acoustic Impedance
DGPC	Directorate General of Petroleum Concessions (Pakistan)
GR log	Gamma Ray log
Ps/m^3	Pascal second per meter cube

Chapter-1

INTRODUCTION

The carbonate basins of northern Pakistan are characterized by tight limestone. Fractures in these basins are important for the production and modeling of reservoirs. This study discusses problems related to the analysis of subsurface fractures, mainly based on an image logs. Natural fractures arise as a systematic and asystematic set of a specific and random orientation. The subsurface factures analysis uses electrical and acoustic logs to characterize the natural or induced appearance of fractures. Conducting or resistive features that represent open or closed (mineralized) fractures are classified. Fractures at large distances are observed in significant carbonate reservoirs, and open fractures are practical in layered layers. Thus, individual fractures in massive carbonates require to be identified for their impact on production. Fractures are observed to occur as discontinuous features of right- or left-stepping geometry and as en echelon features of significantly wider aperture in shear bands. These features together with vugs and leached features may provide zones of higher porosity, permeability, and storage capacity with isolated distribution in tight carbonates (Jadoon et al., 2007).

1.1 Problem Statement

- It appears Chorgali Formation may have at least 30 million barrels of unrecovered oil.
- The 2D, 3D seismic and earlier vintages show that Balkassar is composed of two folds that impart heart shaped geometry.
- The Oxy-1 well is producing viscous oil while Joya-Mir producing light viscous there is structure failure and need to get mapped the subsurface structure.

1.2 Review of Research History

I have reviewed different case studies and research papers for Balkassar block, these are mentioned below:

- In this case study, organized and disorganized (microfractures) Chorgali and Sakesar limestone assemblages were found in image logs. The organized fracture zone test give way only a so-called amount of hydrocarbons (105 barrels per day) from the Sakesar reservoir. While another production test with relatively higher resistance and predominance of micro-fractures (organized) yielded a good amount (1830 bopd) of hydrocarbons from reservoir.

- In this case study, I have studied 2-D (Iqbal et al., 2015) and 3-D Seismic data interpretation, attribute analysis and visualization (Masood et al., 2017) for deeper prospect carried in Balkassar field. Time contour and depth contour map shows potential for deeper prospects. Also attribute analysis and 3d visualization show good results for deeper potential of Tobra and Khewra formations. Seismic amplitude, Reflection strength, Apparent polarity attribute are visualized and interpreted to find the potential for

- Petro-physical properties evaluation was performed by watchful interpretation and analysis of well logs of Balkassar well 7. Based on the statistical analysis performed, it can be accomplished that the Sakesar Limestone in Balkassar oilfield own good petro-physical properties and have the potential to produce hydrocarbons (Shah et al., 2017).

1.3 Study Area

Balkassar field is an exclusive D & P Lease of Pakistan Oilfield Limited (POL), was revealed in 1945 by Attock Oil Company as in figure 1.1. This is located about 105 km southwest of Islamabad in Chakwal District. The location of Balkassar is in the Central portion of Potwar Sub-basin which basically represents the part of Himalayan Foreland Fold-and-Thrust Belt.

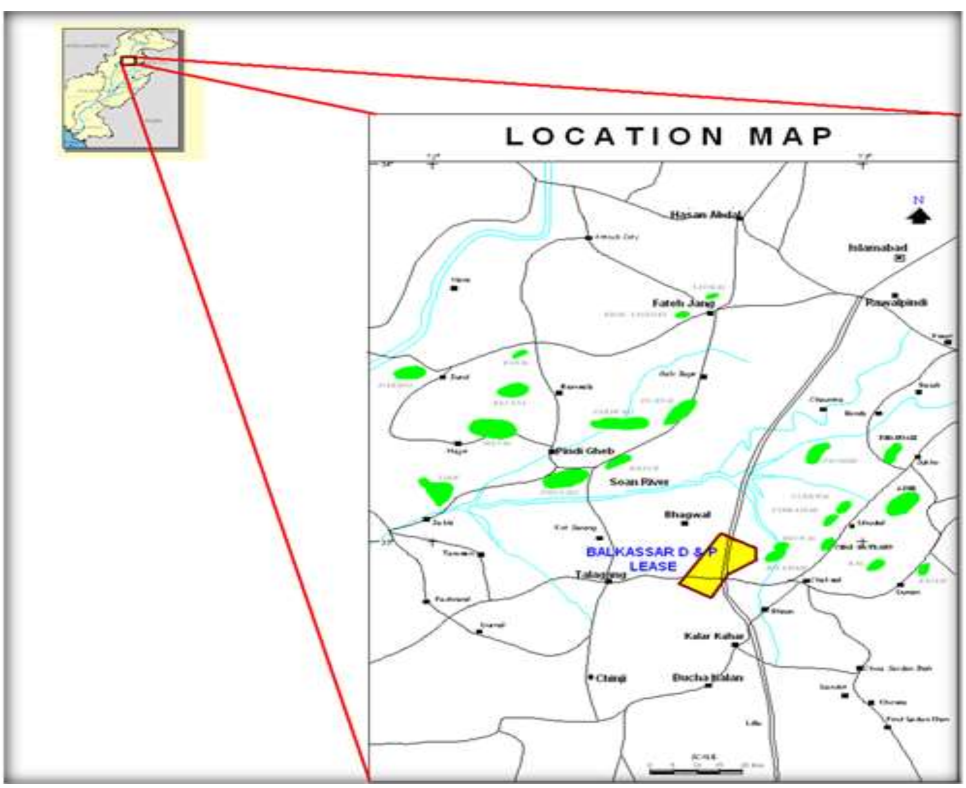


Figure 1.1 Location map of the study area (Highlighted), Potwar sub-basin (Masood et al., 2017)

1.4 Geological Structure of Area

Balkassar lies in Central piece of Potwar Sub-basin which is a piece of Himalayan foreland overlay and-push belt. This structure is situated on the southern appendage of Soan Syncline [8]. Potwar sub-bowl is one of the most seasoned oil territories of the world. The sub-surface picture dependably gives knowledge into casing work and basic styles of the basin. This engineering is an element of complex interaction of compressional powers, incline of cellar, nearness of variable thickness of Pre-Cambrian salt over storm cellar and testimony of thick molasse and structural occasions. For the most part surface components don't reflect subsurface structures due to nearness of decollement at various levels. The Balkassar structure Figure 5 is an "anticlinal pop-up" structures created by both compressional and shear stress regimes. The Eastern flank is bounded by a regional thrust fault, the regionally trends NE-SW along one complex of fault-bend folds. It is becoming narrow towards north where a fault bounded syncline plunges into the middle of anticline and hence resulted in compartmentalization. The anticline has two culminations separated by a small saddle. Most of the wells are drilled in western compartment that is structurally lower than eastern one. The tectonic forces are intense in north as compared to south as seismic correlation shows that the throw of faults gradually dies out as we move from north to south. These pop-up structures have a large thickness of evaporates below the crestal region, while the flanks which are typically reverse fault bounded exhibit salt with drawl. This is quite evident on the seismic profiles. In case of Balkassar, the map view of the structure typically looks like a "heart-shaped" structurally high flanked by reverse faults on both the east and the west shown in 3-D visualization as fault surfaces.

1.5 Material & Methodology

We offer a methodology to achieve this goal. The methodology creates the relationship between hydraulic fracturing and other data sources in a systematic workflow, from one-dimensional static data to a dynamic three-dimensional model. The resulting set of cards is then inserted into the dynamic model of the tank. The methodology was confirmed by a new well, from which it was possible to accurately predict the network of fractures in the reservoir model (Gauthier et al., 2002).

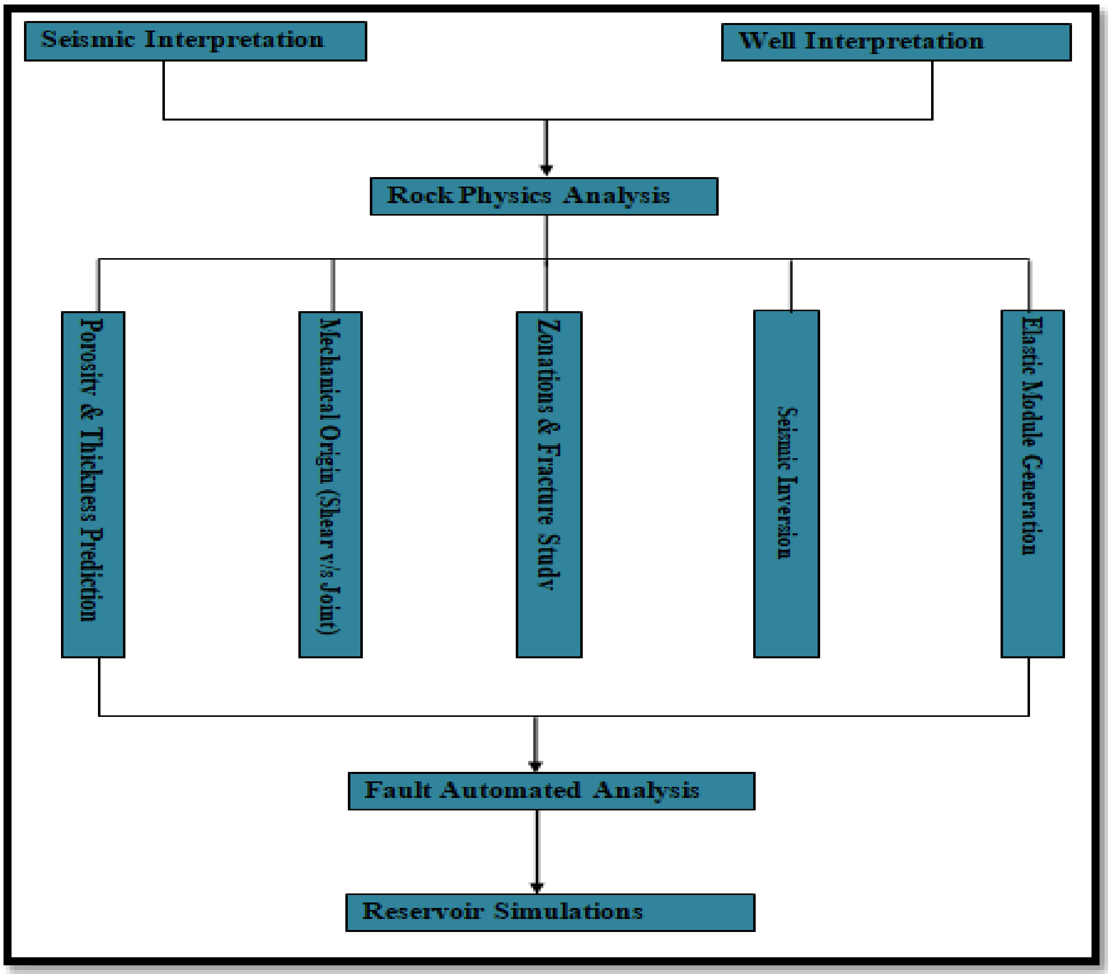


Figure 1.2 Work flow for Balkassar 3D project

1.6 Software used

For unconventional reservoirs, natural fractures are generally poorly understood and hard to identify. This information is critical to defining a hydraulic fracture plan. Fracture categorization is major practice to establish and identify the area, deepness, fracture geometry, fracture orientation, fracture aperture, fracture dip, fracture density and occurrence of fractures.

The following challenges relate to natural fracture network modeling:

- Honoring of natural fracture hard data such as bore-hole image interpretations.
- Obtaining information about subsurface natural fractures.
- Creating realistic fracture surfaces, not planar simplifications.
- Enabling properties to vary within a fracture, and between different fractures and fracture-sets.

- Incorporating secondary knowledge (e.g., seismic attributes) with the natural fracture networking model.
- Understanding the relationship between induced fractures and the natural fracture network.
- Understanding the role natural fracture networks have in well productivity.

Hampson Russel 9.20

Kingdom Software 8.6

K-tron Wavelets

1.7 Objectives

Our scrutiny and literature appraisal of the fractures described above suggests that:

- The automated fault extraction workflow allows you to generate an initial fault network from 3D seismic data with very little manual intervention..
- The conventional logs are the major source to get estimation of reservoir properties.
- The seismic reversal technique is done because it forces us to convert the data identified by the time-dependent reflectivity of the earth into impedance data.
- Integration of reservoir properties is done to get the reservoir characterization.

Chapter-2

GEOLOGY & STRATIGRAPHY OF RESEARCH AREA

2.1 General Geology and Stratigraphy of the Balkassar Area

By the impact of continental lithospheres (Stäcklin et al., 1974; Molnar and Apponnier, 1975) the Himalayan ranges are formed. The continuously northward movement erodes and deposits the sediments impacts begin from Middle to Late Eocene (Beck et al.1995). The convergence of the Eurasian and Indian plates at 2000 km (Patriat, Achache, 1984) can be clarified by the extension of the sea floor spreading. In formation of Himalayan belt and other narrowly situated mountain ranges a range of geodynamical processes are involved i.e. collision and movement of continents, expansion of sea floor (Kazmi and Jan, 1997) and the continuously northward movement of the Indian Plate below the Eurasian Plate during Eocene (Ahmad et al., 2003; Jadoon et al., 2003; Shahzad et al., 2008).

Due to the Cretaceous collision of the Indo-Australian and Eurasian plates, this orogenicity has arisen and continues to this day. Now the progress or southern direction of the deformed regions is not yet complete, but inside the orogenicity it rapidly passes through the deeper tectonic levels. The main limits of this orogenicity are the main Karakorum thrust (MKT), i.e. the area of the Shyok suture zone, the main mantle thrust (MMT), i.e. the region of the Indus suture zone, the Main Central Thrust (MCT), the main limit thrust (MBT) and salt region thrust (Alam et al., 2005; Shahzad et al., 2008).

The foundation for this orogenicity is from the Main Thrust of the Mantle (MMT) to the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT). Salt Ridge and the Potwar Plateau are located in the south of the MBT and reflecting the drive and pull belt of the Himalayas in Pakistan (Sethi et al., 2005). The Potwar Basin is part of the active folding and pressure belt in the Himalayas (northern Pakistan) (Burbank and Raynolds, 1988; Jaume and Lillie, 1988).

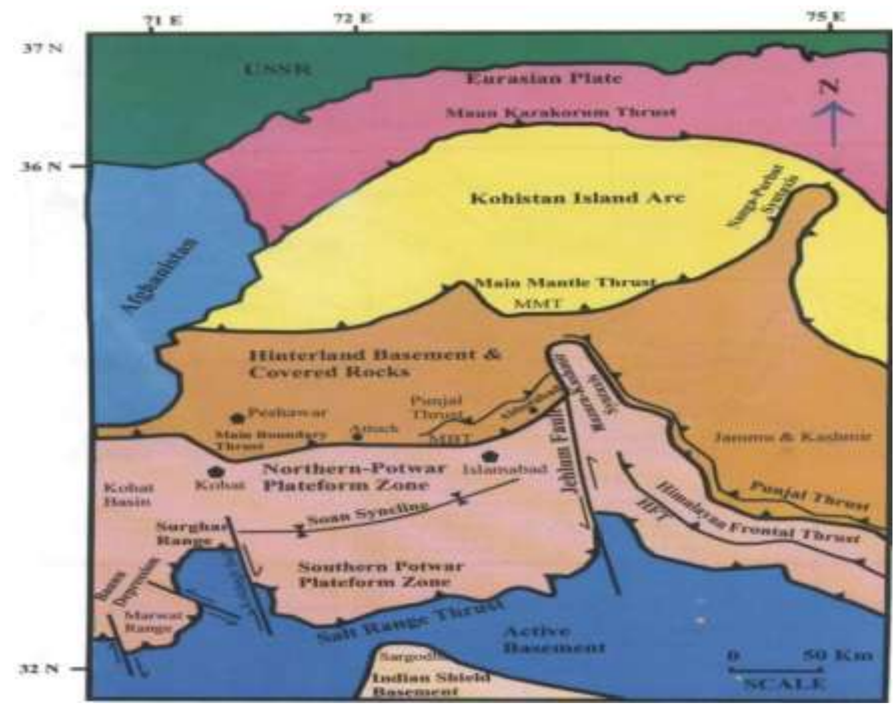


Figure 2.1 Tectonic boundaries of the Himalayan Orogeny (Modified after Shami & Baig, 2003)

2.2 Structural Description of Potwar Basin

Given below is the structural description of the Potwar Basin:

