QUAID E AZAM UNIVERSITY, ISLAMABAD

DEPARTMENT OF EARTH SCIENCES

INTERGRATED SEISMIC INTERPRETATION

"Rock Physics, Engineering, 1-D & 2-D Modelling, Well & Seismic Log Analysis

Of Bitrism Area, Lower Indus Basin, Pakistan"

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Certificate

It is certified that **SUMAN SAEED** D/O **MUHAMMAD SAEED** carried out the work contained in this dissertation under my supervision and accepted in its present form by Department of earth sciences as satisfying the requirements for BS Geophysics.

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Acknowledgement

In the name of Allah, the most Beneficent, the most Merciful. All praises to Almighty Allah, the creator of universe. I bear witness that there is no God but Allah and Holy Prophet Hazrat Muhammad (P.B.U.H) is the last messenger of Allah, whose life is a perfect model for the whole mankind till the Day of Judgment. Allah blessed me with knowledge related to Earth. Without the blessing of Allah, I could not be able to complete my work as well as to be at such a place.

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Abstract

Bitrisim area is a common example of extensional tectonics represented by Horst & Graben structures. To carry out the structural and stratigraphic interpretation of the Bitrisim area, three seismic dip lines and are interpreted. Two-way time and depth mapping helped in delineated the structural trend and understanding the tectonics of the area. Subsurface mapping reveals that major fault trend is NE-SW. There are indications of reactivation of faults indicating the occurrence of various tectonic periods. Existing structural trend of the area provides basic components of a profile petroleum system.

1-D modeling is done for the well Fateh-01 and. Zone of interest is the Lower Goru. Porosity calculations are made to find out the hydrocarbon saturation. The rock physics analysis is done, based on which we interpret the reservoir rock characteristics. Moreover, water saturation is also calculated.

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CHAPTER 1

1. Introduction to the Project

1.1. Introduction

Hydrocarbons play a vital role in the growth of economy of any country and have wide uses at smaller scales in everyday life as well. Geoscientists are trying since a long time for the exploration of hydrocarbons from subsurface and are applying different methods in this regard. Geophysical methods are the most widely used methods in the exploration of hydrocarbons; especially in Seismic Reflection Seismology has a great importance in this regard.

The seismic method is rather simple in concept. In which an energy source is used to produce seismic waves (like sound) that travel through the earth and the motion or pressure variations to electricity which is recorded by electronic instruments (Gadallah & Fisher, 2009).

Pakistan has a high potential of hydrocarbons and consists of three major sedimentary basins (covering more than $2/3^{rd}$ of its area) namely, Indus Basin in the east, Baluchistan Basin in the west and Pishin basin in the northwest. Indus and Baluchistan basin are separated by Ornach Bela Transform Fault Zone and the Pishin basin lies between Indus and Chamman Transform Fault. A variety of sub-basins, fold belts and monoclines with variable structural styles resulting from diverse geodynamic conditions have been identified in Baluchistan Basin and Indus Basin (Kadri, 1995). Indus is the only producing basin of Pakistan where 83 oil and gas fields have been discovered. The Indus Basin covers an area of about 533,500 Km^2 and contains more than 15,000m thick sediments ranging in age from the Precambrian to recent. This giant basin has been divided into three compartments based on structural highs namely, The Jacobabad Khairpur High, Mari Khandkot High (Sukkur Rift) and the Sargodha High (Kazmi & Jan 1997). Indus basin is divided into Upper Indus Basin, Middle Indus or Central Indus Basin and Lower Indus or Southern Indus Basin

1.2.Introduction to the Study Area

The study area is bounded by 26°16´ - 26°29´ N Latitude and 68°54´ - 69°0´ Longitude, located in the Sindh province, Pakistan. Geologically Bitrism area is situated within Southern Indus Basin to the south of the Sukkur Rift. Geologically, Bitrism area is situated within Jacobabad Khairpur high in lower Indus Basin of Pakistan. Until today, several wells have been drilled in Lower Goru formation of Cretaceous age, but without any commercial hydrocarbon discovery.   The present study is based on of 2D seismic survey, Carried out by Oil and Gas Development Corporation Limited (OGDCL) in 1996, 1997, 2001."

The study mainly focuses on the interpretation of reflection data of Seismic lines 017-BTM-03, 027-BTM-06 and 027-BTM-16 which are to be interpreted in this dissertation highlighted in Fig 1.2, the Base map has been generated using Precision Matrix an Integrated Geo Systems application developed by (Khan, 2000). A satellite image of Pakistan is given in Fig 1.1 highlighting the Bitrism area. The imagery has been obtained from the Image Base databank which was developed using the Projection Independent Multi-Resolution Imagery Tiles Architecture (PIMRITA) as used by Khan et al in (2008).

A summary of seismic lines and wells used in the study are given in Table 1. This seismic line is an infill line which was planned to confirm the structures that were interpreted with the help of seismic survey.

1.3. Objectives

- The purpose of this dissertation is to understand the stratigraphic and structural frameworks of the area by using the seismic and well data**.**
- To understand and correlate both surface and sub-surface conditions of geology.
- The preparation of average velocity means velocity and Iso-velocity graph to investigate the lateral and vertical variation in velocity.
- To prepare time and depth section and study the difference between both.
- The identification of seismic horizons by using well tops.
- To map the prospective reservoir in the area
- Well correlation along with crustal shortening to see the seismic behavior at lithological boundaries.

1.4. Survey Information

Acquisition of the seismic lines data was done for Oil and Gas Development Corporation Limited (OGDCL). The data was recorded by seismic party in 2001-2002. The energy source used in this survey was dynamite with S.P interval as 50 meters and average shot depth was 30 meters. The field sampling interval was 2 mille second and the group interval of 50 meters.

Figure 1-1 Map showing the location of Bitrism area by 26°16′ - 26°29′ N Latitude and 68°54′ - 69°0′ Longitude

1.4.1. Seismic data

The 2-D Seismic data was collected from Directorate General Petroleum Concession ***(*DGPC)** Pakistan**.** 2D seismic data are displayed as a single vertical plane or cross-section sliced into the earth beneath the seismic line. Seismic data helps us build a regional geological picture about the areas we are currently exploring. Seismic surveys are a way to probe beneath the surface to see underlying features that make up the underground structure of a prospect. In addition to delineating subsurface structures, seismic data can be computer processed for attributes such as AVO, which can serve as a direct hydrocarbon indicator. Lines along with their orientations and the locations of wells in the study area are shown in *Table 1.1*.

Line name	***Nature of line***	***Orientation***	***Wells***
20017-BTM-03	**Dip**	**SW-NE**	
20027-BTM-01	Dip	SW-NE	
20017-BTM-04	**Dip**	**SW-NE**	
986-BTM-08	Dip	SW-NE	
20027-BTM-02	Dip	SW-NE	
20017 BTM-02	**Strike**	**NW-SE**	FATEH-01
20017-BTM-08	Dip	SW-NE	
20017-BTM-09	Dip	SW-NE	
20017-BTM-05	**Dip**	**SW-NE**	
20017-BTM-06	**Dip**	**SW-NE**	
20027-BTM-03	Dip	SW-NE	

20027-BTM-08	Strike	NW-SE	
20017-BTM-07	**Dip**	**SW-NE**	
986-BTM-09	Dip	SW-NE	

Table 1-1 Names and directions of seismic lines used for base map. Colored rows i.e. blue (strike) and green (dips) used in the generation of base map.

1.4.2. Data Format

Data set was obtained from Directorate General Petroleum Concession (DGPC) Pakistan. The data set used extensively in preparing this dissertation contained data regarding.

- SEG Y of the Seismic Lines mentioned in Table 1.
- Navigation data for Generation of Base map- .DBO file
- LAS data of Fateh-01
- Seismic velocities-VEL Format

SEG-Y, LAS, navigation and velocity data was provided by the Directorate General Petroleum Concession (DGPC), Government of Pakistan while imagery, SRTM30 Digital Elevation Model (DEM) and other cultural mapping data was obtained from Pakistan Digital databank.

A base map is the map on which data can be plotted. The base map is important for interpretation point of view because it depicts the spatial location of seismic section and shows how seismic section are interconnected. A base map typically includes location of lease and concession boundaries, wells, and seismic survey points. Base map provides the structure for contouring. The base map of the area is generated by plotting data in Universal Transverse Mercator (UTM, Zone 42N) geodetic reference system. The base map given in Fig 1.2 shows the orientation of the lines used for study which are present in the Bitrisim area. The lines under study; 20017-BTM-03, 20017-BTM-04, 20027-BTM-05, 20017-BTM-06, 20017-BTM-07 (have been highlighted with blue) and 20017-BTM-02 (which has been highlighted with red). The well is used for marking the horizons is **Fateh-01**

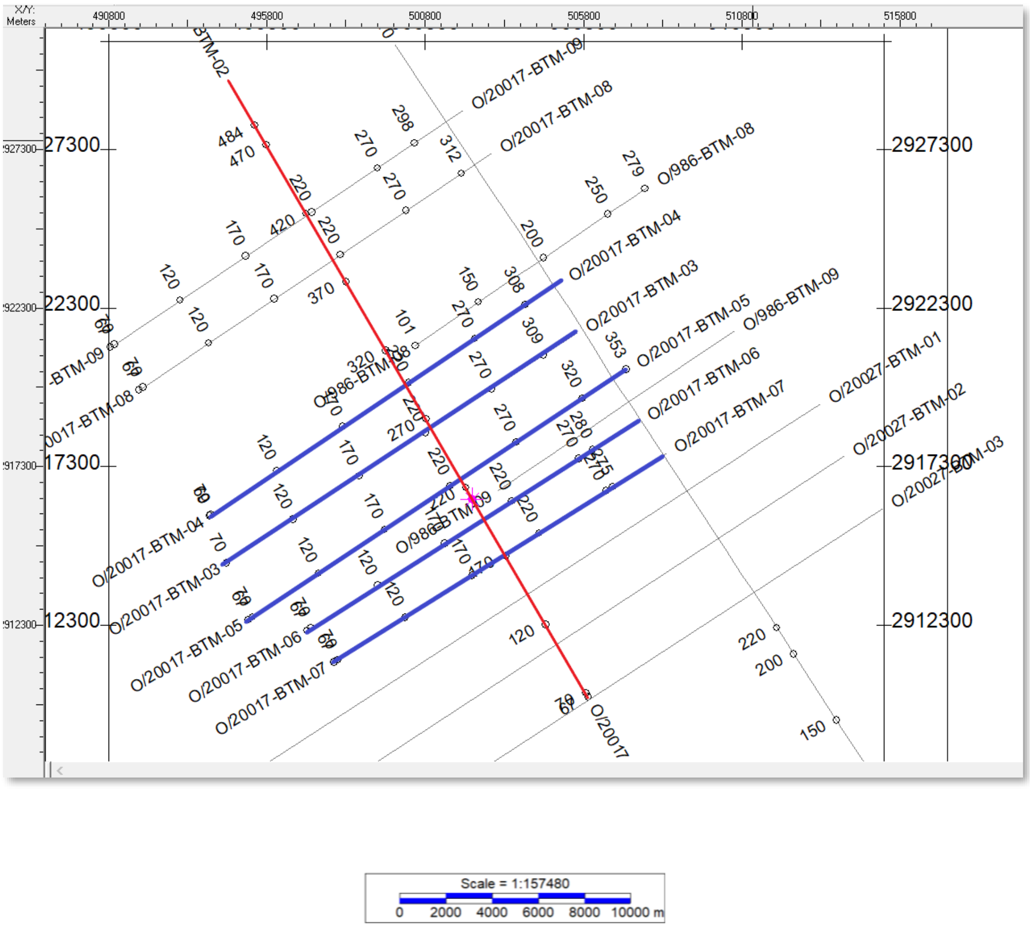

Figure 1-2 *Base Map of the area showing the orientation of seismic lines. Study lines are marked Blue (dips) and Red (strike).*

1.5. Seismic Acquisition Parameters

The seismic acquisition and processing parameters are presented in this segment.

1.5.1 Instruments

Summing computer	**SN-388**
Low cut filter	**Out**
Notch filter	**In (50 Hz)**
High Cut filter	**125 Hz -72DB/OCT**
Sample rate	**2 MSEC**
Record length	**1700 MSEC**
Summing	**Diversity Average**
Format	**SEG-D**
Density Notch filter	**1600 BPI**
No. of channels	**120**

1.5.2. Source

Energy Source	**Dynamite**
Charge Pattern	**1 hole**
Ave. Shot Depth	**30 meters**
S.P Interval	**50 meters**

1.5.3. Cable

Spread	**3075-125-*-125-3075**
Group Interval	**50 meters**
Type of Geophones	**SM4**

Geophone Code	**0312**
Group length	**97.30 meters**
Geophone Interval	**Eters**

1.6 Processing

After the raw data has been collected from field. The field passes through the whole processing sequence that includes different data processing techniques which are used to suppress the noise and enhance the quality of the data for better interpretation. The raw seismic data is processed to enhance the signal to noise ratio and get the final seismic sections. The generalized processing sequence flow chart (Khan, 2009) is given in Fig 1.3

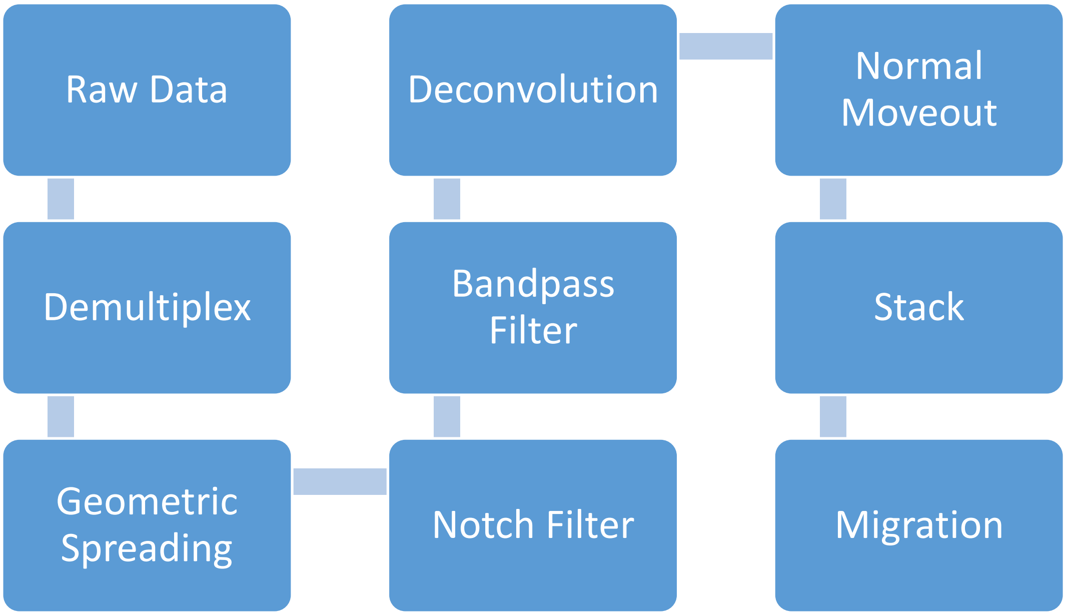

***Figure 1**-3 Seismic data processing flowchart*

1.7. Interpretation and Analysis Methodology

1.7.1 Analytic Workflow

The Interpretation was carried forward using different techniques and steps with each step involve different processes which were performed using the software tools as mentioned above. As it's said that a picture worth's a thousand words. Similarly, the Simplified workflow used in the dissertation is given in Fig 1.4, which provides the complete picture depicting how the dissertation has been carried forward from the initial phase till its completion.

