2D SEISMIC DATA INTERPRETATION AND PETROPHYSICAL ANALYSIS OF BITRISM AREA, LOWER INDUS BASIN, KHAIRPUR DISTRICT SINDH, PAKISTAN

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CERTIFICATE OF APPROVAL

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DEDICATION

My whole work is dedicated to my Parents, Teachers & My Friends and especially to my Sweet brother **Muhammad Nauman Shahid** whose valuable ideas and motivation made me able to touch this Stage and to my loving Sister.

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First and foremost, all praises to **Allah Almighty**, the most beneficent and the most merciful. Secondly, my humblest gratitude to the **Holy Prophet Muhammad** (Peace Be Upon Him) whose way of life has been a continuous guidance and knowledge of humanity for me. This thesis appears in its current form due to the assistance and guidance of several people. It gives me great pleasure to express my gratitude to all those who supported me and have contributed in making this thesis possible.

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To me, there is nothing better than having good friends, so great pride is with me while thanking my friends: Junaid khan, Khurram shazaid, Sohail ahmed, Nasir khan, Yawar amin, Fayyaz ahmad, Bilal aziz, Haris ali and all other fellows. Words are lacking to express my humble obligation for their helping attitude, and Kind Corporation. The time spent with them will remain unforgettable for me.

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

ABSTRACT

Bitrisim area is an common example of extensional tectonics represented by Horst & Graben structures. In order to carry out the structural and stratigraphic interpretation of the Bitrisim area, two seismic dip line sand one strike linear interpreted. Two way time and depth mapping help in delineated the structural trend and understanding the tectonics of the area. Subsurface mapping reveals that major fault trend is NW-SE .There are the reactivation of faults indicating the occurrence of various tectonic periods. Existing structural trend of the area provides basic components of a profile petroleum system.

One D modeling is done for the one well Fateh-01 and zone of interest is the lower Goru. Porosity calculations are made to find out the water saturation and also the hydrocarbon saturation is calculated. The fault seal analysis is done to analyze the fault that is sealing or not. The main constituents of petroleum system are present proven by a number oil and gas discoveries but there is still a requirement of advance techniques to improve seismic resolution and quality of interpretation.

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CHAPTER 1

1.1-INTRODUCTION TO THE AREA OF RESEARCH:

The seismic method is one of the most important and extensively used geophysical method for exploration of hydrocarbons. Seismic sections is the output of seismic acquisition and processing which is interpreted to propose the equivalent geologic section and consequently a subsurface model is prepared to demarcate the existing petroleum play in the study location. Geoscientists are working hard 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 Seismic Method has a great importance in this regard. Hydrocarbons are one of the most important energy resources of the earth and economically these are very important for a country especially for developing countries. The study area is located in Khairpur district Sindh Province 26^0 25’ to 28^o 41’ north latitude and 68^0 0’ to 69^0 31’ east longitude.

Extracted hydrocarbons in a liquid form are referred to as petroleum or mineral oil, whereas hydrocarbons in a gaseous form are referred to as natural gas. Petroleum and natural gas are found in the Earth's subsurface with the tools of petroleum geology and are a significant source of fuel and raw materials for the production of organic chemicals.

1.2-LOCATION:

The study area is located in khairpur district sindh province. Sanghar is the main town which is about 40 km south of the location. It is located in central Sindh Province and is bounded on the North by Jacobabad High (Sukkar ridge), on the East by (Jaisalmir High (Indian Border), on the south by Thar Slope and Nanga parkar Ridge and on the west by Thatha and Hyderabad High.

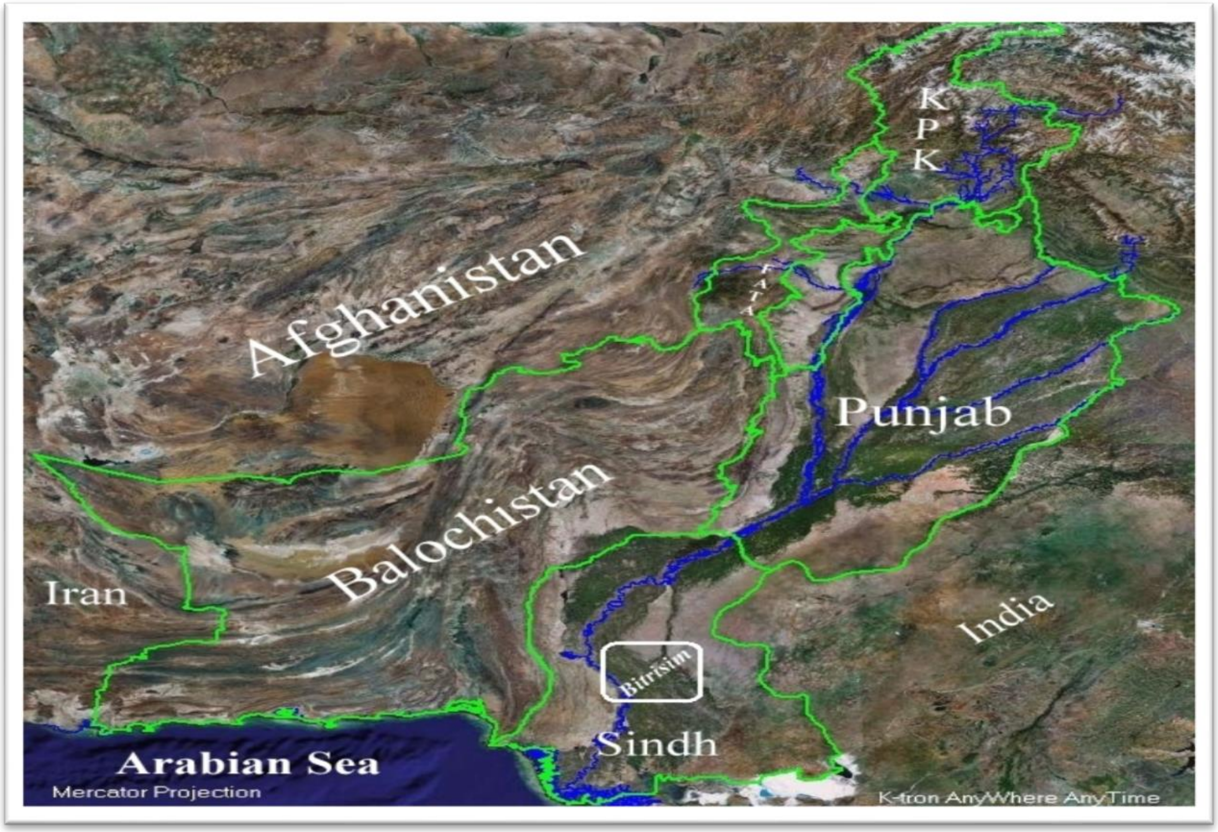


Figure 1 Satellite image of Pakistan showing Bitrism Area (Khan et at, 2008)

1.3-BASE MAP:

The navigation data of selected seismic lines and wells in the Bitrism block, obtained from Directorate General of Petroleum Concessions (DGPC), is used to plot the base map. Base map is the map on which primary data and interpretations can be plotted. The base map is an important component of interpretation, as it displays the spatial position of each picket of a seismic section. It also shows the spatial relationship of all seismic sections under consideration, their tie point locations and provides the framework for contouring. The base map of the area is generated by plotting data in Universal Transverse Mercator (UTM, Zone 43) geodetic reference system. . The base map given in shows the orientation of the lines used for study which are present in the Bitrisim area. The lines under study; 20017-BTM-02, 20017-BTM-03,20017-BTM-05,20017-BTM-06,20017-BTM-07,20017-BTM-08, 20017-BTM-09, and 986-BTM-09, 986-BTM-10.