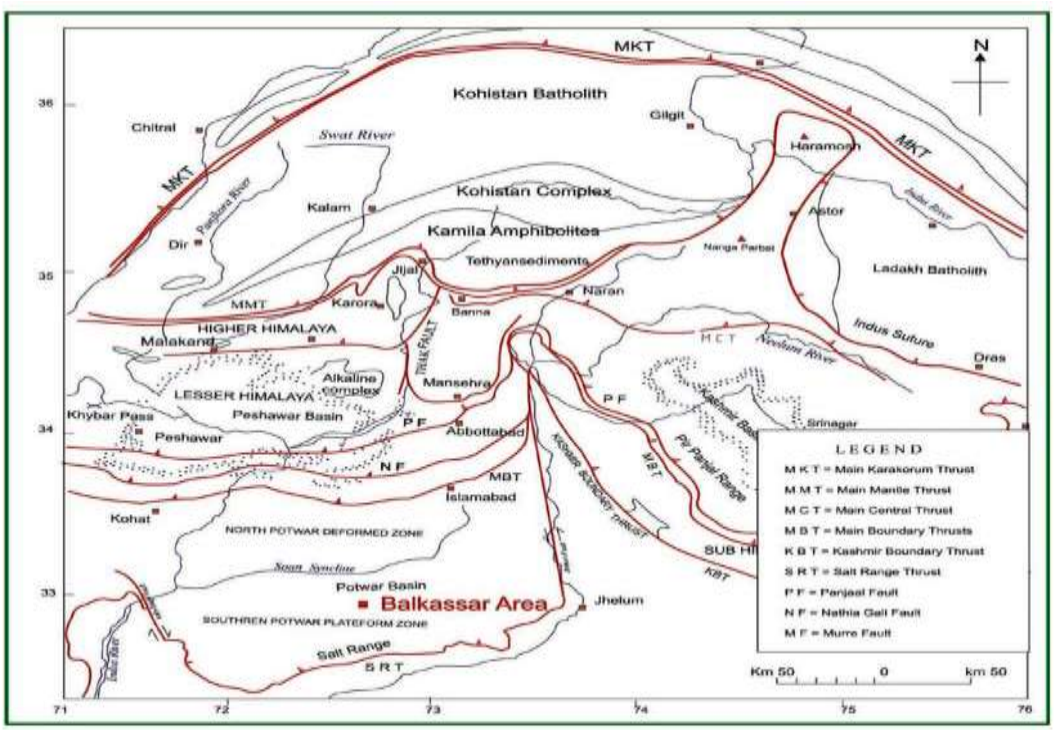


Figure 2.2 Major Structures in Potwar Basin (Iqbal et al., 2015)

2.3 Stratigraphy of the Study Area

EPOCH	FORMATION	ENVIRONMENT	THICKNESS (m)	LITHOLOGY
Pliocene	Nagri	Fluvial Channel	174	Greenish grey Sst and clay, conglomeratic
Miocene	Chinji	Fluvial Streams Channel	945	Bright red clays with Sst.
	Kamlial	Fluvial	106	Massive red and brown Sst., dark red clays
	Murree	Fluvial	906	Interbedded light grey Sst.
Oligocene	Unconformity			
Eocene	Chorgal	Shallow Marine Supratidal Lagoonal	45	Dark – med. Grey argillaceous Lst, minor Evaporites
	Sakesar	Shallow Marine Supratidal Lagoonal	121	Massive and nodular Lst. With marls: chert in upper part
	Nammal	Shallow Marine Restricted Anoxic	13	Dark grey calcareous sh. Light – dark grey Lst. Pyrite and glauconite
Paleocene	Patala	Shallow Marine	13	Dark. Grey greenish sh and Lst.
	Lockhart	Shallow Marine (Distal to Proximal)	41	Massive light – dark grey Lst. With minor sh, pyrite
	Hangu	Very Shallow Marine (Littoral to Paludal)	20	Light grey Sst and dark grey sh.
Cretaceous Jurassic Triassic Late Permian	Composite Unconformity			
Early Permian	Sardhai	Very Shallow Marine to Estuarine	115	Dark purple & Lavendor clays Streaks of Sst.
	Warcha	Fluvial Sub Aerial Paludal Lagoonal	163	Red & light colored Sst. And grit
	Dandot	Shallow Marine Lagoonal	60	Olive – green and gray Sst. & sh
	Tobra	Glacial to Fluvial	51	Conglomeritic Sst. Boulders, sh.
Late Cambrian	Unconformity			
Cambrian	Khewra	Shallow Marine Sub Littoral to Littoral	78	Maroon fine textured Sst. Maroon black
Pre-Cambrian	Salt Range	Restricted Marine Hypersaline	ND	Red gypsum marl, rock salt, Evaporites
	Basement		ND	Biotite schist, quartzitic, rhyolite

FORMATION NAME	LITHOLOGY	AGE
Nagri Formation	Sandstone/Clay Stone	Pliocene
Chinji Formation	Clay Stone/Sandstone	Miocene
Kamalial Formation	Sandstone/Shale/Conglomerates	Miocene
Murree Formation	Sandstone/Clay Stone	Miocene
Chorgali (Bhadrar)Formation	Limestone/Shale	Eocene
Sakesar Limestone	Limestone	Eocene
Patala Formation	Shale	Paleocene
Lockhart Formation	Limestone/Sandstone	Paleocene
Hangu Formation	Limestone/Sandstone/Shale	Paleocene
Sardhai Formation	Sandstone	Permian
Warchha Formation	Sandstone	Permian
Dandot Formation	Shale	Permian
Tobra Formation	Conglomerates	Permian
Khewra Sandstone	Sandstone	Cambrian
Salt Range Formation	Evaporites	Pre- Cambrian

Table 2.1: Stratigraphic Column of the Potwar basin.

2.4 Reservoir Characteristics

The Potwar basin compares to 47% of the oil perceived around the world. It has various great conditions for upgrade of hydrocarbons for example continental margin, broad successions of marine sediments. The companies of a broad sheet of molasses deposits (roughly 3047 m) offer a reasonable profundity range. However oil was gotten from the Potwar basin at a normal depth of 2755-5150 and geothermal gradient is 2 °C/100m (Shami and Baig, 2003). The continuation of the source rocks, reservoir and trap/seal rocks inside the oil window result the gathering of hydrocarbons (oil and gas) i.e., Balkassar, Joya Mir, Toot, Meyal and Dhulian oil fields.

2.4.1 Reservoir Rocks

The major reservoirs of the Potwar basin are the Cambrian, Permian, Paleocene and Eocene. The Eocene Chorgali and Sakesar formations are effective reservoirs in the Balkassar oil field. The Chorgali Formation contains yellowish fractured limestone, partly dolomite and a thin layer, while the Sakesar Formation contains yellowish gray, fractured, hard and partly dolomitic limestone and contains concrete (Siddiqui et al., 2016). The primary porosity of the Chorgali and Sakesar formations is approx. At the Balkassar field, it is below 1%. In the northwestern part of Potwar, secondary porosity extends from northeast to southwest. These fractures accumulate obliquely, parallel, and perpendicular to the axis of the anticlinic shoot (Shami and Baig, 2003).

2.4.2 Source Rock

The major source rock of Potwar basin is Patala Formation (Paleocene) (Khan et al., 1986). TOC (total organic content) of Precambrian Salt Range Formation is vary from 26% to 35% of oil shale whereas Patala formation TOC varies 45% to 60% (Shami and Baig, 2003).

2.4.3 Seal Rock

The Kuldana formation (Eocene) acts as seal for the Chorgali (Miocene) and Sakesar (Eocene) formations. However Murree Formation too offer experienced sideways and vertical sealing anywhere it is making get in touch with the reservoir of Potwar basin (Shami and Baig, 2003).

Chapter – 03

SEISMIC INTERPRETATIONS

3.1 Seismic Interpretation

Seismic data interpretation helps us to recognize the subsurface structures by means of the seismic data. The interpretation is alteration of seismic data into structural image of subsurface by means of different seismic correction and techniques (Dobrin and Savit, 1988). The primary and main object of the seismic data interpretation is to construct the time and depth contour maps on series of reflector level which are picked on the seismic section (Barclay et al., 1984).

All of the information's which are collected at the time of the exploration process must be distinguished in seismic data Interpretation. 3D seismic data having quite higher resolution as compared to 2D. 3D seismic survey has strong capability to express clearly the problem of field assessment, production, exploration and development Tegland (1977). 3D seismic is quite powerful delineation tool, highly costive and generally wells cost quite higher. The achievement of the well is directly related with the quality of structural interpretation of 3D survey (Aurnhammer and Tonnies, 2005).

Seismic data interpretation for the hydrocarbon exploration has been done by two techniques. One is called the qualitative and second is the quantitative interpretation. Any one technique can be adopted according to the geology and the stratigraphy of the area (Sheriff, 1999). Use of the seismic data in the improvement of hydrocarbon field has become dynamic, practically when ripeness is obtained by the field and hydrocarbon pocket started to be exhausted (Bacon.et al., 2007).

After basic interpretation of seismic data, interpreter is able to understand sub-surface geological structure like folds, faults, structural or stratigraphic traps and other features. At the end the conclusion is that all these efforts are made for the exploration of deposit of fresh ground water, minerals and especially the Hydro-carbon.

3.2 Interpretation Workflow

The seismic data interpretation completed after passing through different steps. First of all the navigation data of seismic lines is loaded then the SEG-Y is loaded upon that navigation to from the base map. Then well data is loaded in LAS format. With the help of the well data the synthetic seismogram is generated. The horizon and the fault marking is main work in the seismic interpretation. When the faults and horizon are marked then fault polygon, grid and contours are generated. Hence in this way the seismic interpretation is completed. The schematic work flow for seismic interpretation is given in the Figure 3.1.

3.3 Base Map Preparation

Base map includes locations of lease or concession boundaries and seismic survey points with geographic references such as latitude and longitude. It is develop by loading the navigation, Seismic and well data in Geophysical software (IHS Kingdom Suit 8.6, 2012). 3D base map is developed. Well data is in LAS while the seismic data is in SEG-Y format.

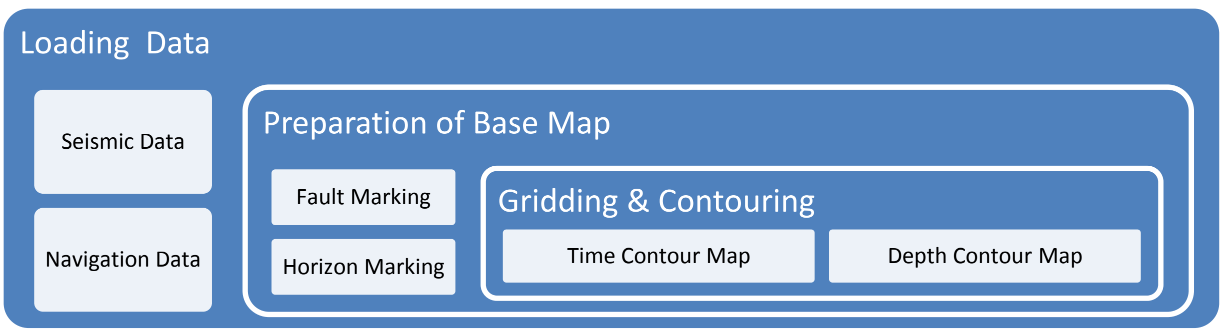


Figure 3.1 Work flow of seismic interpretation

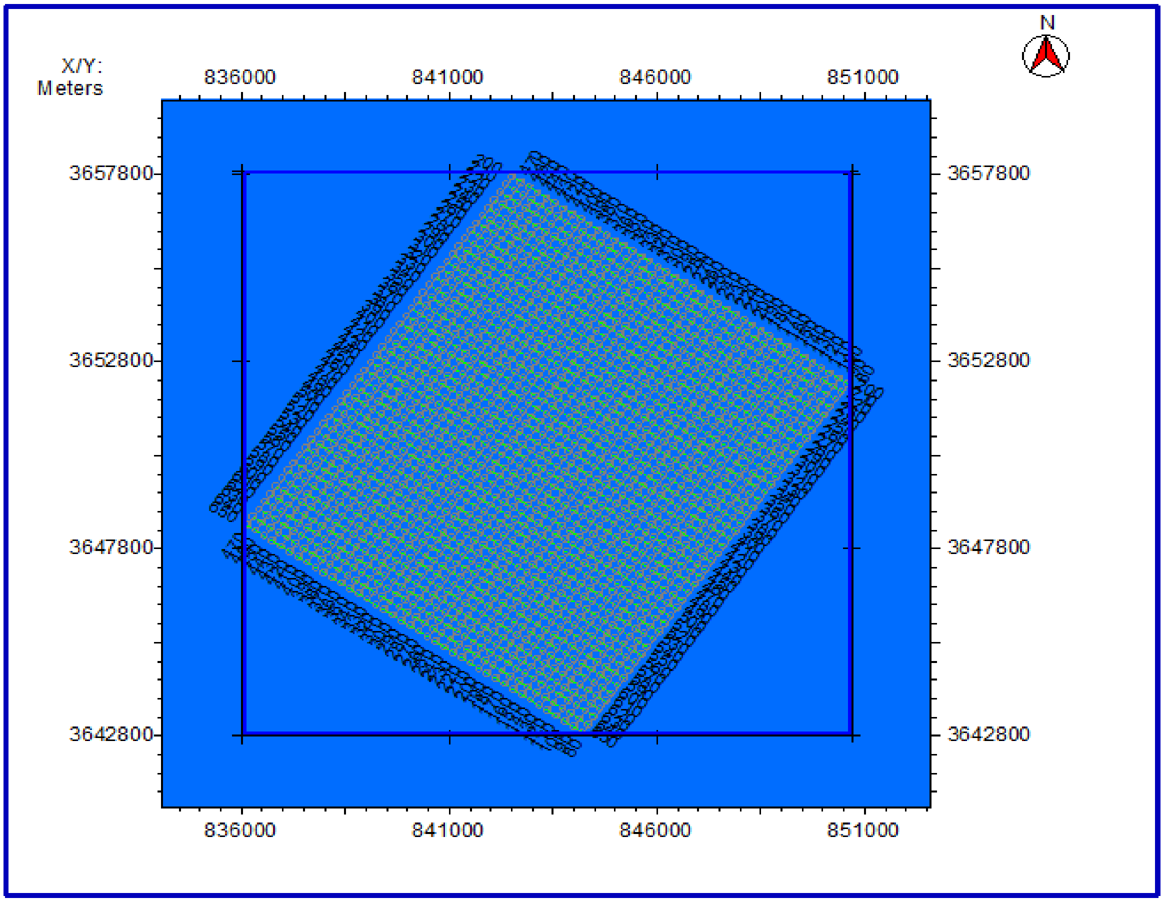


Figure 3.2 Base Map of the study area Balkassar

The major task of the seismic interpretation is the identification of the horizon at different geological interfaces and marking the major discontinuity i.e. faults in that area. Due to which an interpreter must have the strong background of the geology and the stratigraphy of the area (McQuillin et al., 1984).

3.4 Generation of the synthetic seismogram for Well tie on seismic

The control can be enhanced by the correlation of well data with seismic data there are number of approaches for this correlation but the most famous and suitable is the inserting of the synthetic seismogram on the seismic line. Synthetic seismograms are the artificial traces which are used for the correlation of stratigraphy and the seismic reflection (Handwerger et al., 2004).

The synthetic seismograms are most helpful for linking the borehole geology with seismic section because there is direct relation between the observed lithology and the seismic reflection pattern i.e. horizons (Cooper et al., 2004).The synthetic seismogram is generated from the well Balkassar OXY-01 shown in Figure 3.3 by following the below steps.

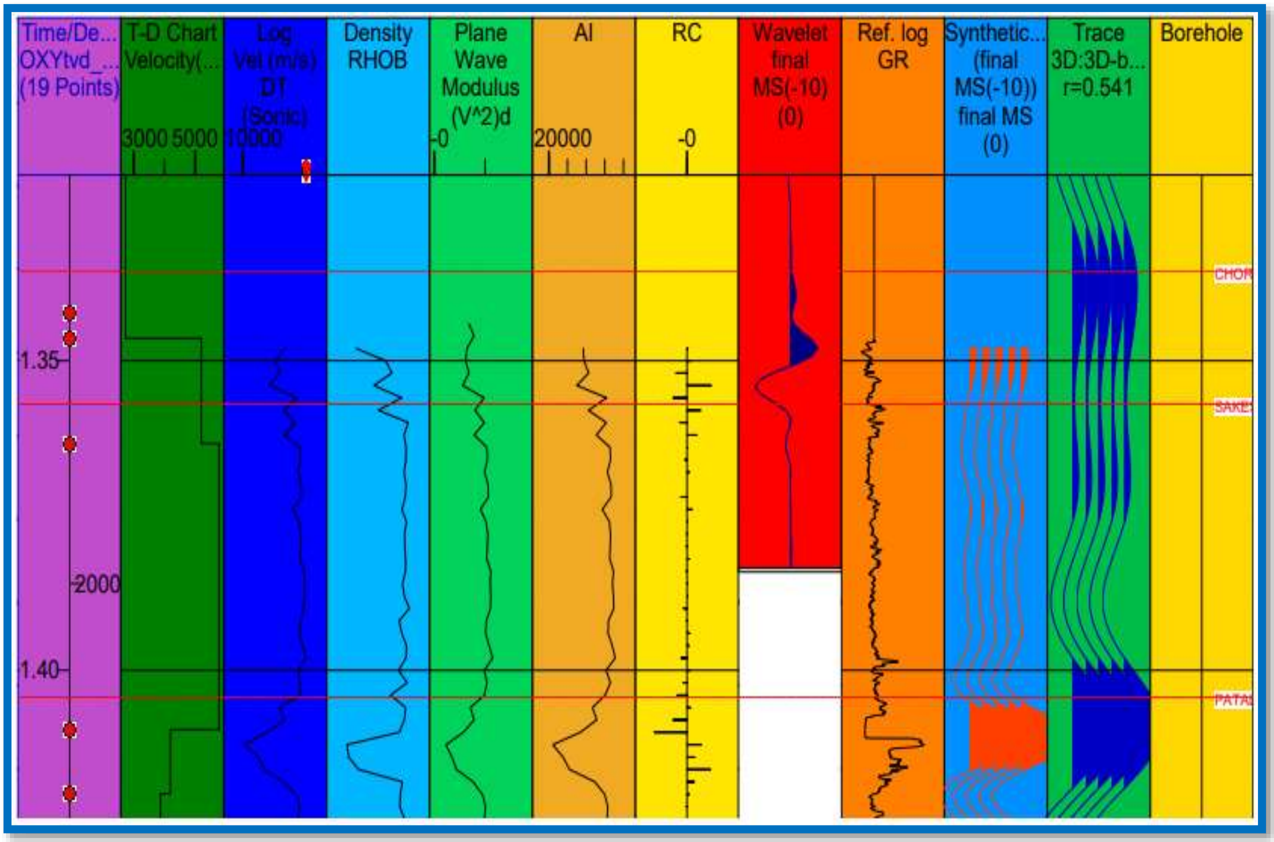


Figure 3.3 Synthetic seismogram of Balkassar OXY-1

1. Loading well data including LAS file, formation tops and well information in IHS kingdom.
2. Opening the SYN-Pak modeling and selecting the desired well logs from the selected well.
3. Calculating the velocity from sonic log by inverting this.
4. Generation of TD chart from the velocity and the formation tops.
5. Multiplying the velocity and the density logs to obtain the acoustic Impedance log.
6. Computing the reflection coefficient series from AI log.
7. Extracting the source wavelet from cube of the seismic data.
8. Selecting the Gamma ray log as reference.
9. Convolving the RC with the source wavelet to obtain the synthetic seismogram.