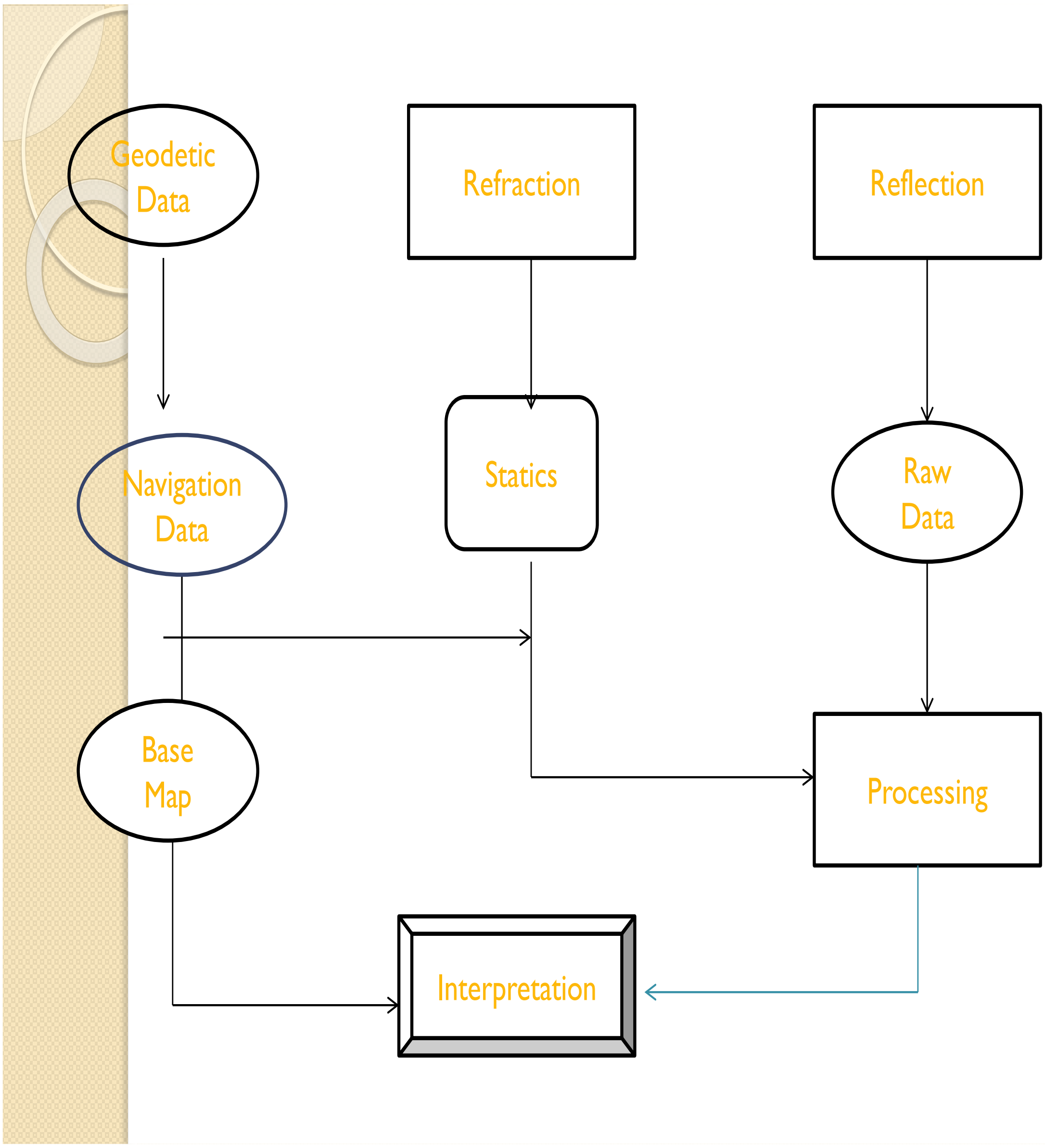

Figure 1-4 *Work flow carried out using different software tools*

1.8 Spatial Data Infrastructure

Spatial Data Infrastructure consists up of an array of database servers for imagery, binary grids, digitized vector layers geophysical and geological databanks, linked with integrated visualization and processing applications is used in the interpretation

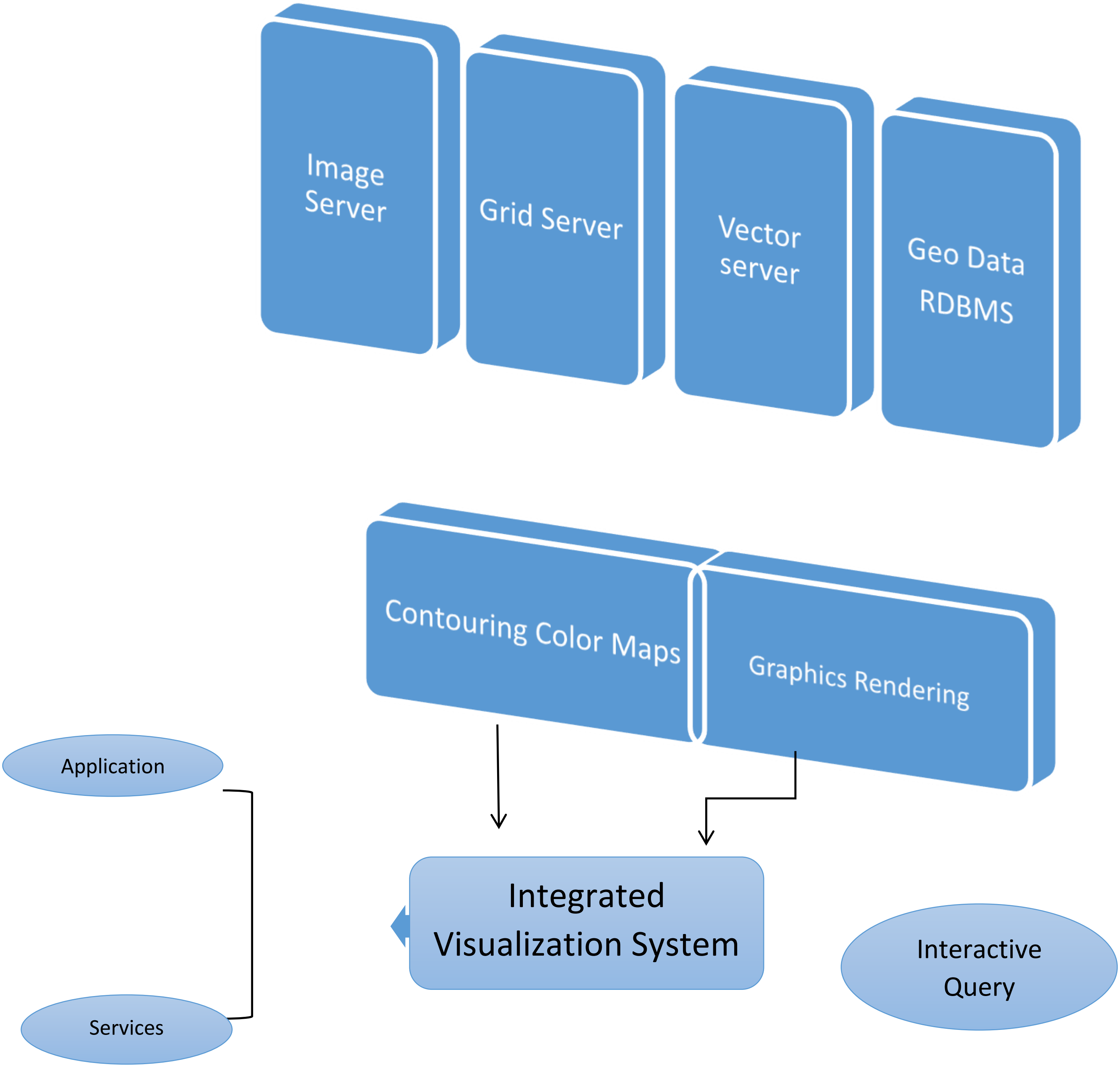

Figure 1-5 *Spatial Data Infrastructure for Digital Pakistan*

1.9 Software Purposes

The complete interpretation and analysis was possible after only identifying the key milestones. The work on these key milestones was very critical, keeping in view the overall scope of dissertation. SMT Kingdom was the main software tool that was used in performing interpretation of the seismic lines mentioned in Table 1. Following steps are involved for the interpretation of processed seismic data.

- Generation of base map with imagery.
- Time & Depth Contour maps.
- DEM contours
- Synthetic Seismogram.
- Petrophysics (volume of shale)
- Facies Analysis
- 2-D Seismic Inversion

CHAPTER 2

1. General Geology and Stratigraphy

2.1 Introduction

Geological and structural knowledge of the area is very significant while performing seismic interpretation. The main reason behind it is that in many cases different lithologies can produce similar seismic signatures and vice versa. To deal with such complexities, an interpreter must have knowledge of the geology and its unconformities, stratification and major structures of the area under study. This section deals with background geological and stratigraphic information with respect to the study area. Pakistan has been geologically well-known for several decades for its great mountains, Extensive glaciers, devastating earthquakes, exotic and prolific Neogene vertebrate fauna Chromites-bearing ophiolites, Precambrian and Paleozoic succession of the Salt Range, the Abundant oroclinal flexures and enigmatic syntaxes in its mountain ranges, and the deep gorge sand canyons that highlight the antecedent drainage. These geologic features had been largely revealed by the reconnaissance surveys of the early pioneers who explored vast areas despite a lack of proper topographic base maps, inhospitable terrain, hostile tribal conditions and absence of roads and communication system. Geological Survey geologists, based at Calcutta, would travel to Sindh, Baluchistan, Punjab, and NWFP on elephants, horses, or on foot (Kadri 1995), and on approaching their destination would often find themselves amid skirmishes between the British troops and the local chieftains or the Afghans.

1.2 Regional Tectonics

Pakistan is unique in as much as it is located at the junction of these two diverse domains. The southern part of Pakistan belongs to Gondwanian Domain and is sustained by the Indo-Pakistan Crustal Plate. The northern most and western region of Pakistan fall in Tethyan Domain and present a complicated geology. Pakistan comprises of three main geological subdivisions referred to as Laurasian, Tethyan and Gondwanaland domains (Kazmi, et al., 1997). Late Paleozoic is their origin. All the continents had drifted apart to form a super continent known as Pangea. By late Triassic, Laurasia drifted to the north and Gondwanaland to the south separated by Tethys seaway resulting in the split up of Pangea.

Pakistan is located at the junction of Gondwanian and Tethyan domain. As already mentioned, the study area is situated in the Southern Indus Bain of Pakistan. The area is mostly dominated by Normal Faults and Horst and Graben structures are common in contrast to the major thrust common in the northern part of Pakistan. The origin of theses crustal features has been recommended by numerous suggestions, but these basements up warps keep on confusing. The late Jurassic-Early Cretaceous rifting of Indian Plate controlled the structures and sedimentology of the Southern Indus Basin. Northeast-Southwest rift systems are possibly produced by Jurassic-Early Cretaceous rifting. Parting of the Madagascar and Indian plates in the middle to Late Cretaceous may have caused sinistral strike-slip faulting, hotspot activity and thermal doming in the area. This separation in turn caused uplift, erosion, extrusion of the Deccan flood basalts and probably the NW-striking normal faults. Eocene passive margin conditions caused structural quiescence and carbonate deposition. Sinistral Transpression with fold-thrust structures overprinted by sinistral flower structures in the west are produced during the Oligocene to present-day Himalayan collision. Figure given below is showing the tectonic map of world.