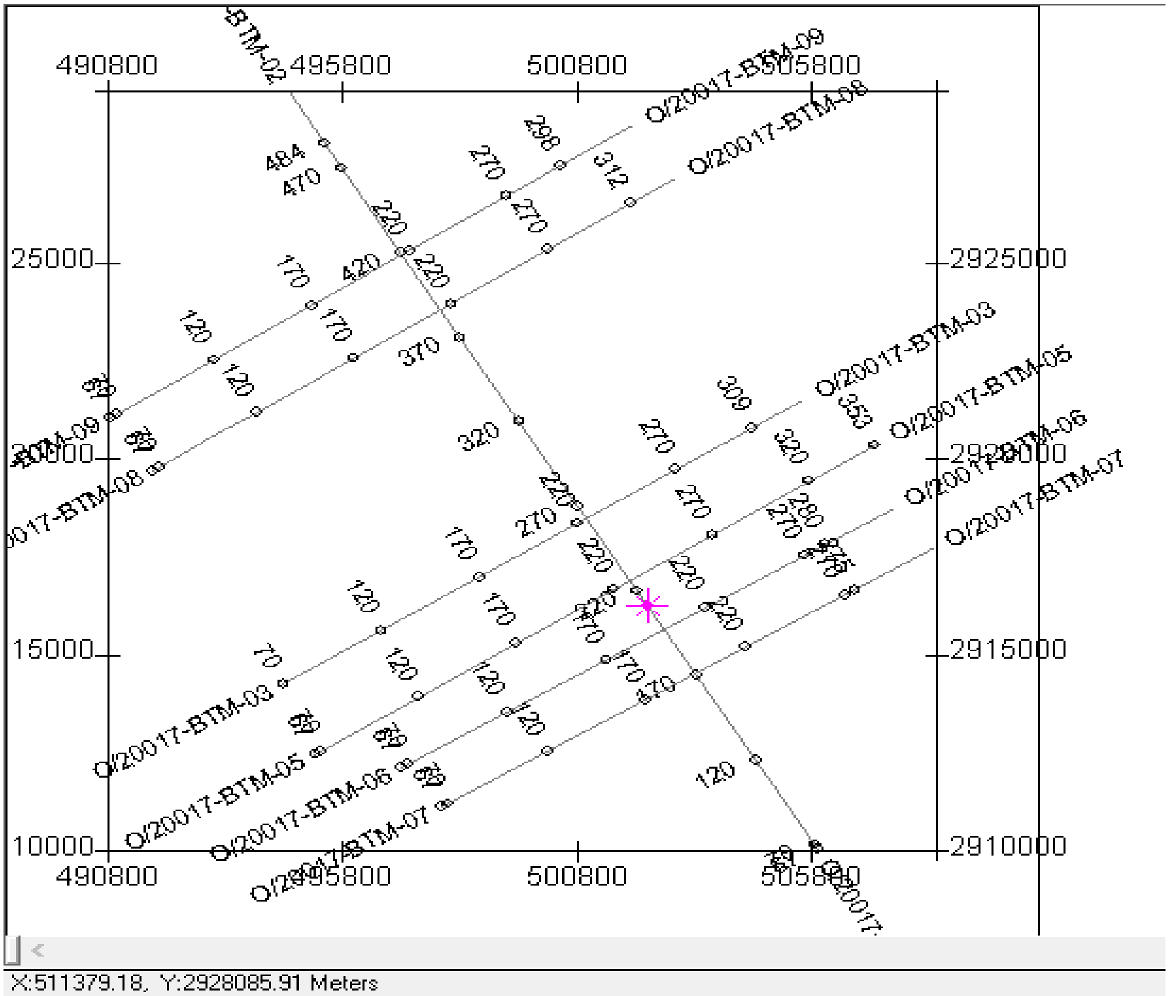


Figure 2 Dip & Strike lines & Location of well on Base-map of Bitrism Area

1.4-OBJECTIVES:

The main objectives of the dissertation are given below:

- Preparation of base map and generation of synthetic seismogram.
- Seismic interpretation is used for the identification of hydrocarbon accumulation.
- To generate time and depth contour maps from seismic section to understand trend of different horizons.
- Petro-physical analysis to estimate petro-physical properties for confirmation of reservoir lithologies.
- Facies modeling to interpret different subsurface lithologies.

1.5-DATA BASE:

A database is an organized collection of data, stored and accessed electronically. Database designers typically organize the data to model aspects of reality in a way that supports processes requiring information, such as (for example) modeling the availability of rooms in hotels in a way that supports finding a hotel with vacancies. The dissertation work is carried out by using the data granted by Directorate General of Petroleum Concession (DGPC). The data contains post stacked, migrated seismic lines (in SEG-Y format) and well data (the LAS files in addition to formation tops).

1.5.1-SEISMIC DATA:

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.

Serial No.	Seismic line	Orientation	Nature of Line	Well
01	20017-BTM-02	NW-SE	Strike	**FATEH-01**
02	20017-BTM-03	NE-SW	Dip	
03	20017-BTM-05	NE-SW	Dip	
04	20017-BTM-06	NE-SW	Dip	
05	20017-BTM-07	NE-SW	Dip	
06	20017-BTM-08	NE-SW	Dip	
07	20017-BTM-09	NE-SW	Dip	
08	986-BTM-10	NW-SE	Strike	

Table. 1.1. Seismic Data Information

1.5.2-Well DATA:

Serial No.	Well Name	Depth (m)	Type	Elevation (KB)	Status
01	**FATEH-01**	3000.0000	Abandoned oil & gas	35.2300	Exploratory

Table. 1.2. Well Data Information

1.6-DATA FORMAT:

In the given table 1.3, migrated seismic section along with supporting data and petro physical data obtained in following formats:

Seismic	**SEG-Y format**
Petro-physics	**LAS format**
Navigation	**DBO format**
Seismic Velocities	**VEL format**
DEM	**GRID format**
Well	**KGD format**
Geo reference satellite image	**GRF, JPG format**

Table. 1.3. Data Format

1.7-TOOLS OF SOFTWARE USED:

1. SMT Kingdom 8.8
2. MS Office Tools

CHAPTER 2

GENERAL GEOLOGY & STRATIGRAPHY OF THE STUDY AREA

2.1-INTRODUCTION:

Geologically, Bitrism area is situated within Southern Indus Basin to the south of the Sukkur Rift. 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 basinal history of the study area is related mainly to rifting and break up of Gondwana in Jurassic period. In the Cretaceous, East Gondwana (India-Antarctica-Australia) separated from the West Gondwana (Africa-South America). The Indian plate separated from East Gondwana in Aptian Time (120 ma). At the end of Cretaceous/early Paleocene, the Seychelles and Madagascar separated from India with associated faulting accompanied by Basaltic flows (Deccan Volcanic) in the southern part of Lower Indus Basin. The regional base Tertiary unconformity is due to thermal doming associated with the separation of the Seychelles and Madagascar from India. After the Paleocene there was a continuing oblique convergence of India and Asia throughout Tertiary time and the collision of India with Asia caused a westward tilting of the entire region. The Jacobabad-Khairpur high on which the study area is located, developed by domal lifting in during the Early Cretaceous and later on along deep seated faults in the Late Cretaceous and Paleocene. During Eocene times there was submergence and by the Oligocene it was uplifted again and then leveled by molasse deposition in Miocene to Recent time in the newly developed alluvial fans of major river system due to uplift of the Himalayas. On the Jacobabad- Khairpur high, Eocene carbonates (Sui Main Limestone) are widely distributed and form good hydrocarbon reservoirs.