3.5 Fault identification and the Horizon Marking

Horizon and faults marking is major and basic work in the structural interpretation. Horizons are the reflection of sedimentary data appeared on the seismic profile. With the help of synthetic seismogram, geological, stratigraphic and acoustic impedance changes horizon are picked and marked on the seismic section. Interpretation of the seismic section and marking horizon for time to depth map is interpreter ability that how much he has strong background about the stratigraphy and geology of that field (Mc. Quillin et al., 1984). Due to strong continuity in reflection and available well tops data four major horizon are marked on the seismic section as shown in Figure 3.4. These four major horizons from top to bottom are:

1. Chorgali Formation
2. Sakesar Formation
3. Patala Formation
4. Khewra Formation

Fault marking on the seismic section in real time domain is most difficult without knowing the tectonic history of the area (Sroor, 2010). Faults are marked by considering the tectonic history of the study area along with sudden break up in horizontal continuity of the seismic reflection. The study area Balkassar is lying in Potwar sub basin of upper Indus basin hence it occurs in strong compression regime. Due to existence in compression regime reverse faults are present in this area causing the severe structural disturbance. Two major reverse faults F-1 and F-2 are marked around the crest of the Balkassar anticline as shown in Figure 3.4. Due to compression regime pop-up and anticline traps are favorable structures for hydrocarbon accumulation.

3.6 Interpretation of seismic Inline

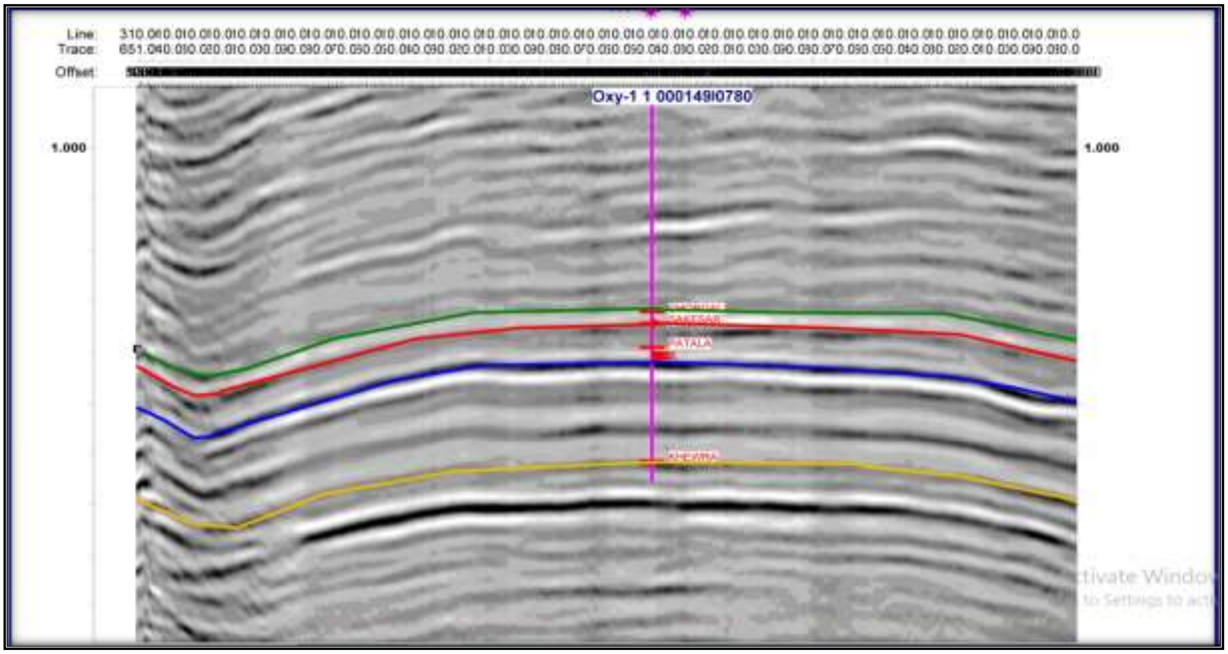
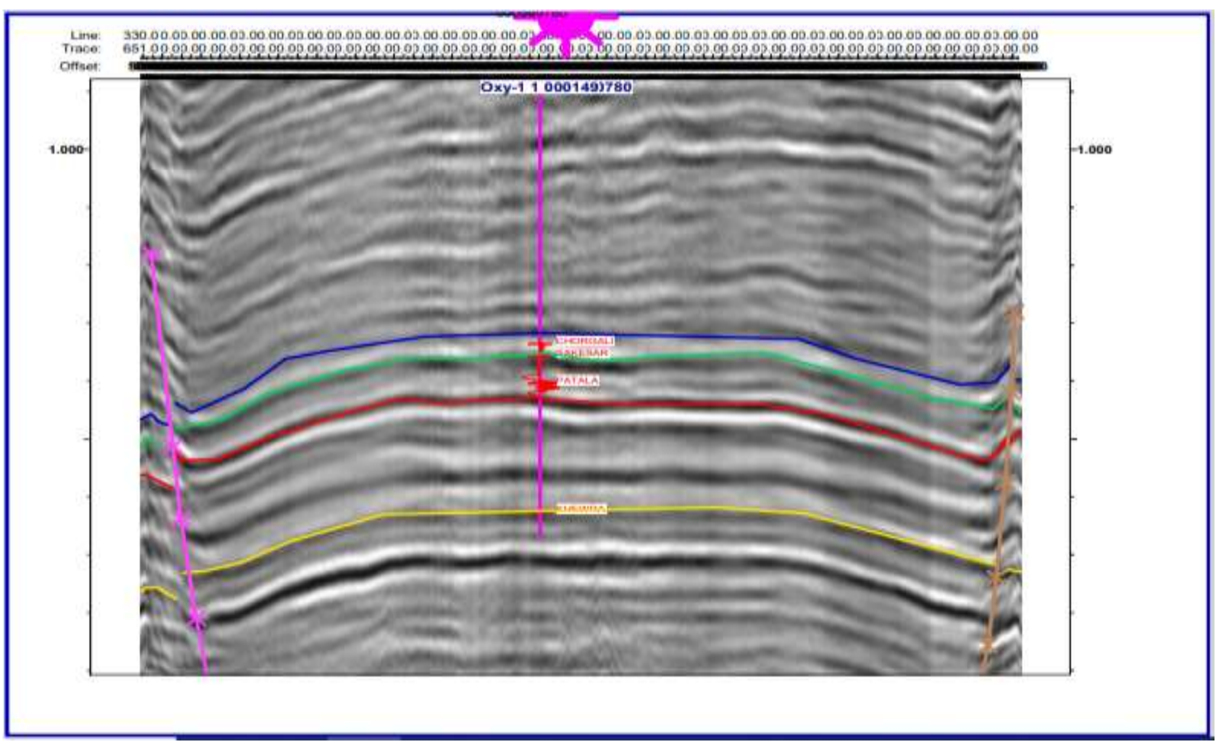


Figure 3.4 (a) Interpretation of 3D seismic Cube Inline310, (b) Interpretation of 3D seismic Cube Inline330,



These horizons are marked with the help of the well tops inserting on the seismic section as shown in Figure 3.4. These horizon are forming asymmetric Balkassar anticline which having the steep limbs in NE and gentle limbs in SW. The anticline is formed due to salt tectonic. Each limbs of the anticline are sealed by the reverse faults F1 and F2.

3.7 Seismic Gridding

After passing from all above steps the next step is generation of Grids which is necessary for the contour maps generation. Grids give the variation in different geophysical quantities on full base map in Time, Depth and amplitude units etc. Basically grid is extrapolation of the seismic data at blank spaces among the different seismic survey lines where data is not acquired. The grids constructed at the Chorgali Formation, Sakesar Limestone, Patala Formation and Khewra Formation in time horizons are shown in Figure 3.5, 3.6, 3.7and 3.8.