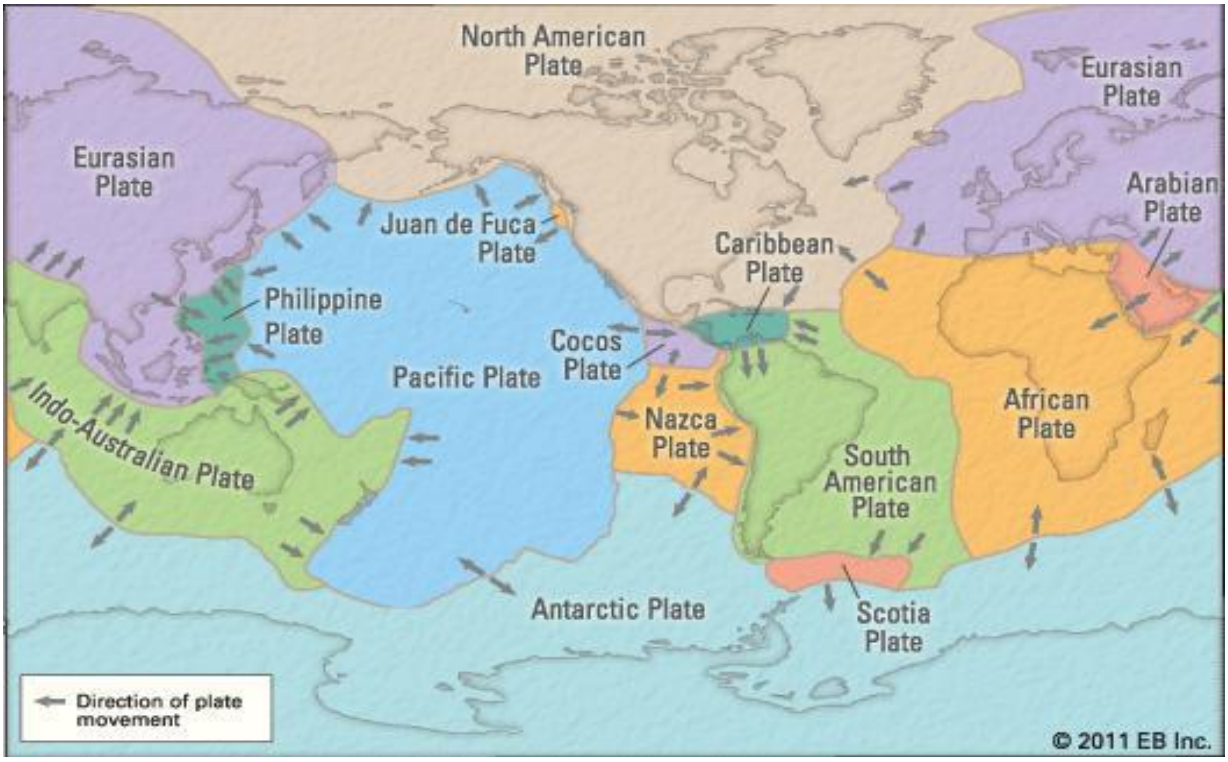

Figure 2-1 Tectonic Map of the World

1.3 Petroleum Geology of an Area

The oldest lithology penetrated in the study area is the Jurassic Chiltan Limestone. It is overlain by the Lower Cretaceous Sembar and Goru formations. The Goru Formation has conformable contact with overlying Parh Limestone of Late Cretaceous age which is capped unconformably by the Ranikot Group. The Lower Goru is mostly composed of interbedded sandstone and shale in different proportions and is the main reservoir rock in the area. The Lower Goru horizon has been divided into five parts based on lithology; the Basal Sand unit, lower Shale, Massive Sand unit, Upper Shale and Upper Sand. The Ranikot Group is capped unconformable by the Laki Formation of the Eocene age. During Oligocene the Proto-Indus River began to deposit Nari/Gaj sediments from the north into shallow embayment in the Karachi area. At the end of the Gaj depositional cycle, the eastward movement of the Afghan Plate along the Murray Ridge began, and the Indus course was shifted eastward by the compressional uplift in the Karachi area.

2.4 Basin Architecture of Pakistan

In terms of genesis and different geological histories, Pakistan comprises two main sedimentary basins namely Indus Basin and Baluchistan Basin. Both the basins evolved through different geological episodes and were finally, welded together during Cretaceous/Paleocene along Ornach Nal/Chaman strike slip faults. The geological history of the Indus Basin goes back to Precambrian age. The Paleotopographic features influenced, to a large extent, the depositional processes throughout the basin development. These features also marked the limit of the basin and its divisions (Kadri, 1995). Different Basins of Pakistan includes:

- Upper Indus Basin.
- Middle Indus Basin.
- Lower Indus Basin.
- Baluchistan Basin.
- Kakar Khorasan Basin.
- Pishin Basin.

2.4.1 Basin Classification of Lower Indus Basin

The Lower Indus Platform Basin is bounded to the north by the Central Indus Basin, Sulaiman Fold belt to the northwest and Kirthar Fold Belt in the south-west. The main tectonic events which have controlled the structures and sedimentology of the Lower Indus Basin are rifting of the Indian Plate from Gondwanaland (Jurassic or Early Cretaceous) which probably created NE-SW to N-S rift systems, isostatic uplift or ridge-push at the margins of the newly developed ocean probably caused uplift and eastwards tilting at the start of the Cretaceous. Separation of the Madagascan and Indian plates in the mid to Late Cretaceous which may have caused some sinistral strike-slip faulting in the region, hotspot activity and thermal doming at the Cretaceous-Tertiary boundary. This in turn caused uplift, erosion, extrusion of the Deccan flood basalts and probably the NNW-striking normal faults. Paleocene-Eocene emplacement of the Bela Ophiolites may have caused gentle folding. Eocene passive margin conditions caused structural quiescence and carbonate deposition. Oligocene to present-day Himalayan collision caused Sinistral Transpression in the west of the Lower Indus Basin, with fold-thrust structures overprinted by sinistral flower structures (Bender, 1995).

It comprises the following main units:

- Thar Platform
- Karachi Trough
- Kirthar Foredeep
- Kirthar Fold Belt
- Offshore Indus

The Southern Indus Basin is bounded by the Indian Shield to the east and the marginal zone of Indian Plate to the west. Its southward extension is confined by offshore Murray Ridge-Oven fracture plate boundary. The oldest rocks encountered in the area are of Triassic age. Central and southern Indus basins were undivided until Khairpur-Jacobabad High became a prominent positive feature. This is indicated by homogeneous lithology of Chiltan Limestone (Jurassic) and Sember Formation (Lower Cretaceous) across the High. Sand Facies of Goru Formation (Lower Middle Cretaceous) are also extending up to Kandhkot and Giandari area. This is further substantiated by Khairpur and Jhatpat wells located on the High. In Khairpur-2 well, significant amount of Lower Cretaceous and Paleocene is missing while in Jhat Pat-4, the whole Cretaceous and Paleocene are absent with Eocene directly overlying Chiltan Limestone (Jurassic). Paleocene facies south of the High are quite different from that in north and are dominated by clastic sediments derived from the positive areas (Khairpur- Jacobabad High and Nabisar Arc).

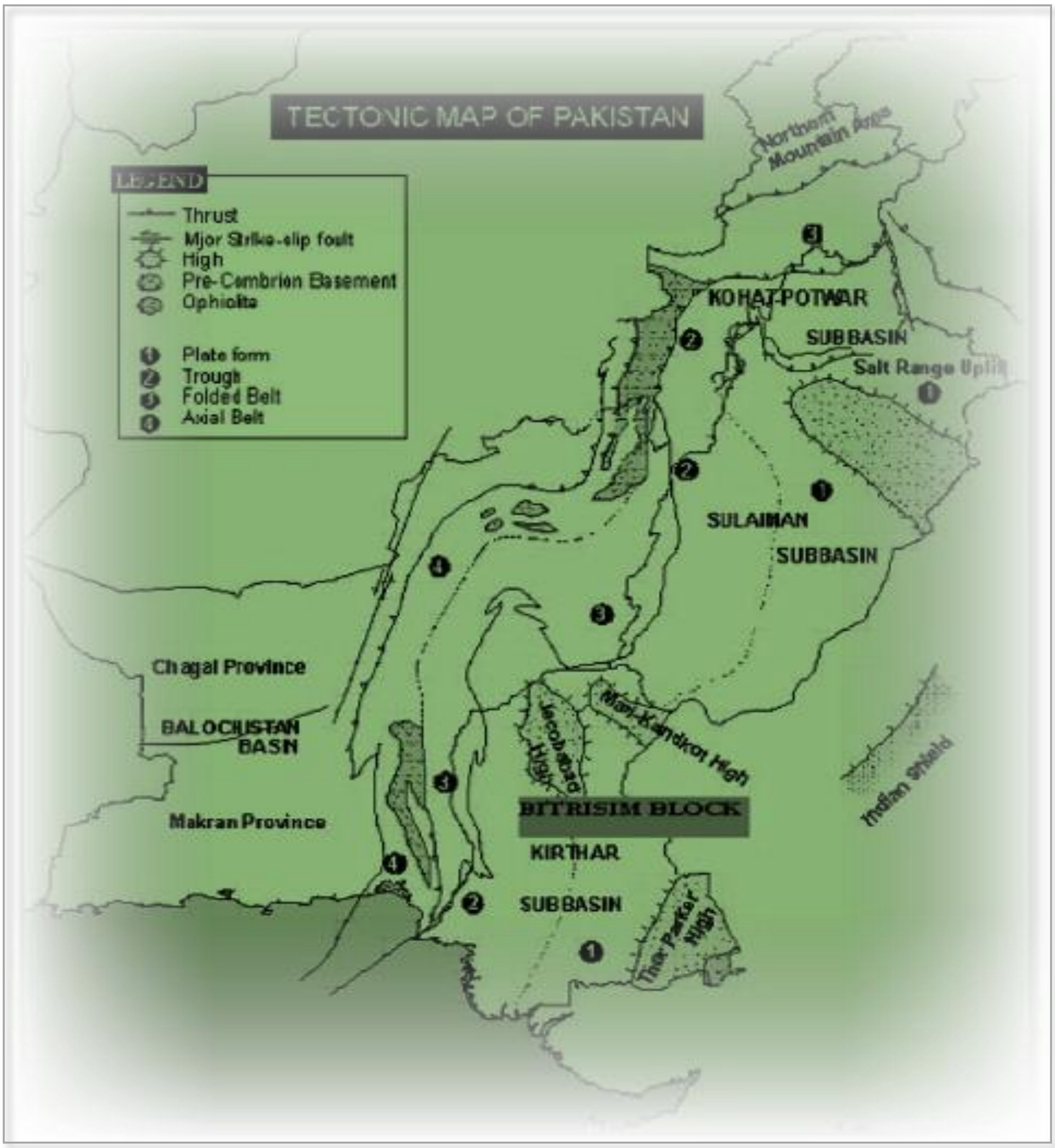

Figure 2-2 *Tectonic map highlighting Bitrism area*

2.5 Stratigraphy of the Study Area

The stratigraphic succession changes from east to west. Precambrian basement is elevated in the south-eastern corner of the basin. The thickness of the sediments increases westward. In the eastern part of the basin tertiary sequence has direct contact/ Interaction with Jurassic sequence. The stratigraphic chart of the study area is given in Figure 2.3.

2.5.1 Jurassic Stratigraphy

Chiltan Limestone

***Age**:* Age of Chiltan limestone is middle to late Jurassic.

***Lithology**:* This formation is mainly consisting of limestone with traces of shale. The color of limestone is light grey to dark grey and it is dense, compact and massive limestone.

2.5.2 Cretaceous Stratigraphy

Sember Formation

Age: Age of Sember Formation is early Cretaceous.

***Lithology**:* Sember Formation is mainly consisting of black shale with interbedded siltstone, argillaceous limestone and sandy shale is present at basal part.

Thickness: The thickness of this rock unit in type locality is 133 meters.

Goru Formation

***Age**:* Age of Goru Formation is early Cretaceous.

***Lithology**:* Goru Formation is comprising of interbeds of limestone, shale and siltstone. The limestone is fine grained and thin bedded. Sand beds have been also being in this rock unit.

***Thickness**:* The thickness of Goru Formation is 536 meters in type locality.

Goru Formation is divided into two members:

- ✓ *Lower Goru*
- ✓ *Upper Goru*

Fossils: Fossils found in Goru Formation are foraminifera and belemnites.

2.5.3 Paleocene Stratigraphy

Ranikot Formation

Age: Age of Ranikot Formation is early Paleocene.

Lithology: Basal marine sequence of sand stone and shale with interbeds of limestone (Raza 2003). Ranikot Formation is mainly comprised of grey limestone with some brown sandstone and shale in the upper part while sandstone with shale and limestone interbeds are found in lower part.