The presence of Jurassic rocks in the area show deposition during rifting. The drifting of East Gondwana began in the early Cretaceous and with continued deposition on the marginal slopes of the northward drifting Indian plate till early the Tertiary. The collision of India and Asia took place in phases at the end of Cretaceous and the Tethys became closed during the Paleocene-Eocene. The spur of Tethys is now marked by exposures of ophiolites along the Axial Belt.

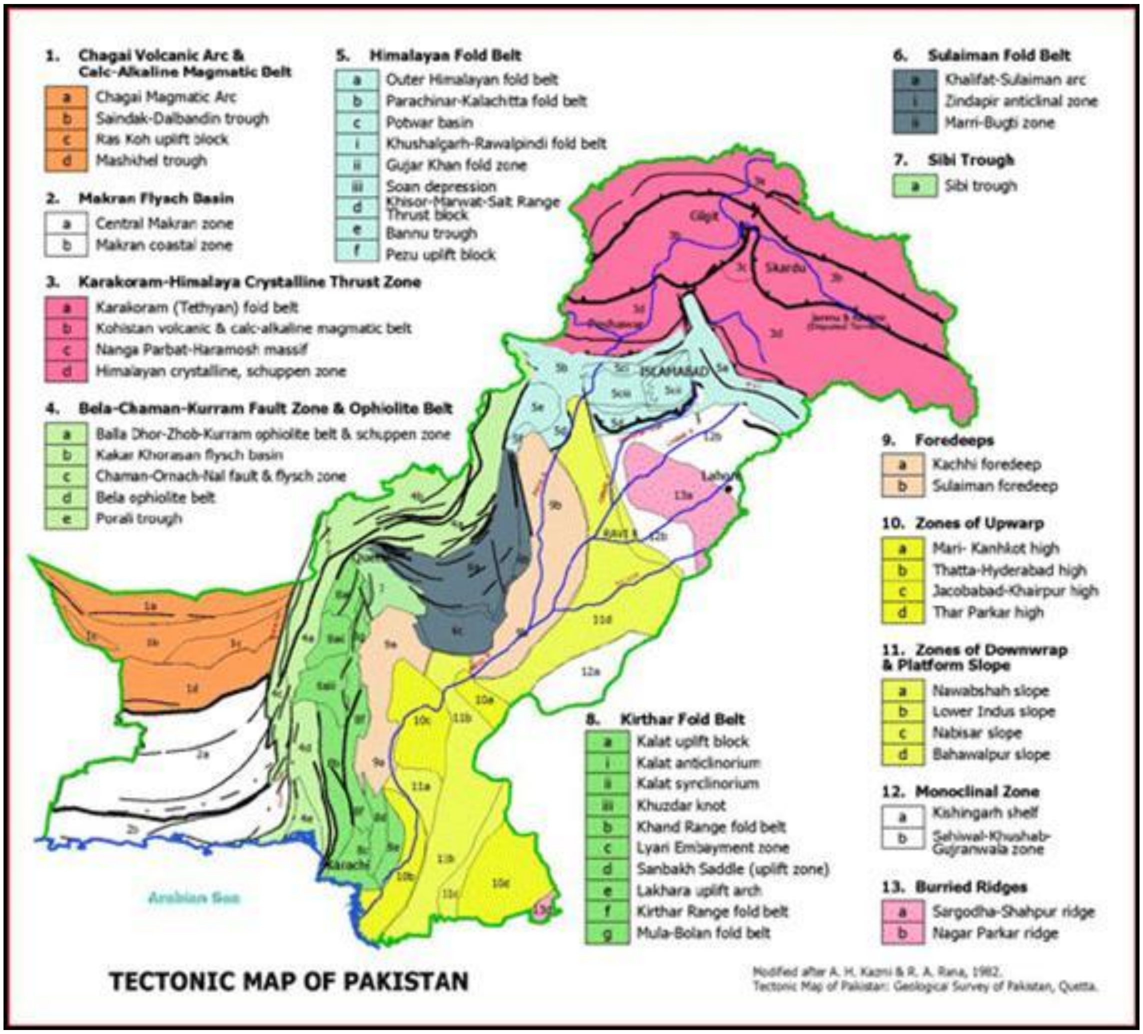


Figure 3 Tectonic Zones of Pakistan (Kazmi & Jan,1997)

2.2-BASINS OF PAKISTAN:

The structure in Pakistan or we can write it as Indus basin is divided into number of regime i.e. compression regime at foreland margins, basement uplift in the Central Indus Basin and extensional regime in the Lower Indus Basin (Kadri, 1995).

The Basin and their subdivision includes the following:

1. Indus Basin
   a. Upper Indus Basin
   b. Lower Indus Basin
   c. Central Indus Basin
   d. Southern Indus Basin

2. Baluchistan Basin
3. Kakar Khorasaan Basin

2.3-LOWER INDUS BASIN:

Lower Indus basin is characterized by passive roof complex-type structure and a passive back thrust along the Kirthar fold belt, a passive roof thrust forming a frontal culmination wall along the margin of the fold belt and the Kirthar depression and out of syncline intra-molasses detachment in the Kirthar depression sequence. Lower Indus Basin is interpreted as an extensional regime which is developed as a consequences of divergence of Indian Plate from Gondwanaland (*Sheikh & Giano, 2017*).During northward drift of Indian Plate, Southern Indus Basin underwent regional erosion and erosive surfaces were overlain by shelf to shallow marine shales, sandstone and limestone of Sembar and Goru formations. Indian Plate persisted its drift when flysch accumulated around its southern edge and a transform fault become active along Ninety-East Ridge during Late Cretaceous. The western part of the plate sheared southward reactivating the extensional faulting. 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.

2.4-STRATIGRAPHY OF THE STUDY AREA:

2.4.1-JURASSIC STRATIGRAPHY:

2.4.1.1-CHILTAN LIMESTONE:

The Chiltan limestone correlates with the Samana Suk Formation of the Upper Indus Basin Age is Jurassic. Lithology is limestone with traces of shale. Light grey to dark grey, off white, medium hard to hard, compact, dense, massive, crystalline to crypto crystalline, locally marly, oolitic to pisolitic with calcite veins and at bottom slightly arenaceous limestone. Dark grey to greenish grey, occasionally brownish grey, moderately indurated to medium hard, laminated, pyritic and calcareous shale.