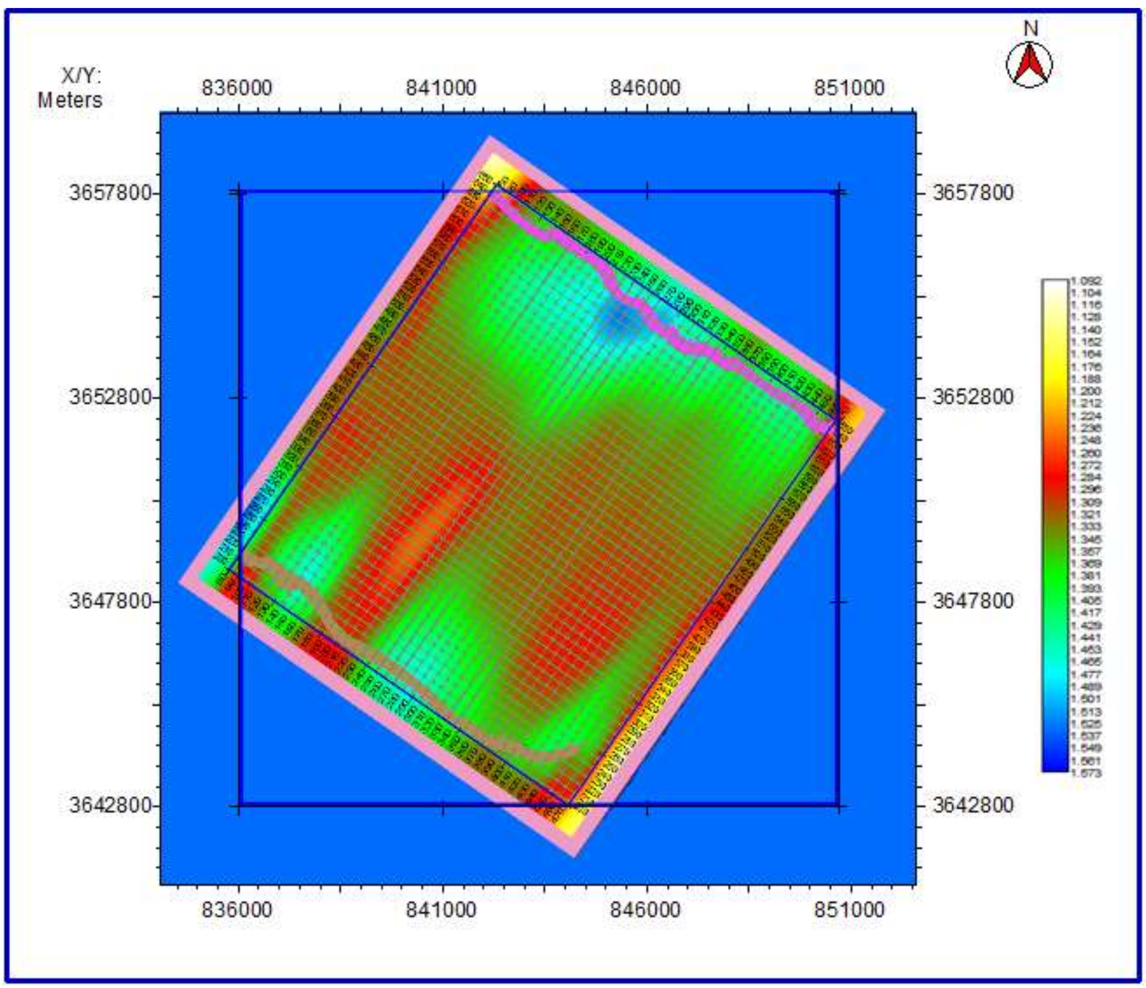


Figure 3.5 Time Grid at Chorgali Formation

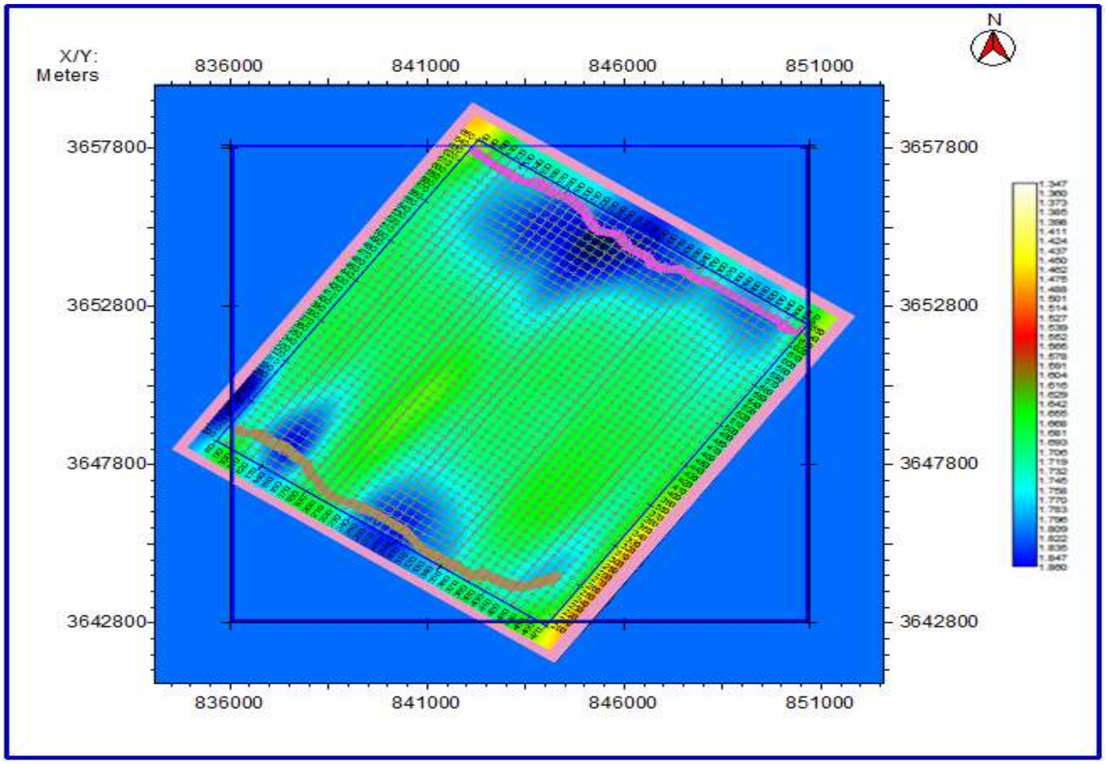


Figure 3.6 Time Grid at Sakesar Limestone

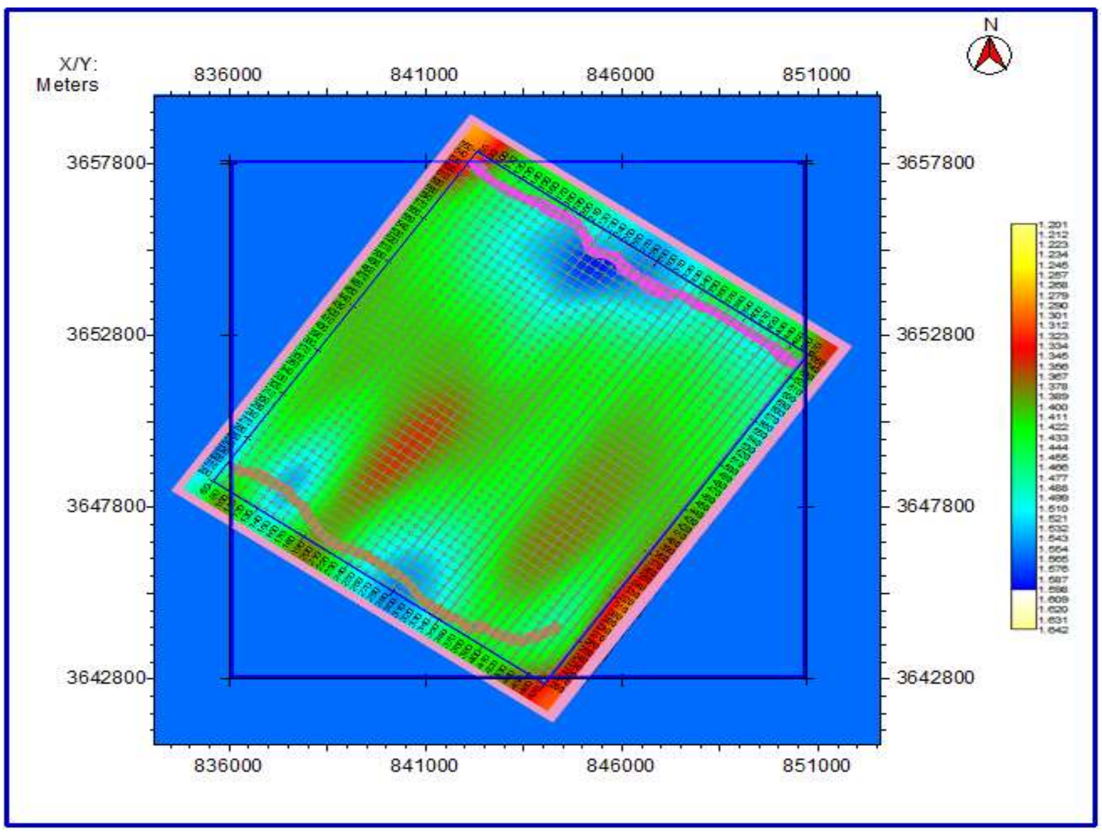


Figure 3.7 Time Grid at Patala Formation

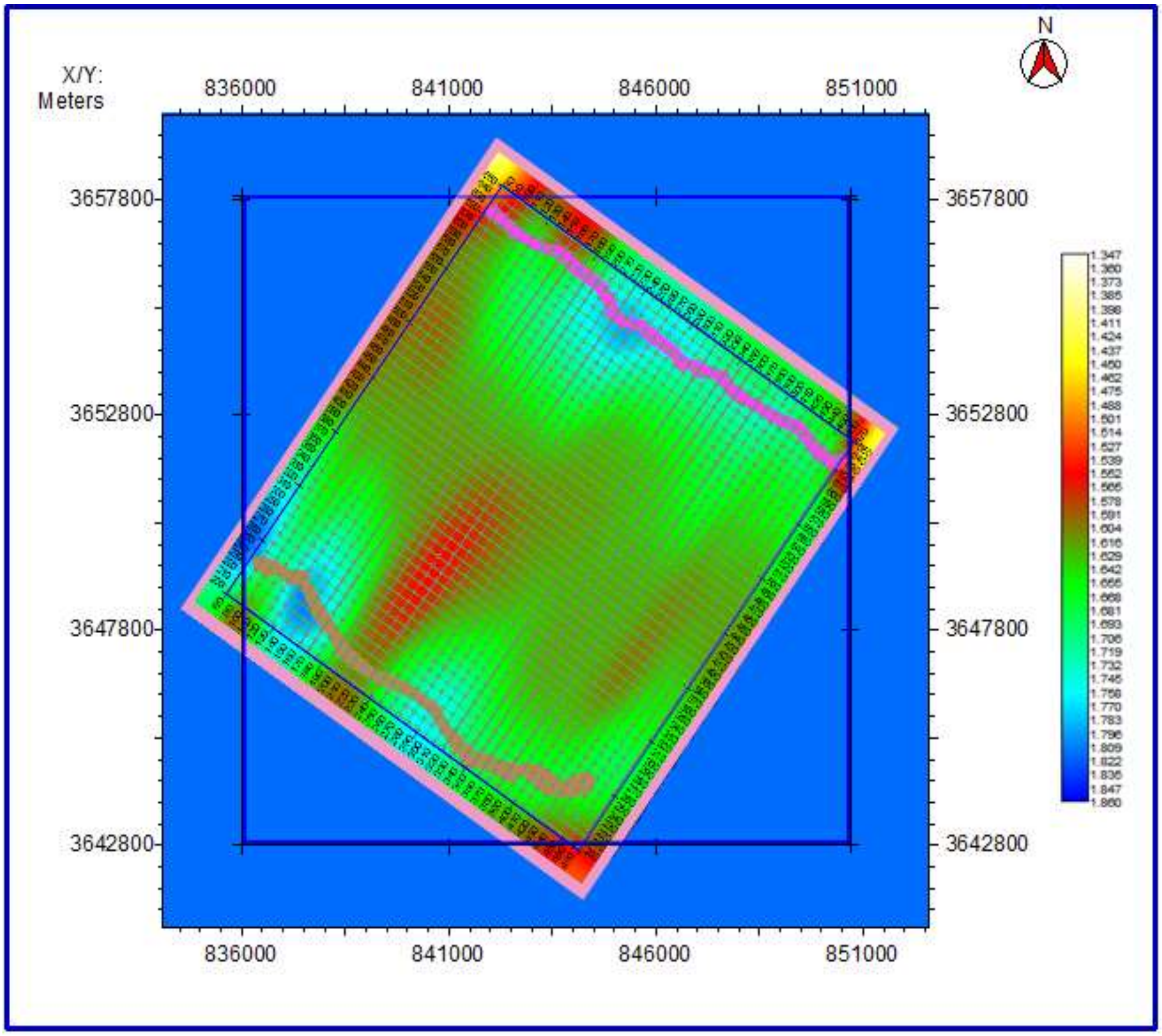


Figure 3.8 Time Grid at Khewra Formation

3.8 Contour Maps Generation

The final product in the seismic data interpretation is the construction of Contours map. Contouring is most essential and important part in the seismic data interpretation. Generally contours are lines which are joining the equal points of time and depth etc. (Coffeen, 1986). Simply contours join the points of same values. After gridding the difference in depth, time and the amplitudes are required to observe at specific intervals for which can be performed with help of the contours.

3.8.1 Time contour maps of the Chorgali and Sakesar formation

Contours represent the 3-D earth into 2-D. These contour plots depict gradient of formation, structural break of the formation and any type of structural disturbance including faults, folds etc. These time and depth contour maps are generated in IHS Kingdom 8.8.

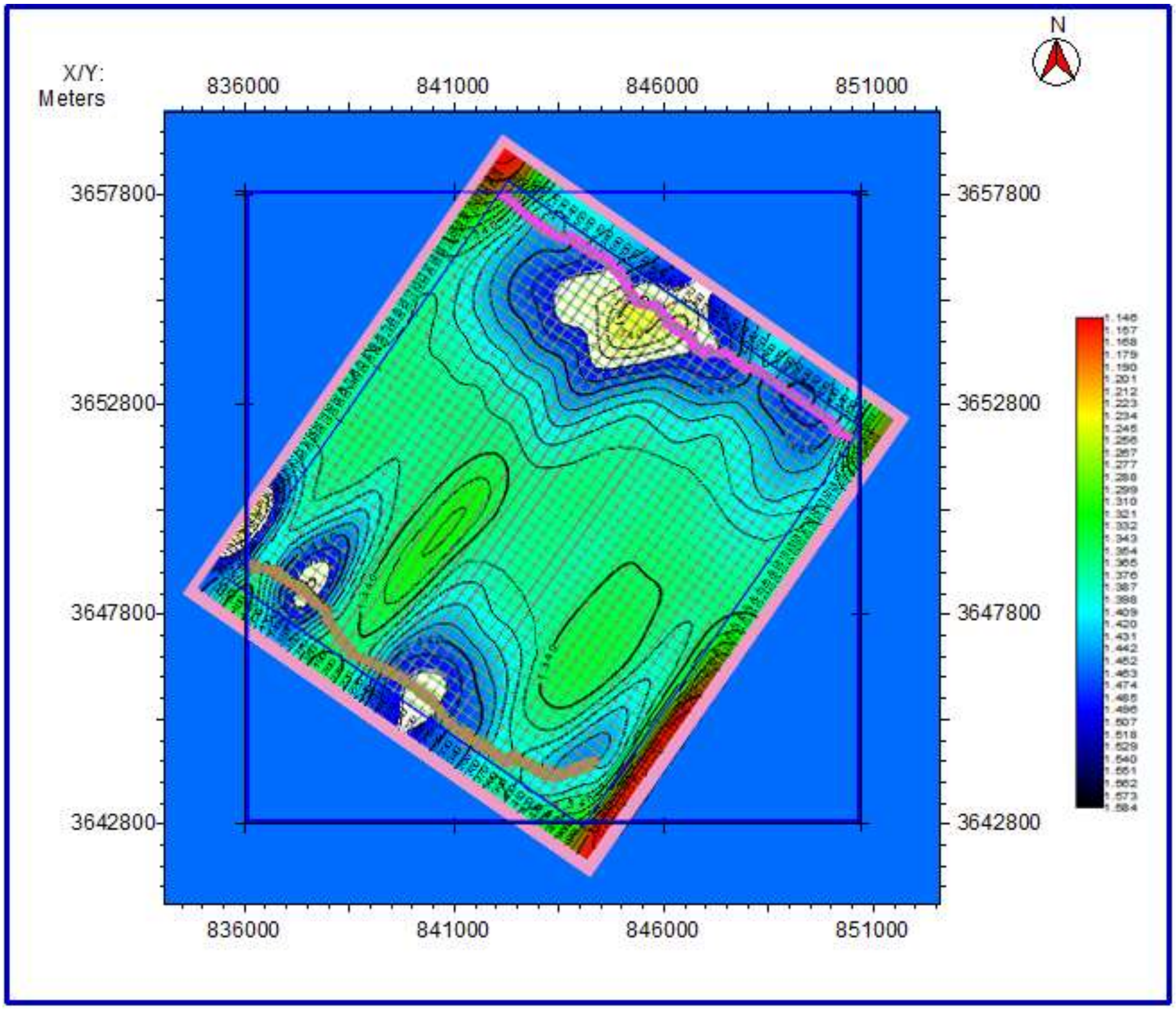


Figure 3.9 Time Contour map of Chorgali Formation

Time contour map of the Chorgali and the Sakesar Formations are shown in Figure 3.9 and 3.10. In these time contour maps central part in NE-SW direction of contour between two faults is represented by the light colors showing less time as compared to away from faults. According to scale this is uplifted shallow area forming the flat shaped crestal part of the anticline. Both limbs of the anticline are steeply dipping terminated by regionally extended thrust faults. These maps clearly give us the indication of back thrusting in study area Balkassar. Closed contours in central crest part can be considered as favorable structural trap for hydro-carbon accumulation. Both the contours maps of the Chorgali and Sakesar Formations showing the same pattern as anticline structures. These time contours maps are generated using weighted average algorithm. This is most suitable algorithm for most complex area like Balkassar.

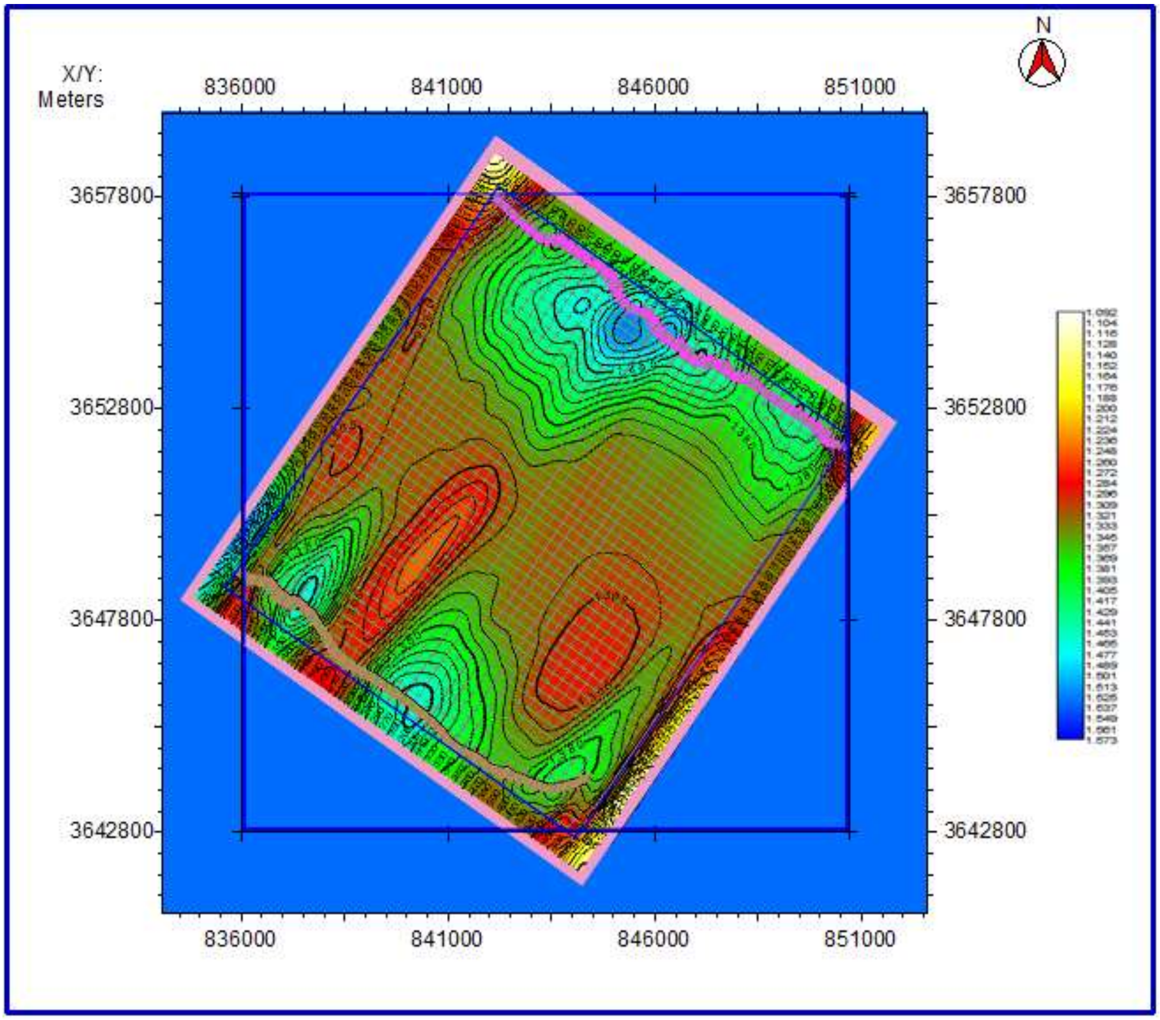


Figure 3.10 Time contour map Sakesar Limestone

3.8.2 Depth contouring of Chorgali and Sakesar Formation

Depth contours join the points of same depth. Depth contour maps of the Sakesar Limestone are prepared as in Figure 3.11. Depth range is shown in color bar to the right side of below figure.

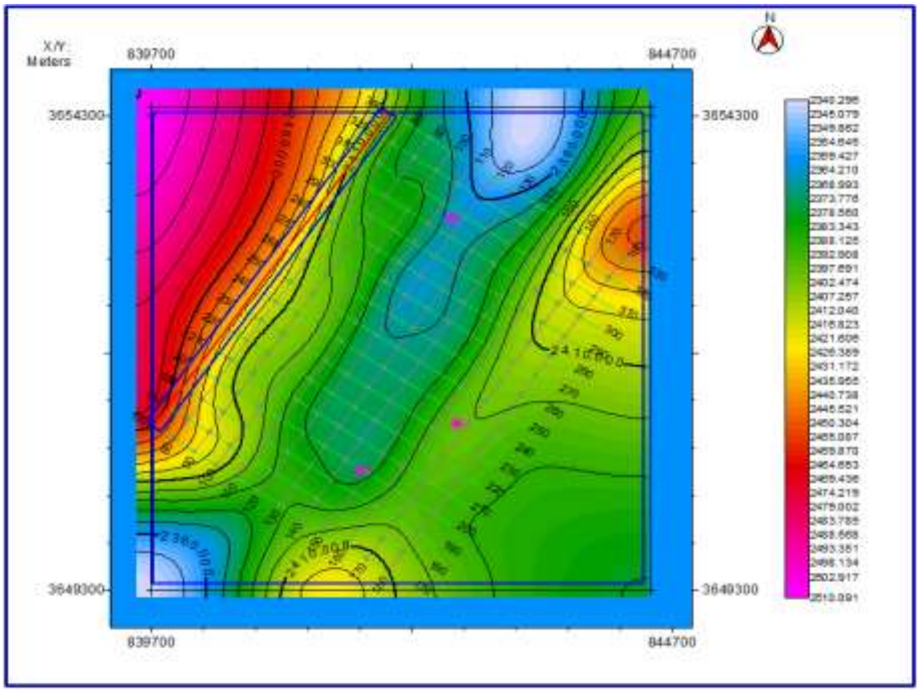


Figure 3.11 Depth contour map of Chorgali Formation (Restricted inline80-220 and cross-line160-320)

3.9 3D Visualization

True picture of subsurface can be presented by the 3D Visualization because it enables a viewer that what is true picture of the subsurface structure. From 3D visualization makes clear cut anticlinal structure which is also interpreted in contouring and gridding.