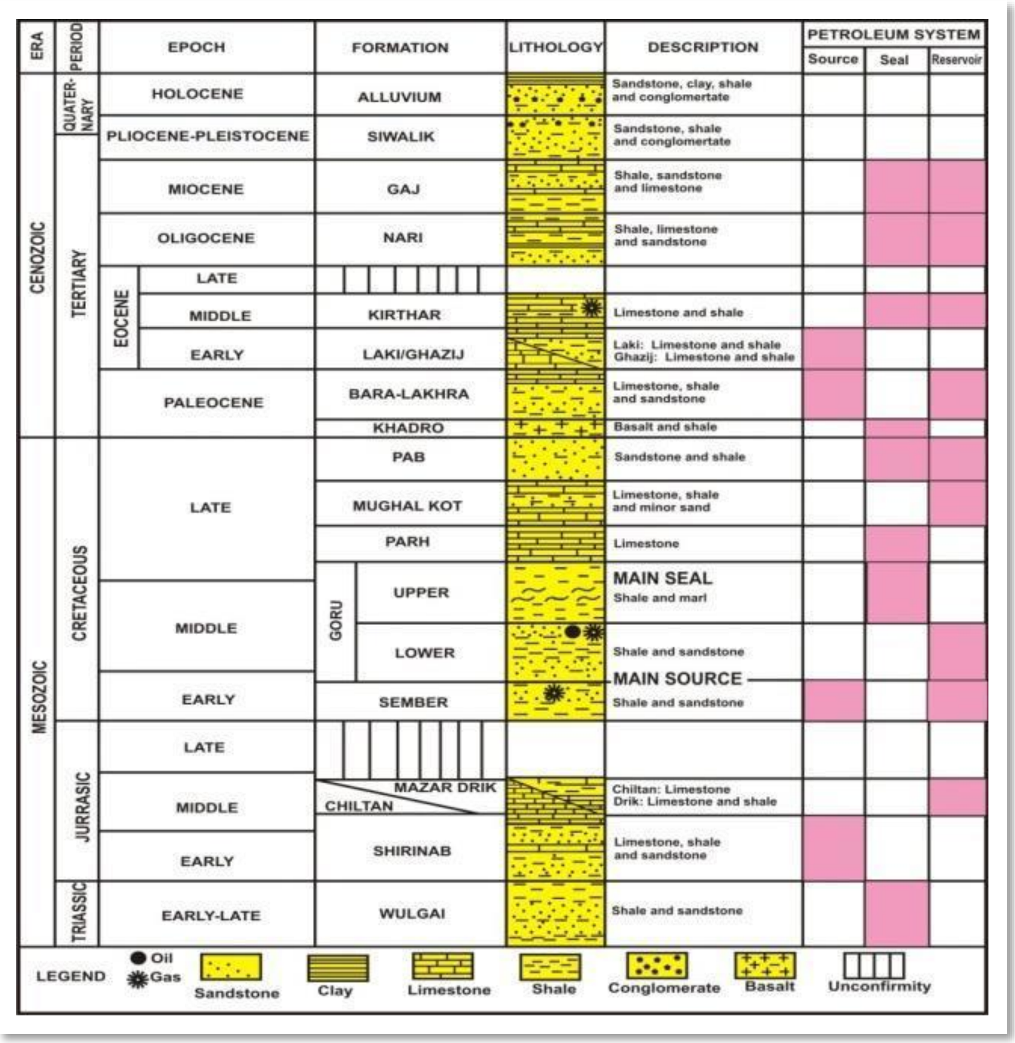

Figure 2-3 Stratigraphic Chart of Study Area

2.6 Petroleum Play of Area

2.6.1 Play Elements

Within a basin the presence of play elements plays important role in hydrocarbon accumulation. The seven play elements are:

- Source Rock
- Maturation
- Migration
- Seal or Cap

- Reservoir Rock
- Trap
- Timing

2.6.2 Source Rocks

While the Sembar has been identified as the primary source rock for much of the Greater Indus Basin, there are other known and potential source rocks. Rock units containing known or potential source rocks include the Salt Range Formation "Eocambrian" shale, Permian Dandot and Tredian Formations, Triassic Wulgai Formation, Jurassic Datta Formation, Paleocene Patala Formation, Eocene Ghazij formation, and lower Miocene shales. Of all the possible source rocks in the Indus Basin, however, the Sembar is the most likely source for the largest portion of the produced oil and gas in the Indus foreland. The Lower Cretaceous Sembar Formation consists mainly of shale with subordinate amounts of siltstone and sandstone. The Sembar was deposited over most of the Greater Indus Basin in marine environments and ranges in thickness from 0 to more than 260 m.

2.6.3 Reservoir Rocks

The principal reservoirs are deltaic and shallow-marine sandstones in the lower part of the Goru in the Lower Indus Basin and the Lumshiwal Formation in the Middle Indus Basin and limestone in the Eocene Ghazij and equivalent stratigraphic units. Potential reservoirs are as thick as 400 m. Sandstone porosities are as high as 30 percent, but more commonly range from about 12 to 16 % and limestone porosities range from 9 to 16 percent. The permeability of these reservoirs ranges from 1 to > 2,000 milli Darcie's. Reservoir quality generally diminishes in a westward direction but reservoir thickness increases. Because of the progressive eastward erosion and truncation of Cretaceous rocks, the Cretaceous reservoirs all have erosional up dip limits, whereas Tertiary reservoirs extend farther east overlying progressively older rocks.

2.6.4 Seal Rock

The known seals in the system are composed of shales that are interbedded with and overlying the reservoirs. In producing fields, thin shale beds of variable thickness are effective seals. Additional seals that may be effective include impermeable seals above truncation traps, faults and up dip facies changes. The thick sequence of shale and marl of upper Goru Formation serves as cap rock for underlying Lower Goru reservoir.

2.6.5 Traps

All production in the study area is from structural traps. The tilted fault traps in the Lower Indus Basin are a product of extension related to rifting and the formation of Horst and Graben structures. The temporal relationships among trap formation and hydrocarbon generation, expulsion, migration, and entrapment are variable- throughout the Indus Basin. These provide the significant trapping system along tilted fault blocks and negative flower structure.

CHAPTER 3

3. Seismic Data Interpretation and Modelling

3.1 Introduction

Seismic interpretation is the progression of determining information about the subsurface of the earth from seismic data. It may resolve general information about an area, locate prospects for drilling exploratory wells, or guide development of an already-discovered field (Coffeen, 1986).

Conventional seismic interpretation implies picking and tracking laterally consistent seismic reflectors for the purpose of mapping geologic structures, stratigraphy and reservoir architecture. The ultimate goal is to detect hydrocarbon accumulations delineate their extent and calculate their volumes. Conventional seismic interpretation is an art that requires skill and thorough experience in geology and geophysics. To meet the challenges of exploring ever increasingly complex targets, there have been tremendous advancements in data acquisition equipment, computer hardware and seismic processing algorithms in the last three decades (Khan, 1995).

The seismic method has thus evolved into a computationally complex science. The computer-based working (Processing & Interpretation) is more accurate, precise, efficient and satisfactory which provides more time for further analysis of data. This whole work is carried out using a combination of computer software , which includes QGIS & SMT Kingdom Suite.

3.2 TYPES OF SEISMIC INTERPRETATION

3.2.1 Structural Analysis

This type of analysis is very suitable in case of Pakistan, as most of the hydrocarbon is being extracted from the structural traps. It is study of reflector geometry on the basis of reflection time. The main application of the structural analysis of seismic section is in the search for structural traps containing hydrocarbon. Most structural interpretation use two-way reflection time rather depth and time structural maps are constructed to display the geometry of selected reflection events. Discontinue reflections clearly indicate faults and undulating reflections reveal folded beds (Telford et al., 1990).

3.2.2 Stratigraphic Analysis

Stratigraphic analysis greatly enhances the chances of successfully locating hydrocarbon traps in sedimentary basin environment. Seismic stratigraphy is used to find out the depositional processes and environmental settings, because genetically related sedimentary sequence normally consists of concordant strata that show discordance with sequence above and below it.

3.3 Work Procedure

The seismic method has thus, evolved into a computationally complex knowledge. The provided Navigation Data DBO format by using SMT Kingdom Suite. Seismic is correlated with the formation tops encountered in the wells. Interpretation was done by picking horizons. Major faults were picked on the dip lines and their parts were correlated across the dip lines to map the structures throughout the area.

All digital maps along with geo-referenced imagery are generated by using QGIS. The interpretation using software gives us an interactive tool for marking horizons & faults, exporting horizon's time, velocity and depth data for contouring and for further analysis such as crustal shortening and 2-D Seismic Modeling. The seismic velocities are processed (Resolved, Interpolated and Smoothed) by using Velocity Analysis System (VAS) software which is then used in different applications like Time-to-Depth conversion, Modeling and Rock Physics. Contour maps and seismic attributes analysis have been generated using SMT Kingdom Suite.

3.4 Seismic Horizons

The main task of interpretation is to identify various reflectors or horizons as interface between geological formations. This requires good structural and stratigraphic knowledge of the area (Mcquillin et al., 1984). Thus during interpretation, the horizons and faults are marked on the seismic section. As seismic data was provided in SEG-Y digital format, to develop the seismic time section, SEG-Y data is loaded in Kingdom. In this process we clicked on the upper left, upper right and lower left corners of seismic section image and assign the CDP numbers and time information at these points. After referencing the software can pick the horizon time and CDP numbers, similar to an interpretation workstation. The interpreted information is stored in a digital format. Another advantage of the application is that the times for the prospective horizon can be sent to gridding and contouring software for generating time and depth contour maps. The software can also load the velocity functions and convert the time section into depth section. Since velocity varies vertically as well as laterally it does not apply a regional velocity function, instead it generates a velocity section which is used in time to depth conversion. Each reflector is marked with different colors so that they can be easily distinguished, and faults are marked with black color.

The basic way to interpret multiple seismic lines is, first interpret that seismic line on which there is well, so according to well tops that seismic line is interpreted and further considered it as a reference line for the interpretation of other lines. If it is a dip line, then a strike line will tie it at a certain source point, note that source point from the base map and multiplying with 2 to convert source point into CDP numbers and the time along y-axis at which the reflectors are marked on that reference line, so marked all the reflectors at the tie points and extend them on the bases of character and continuity. Now this interpreted strike line will tie all the dip lines so interpret them at the tie points and same were the procedure for the interpretation of other lines.

Fateh-01 well lies on the seismic line 20017-BTM-02 and the well tops were matched with the two seismic reflectors (Upper Goru and Lower Goru) in depth domain to identify the geologic formations. Total depth of Fateh-01 is 3000.5 but well tops provided only to the depth of 2083m.

3.4.1 Well Information

Well Name	FATEH_01
Longitude	69.024497°
Latitude	26.366536°
K.B. Elevation	35.23 meters
Total Depth	3000.5 meters
Type	EX
Status	ABD
Operator	O.G.D.C.L
Concession	BITRISIM (2568-4)

3.4.2 Formation Tops

Formations	Depth (m)
ALLUVIUM	0
KIRTHAR	654
LAKI	885
SUI MAIN LIMESTONE	1085
UPPER RANIKOT	1196
LOWER RANIKOT	1365
UPPER GORU	1810
LOWER GORU	2083

3.5 Seismic Time Section

The time section gives the position and configuration of reflectors in time domain. Six reflectors are marked on seismic line 20027-BTM-06 (Figure 3.1), which are named on the basis of stratigraphic column encountered in well Fateh-1. Each reflector is marked with different color so that they can be easily distinguished. However, the aim is to target, the source, reservoir and seal rock formations. The time section of seismic line 20017-BTM-06, 20017-BTM-03, 20017-BTM-05 and 20017-BTM-07 is given in Figure 3-1, Figure 3-2, Figure 3-3 and Figure 3-4. The seismic sections are in time domain, but the real subsurface structures are in depth domain, so we have to convert time sections into depth sections using velocities data.

Formation Top	Color	Depth (meter)
Upeer Goru	Green	1810
Lower goru	Yellow	2083

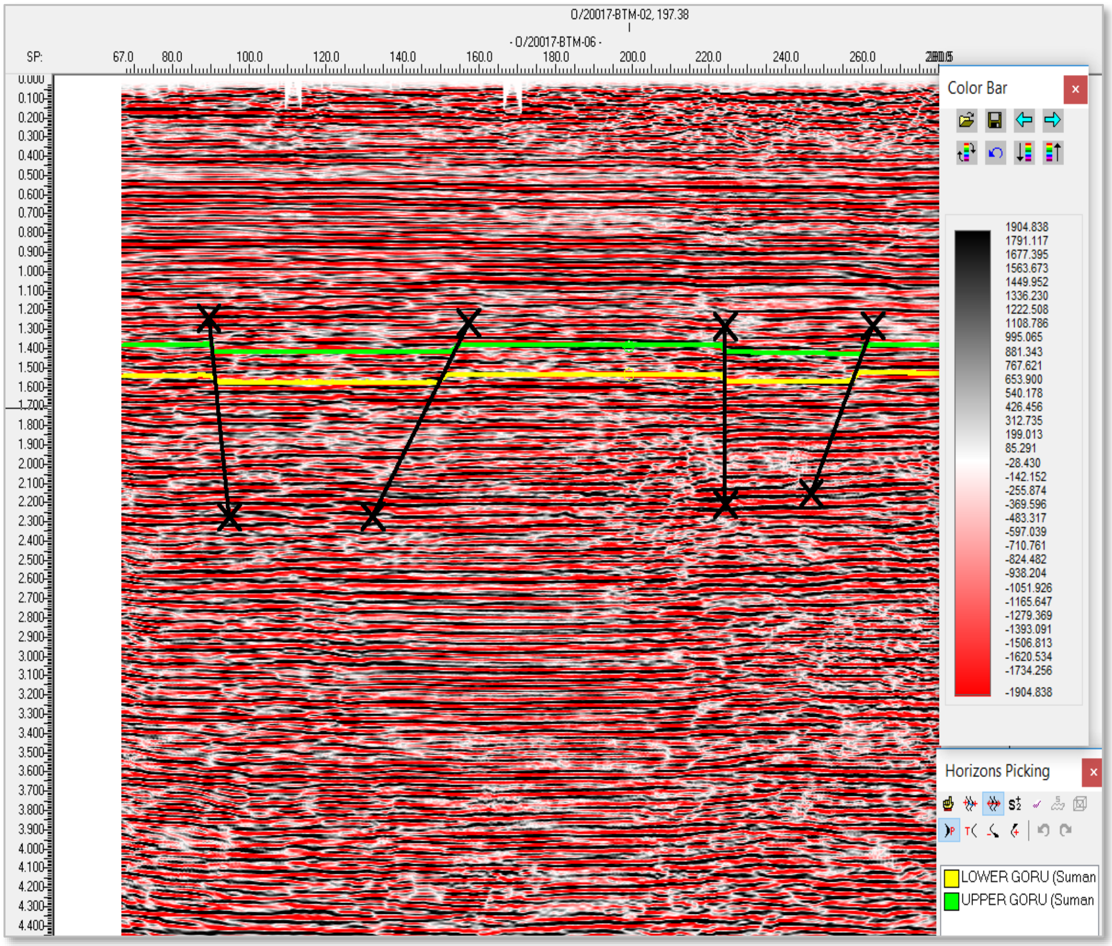

Figure 3-1 *Referenced Time Section with Interpreted Geological Cross section 20017-BTM-06*