2.4.2-CRETACEOUS STRATIGRAPHY:

2.4.2.1-SEMBAR FORMATION:

Sember formation of Early Cretaceous consists of black shale with interbeded siltstone, argillaceous limestone with glauconitic and phosphatic nodules & sandy shale is present in basal part. The thickness of Sember formation at type locality is 133 meter while its environment of deposition is deep marine. . It primarily contains shale followed by sandstone, siltstone and some argillaceous limestone. It also contains characteristics glauconite in most occurrences. The Formation is 133 m thick in type area (Sembar Pass) and 262 m in the Mughal Kot section. The fossils most commonly found in the Sembar Formation are belemnites *Hibolithes pistilliformis, H. subfusiformis,* and *Duvalia sp.*

2.4.2.2-GORU FORMATION:

The Goru formation consists of interbedded sandstone, shale and siltstone. The limestone is grained, thin bedded, light to medium grey in color. . The limestone is fine grained and thin bedded. Sand beds have been recognized which are intercalated with shale. On the basis of lithology, Goru formation has been dived into two members i.e. Lower Goru member and Upper Goru member.

2.4.2.2.1-LOWER GORU:

The lower Goru is main reservoir rock within the area. The lower Goru horizon as a general 5 divisions based on predominant lithologies.

- The Basal Sand Unit
- Lower Shale
- Middle Sand Unit(which has a good reservoir potential)
- Upper Shale
- Upper Sand

2.4.2.2.2-UPPER GORU:

The upper Goru sequence of middle to late cretaceous overlies the lower Goru formation which consists of mainly marl and calcareous claystone occasionally with interbeds of silt and limestone. The Goru Formation is widely distributed in the Kirthar and Sulaiman Province. The lower contact with the Sember Formations is conformable. The upper contact is transitional with the Goru Formation may be correlated with the Lumshiwal Formation of the Kohat-Potowar Province.

2.4.3-PALEOCENE STRATIGRAPHY:

2.4.3.1-RANIKOT FORMATION:

Vredenberg (1909a) subdivided the Ranikot group into Lower Ranikot (sandstone) an Upper Ranikot (limestone).Ranikot Formation is correlative with Khadro Formation. Paleocene Ranikot group comprises fluvial sandstones, estuarine shale and limestone which are found good for petroleum prospect as good source as well as reservoir. Ranikot Formation of Early Paleocene age comprises of grey limestone with some brown sandstone and shale in the upper part while sandstone with shale and limestone inter-beds are found in lower part. Its upper contact is conformable with Laki Formation while its lower contact is unconformable with Khadro Formation. The environment of deposition is shallow marine.

2.4.4-EOCENE STRATIGRAPHY:

2.4.4.1-LAKI FORMATION:

The formation comprises cream coloured to grey limestone, with subordinate marl calcareous shale, sandstone and lateritic clay. It contains a rich fossil assemblage of foraminifera, gastropods, bivalves, echinoid and algae. Laki formation of Early Eocene comprises mainly of cream colored to grey limestone, with subordinate marl, calcareous shale, sandstone and laterite. The depositional environment of shallow marine and its thickness is 100 meter. The formation is further subdivided into two members.i.e. Meting limestone member and Sohnari member.

2.4.4.2-KIRTHAR FORMATION:

Shah (1999) defined the Kirthar formation as predominantly limestone, shale and marl. Kirthar Formation of middle Eocene overlies the Ghazij Formation conformably and its upper contact is disconformable with Siwalikhs. The formation is mainly fossil ferous limestone interbedded with subordinate shale and marl. The limestone is thick bedded to massive and nodular in places. The environment of deposition is shallow marine.

2.5-PETROLEUM PLAYS:

A play is a “a group of geologically related prospects having similar conditions of source, reservoir and trap”. (*Qadri, I.B, 1995*)

2.6-PLAY ELEMENTS:

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

- Source Rocks
- Reservoir Rocks
- Cap/Seal Rocks
- Traps
- Maturation
- Migration
- Timing

2.7-PETROLEUM PROSPECTS OF THE AREA:

2.7.1- SOURCE ROCKS:

Rock units containing known or potential source rocks include the Salt Range Formation "Eocambrian" shales, Permian Dandot and Tredian Formations, Triassic Wulgai Formation, Jurassic Datta Formation, Paleocene Patala Formation, Eocene Ghazij Formation, and the lower Miocene shales. 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 (Iqbal and Shah, 1980).

2.7.2- RESERVOIR ROCKS:

Ranikot Sandstone is the main reservoir in the Dhoduk oil and gas field and Savi Ragha gas condensate discovery that lies south of the study area. . Massive sands are another interesting producing reservoir from its various sand sheet of multiple thickness possibility of reservoir in lower guru sand overlain on basal sands These principle reservoirs are deltaic and shallow-marine sandstones in lower part of the Goru in this area. Reservoir qualities generally diminishes west ward while reservoir thickness increases. Potential reservoir in the Eocene include Limestone of Habibrahi and Pirkoh members of the Kirthar Formation.

2.7.3- SEAL/CAP ROCKS:

The Paleocene and Eocene successions of Northern Sulaiman Ranges comprise thick shale horizons and are the potential sealing horizons underneath these ranges in addition to several intra-formational thick shale beds at various levels. Top of the Lower Goru and Upper Goru containing thick shale and marl are the main stratigraphic trap to the major Cretaceous reservoirs in Middle and Lower Indus Basin. Additional seals that may be effective include: faults, and up-dip facies changes. The known seals in the study area are composed of inter bedded shale which is over lained the reservoirs. . Fine-grained rocks such as shale or evaporites have the tendency as effective cap rocks.

2.7.4- TRAPS:

The temporal relationships among trap formation and hydrocarbon generation, expulsion, migration, and entrapment are variable- throughout the Indus Basin. 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.

CHAPTER 3

SEISMIC INTERPRETATION OF THE LINE

3.1-SEISMIC INTERPRETATION:

Seismic interpretation is the science of inferring the geology at some depth from the processed seismic record. The seismic record contains two basic elements for the interpreter to study. The **first** is the time of arrival of any reflection or refraction from a geological surface. The actual depth to this surface is a function of the thickness and velocity of overlying rock layers. The **second** is the shape of the reflection, which includes how strong the signal is, what frequencies it contains, and how the frequencies are distributed over the pulse. This information can often be used to support conclusions about the lithology and fluid content of the seismic reflector being evaluated.

The interpretation process can be subdivided into three interrelated categories: structural, stratigraphic, and lithological.

3.1.1-STRUCTURAL SEISMIC INTERPRETATION: is directed toward the creation of structural maps of the subsurface from the observed three-dimensional configuration of arrival times.

3.1.2-SEQUENCE STRATIGRAPHIC SEISMIC INTERPRETATION: relates the pattern of reflections observed to a model of cyclic episodes of deposition. The aim is to develop a chrono-stratigraphic framework of cyclic, genetically related strata.

3.1.3-LITHOLOGICAL INTERPRETATION: is aimed at determining changes in pore fluid, porosity, fracture, intensity, lithology, and so on from seismic data. Direct hydrocarbon indicators (DHI, HCIs, bright spots, or dim-outs) are elements employed in this lithological interpretation process.