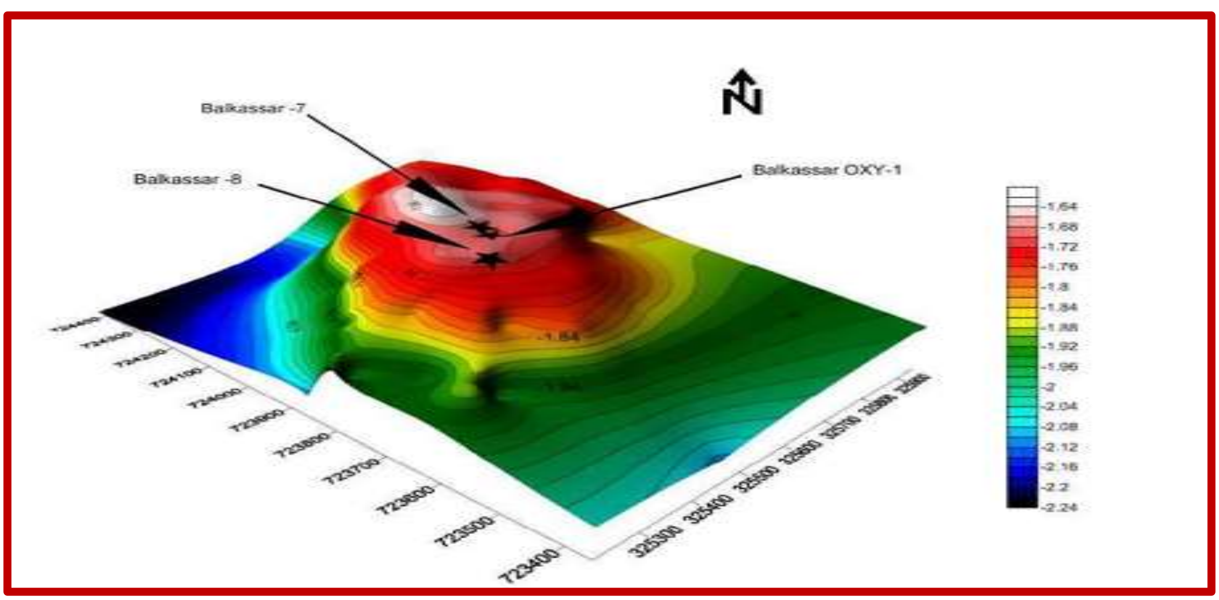


Figure 3.12 3D visualization of Sakesar Limestone time grid

3.10 Result and Discussion

Depth contour Maps are generated with mathematical calculation. For this purpose time is taken from the seismic section using the software time locater tool at well location. Now at well location TWT for Sakesar is 1.50 sec. Similarly at well location the depth of the Sakesar formation from the well top is 2467.2m. So velocity calculated at well point using relation (S=v*t/2) is 2530.45 m/sec, which is only velocity information according to provided data set from DGPC. After calculating this velocity (S=v*t/2) is applied for entire data set on full base map for depth grid generation.

After the depth grid generation depth contour maps are generated for Chorgali and Sakesar Formations. Depth contour Maps reveal clearly that central part between two faults is shallow portion which is crest of Balkassar anticline forming the suitable structural trap for hydrocarbon accumulation.

Chapter – 04

PETRO-PHYSICAL ANALYSIS AND ROCK PHYSICS & ENGINEERING PROPERTIES AND FACIES ANALYSIS

4.1 Introduction to Petrophysics

Petro-physics is the categorization and interface of the rock and fluid properties of reservoirs and non- reservoirs. Main objectives of petro-physics are

1. Determining porosity
2. Water saturation
3. Permeability

Well logging, also known as drilling logging, is the training of detailed logging of geological formations penetrated by drilling (Well log). Interpretation of the log, or evaluation of formation, requires physics of the results of the logging tool, geological knowledge, and additional measurements of the information to evaluate the maximum petrophysical data associated with the surface information (Ellis & Singer, 2007).

A significant explanation for petrophysical calculations is the use of all available information, adjustment to the best standard, introduction of the most exact quantitative inference of petrophysical limits (e.g., lithology, net pay, slate, porosity, water saturation, and porosity). The information used for petrophysical studies is well compiled (Cannon, 2016).

1. During Well Log Interpretation, the aim is to
2. Recognize the depth and type of hydrocarbon (oil or gas) available
3. Compute the hydrocarbon zones
4. Approximate the recoverable hydrocarbons

4.2 Data Set Used

For the estimation of reservoir characterization of Balkassar area, petrophysical analysis of OXY-1, BLK-07 has been carried out. Mostly used logs for petrophysical analysis are gamma Ray (GR) log, spontaneous potential log, resistivity (LLD, LLS, MSFL) logs, neutron (NPHI) porosity, density (RHOB) and sonic (DT) logs were present in the Las file of above mentioned wells.

The following petrophysical variables has been estimated using available logs data

1. Volume of Shale (Vsh) using GR log
2. Porosity (Average and Effective Porosities) using porosity logs
3. Saturation of Water using Resistivity logs, GR log and Porosity Log
4. Net limestone and Net Pay thickness using cutoffs porosity and Vsh

Sketchy workflow of petrophysical analysis and order of displaying logs in respective tracks are shown below in Fig 4.1.

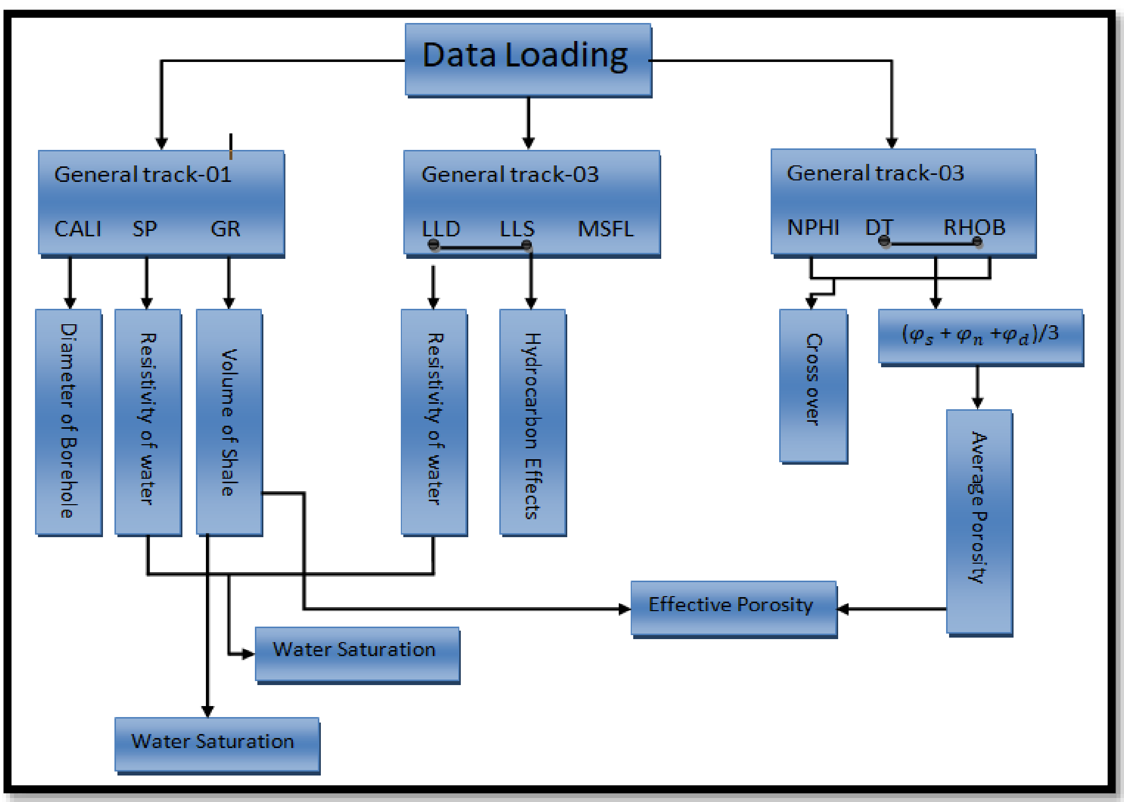


Figure 4.1 Workflow of petrophysical evaluation

4.3 Gamma ray log

The gamma ray log is a testimony of preparations of radioactivity. The radiation originates from normally occurrence uranium, thorium and potassium. Generally rocks are radioactive fairly, anyhow take in by sediments, shale have undoubtedly the most grounded radiation., that is the reason the basic gamma ray log has been known as the 'shale log' (Rider, 2002). Volume of shale can then be estimated from gamma ray log response.

4.3.1 Volume of Shale (v_{sh})

If the scale of Gamma Ray log is considered to be linear, any value of the gamma ray log will give the volume of shale from the simple Eq 4.1

Volume of Shale $V_{sh} = \frac{I_{GR}}{3-2I_{GR}}$ (4.1)

Where

$V_{s□}$ is Volume of shale of reservoir zone

GRlog is the GR log value

GRmin is the minimum value in GR log (clean zone)

GRmax is the maximum value in GR log (shale zone)

4.4 Porosity

Porosity (Phi or Φ) is defined as "the ratio of the volume of pore (void) space (Vp) to the total volume of rock (V_t)".

In a reservoir zone, porosity may fluctuate from 3% to 12%, but on average it will fall in the zone in between 2% and 6%.

4.5 Electrical Logs

Resistivity logs are electric logs which are used to

1. Evaluated hydrocarbon versus water-bearing zones
2. Identify permeable zones

3. Evaluate resistivity porosity

They offer a method of manipulative the water saturation, upon which the present petrophysical analysis is based. The resistivity is strongly influenced by the invasion of drilling mud into the invaded zone.

Most of the logs are designed to calculate the resistivity as far into the rock from the well as possible, beyond the zone impregnated with drilling mud. This is called to be as lateral-log.

A further adaptation, the Dual Induction Focused Log, measures the resistivity both adjacent to the well and further into the rock, comparing the paired readings to review the effect of the drilling mud in the formation. Up till now an additional type, the Micro log (ML), is used to find out the thickness of the drilling mud (mudcake) adhering to the well wall (Knut Olai Bjørlykke, 2010).

4.6 Resistivity of Water (Rw)

An approximation of formation water resistivity R_w is required for the calculation of water saturation S_w. However an uncontaminated sample of water obtained from a well through drill stem test or a wire line formation test, this is the mainly dependable method of determining.

The process of assessment tends to be iterative in that as more data are gathered a better evaluation is developed. R_w is reliant on two linked variables, temperature and salinity; as these properties vary in the reservoir, so does R_w.

There are number of methods that can be used to determine R_w and these should be compared to find the most reliable for a particular field or zone (Cannon, 2016).

1. SP method
2. Resistivity Cross-Plot Method
3. Pickett Plot
4. Apparent R_w method

4.7 Water Saturation (Sw)

Water saturation is eventually the final step in petrophysical analysis. Archie developed a mathematical relation (equation 4.6) to analyze water saturation in the formation (Rider, 2002)

$$Sw=\sqrt{}(n\&(F*Rw)/Rt) \quad (4.2)$$

4.8 Petro-physical Evaluation

This section particulars the petro-physical evaluation of a well: OXY-1. The results contribute to the reservoir characterization of Balkassar Area.

The valuation is based on petro-physical interpretation of obtainable digital wire line log curve data for the well transversely the whole logged interval. Outputs of this appraisal would be interpretations of volume of shale, resistivity logs behavior and taking apart between LLD and LLS, porosity log curves. It also involves the evaluation of net reservoir thickness, evaluation of effective porosity, and at last the purpose of water saturation, which is the eventual goal of every petrophysical analysis.

4.8.1 Petro-physical Interpretation of OXY-1

Petrophysical interpretation help in description and considerate of reservoir by fluid properties such as: porosity, fluid, saturations and lithological properties. In this study, reservoir limestone is evaluated from a composite log suite comprising gamma ray, resistivity, and density and neutron logs of well OXY-1. There are three zones marked as reservoir zone and read out values are given below:

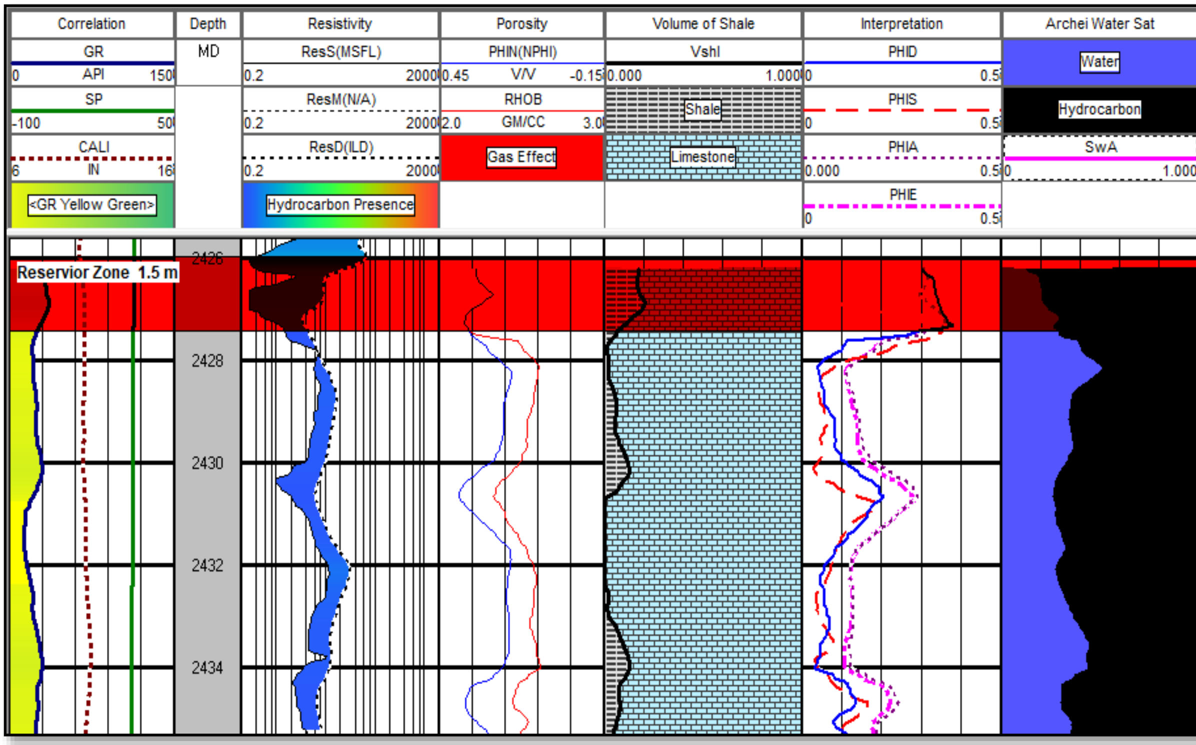


Figure 4.2 Petrophysical analysis of OXY-1 well (Zone:1 2426-2427.5m)

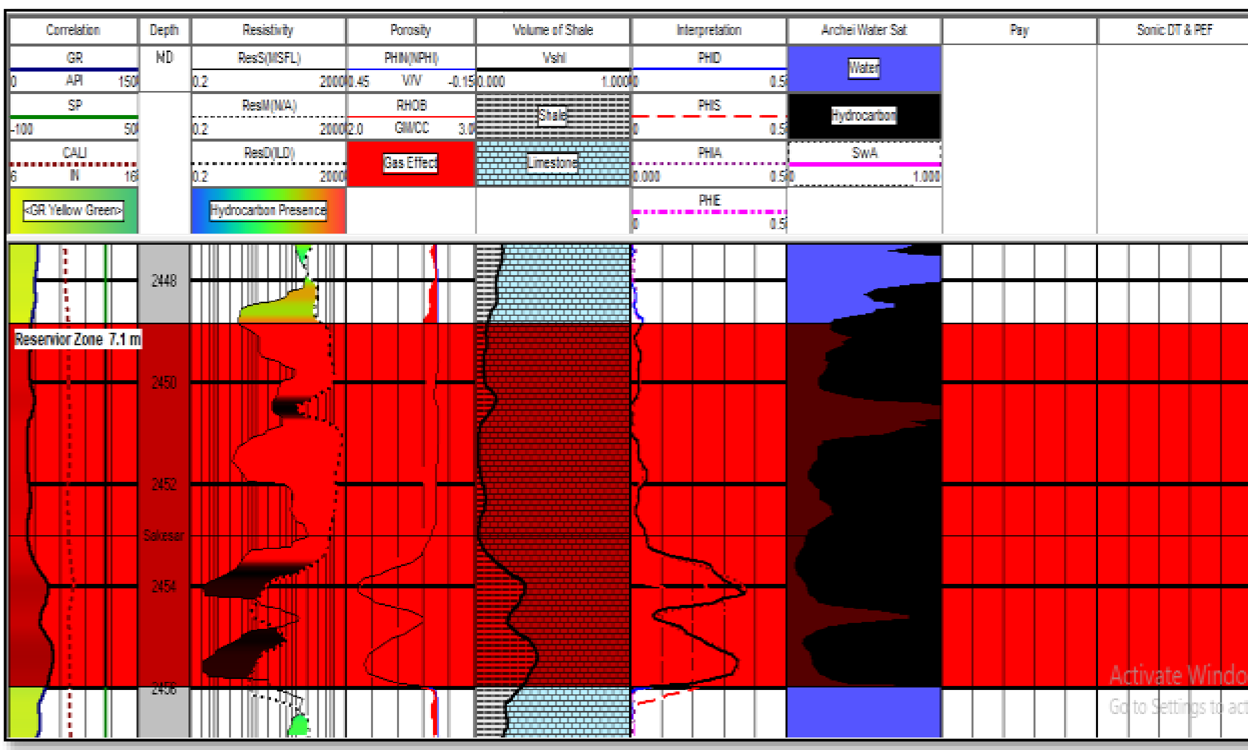


Figure 4.3 Petrophysical analysis of OXY-1 well (Zone:2 2452-2457m)