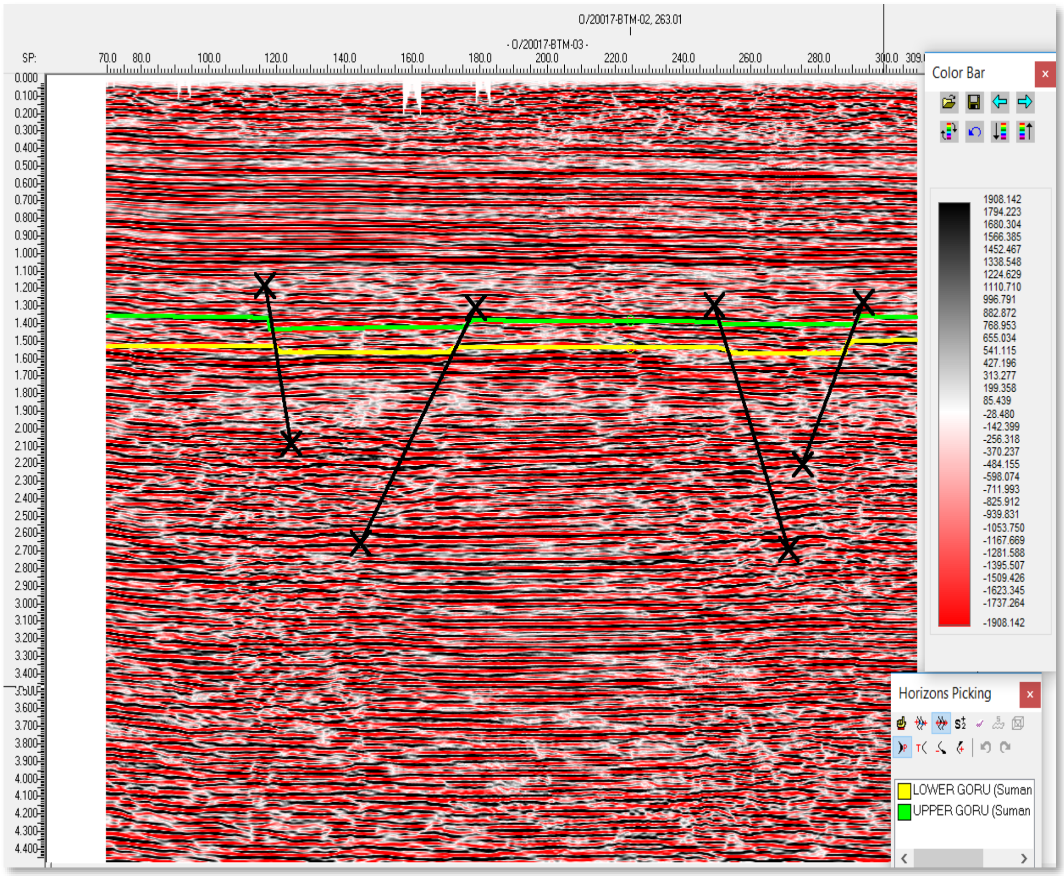

Figure 3-2 *Referenced Time Section with Interpreted Geological Cross section 20017-BTM-03*

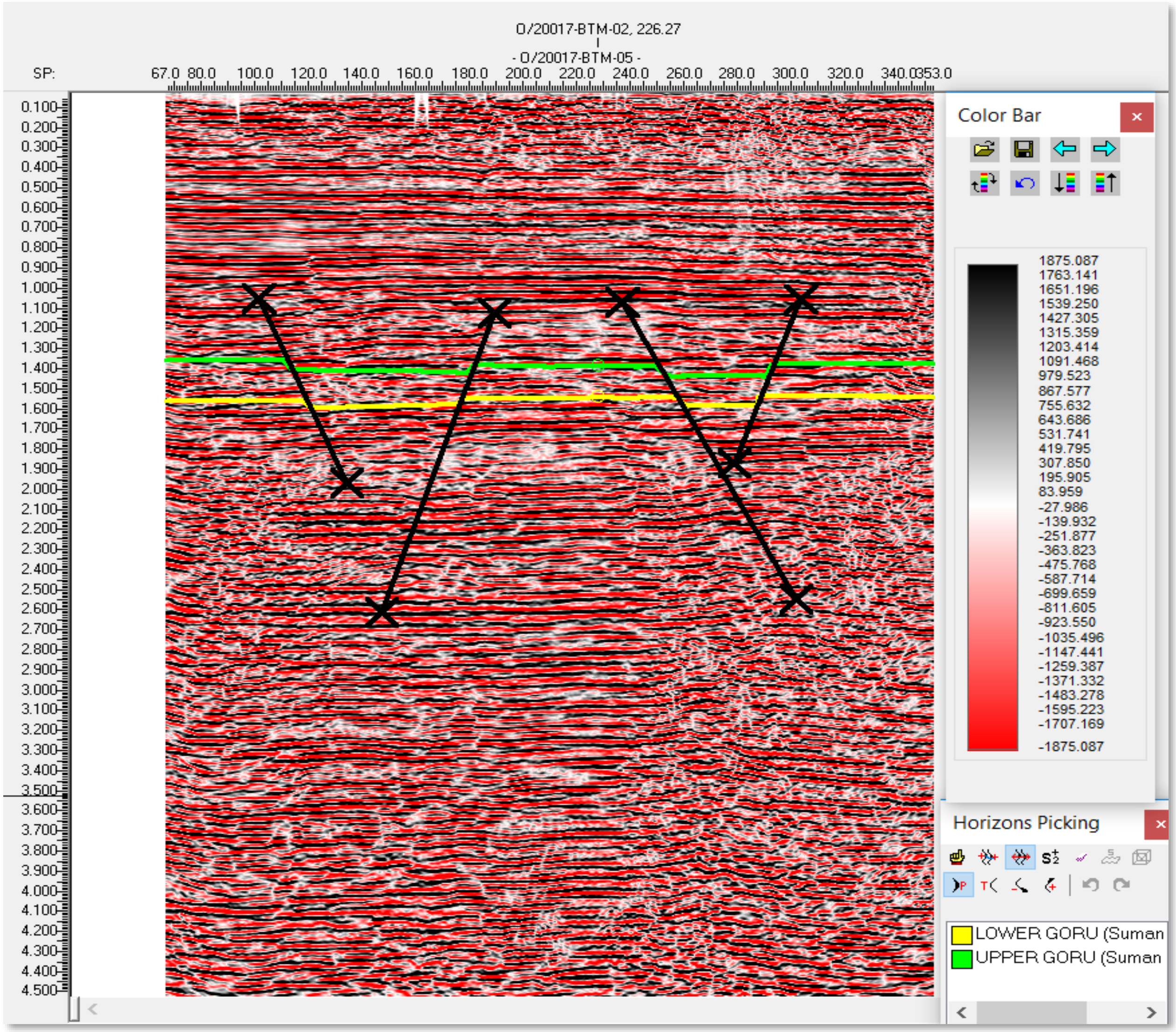

Figure 3-3 Referenced Time Section with Interpreted Geological Cross section 20017-BTM-05

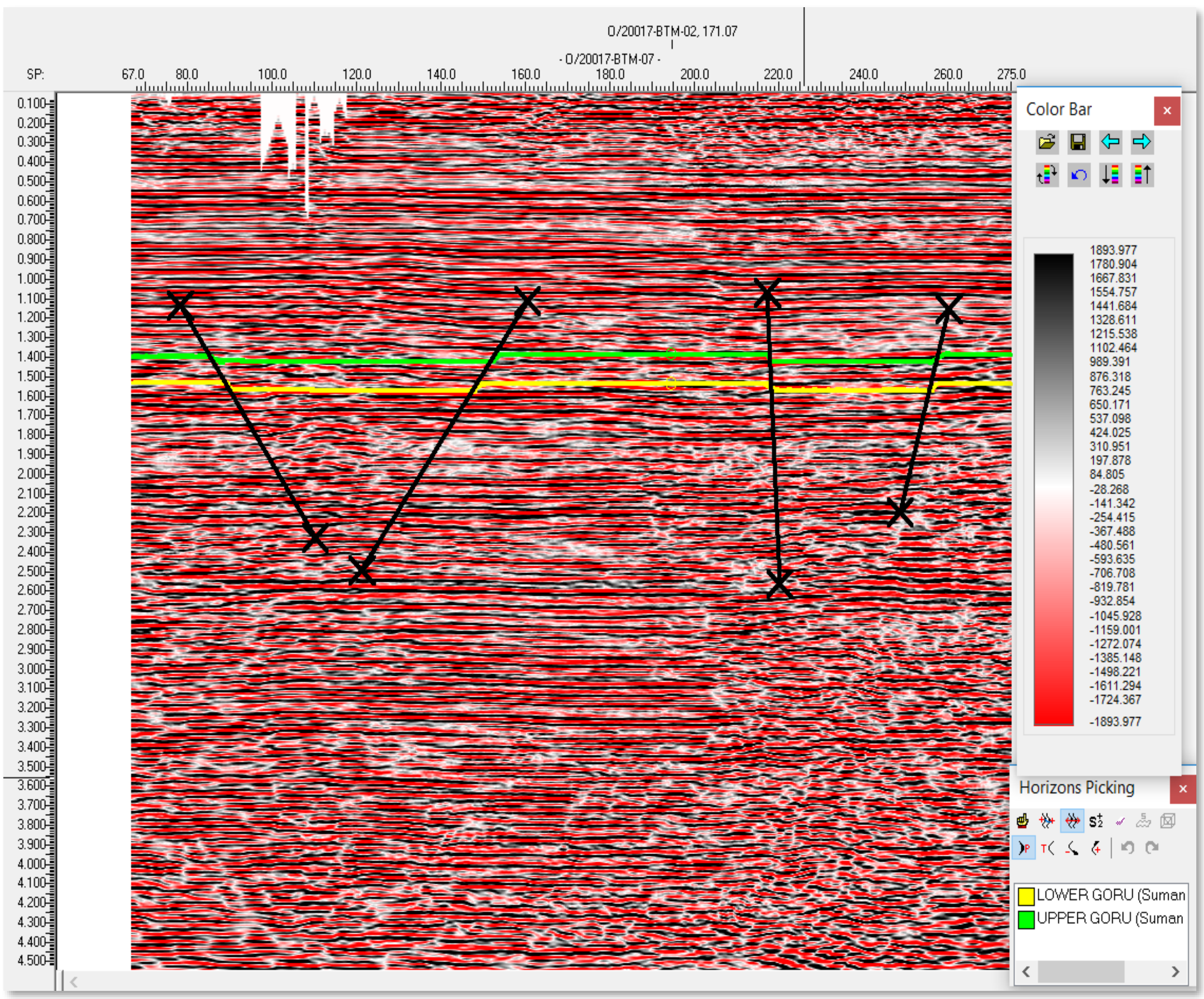

Figure 3-4 Referenced Time Section with Interpreted Geological Cross section 20017-BTM-07

3.6 SEISMIC DEPTH SECTION

It is very tough and time taking process to mark the horizons. Time-domain seismic imaging is a robust and proficient process routinely applied to seismic data (Yilmaz, 2001). A good seismic illustration is not enough for an exploration or field development interpretation. Good well ties and reliable depth conversion are also required. For time to depth alteration average velocities are used. The maps of two-way-time to various horizons and of the average velocities between the formations are used to generate a depth contour map (Paturet, 1971). These velocities are multiplied with time of each reflector and divided by two to get the depth sections. To convert time into depth, following conversion is used.

$$Depth = V_{av} * \frac{T}{2}$$

3.7 Contour Maps

The results of seismic interpretation are usually displayed in map form. Mapping is part of the interpretation of the data. The seismic map is usually the final product of seismic exploration, the one on which the entire operation depends for its usefulness. The contours are the lines of equal time or depth drifting around the map as dictated by the data (Coffeen, 1986).

After completing horizons and fault interpretation time contour maps are constructed. There are some reasons for making time maps. The times are read directly from the sections and are immediately available for mapping. When we read the time of a horizon from the section it intends to show the structure of the horizon in the subsurface, it does not show us the structure directly.

Depth conversion and depth contour maps are constructed to see the horizons in the subsurface at their true positions. Depth must be calculated from time to make a map that is more truly related to the subsurface shapes, because structure is a matter of depth. The idea of converting the times into depths is very reasonable in case of showing the subsurface structures.

In constructing a subsurface map from seismic data, a reference datum must first be selected. The datum may be sea level or any other depth above or below sea level. Frequently, another datum above sea level is selected in order to image a shallow marker on the seismic cross-section, which may have a great impact on the interpretation of the zone of interest (Gadallah & Fisher, 2009).

Contouring represents the three-dimensional earth on a two dimensional surface. The spacing of the contour lines is a measure of the steepness of the slope; the closer the spacing, the steeper the slope. A subsurface structural map shows relief on a subsurface horizon with contour lines that represent equal depth below a reference datum or two way time from the surface. These contour maps reveal the slope of the formation, structural relief of the formation, its dip, and any faulting and folding. The interpreted seismic data is contoured for producing seismic maps which provide a three-dimensional picture of the various layers within an area which is circumscribed by intersecting shooting lines. The picked times for each reflector are exported along with the navigation data in the form of an XYZ file to be used for contouring.