The ultimate goal is to detect hydrocarbon accumulations, delineate their extent, and calculate their volumes. The physical basis is important because any interpretation concept, display and product must ultimately make sense in terms of reflection geophysics as well as be geologically compelling.

A successful interpretation requires background information prior to the data loading in workstation.

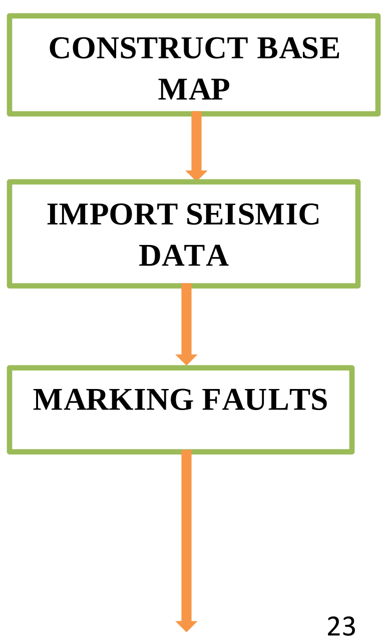
- We have to understand the regional tectonic setting and subsequent structural styles in the study area.
- We have to a knowledge about the major lithologies (carbonates or clastics, salt intrusions), interfaces and contacts.
- We have to understand the regional stratigraphy and depositional environments of the key formations.
- We have to be aware of the wells drilled in the area and their status as well as the information about producing formations.

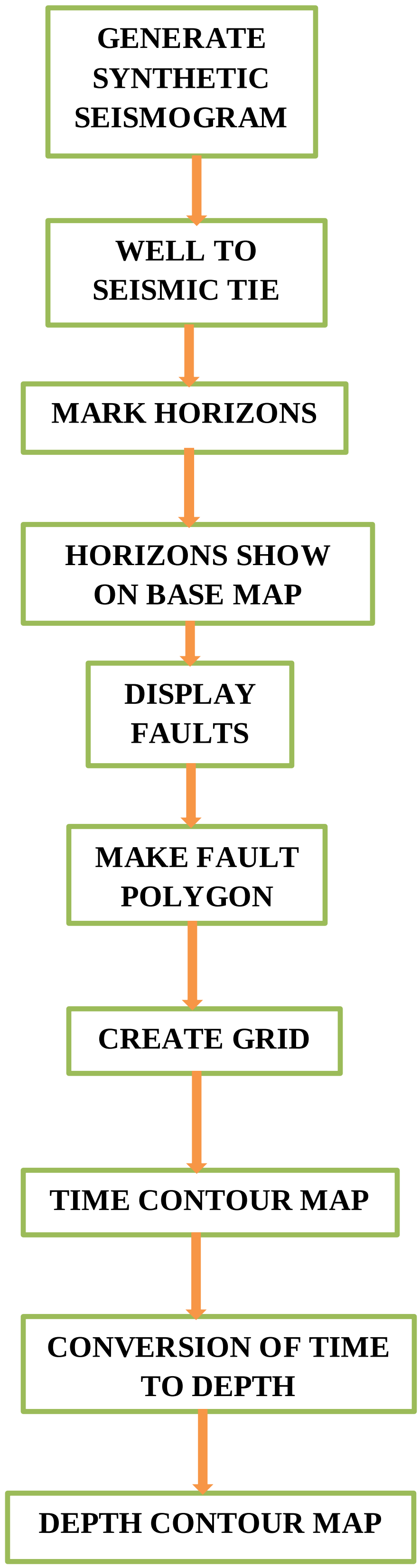
3.2-SEISMIC DATA IS INTERPRETED BOTH QUALITATIVELY AND QUANTITATIVELY:

The **qualitative interpretation** includes the thorough mapping of geometrical expression of the seismic reflectors in space and travel time domain.

The **quantitative interpretation** emphasizes the understanding of amplitude variations. Post-stack amplitude analysis, offset dependent amplitude analysis, elastic and acoustic impedance inversion and forward modeling are the major techniques which can validate hydrocarbon anomalies and characterize the reservoir well.

3.3-GEOPHYSICAL INTERPRETATION FLOWCHART:




GENERATE SYNTHETIC SEISMOGRAM
WELL TO SEISMIC TIE
MARK HORIZONS
HORIZONS SHOW ON BASE MAP
DISPLAY FAULTS
MAKE FAULT POLYGON
CREATE GRID
TIME CONTOUR MAP
CONVERSION OF TIME TO DEPTH
DEPTH CONTOUR MAP

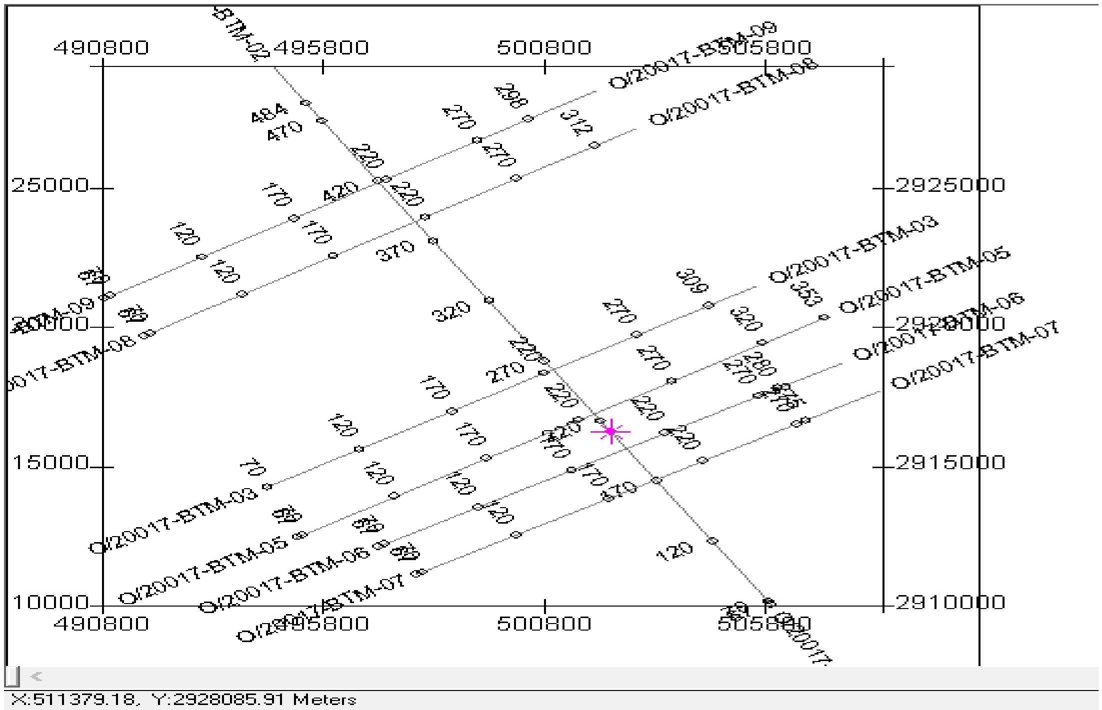


Figure 4 Basemap of Well Fateh-01

3.4-SYNTHETIC SEISMOGRAM:

Synthetic Seismogram is 1D forward model which assists in seismic-well tie. It is the result of the source wavelet convolved with the reflectivity series for normal incidence at interface.