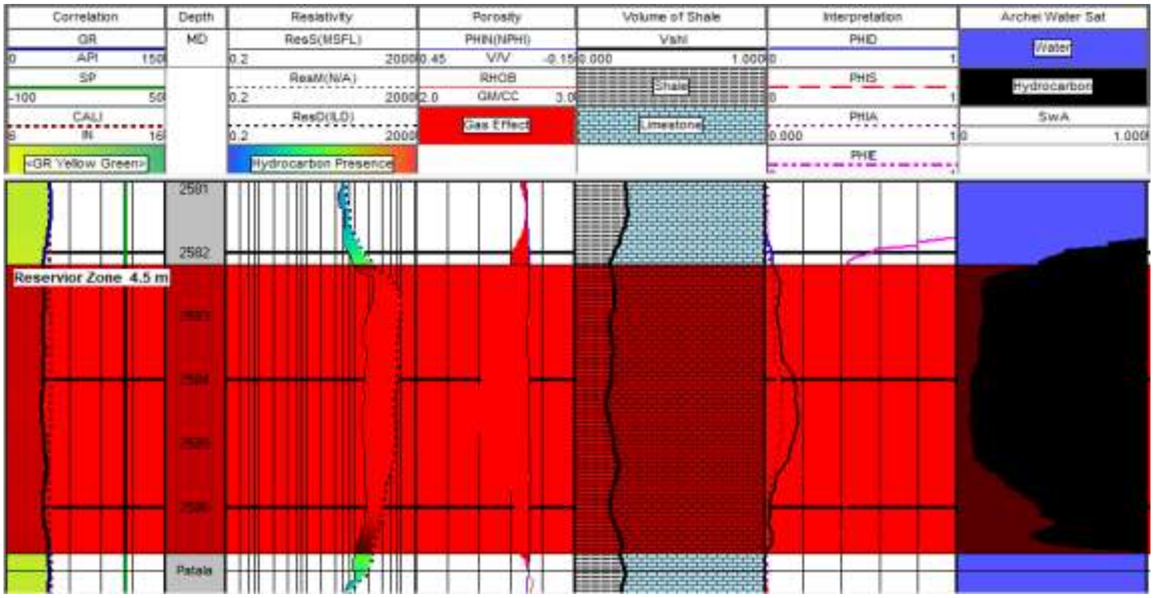


Figure 4.4 Petrophysical analysis of OXY-1 well (Zone:2 2582.5-2586.5m)

Petro-physical Outcomes of Chorgali Limestone Zone-1 (2426-2427m), OXY-1					
Petro-physical Property	Volume of Shale (Vsh)	Total Porosity (Φ_t)	Effective Porosity (Φ_e)	Water Saturation (S_w)	Hydrocarbon Saturation (S_{HC})
Units	v/v	v/v	v/v	v/v	v/v
Value	19%	8%	6%	31%	69%
Petro-physical Outcomes of Sakesar Limestone Zone-2 (2452-2457m), OXY-1					
Petro-physical Property	Volume of Shale (Vsh)	Total Porosity (Φ_t)	Effective Porosity (Φ_e)	Water Saturation (S_w)	Hydrocarbon Saturation (S_{HC})
Units	v/v	v/v	v/v	v/v	v/v
Value	22%	4%	3%	20%	80%
Petro-physical Outcomes of Sakesar Limestone Zone-3 (2582.5-2586.5m), OXY-1#					
Petro-physical Property	Volume of Shale (Vsh)	Total Porosity (Φ_t)	Effective Porosity (Φ_e)	Water Saturation (S_w)	Hydrocarbon Saturation (S_{HC})
Units	v/v	v/v	v/v	v/v	v/v
Value	33%	8%	6%	34%	66%

Table 4.1 Petro-physics Outcomes of Reservoirs zones

4.9 Estimating the Rock Physics

The main goal of rock physics studies is to link the physical and elastic properties of rocks to better associate between geophysical measurements and rock properties. This depends on general velocity data (seismic, sonic, or ultrasonic measurements) collective with reservoir properties such as clay porosity, density, saturation, and volume from well logs and / or seismic inversion.

In rock physics modeling, we need to define efficient elastic modules that depend on (1) the modulus of elasticity of the components, (2) their volume fractions, and Vernik and Milovac (2010), who helped to compared petrophysical models for reservoir properties. The depth of the deposited deposits varies in intervals of approximately 2420–2660 m, and the lithostratigraphic distribution examined in the study area and the depth intervals are 2450–2570m (reservoir area).

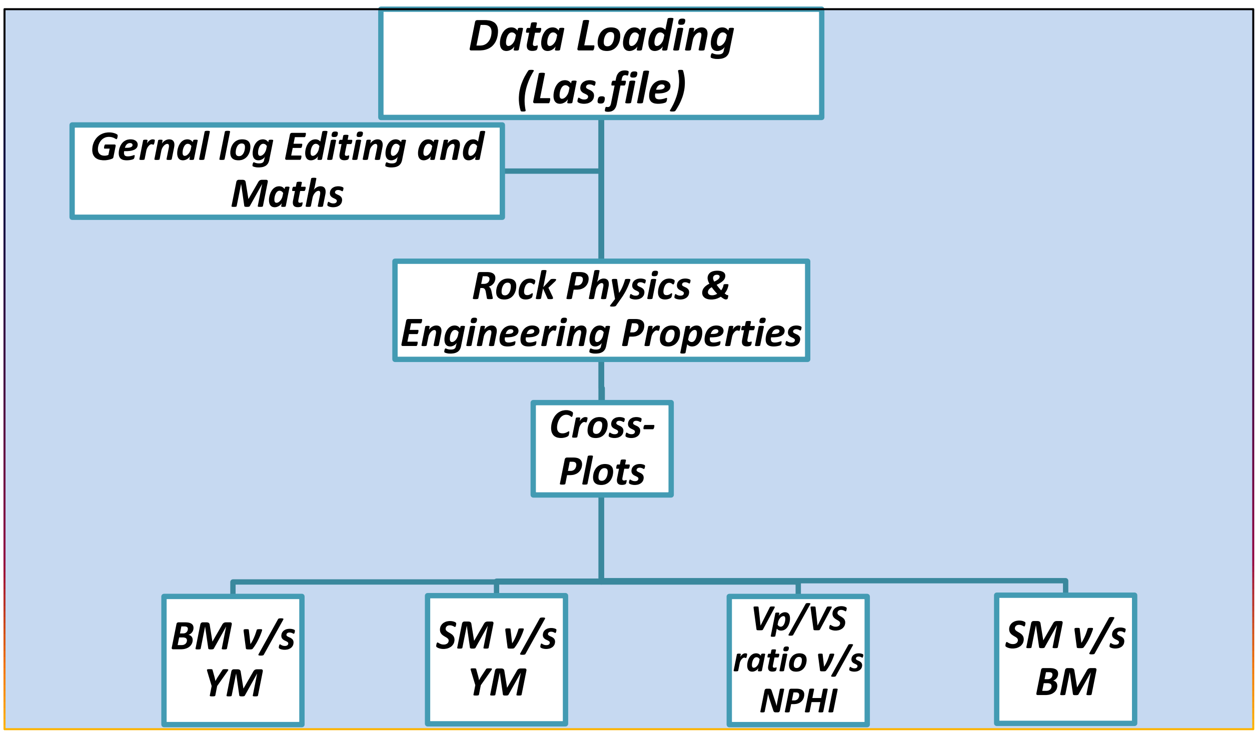


Figure 4.5 Workflow of Rock Physics Analysis

4.10 Well Log Data

The compilation of wire-line log data comprise sonic log, density log, resistivity log, caliper log, porosity log, Impedance log, Vp/Vs ratio log, bulk modulus (BM), young modulus (YM) and shear modulus (SM) as shown in figures 4.6.

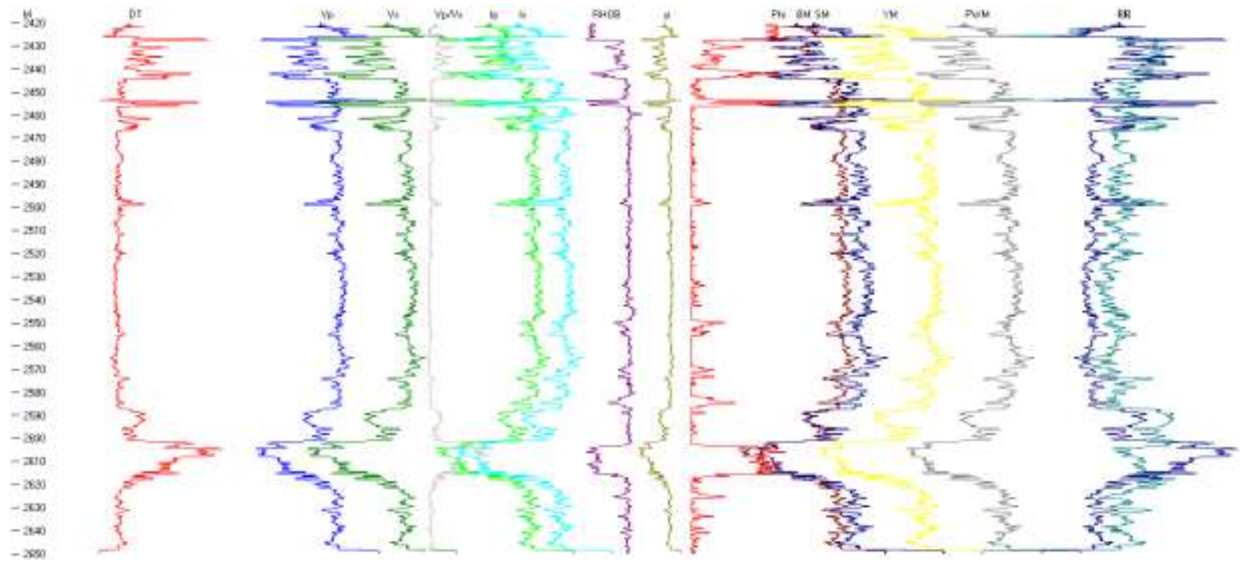


Figure 4.6 Logs response of different engineering properties logs

4.11 Engineering Properties

The load capacity of the material depends on the technical properties. Using the results of the evaluation of petrophysical formation, we performed the lithological peculiarity. Three petrophysical zones were identified using defined boundary criteria. These were:

The average mineral symphony of the matrix for each lithological group is then obtained. We evaluated the probe log data and constructed cross-sections of rock attributes.

4.11.1 VP, VS Ratio

I have investigate the relationship between compression seismic velocity and shear wave Vp / Vs ratio and sedimentary rock petrology. Cross-sectional graphs of Vp / Vs and other logarithmic values propose that fracture or pore geometry has a hefty effect on the experimental Vp / Vs values than the elastic constants of the minerals containing the matrix. Moreover, it can be assumed that the experimental relationship among lithology and Vp / Vs is the effect of the relationship among lithology and the distribution of pore and fractured forms.

4.11.2 Neutron Porosity (NPHI) logs

To accurately take off porosity, the neutron log matrix setting must be in contact with the rock type. Determining these parameters is not a big problem if one has a good geological knowledge of the formation and if the lithologies found are simple, such as pure sandstone or limestone reservoir. However, what to do if you are unsure of petrology or if it is known that its composition differs significantly, as in the case of limestone formations with variable dolomite and anhydrite inclusions, in calcite-cemented shale?

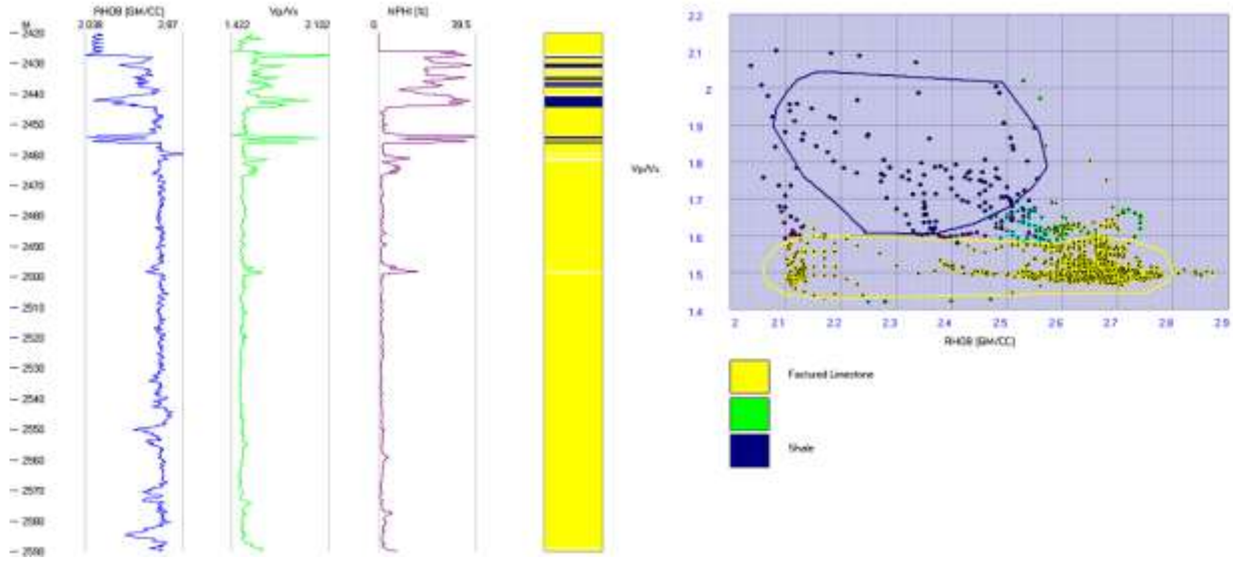


Figure 4.7 Cross plot of Vp/Vs ratio and NPHI in the presences of GR-log

4.12 Reservoir Characterization

Although here we can be easily differentiate and represent limestone and facture limestone from the logs of the Chorgali Formation. The depth varies from 2430 m to 2450 m, the Vp / Vs ratio ranges from 1.5 to 2.1, the AI is 6-13 (Pa · sm ^ 3), which describe a good range of porosity, i.e. At a depth of 2450 to 2590 m, the Vp / Vs ranges from 1.45 to 1.59, and the AI (13.5-17.8 Pa · cm ^ 3) tells the area of hard limestone in the Chorgali Formation

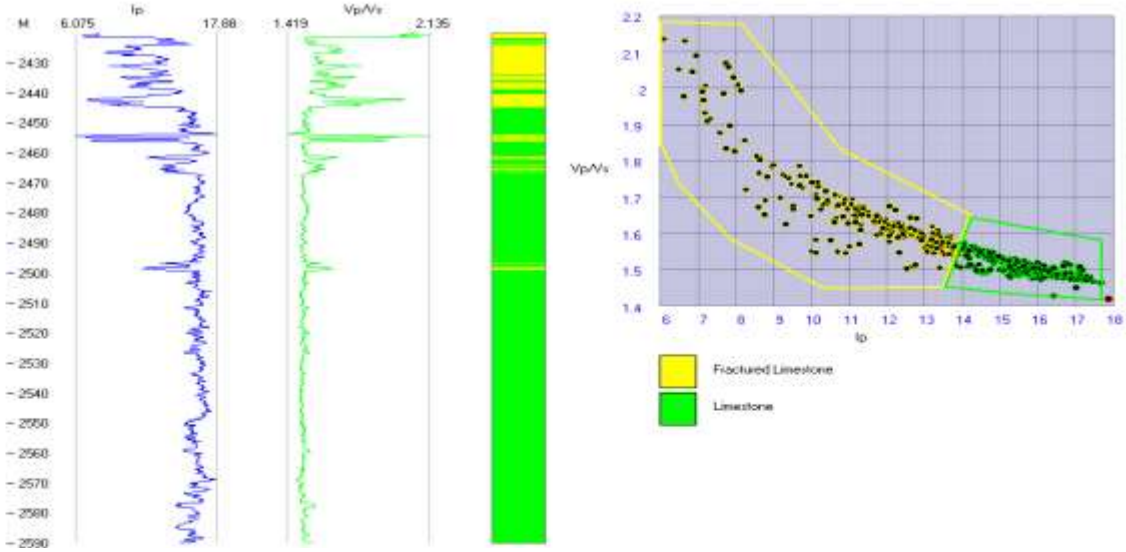


Figure 4. 8 Cross-plot of Vp-Vs Ratio and acoustic impedance Characterizing Limestone and fractured limestone in Chorgali Formation.

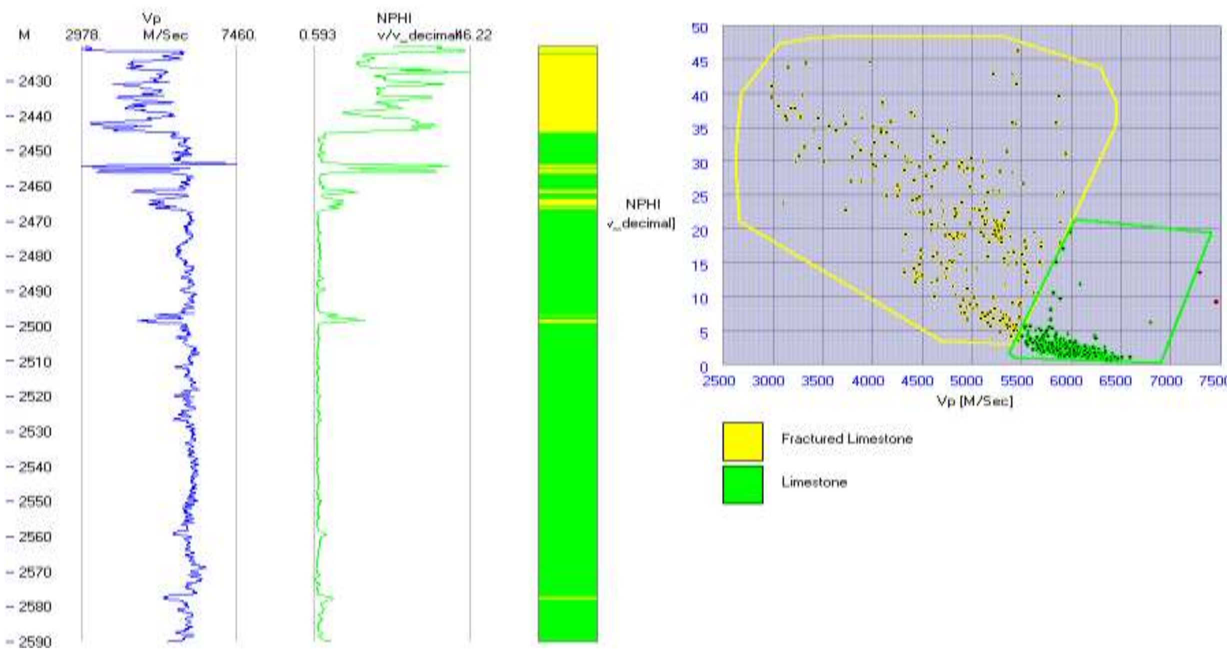


Figure 4.9 P-Wave velocity-density cross-plot based characterization.