3.7.1 Time and Depth Contour Maps of Upper Goru Formation.

3.7.1.1 Time Contour Map of Upper Goru Formation

A two way time contour map is constructed on Top Upper Goru formation shown in Figure 3.5. Along the main normal fault there are other normal faults that can be seen on the dipping lines

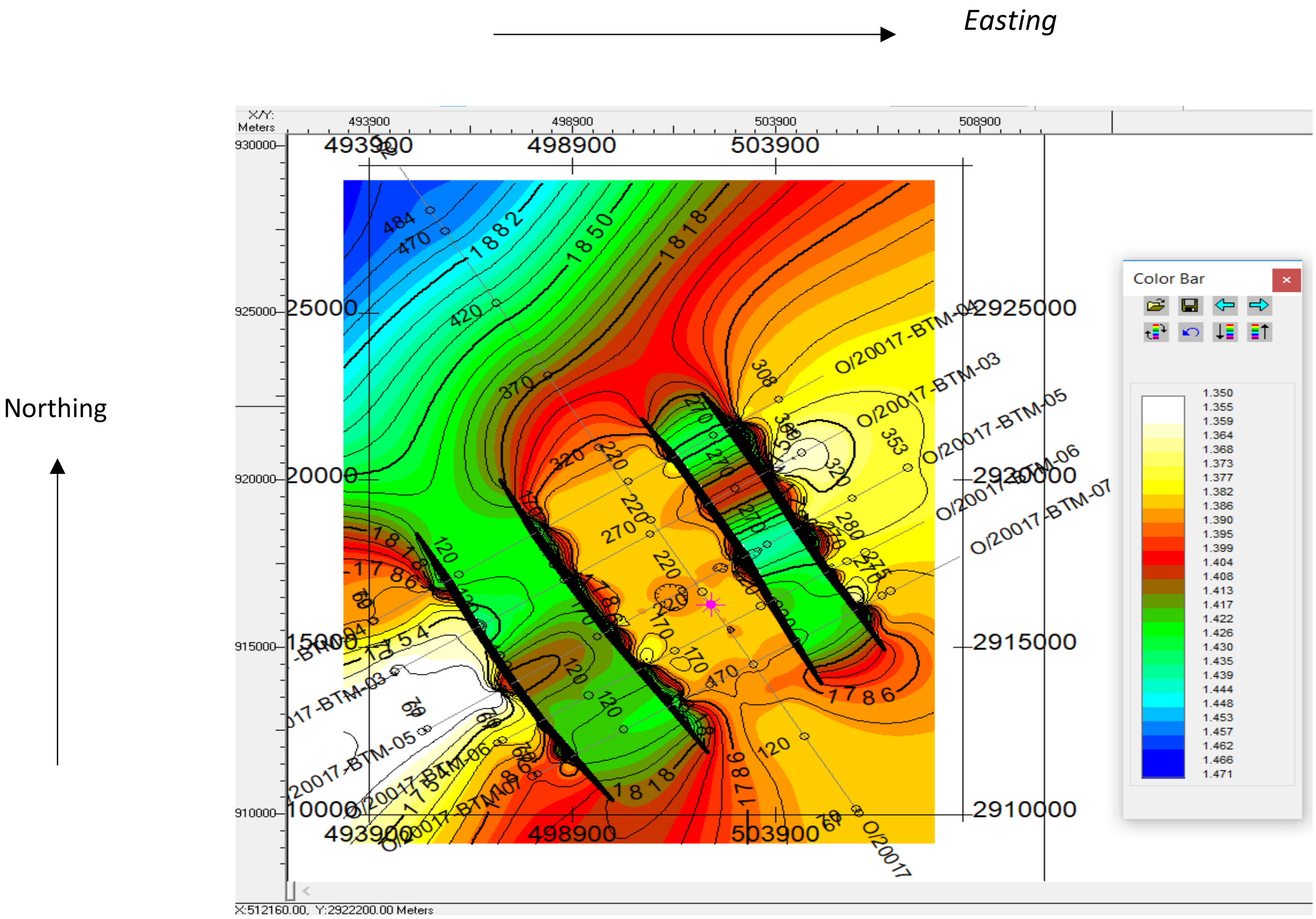

Figure 3-5 Time Contour Map of Upper Goru Formation

3.7.1.2 Depth Contour Map of Upper Goru Formation

A two way depth contour map is constructed on Top Upper Goru formation shown in Figure 3.6. Along the main normal fault there are other normal faults that can be seen on the dip

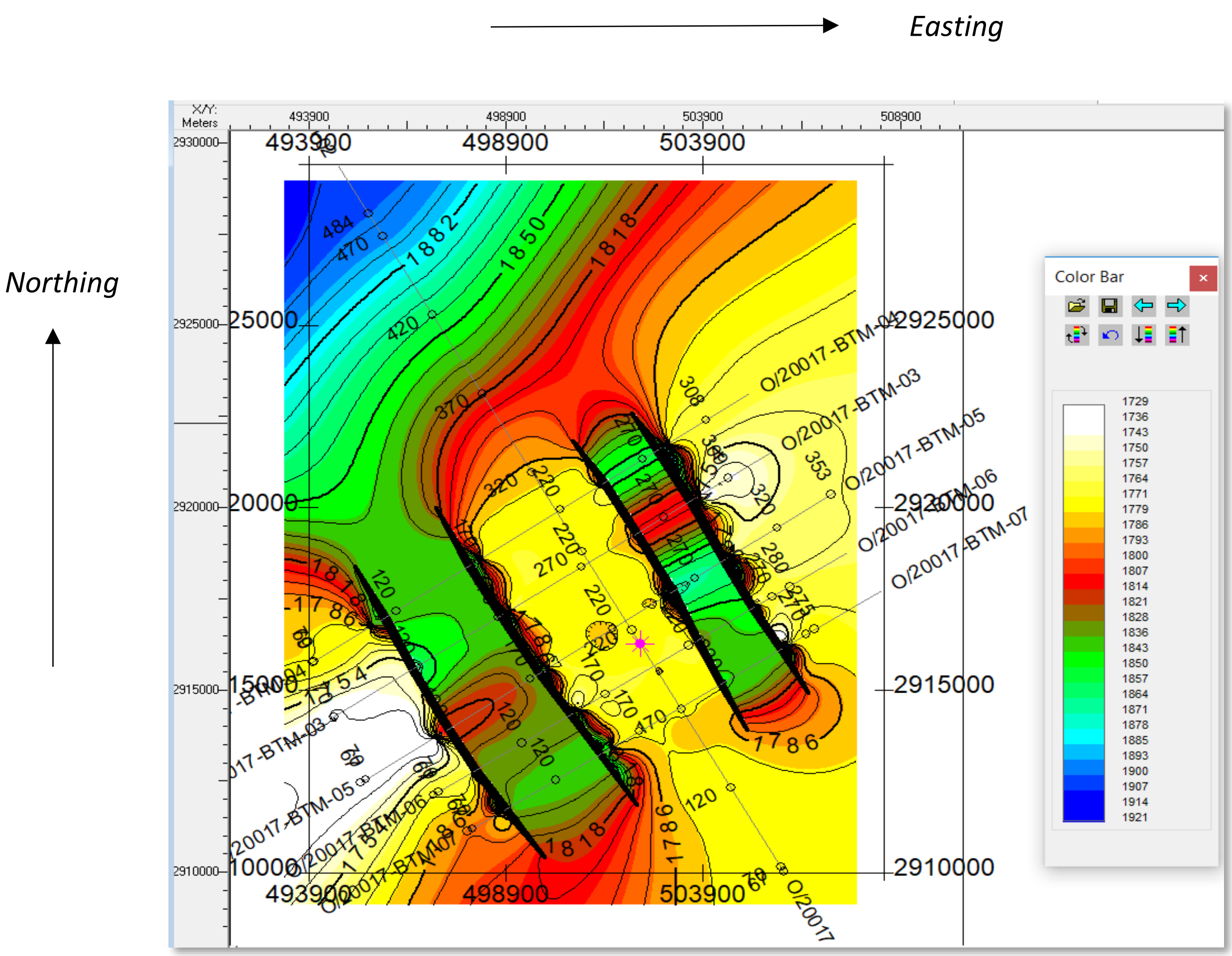

Figure 3-6 Depth Contour Map of Upper Goru Formation

3.7.2 Time, Depth and Velocity Contour Maps of Lower Goru Formation

3.7.2.1 Time Contour Map of Lower Goru Formation

A two way time contour map is constructed on Top Lower Goru formation shown in Figure 3.7. The general dipping trend of the horizon is from South-West to North-East. Along the main normal fault there are other normal faults that can be seen on the dipping lines.

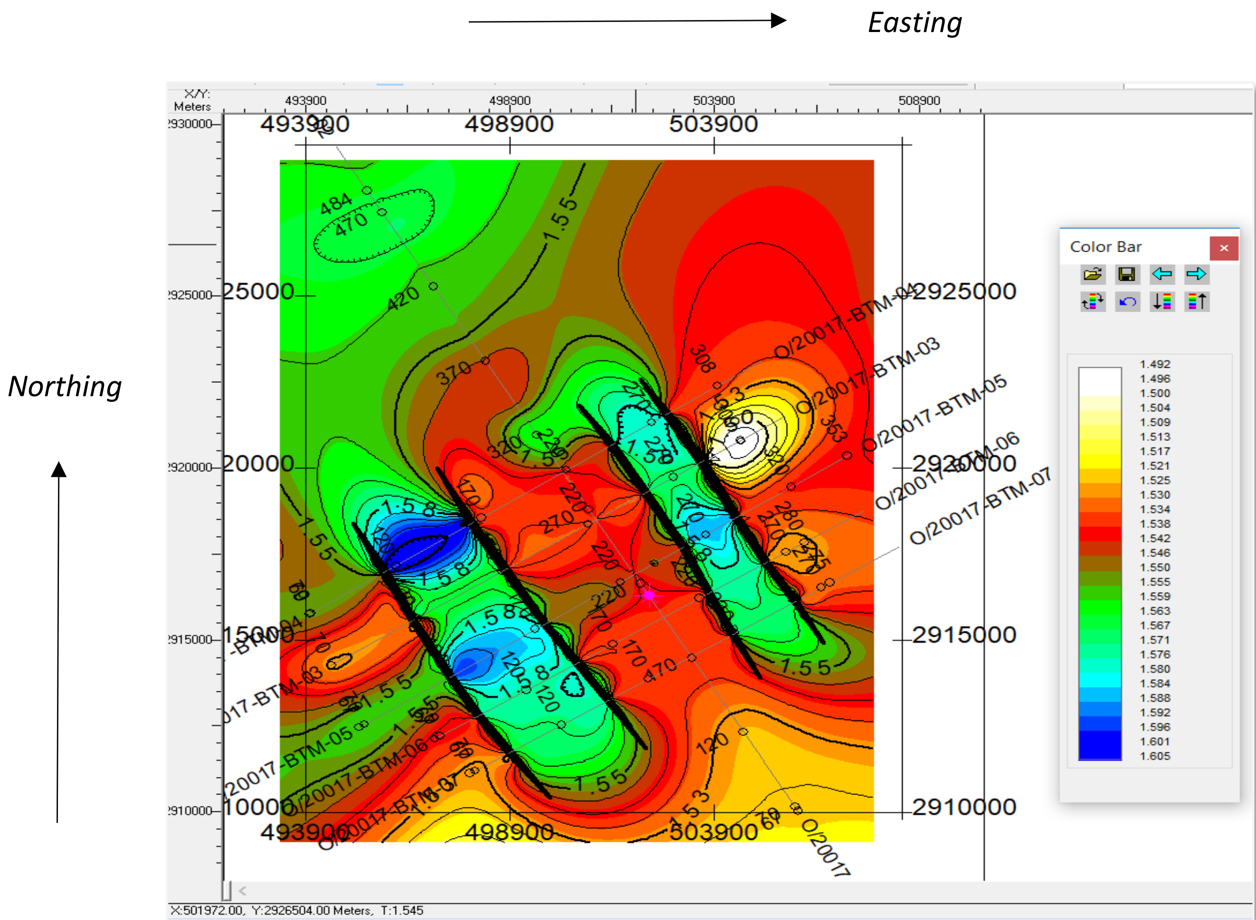

Figure 3-7 *Time Contour map of Lower Goru formation*

3.7.2.2 Depth Contour Map of Lower Goru Formation

A two way time contour map is constructed on Top Lower Goru formation shown in Figure 3.8. The general plunging trend of the horizon is from South-West to North-East. Along the main normal fault there are other normal faults that can be seen on the dipping lines.

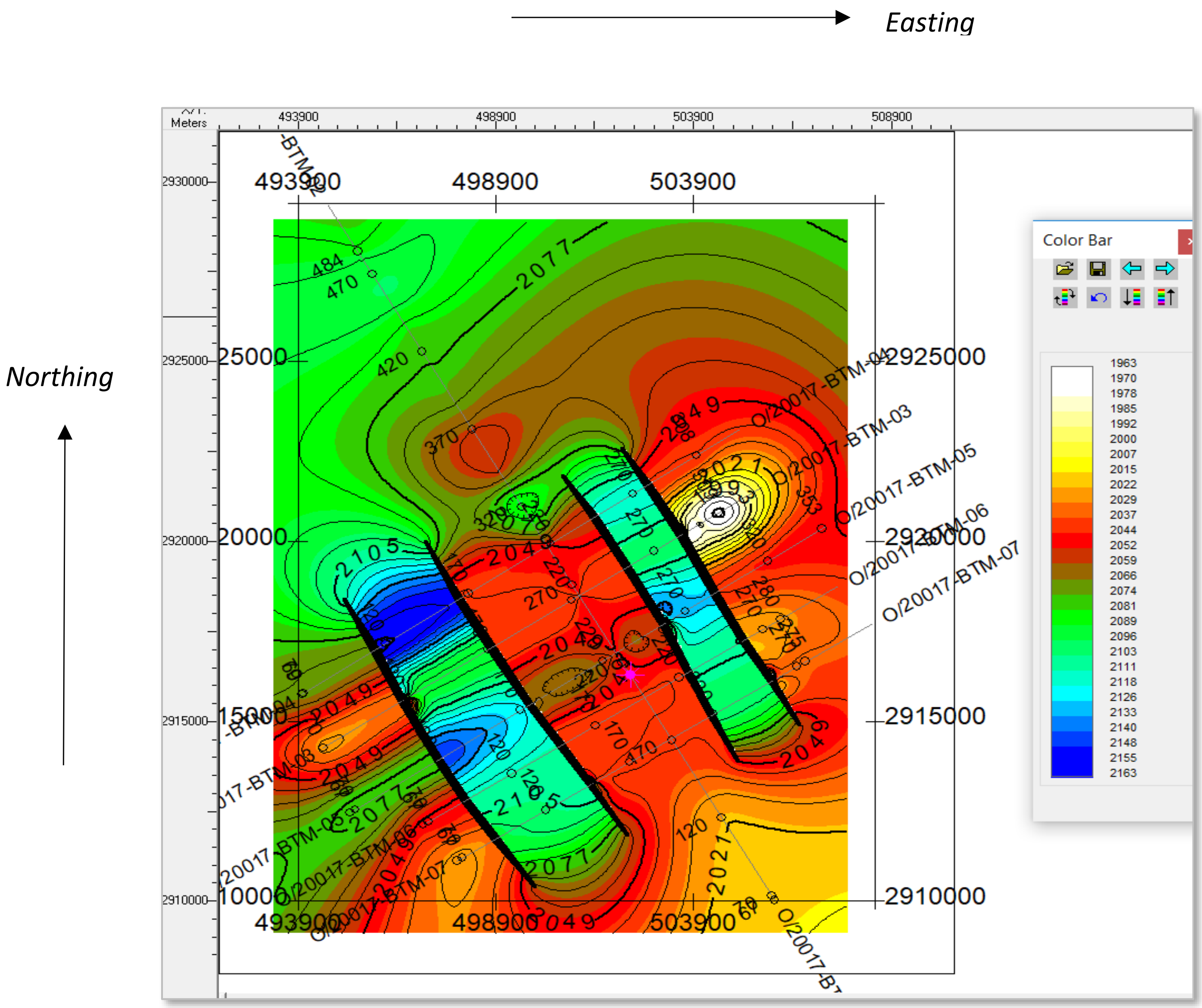

Figure 3-8 *Depth Contour map of Lower Goru Formation*

CHAPTER 4

4. Well Log/Petrophysical Interpretation

4.1 Well Logging

To determine various properties of different lithologies and the actual depth, thickness, two way travel time and interval velocities of these lithologies is the main purpose of well logging. In well logging the cutting of different lithology which come up with mud filtrate give information about type of material, type of fossil in it and also give us the information about depositional history of that material. In well logging different types of logs are obtained with the help of a sonde. In early ages different sondes are used for different type of logging in the well but now a day we use only one sonde which has ability to do all type of logging both cased or uncased logging

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4.1.1 Logs Used

The well logs analysis was carried out by using the following logs:

- Density Log
- Neutron Log
- Resistivity Log
- Gamma Ray Log
- Sonic Log

4.1.2 Log Data

The log data of FATEH-01 was available in Logging ASCII Standard (LAS) format. The log curves along with some parameters given in the LAS file header are used to calculate all basic and advance parameters. Well logs are shown in Figure 4.1.