The procedure followed for synthetic seismogram generation is as follows:

- Calculate the reflection coefficient for normal incidence which represents the variation and contrast in acoustic impedances of the reflectors.
- Calculate the seismic velocities from sonic log and densities from the density log.
- Convolve the reflectivity series with the seismic source wavelet to have the synthetic trace.
- Determine time-depth curve by using sonic velocities for the borehole.
- Determine the acoustic impedance which is the product of seismic velocity and density.

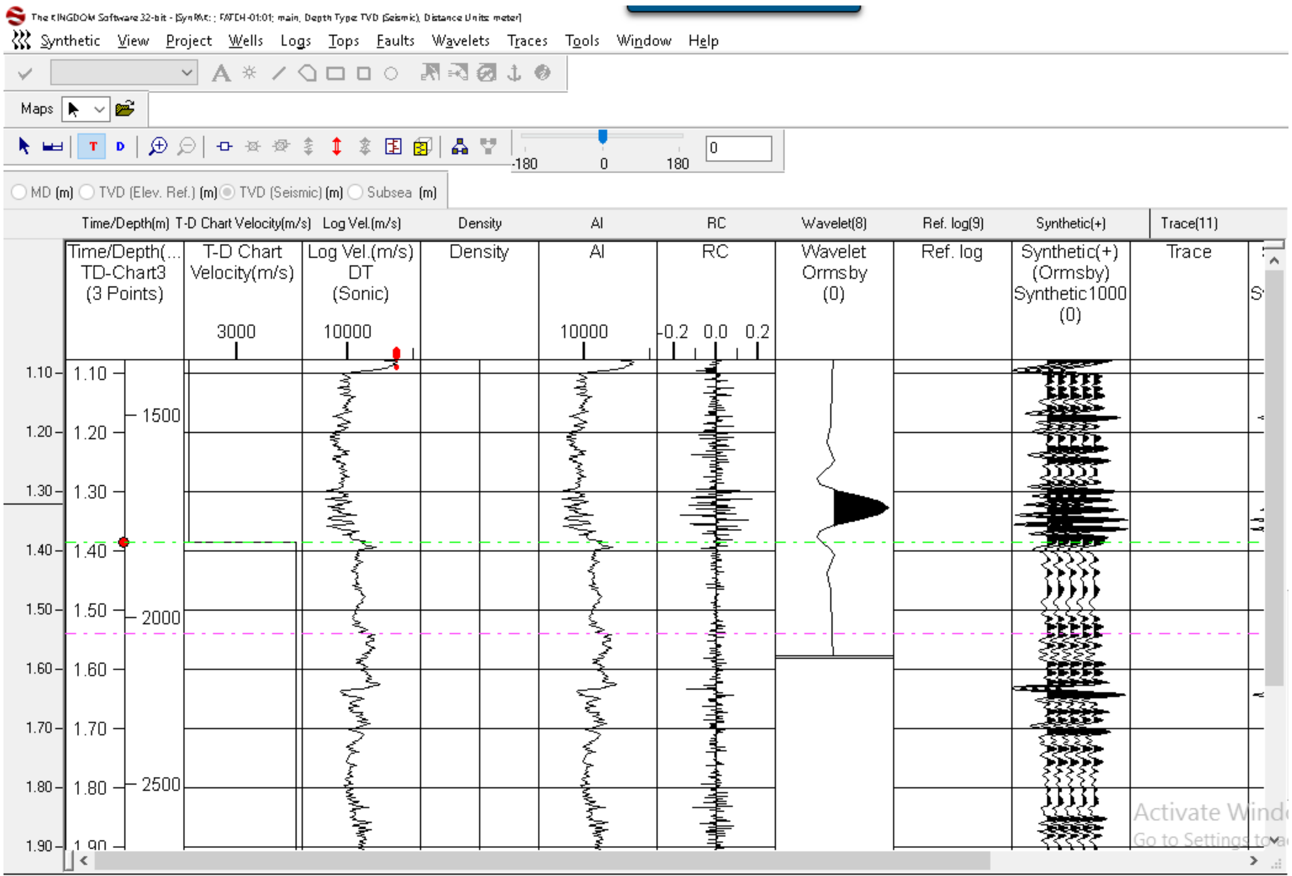


Figure 5 Synthetic Seismogram of Well Fateh-01

3.5-FAULT IDENTIFICATION:

Faults are the structural discontinuities in the geological layers such that adjacent blocks get a relative disruption. Since faults can act as petroleum traps and flow barriers, their identification and mapping is an important aspect of seismic interpretation. In vertical seismic section, faults are identified by:

- Aligned bed/reflectors terminations.
- Aligned abrupt dip changes.
- Dim-out or fault shadow.