4.13 Elastics Module

Bulk Modulus

The bulk modulus calculates its total volumetric stiffness. The Lamé parameter λ can therefore be consideration of as a material's resistance to entirely normal stresses, whereas μ enumerate the material's resistance to shape deformations, that can consequence from both normal and non-normal stress regimes. Whereas bulk modulus can be mathematically calculated as:

$$K = \rho(Vp^2 - 4/3Vs^2) \qquad (4.3)$$

Young Modulus

Young's modulus or lambda E is a flexible modulus, a measure of the stiffness of a material. It is widely used in quantitative seismic interpretation, rock physics, and rock mechanics. When using linear elasticity, the ratio of uniaxial stress to uniaxial stress is determined.

$$E = \frac{\rho Vs^2(3Vp^2 - 4Vs^2)}{Vp^2 - Vs^2} \qquad (4.4)$$

Cross-plots are a visual representation of the relationship between two or more variables and are used to visually identify or detect abnormalities that can be interpreted as the presence of hydrocarbons or other fluids and lithology. Cross-analysis is performed to determine the properties / properties of the rock that best distinguish the reservoir (Omudu et al., 2007).

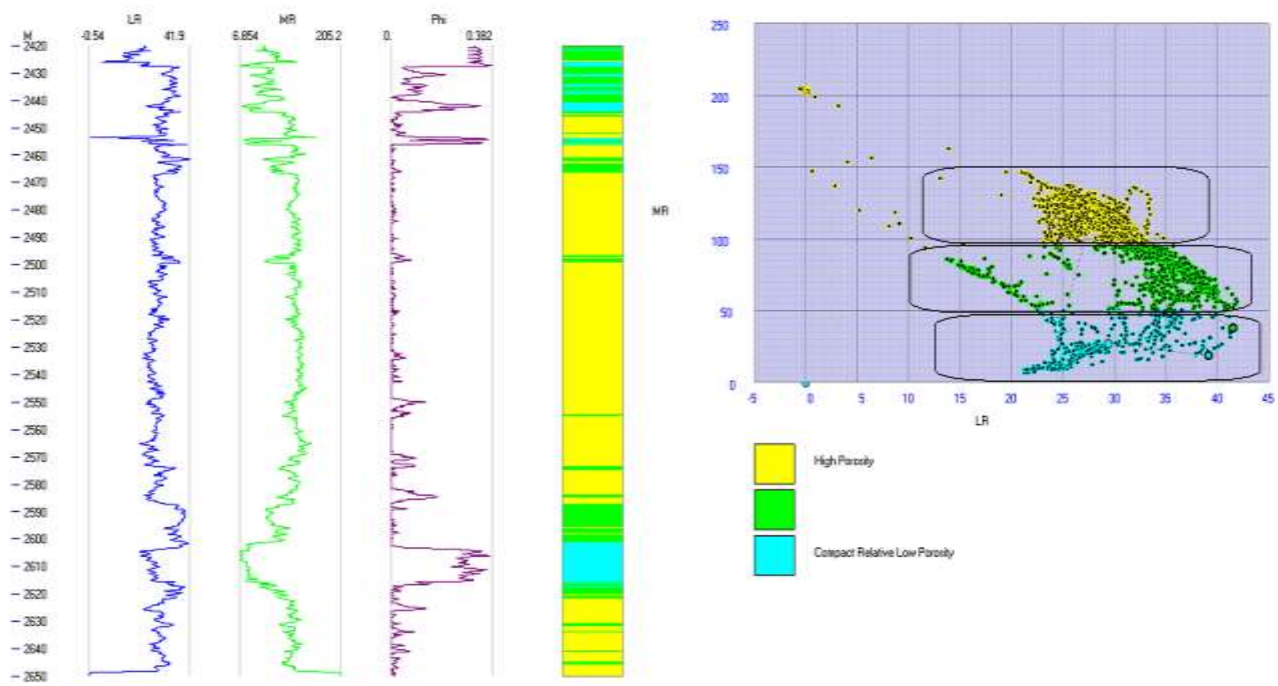


Figure 4.10 Lambda Rho and Muhu Rho Cross-plot based characterization.

4.14 Result and Discussion

Three reservoir zones with depths Zone-1 (2426- 2427.5m), Zone-2 (2549-2556m) and Zone-3 (2582.5-2586m) respectively marked on the basis of petrophysics by using different electrical logs and further these are confirmed using engineering properties of rock physics and results are displayed above in table 4.1.

Chapter – 05

SEISMIC INVERSION

Seismic inversion is generally used to aid in the interest of hydrocarbons by providing wadding information on the properties of rocks between wells. Several inversion methods are obtainable that use seismic properties depending upon association among the properties (e.g., acoustic impedance, porosity, Poisson's ratio) and seismic.

The use of the seismic inversion technique provides us to convert the data identified by the time-dependent reflectivity of the earth into impedance data. The cycle uses a seismic estimate structure that has recorded the structure of the earth's surface through beats that are further reflected from the surface layers and show the contraction of the layer. The fundamentally distortion along the way and provides low quality information by heartbeat transmission. The use of seismic-dependent novelty is benefit that can wrap a huge area where the road to auctioning journals provides feasible in excess of these positions. Currently, various instinctive 3D-dependent images are divided by seismic inversion.

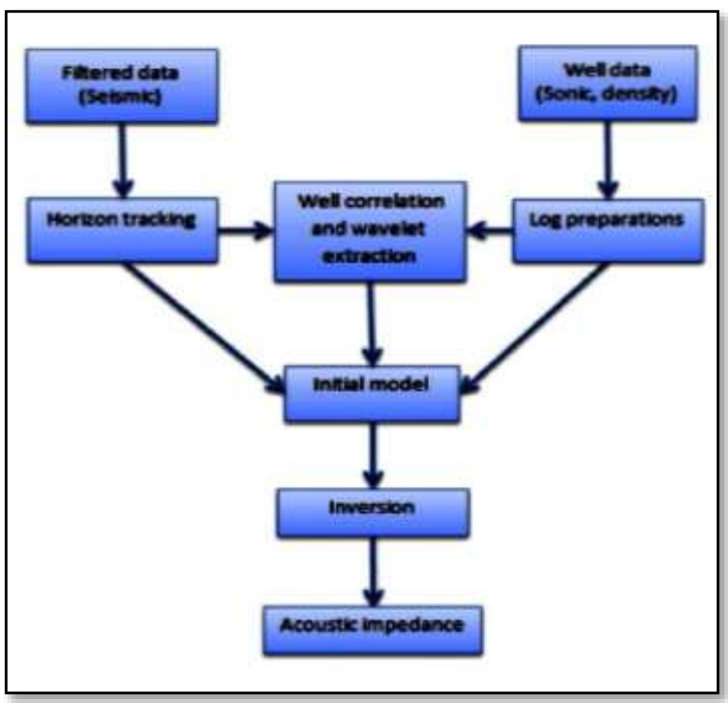


Figure 5.1 Workflow for seismic inversion

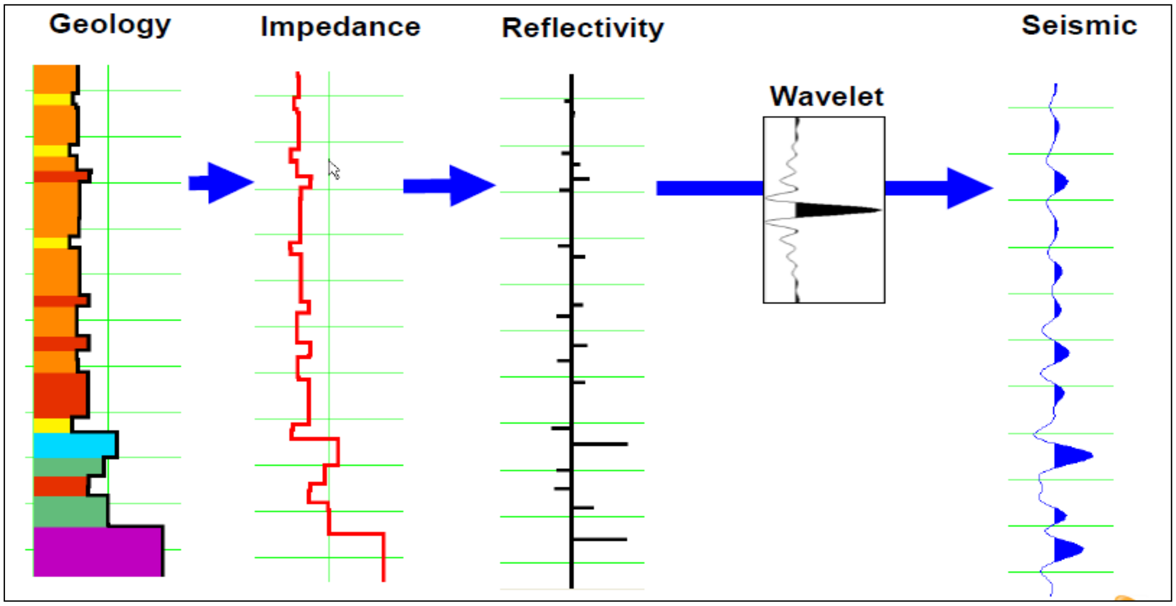


Figure 5.2 Basic methods of seismic inversion

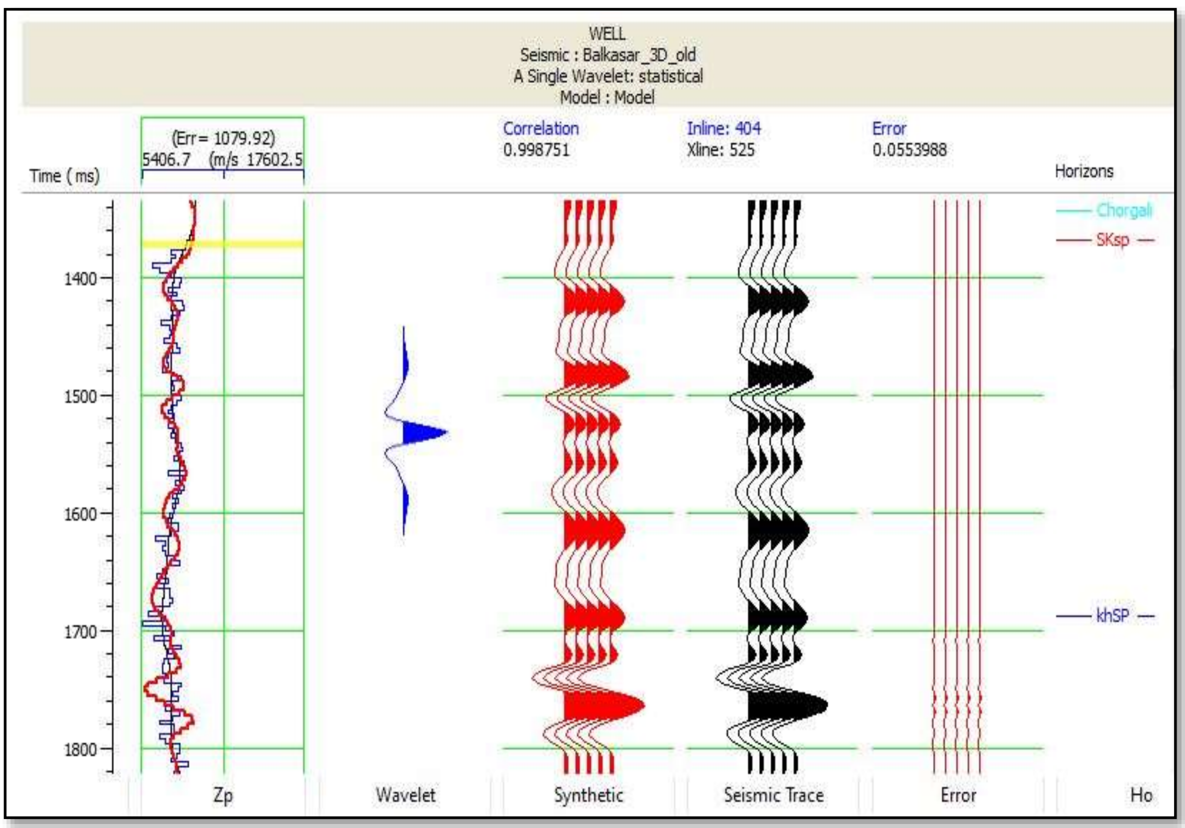


Figure 5.3 Wavelet extraction and seismic inversion synthetic model generation.

5.1 Post-Stack Seismic Inversion

Overall, the seismic inversion practice is the course of converting a seismic amplitude value into an impedance value. It is to be done in the course of a de-convolutionary process that transforms seismic traces into earth impedance. Inversion is an underground modeling technique that produces a geological logical structure using seismic data as input and control of data from the well. Seismic data (zero offset) used by post-stack seismic reversal technique take in-depth or time images of AI.

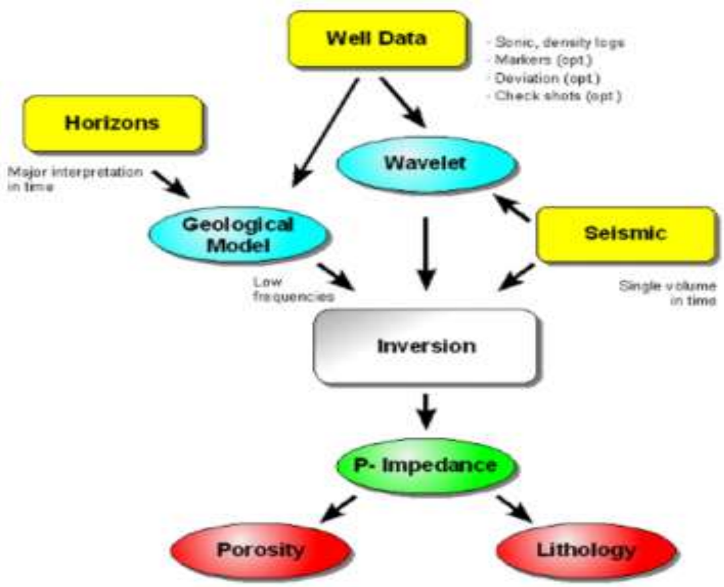


Figure 5.4 Post stack Inversion process (wiki.seg)

5.2 Methodology for Model Based Inversion

In the basic period, the well turns into a seismic connection, which model to follow, depending on the synthetic traces and which is used to make predetermined connections with the seismic traces.

The subsequent section includes the wave extract, which is considered a signal and only results in the need for a degree of seismic information reversal. Inversion is measured the center of a strong wave. Scene spectrum and abundance are important for the extraction associated with the spatial repetition of the wave. The included cycle is easy to measure, deterministic based on wave extraction, which can also be used as information for the well log, while the correlation or analysis between seismic information and log can be made (Karim et al., 2015).

The missing frequency of seismic information for low and high segment structures is given by the initial model. An additional use model is to reduce the uniqueness of the layout.

Subsequent inversion of the seismic pile requires the amount of seismic logs and density in the pile, in addition to the well logs. In addition to equipment, the proposed approach generally improves synthetic tracing and seismic data acquisition. The expected minimization of seismic traces and observed seismic traces has been achieved by a highly reflective setup (Karim et al., 2015). HRS (Hampson Rass Software) was used in the survey to facilitate seismic inversion. The model-based inversion artifact is shown in the block diagram as calculated. The figure shows a statistically generated wavelength that shows both time interval and frequency using seismic data entered near the well.

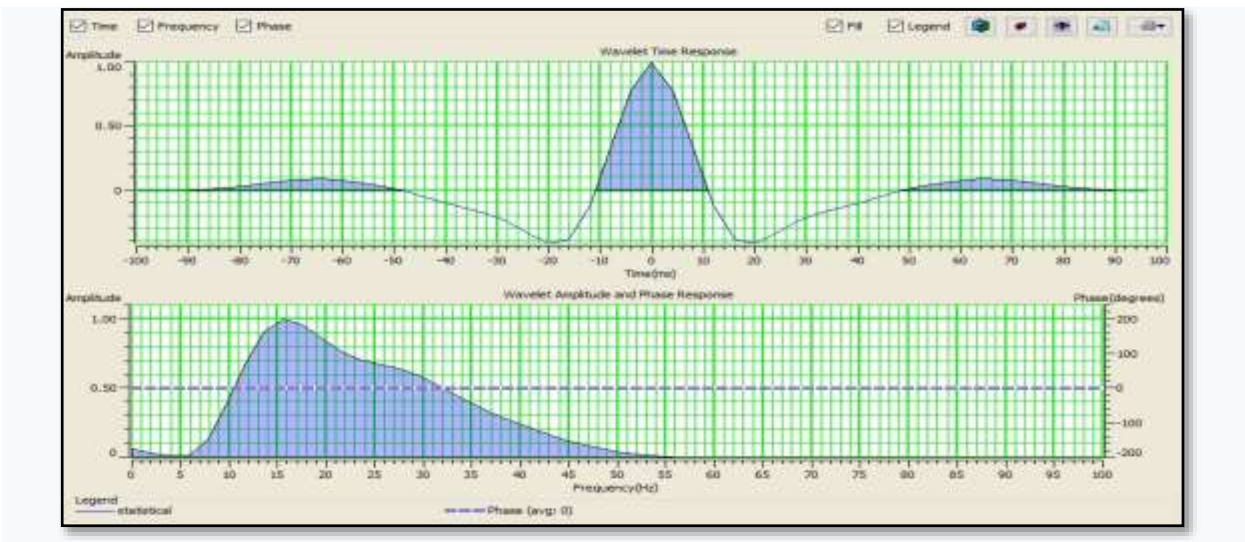


Figure 5.5 Wavelet extracted from well data worn for synthetic model for inversion.