4.2 Petrophysical Analysis

Following are the Petrophysical properties calculated for Petrophysical Analysis by using MS Excel.

4.2.1 Volume of Shale

Shale is more radioactive than carbonate or sand, gamma ray logs can be used to calculate volume of shale in porous reservoirs. The volume of shale can then be applied for analysis of shaly sands. Calculation of the gamma ray index is the first step to determine the shale volume from a gamma ray log (the following formulae from Schlumberger, 1974).

IGR = (GRlog –GRmin)/ (GRmax- GRmin)

IGR = Gamma Ray Index

GRlog = Gamma Ray reading of the formation

GRmax =Maximum gamma Ray (shale)

GRmin = Minimum gamma Ray (clean sand and carbonate)

Then following formula is used to find volume of shale

Consolidated:

- **Larionov (1969) for older rock :**

$$V_{sh} = 0.33 \times (2^{2I_{GR}} - 1)$$

Unconsolidated:

- **Larionov (1969) for Tertiary rocks :**

$$V_{sh} = 0.083(2^{3.7I_{GR}} - 1)$$

4.2.2 Porosity from logs

4.2.2.1 Sonic Porosity (ΦS)

Using sonic log porosity can also be easily calculated which is almost near or equal to actual porosity. The interval transit time (ΔT) is dependent upon both lithology and porosity of the medium. Therefore, a formation's matrix velocity given must be known to drive sonic porosity by the following formula given by Wyllie et al in 1958. Sonic porosity has been calculated by using the following the formula:

$\Phi S = (\Delta T - \Delta Tmat)/ (\Delta Tf - \Delta Tmat)$

Where,

ΦS=Sonic porosity μs/ft

ΔT =Log response

ΔTmat = Transit time in matrix

ΔTf= Transit time in fluids

Wyllie formula for calculating sonic porosity can be used to determine porosity of consolidated sandstone and carbonates. According to Wyllie interval transit time (ΔT) increased due to the presence of hydrocarbon (i.e. hydrocarbon effect). In order to correct this Wyllie suggested the following empirical correction for hydrocarbon effect.

$\Phi = \Phi s \times 0.7$ (for gas)

$\Phi = \Phi s \times 0.9$ (for oil)

4.2.2.2 Density Porosity (ΦD)

Density porosity has been calculated with the help of following formula.

$\Phi D = \rho m - \rho b / \rho m - \rho f$

Where,

ρm =2.71 gm/cm3 (for Carbonates)

ρf = 1 gm/cm3

ρb = log Response in zone of interest

4.2.2.3 Total porosity (ΦT)

Total porosity has been calculated by the help of following formula:

$\Phi T = \mathbf{12} (\Phi S + \Phi D)$

Where,

ΦT=Total Porosity

ΦD=Density Porosity

ΦS=Sonic Porosity

4.2.3 Water Saturation (S_w) Determination

Water saturation has been calculated with help of the Archie's Equation:

$S_w = (a/\Phi m) \times (R_w/R_t)$

Where,

S_w = water saturation

R_w =water resistivity (formation)

Φ = effective porosity

m (cementation factor) = 2

a (constant)= 1

R_t = log response (LLD)

R_w has been calculated with help of the following formula:

$R_w = \Phi 2 \times R_t$

Where,

Φ = porosity in clean zone

Rt =Observed LLD curve in clean zone

4.2.4 Saturation of Hydrocarbon

It is denoted as Shc. Saturation of hydrocarbon is calculated by given formula below;

$Shc = 1 - S_w$

S_w = Saturation of water

Shc= Saturation of hydrocarbon

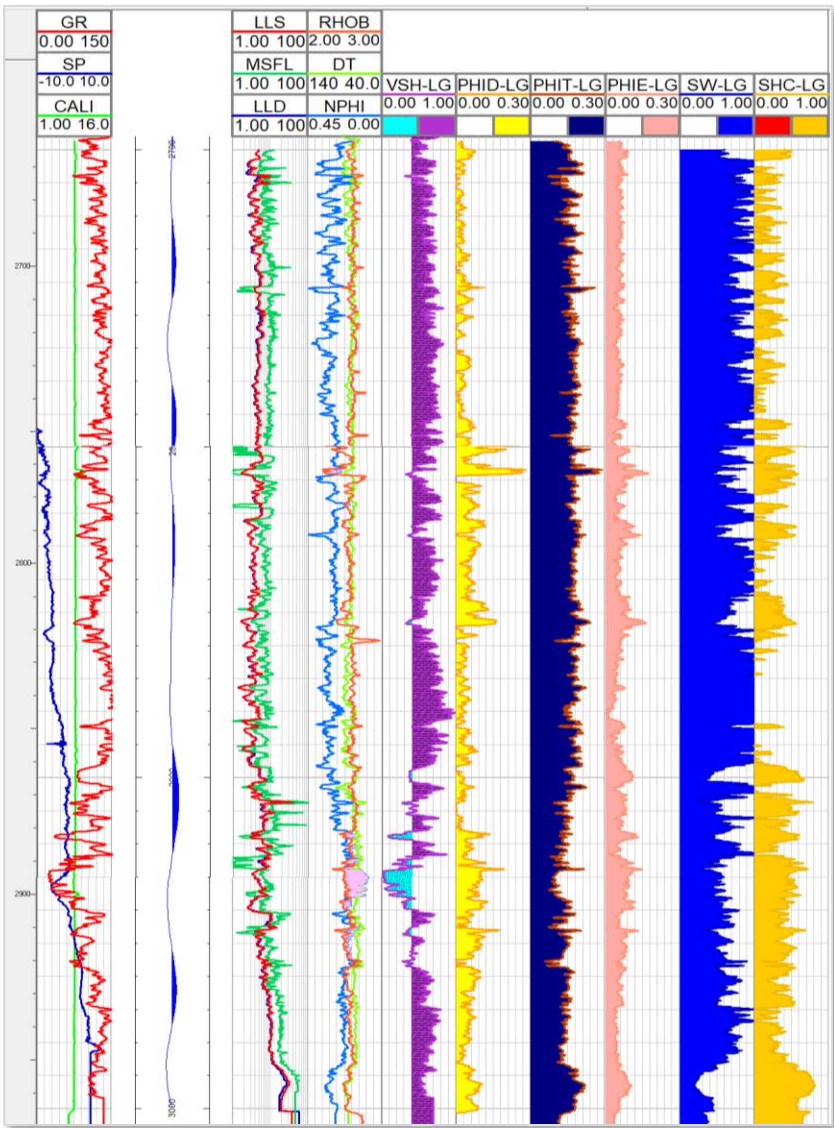

Figure 4-1 Log Curves of FATEH-01

4.3 Petrophysical Interpretation

The well log curves show that the hydrocarbons may be present but at the same time by interpreting all the other logs, I concluded that Well Fateh-01 is dry and there are no hydrocarbons present since the main lithology of the area comprised of sandy shale. Correspondingly, the well was located at an extensional regime which consisted of a series of horst and graben structures which owed to the fact that a barren ground is found.

CHAPTER 5

5. Facies Analysis

5.1 Introduction

The identification of a bed's lithology is fundamental to all reservoir characterization because the physical and chemical properties of the rock that holds hydrocarbons and/or water affect the response of every tool used to measure formation properties. Understanding reservoir lithology is the foundation from which all other Petrophysical calculations are made. To make accurate Petrophysical calculations of porosity, water saturation (S_w), and permeability, the various lithologies of the reservoir interval must be identified and their implications understood. Lithology means "the composition or type of rock such as sandstone or limestone." These few words belie a host of details about reservoir rocks (Hynes, 1991). Horizontal wells are rarely cored, a method is needed to indirectly derive the facies distributions within the formations penetrated by those wells. There is a material correlation between the behavior of well logs and the lithologic and depositional facies of penetrated formations, since modern logs are sensitive to factors that vary with the makeup of those formations (Saggaf and Nebrija, 2000).

5.2 Methods of Facies Analysis

There are different approaches used for performing Facies analysis, (Saggaf and Nebrija, 2000). These are listed as

- Supervised analysis
- Unsupervised analysis

5.2.1 Supervised Analysis

Supervised analysis is used to identify the Facies types which are present in a certain well (by using Facies that are identified from cores in a nearby well). The method is suitable for analyzing lithologies and depositional Facies of horizontal wells, which are almost never cored, especially if core data is available for nearby vertical wells. This mode is often called guided or directed classification (Saggaf and Nebrija, 2000).

5.2.2 Unsupervised Analysis

The objective of the unsupervised mode of analysis is to segregate the well into distinct Facies classes based on their log behavior. This process emulates of what a petro physicist would execute by performing a cautious examination of the log characteristics at various intervals in the well. This mode of analysis is implemented by a single-layer competitive neural network that takes the various well logs as an input and classifies each depth interval into its corresponding Facies category. As it performs clustering, or quantization of the input space, this mode is also called a feature discovery or "let-the data-talk" scheme (Saggaf and Nebrija, 2000).

5.3 Use of Acoustic Logs

Acoustic velocity is primarily a function of the rock matrix and can be used to identify different lithologies and for stratigraphic correlations (Clavier et al., 1976). A variety of cross-plot techniques, using acoustic measurements alone, or in combination with other porosity logs (neutron and density), have been devised to assist in lithological identification (Bruke et al. 1969)

Behavior of Acoustic and Porosity logs

Behavior of acoustic log and porosity log with respect to depth is shown in figure 5.1. This comparison shows that the Major lithology of reservoir zone is Shale.

5.3.1 Cross-plot between Sonic and Density (RHOB) log

A standard cross-plot between sonic log **(DT**) and density log **(RHOB)** is given in figure 5.2. Same cross-plot is prepared with log data of FATEH-01, with Gamma ray log as reference log at z axis. The depth range selected for this cross-plot is 2083-3005 meters because major reservoir rocks (Lower Goru) lies between this depths.

By comparison of figures different polygons are drawn and labeled according to the standard cross-plots. Cluster of dots is thick in the shale polygon. So it is interpreted that the reservoir is mainly comprises of shale or sandy shale.

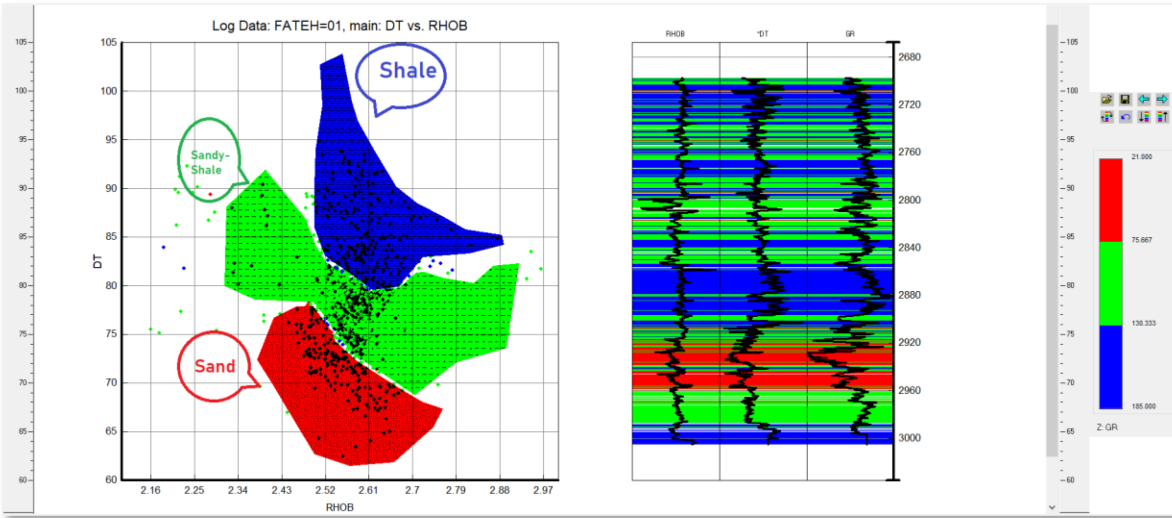

Figure 5-2. Generated cross-plot from log data between sonic log (DT) and Density log (RHOB)

5.3.2 Cross-plot between Density-Porosity (PHIE) and Water Saturation (Sw)

According to Vsh values there are three different lithologies present in the Lower Goru Formation. High vales of Vsh log indicate the presence of shale which is backed by comparatively lower values of effective porosity. Sand beds are present in minor quantity. The effective porosity values for sand beds are high. The average values of effective porosity show sandy shale beds. Saturation of water is high throughout the bed therefore hydrocarbons are present in less amount. Figure 5-3 shows the cross-plot of two logs with Vsh on the z axis.