Then to associate the seismic data and probes with synthetic traces shaped by means of the extracted waveform. This will permit a bond to be institute between the well and the seismic data, which is very significant for the interpretation of seismic data. The utmost correlation coefficient of the Balkassar OXY-1 well and related seismic data is 0.936.

Subsequent to get holding of the first model, a repetitive practice was performed to get holding of the best fit between the synthetic traces and the seismic data. Subsequently applying 20 repetitions, the correlation of the fit will be close to 0.978, which is 97.8%, with an error of 0.22, which is 2.2%. This high percentage of correspondence results in a good impedance model.

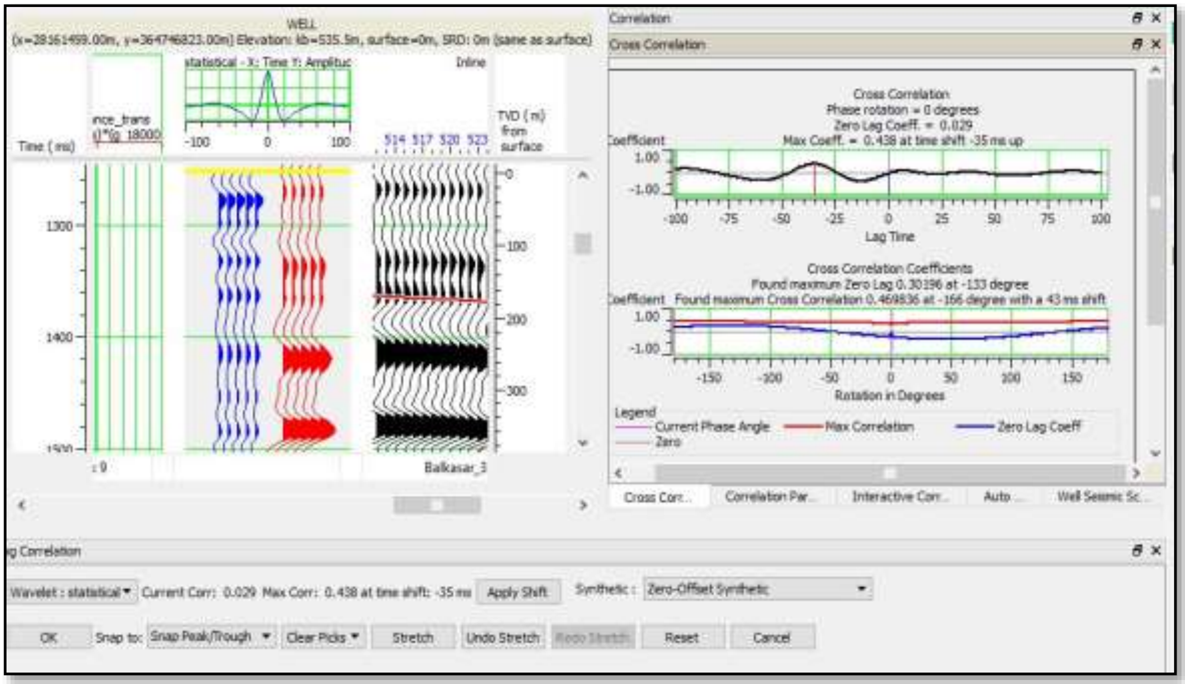


Figure 5.6 Cross correlation for better well to seismic tie.

Now, using the impedance curve generated by the probe data, an initial model is created between 1300 ms and 1450 ms which include the formation of attention. Here the first map assist to convalesce mislaid low frequencies for data mislaid throughout data processing and aggregation, which are important parameters for model-based inversion.

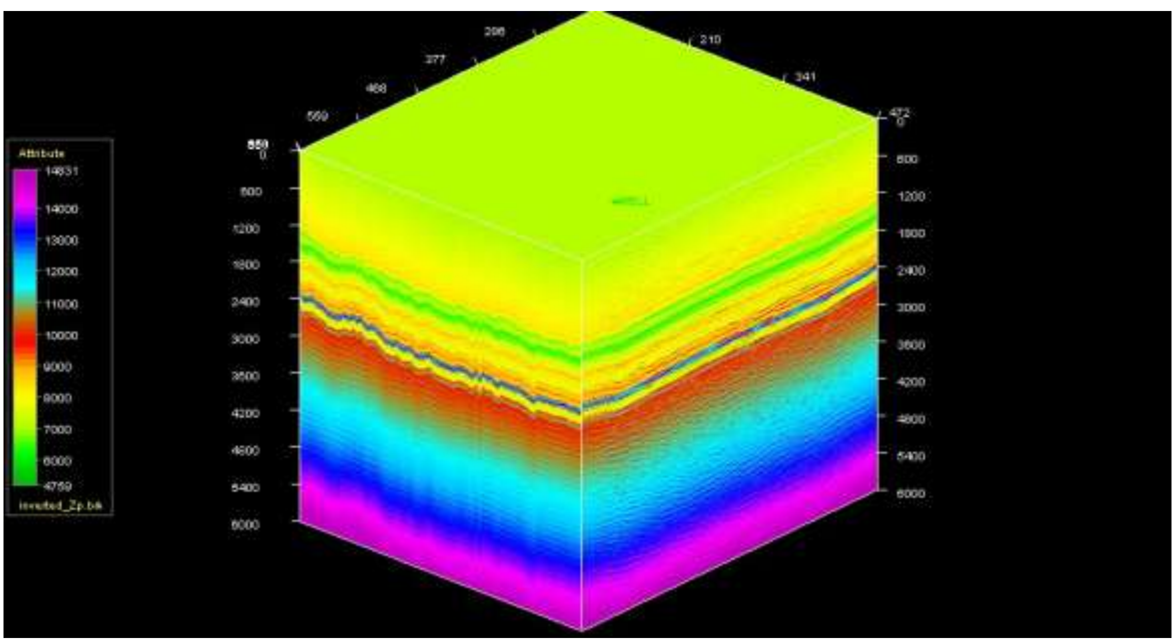


Figure 5.7 P-Impedance conversions on full cube

The 3D cube used in the above analysis of the Balkassar block shows the change in impedance at the horizon of the Chorgali and Sakesar blocks. High impedance values are observed in the seismic cube of 2600 m, and these values decrease slightly as we move upwards.

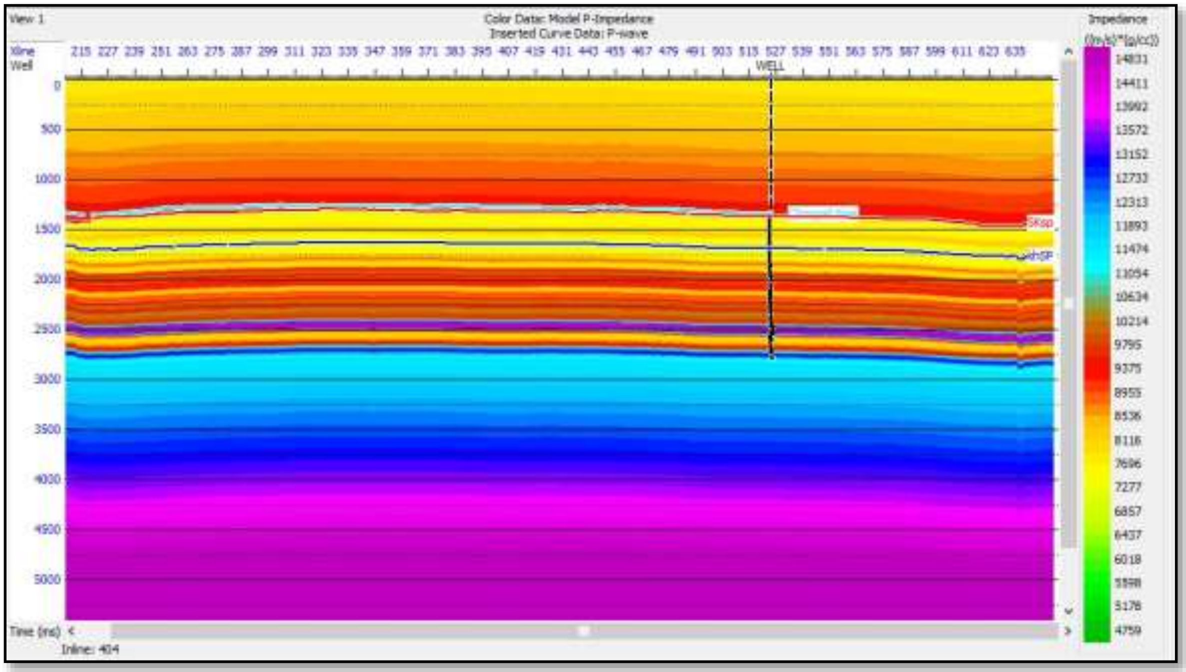


Figure 5.8 P-Impedance variations in reservoir zone at inline 404

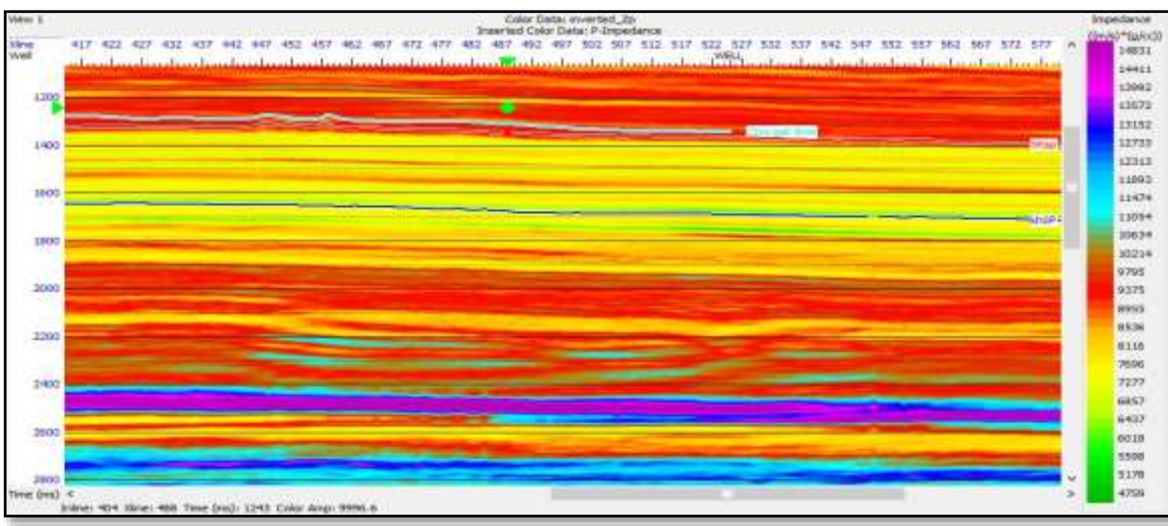


Figure 5.9 P-Impedance variation in reservoir zone at inline 404 (Zoomed view)

After receiving the impedance estimate for the affected area, a porosity estimate was performed using the above impedance model. For this, the porosity logo of the probe generated during the petrophysical analysis of the OXY-1 probe and the impedance logo generated during the model-based inversion were drawn. For this analysis, a 200 ms window was selected during target formation. The log value between this areas of the window is displayed graphically and is related to the amount of slate in that area. We then crossed the most appropriate line in all the points presented to obtain the equation calculated for the whole area, with the maximum correlation of the logs. The correlation of the presented values is 0.84 or 84%.

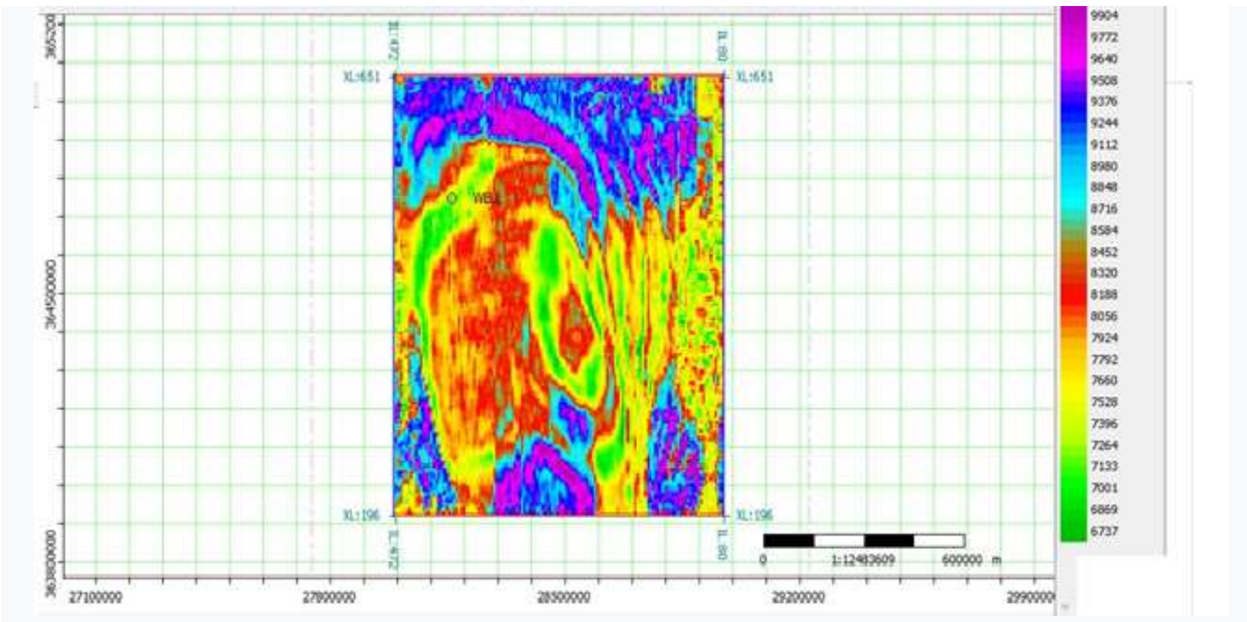


Figure 5.10 Horizon Time slice of Chorgali Balkassar 3D at 1342 msec

5.3 Result and Discussion

Now, using the impedance graph spawn from the well data, we create a preliminary model in the range between 1300 ms and 1450 ms in which the attention formation is. This original sculpts helps to recover mislaid low frequencies for data mislaid throughout data processing and aggregation. It is a major consideration for model-based inversion.

The full 3D cube of the Balkassar block used in the study shows the modification in impedance along the Chorgali horizon. High impedance values are observed on a 2600 m seismic cube, and these values gradually decrease as we move upwards. This shows that we have the Patala slate at 2600 m and, as we move upwards, we inevitably approach the reservoir area of 2400-2580 m. The above time interval shows low impedance in the east-west direction, but values raised in a north-south direction, as shown in Figs. 5.11.

INTEGRATION OF RESEARCH WORK

In this research, to make sure precision, four techniques were integrated to characterize reservoirs in Balkassar field. Petrophysical analysis, seismic interpretation, and modeling, rock physics analysis and seismic inversion were utilized. Its objectives were: to develop a template to facilitate improvements in future reservoir characterization research works and producibility determination; to utilize rock physics models to quality check the seismic results and to properly define the pore connectivity of the reservoirs, and to locate the best productive zones for future wells in the field. Two major reverse faults were marked and fault polygon were generated and its confirmed by gridding as well. Structural maps were generated for both reservoirs from which majorly fault assisted and dependent closures were observed. The petrophysical analysis indicated that the reservoirs have good pore interconnectivity (Average Φ (effective) = 6% & 10%). The seismic interpretation and modeling alongside the petrophysical analysis were then quality checked via qualitative rock physics analysis. From the Kdry/Porosity plot, the limestones were generally observed to lie within the 2420-2580m which indicates a high level of compaction. From high impedance values can be observed on a seismic cube of 2600 m, and these values decrease slightly as you go up. This shows that we have Patala shale at 2,600m and as we go up we are approaching the reservoir area at 2,400-2,580m.

CONCLUSION

1. Interpretation of seismic structural model shows severe thrust faults which confirm the compression tectonic regime with anticlinal structure in the proposed area.
2. Interpreted seismic sections in time and depth show that there are two main inverse faults (F1, F2) that plunge into each other and form a buoyant structure due to the compression system.
3. Rock properties are calculated, these are helpful to confirm the nature and type of sub-surface material. Porosity and density are confirming the reservoir zone.
4. The three reservoir zones are designated Zone 1 (2426-2427.5 m), Zone 2 (2549-2556 m) and Zone 3 (2582.5-2586 m) based on petrophysical data using various electrical logs.

RECOMMENDATIONS

1. To better evaluate the reservoir, we need to process the analysis of amplitude, fluid displacement and AVO (Advanced Seismic Interpretation).

2. For a good and reliable correlation, we need to use VSP (vertical seismic profile) data to understand the reverse of the seismic data depth.

4. The following highly recommends Inline 414.

5. To obtain a static reservoir model, it is necessary to analyze the IMF and the broken network.

6. The result should be compared with real-time data, for example, data from the base sample should be compared with the log values to get the best fit from the reservoir.

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