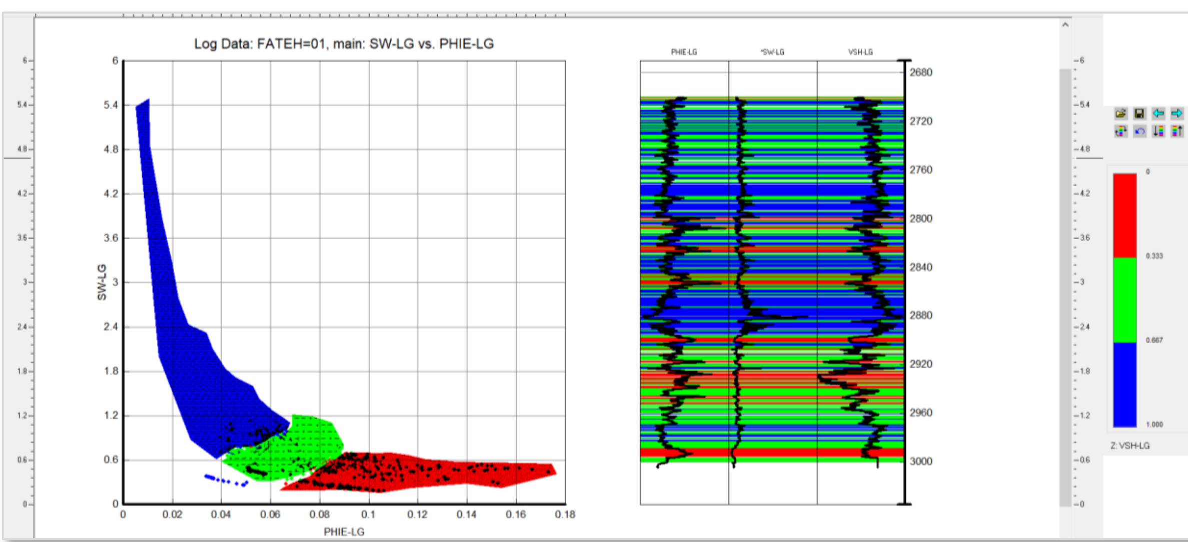

Figure 5-3 Generated cross-plot from log data between Density-porosity (PHIE) and Water Saturation (Sw)

5.4 Conclusions of Facies Analysis

Unsupervised analysis has been approached to analyses the reservoir lithology. Acoustic log and porosity logs has been studied and different lithologies marked on the basis of some standard values. To confirm this different cross-plots is prepared by the combination of acoustic and porosity logs. From these plots we get exactly the same results which confirms the interpretation that reservoir lithology is dominantly composed of Shale.

CHAPTER 6

6. SEISMIC INVERSION AND 1D FORWARD MODELING

6.1 Seismic Inversion

Generating a set of pseudo logs from seismic data is the process known as seismic inversion, a type of indirect modeling or reverse seismic modeling (Al-Sadi, 1980). Seismic inversion is the process of transforming seismic reflection data into a quantitative rock-property description of a reservoir. Seismic inversion may be pre- or post-stack, deterministic, random or geostatistical, and typically includes other reservoir measurements such as well logs and cores. Seismic data may be inspected and interpreted on its own without inversion, but this does not provide the most detailed view of the subsurface and can be misleading under certain conditions. Because of its efficiency and quality, most oil and gas companies now use seismic inversion to increase the resolution and reliability of the data and to improve estimation of rock properties including porosity and net pay.

An aspect of seismic inversion has been studied by identifying the variations in the lithologies via superimposing GR, LLD, DT and acoustic impedance (AI) log on two attributes of seismic data i.e. Instantaneous Frequency and Acoustic impedance attribute. Figure shows an analysis comparing the acoustic impedance from the well-logs with the acoustic impedance. The high correlation between the logs and the acoustic impedance, especially in the blind wells, gives good confidence in the inversion. The correlation is not unity due to the higher dependence on the seismic than the low-frequency model when creating the impedance trace still it gives enough interpretation that the logs shows variations at places where acoustic impedance changes which confirms the inversion and also the seismic interpretation. As the study area has a dry well so there is no direction identification of hydrocarbon as well. Figure shows the relation of frequency attribute and well logs. As Instantaneous frequency is the time derivative of the phase, i.e., the rate of change of the phase. It represents amplitude of the wavelet. Instantaneous frequency can indicate bed thickness and also lithology parameters and corresponds to the average frequency (centroid) of the amplitude spectrum of the seismic wavelet. Instantaneous frequency can provide information about the frequency signature of events, the effects of absorption and fracturing, and depositional thickness. Likewise acoustic impedance its correlation with logs gives same results as where frequency shows variations logs also shows variation, low values of GR log and high values of LLD log, which confirms the seismic data and interpretation.

Hence basic reason of this correlation of well log data and seismic attribute is to confirm the seismic data and to confirm the correlation between the well and seismic data which further studied for the seismic inversion and 1D forward modeling.

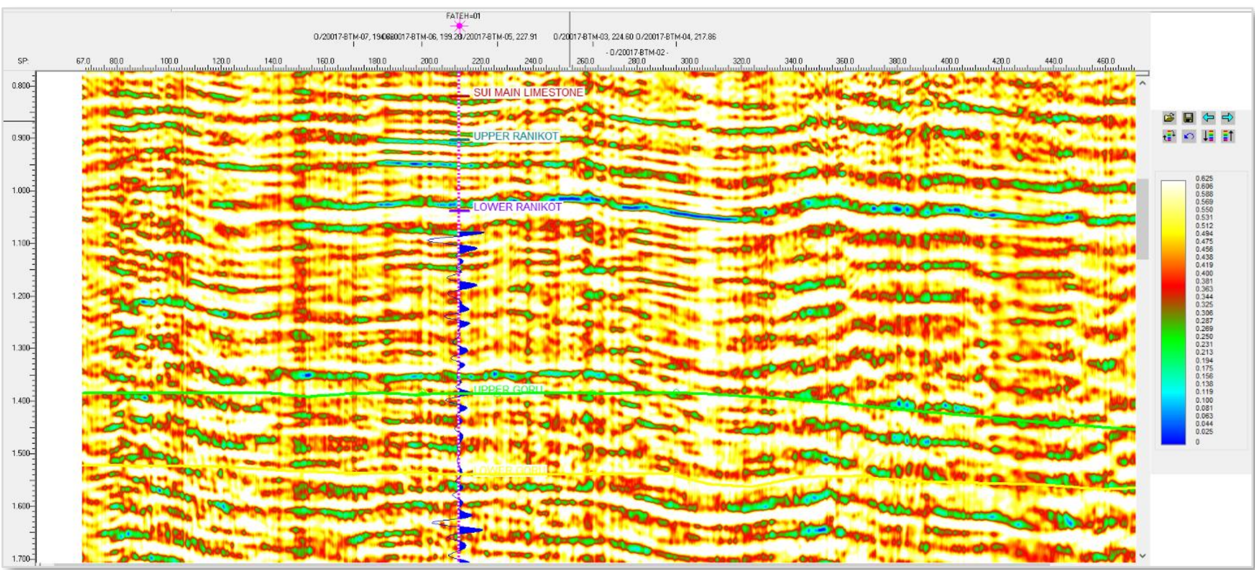

Figure 6-1 *Display of Colored Inversion performed on 20017-BTM-02*

6.2 Forward Modeling

Forward seismic modeling is the operation that takes an assumed geological model and constructs the pseudo seismic response that we would expect to get from it. If this synthesized response matches the original seismic data our confidence in the model is increased. Generation of a synthetic seismogram from a well log and comparing this synthetic or pseudo seismic trace, with seismic data is a common direct modeling procedure called the forward modeling (Al-Sadi, 1980).

6.3 Seismic Synthetic Modeling

The seismic synthetic modeling is the result of forward modeling to predict the seismic response of the subsurface. A more common definition used by seismic interpreters is that a synthetic seismogram is a direct one-dimensional model of acoustic impudence energy traveling through the layers of the earth. Synthetic seismogram or pseudo seismic section is a forward model of the earth that is constructed to mark the different geological horizon on the seismic section. The synthetic seismogram is generated by convolving the reflection coefficient derived from digitized sonic and density logs with the wavelet derived from seismic data. By comparing lithology or other correlation points picked on well logs with major reflections on the seismic section, interpretations of the seismic data can be improved. The quality of the tie between a synthetic seismogram and seismic data depends on well log quality, seismic data processing quality, and the ability to extract a representative wavelet from seismic data, among other factors. When the synthetic seismic response shows a good comparison to seismic section, the resultant model is considered to be representative of the true subsurface lithology.

Synthetic Seismogram = RC* Ricker Wavelet

Where $RC = (V_2 - V_1) / (V_2 + V_1)$

Following parameters are used in generation of Synthetic **Seismogram**:

- Type of wavelet: Ricker
- Central Dominant Frequency: 35 Hz
- Sampling Rate: 2 milliseconds
- Phase: Minimum phase
- Number of Sample: 39

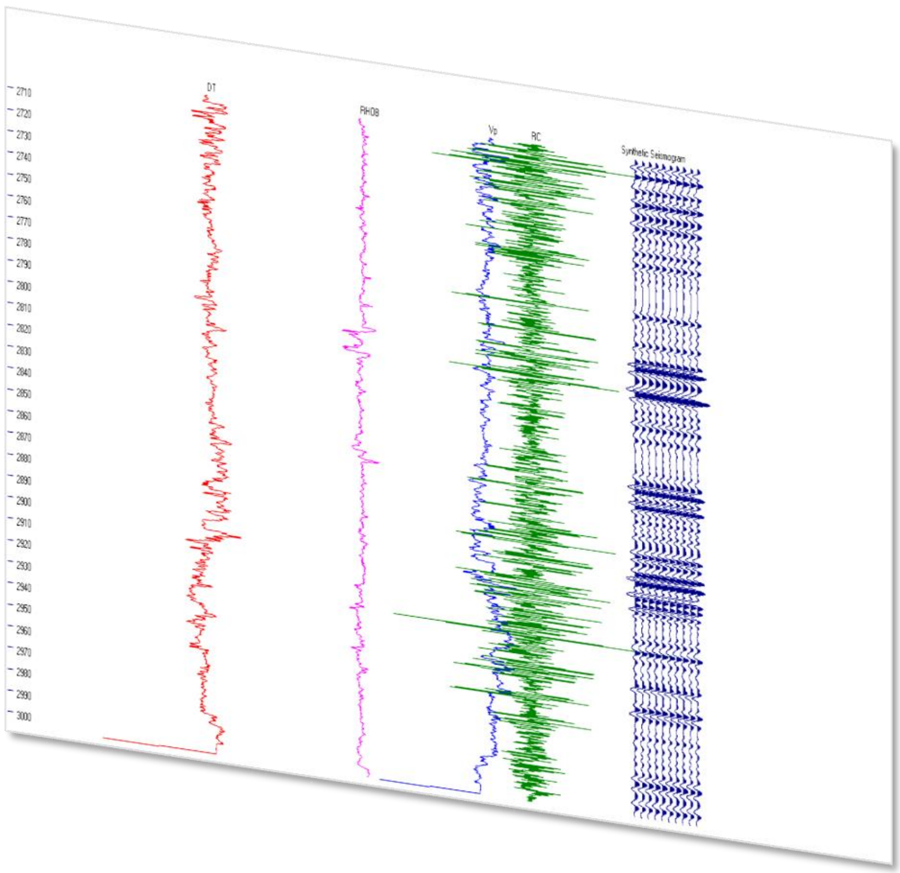

Figure 6-2 *Synthetic Seismogram of well FATEH-01*

6.4 Conclusions

On the basis of general stratigraphic column present in the area and the formation tops of the Fateh-01 well, two reflectors are marked on line 20017-BTM-02.

- First horizon is named as Upper Goru and second horizon is named as Lower Guru.
- The study Area is in extensional regime, step faults with Horst and Graben structures are present and normal faulting is dominated throughout the area. The horizons which were marked on seismic section confirmed the presence of these structures.
- The contour map showed vertical and lateral variations in velocity throughout the study area. There is a general trend of increase in the velocities with depth due to compaction of rocks.
- Time to depth conversion of seismic sections gave a true picture of sub-surface structure.
- Rock physics studies showed that both stiffer and softer lithologies are interbedded throughout the Lower Goru Formation
- Suitable traps for hydrocarbons are interpreted in the area. As the study area lies in Extensional regime, regional scale normal faults are observed. Along with these regional scale normal faults, localized normal faults are also present.
- The well FATEH-01 drilled in the study area failed and were abandoned. The first reason for failure is the immature migration of hydrocarbons whilst second reason for this failure might be the absence of suitable traps or presence of complex structural geometry in the study area.
- The well log curves show that the hydrocarbons may be present but at the same time by interpreting all the other logs, I concluded that Well Fateh-01 is dry and there are no hydrocarbons present since the main lithology of the area comprised of sandy shale. Correspondingly, the well was located at an extensional regime which consisted of a series of horst and graben structures which owed to the fact that a barren ground is found.

- Unsupervised analysis has been approached to analyses the reservoir lithology. Acoustic log and porosity logs has been studied and different lithologies marked based on some standard values. To confirm this different cross-plots is prepared by the combination of acoustic and porosity logs. From these plots we get the similar results which confirms the interpretation that reservoir lithology is dominantly composed of Shale.

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