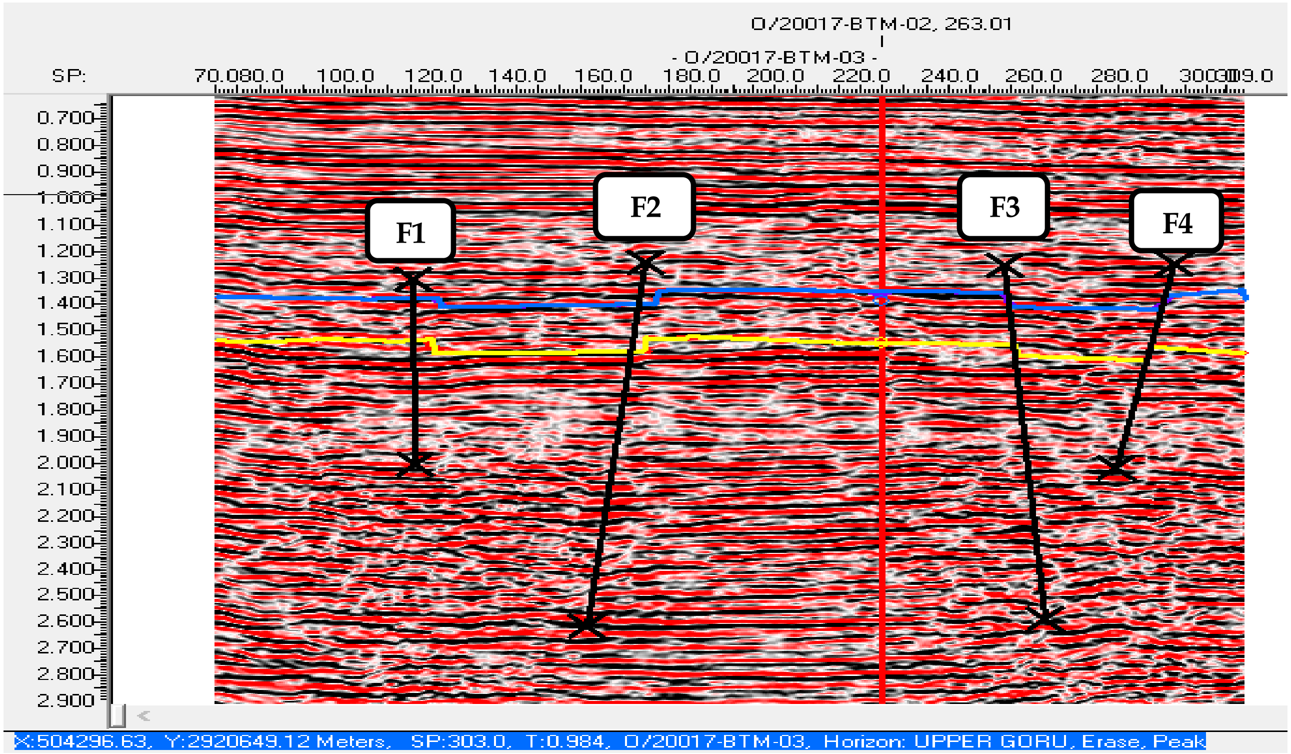


Figure6 Seismic time-amplitude of line: 20017-BTM-03

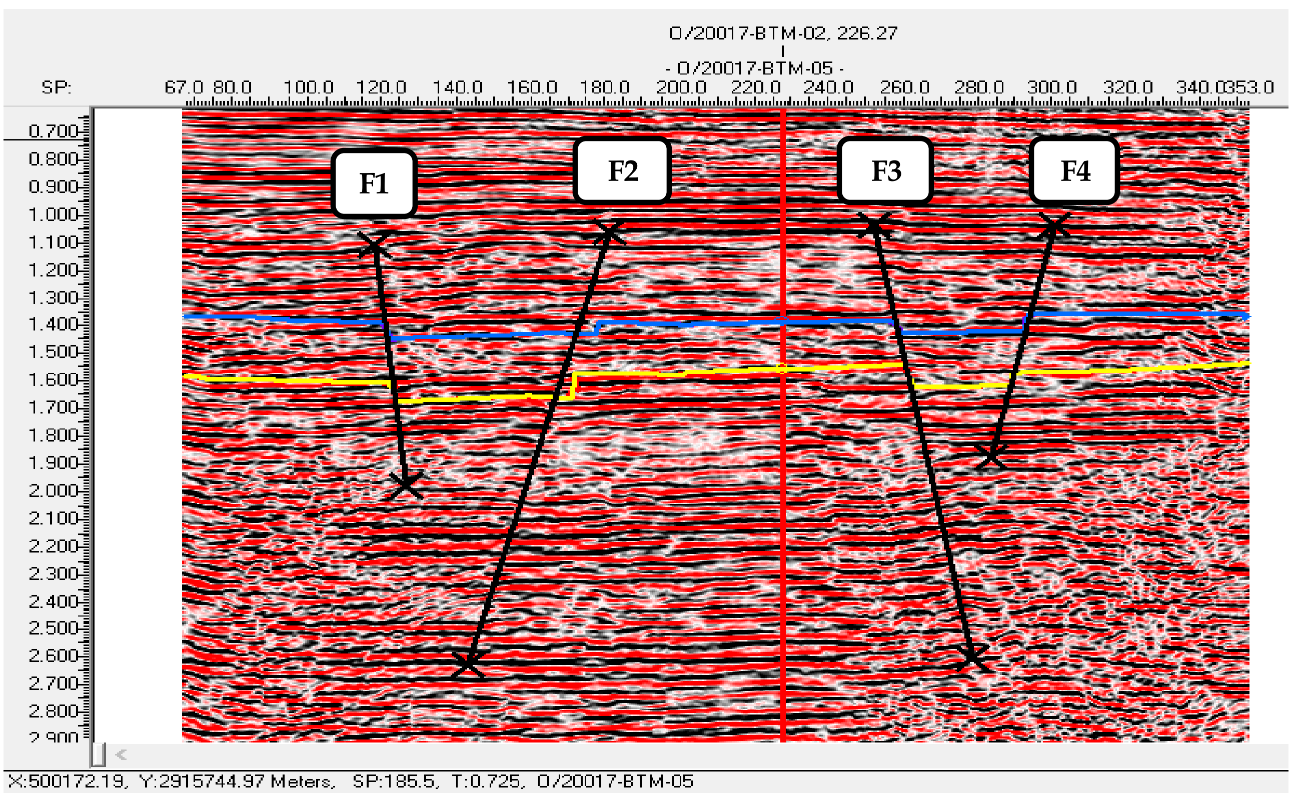


Figure7 Seismic time-amplitude of line: 20017-BTM-05

3.6-HORIZON TRACKING:

Horizon tracking implies an event of interest in the seismic section. The event may represent the limit of a formation in the form of reflector. It is assisted by synthetic seismogram in substantially drilled area by seismic-well tie. Prior to horizon tracking, faults are identified which split the seismic section into blocks. For each block horizons can be traced by auto-picking. The reflection amplitude dim out along the reflector because of noise or some structural behavior and region is skipped by the auto-picking technique. It is then picked manually and correlated with the auto-picked reflector of that particular event. For a given reflection event of interest, interpreter chooses a seed point (peak, trough, root square amplitude or phase reversal point) which is followed in whole data for the subject event.

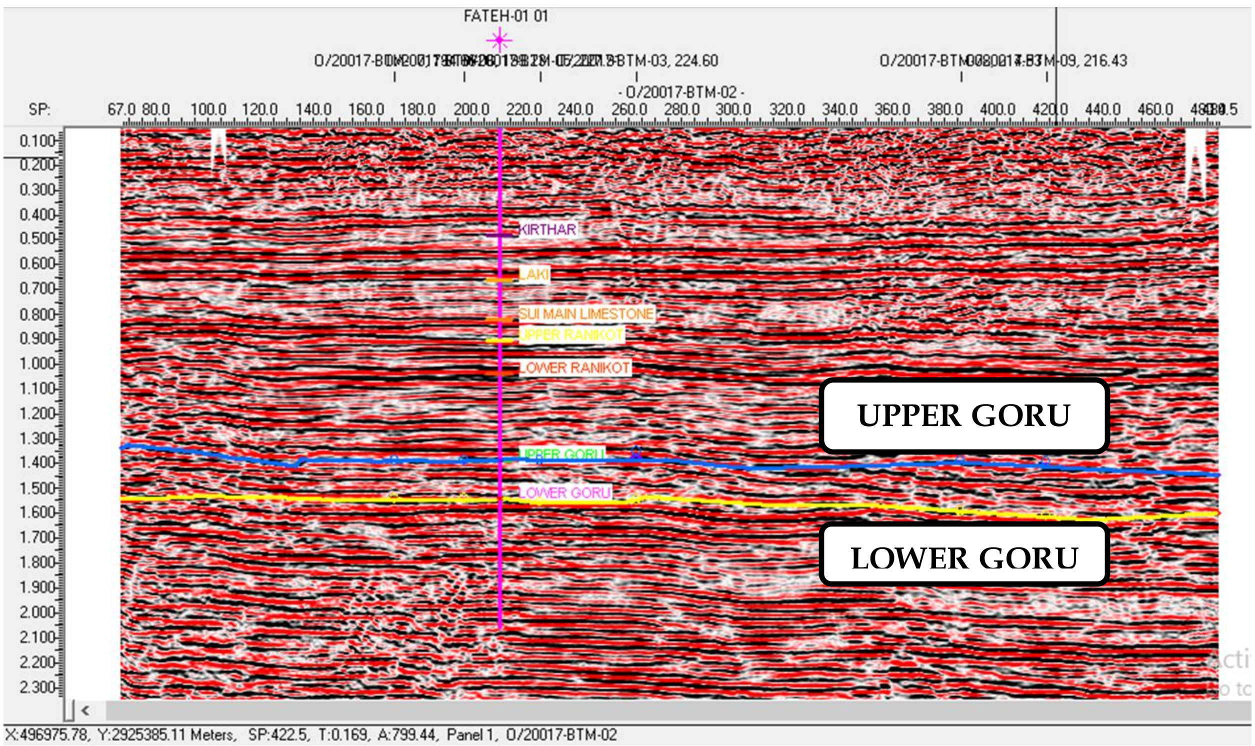


Figure 8 Seismic time-amplitude of line: 20017-BTM-02

3.7-FAULT POLYGON GENERATION:

Fault polygon subsurface is the representation of fault plane continuity and give the break in contours. It also represents lateral extension of the faults. In other words it is the surface projection of subsurface faults for a given horizon and deciphers the striking direction or the orientation of fault surface. Fault polygons assist the contouring software to recognize the discontinuities and barriers and consequently delineate the structural closures respectively. fig 9 and 10

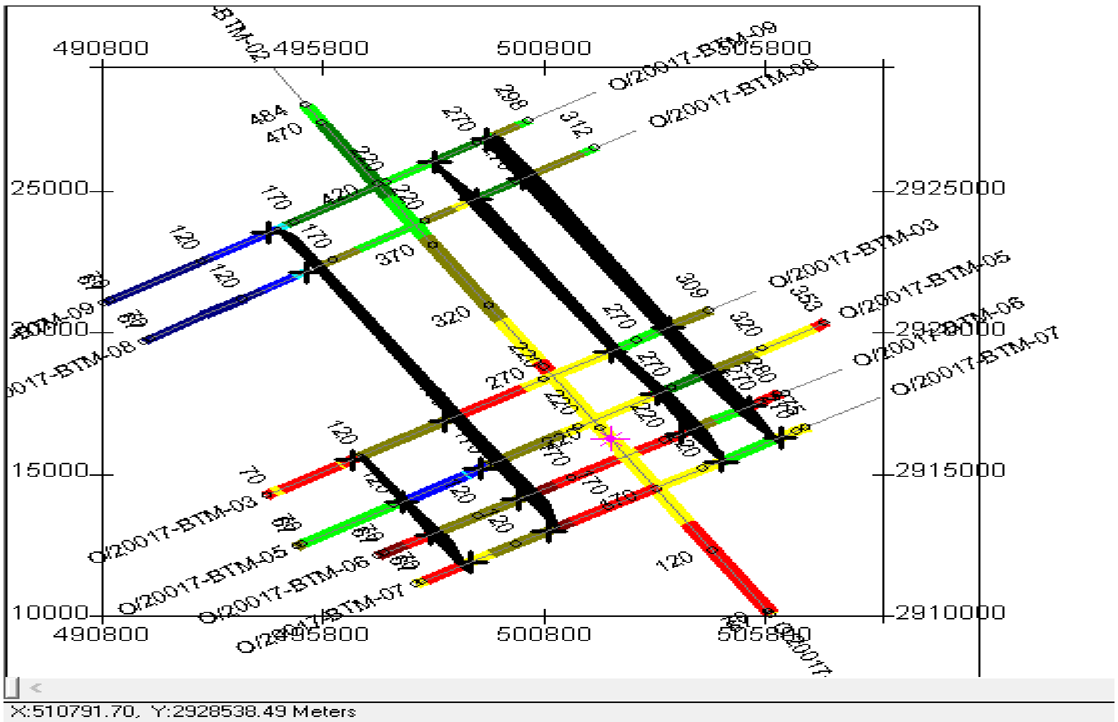


Figure 9 Fault Polygon of Lower Goru (Time Contours)

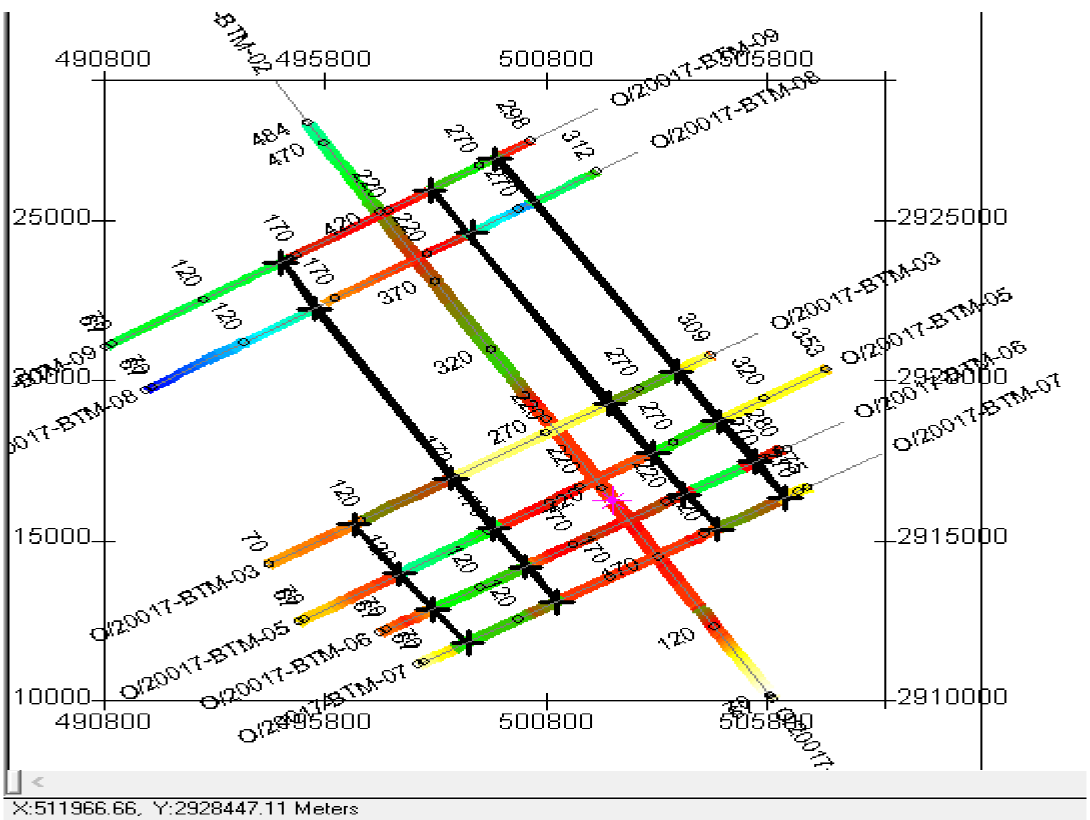


Figure 10 Fault Polygon of Upper Goru (Time Contours)

3.8-TIME CONTOURS:

In this figures 11 and 12 shows horst and graben structures and normal fault is placed. There is less time shallow depth and favorable petroleum play. Time contour maps of a formation or horizons describe the two way time distribution in space. The time contours decipher the structural highs, lows and assist to propose lead at structure closure. The time contours are generated by horizon tracking on seismic time sections of multiple lines in the study area and correlating them. The area between the lines is interpolated by flex gridding or kinking.

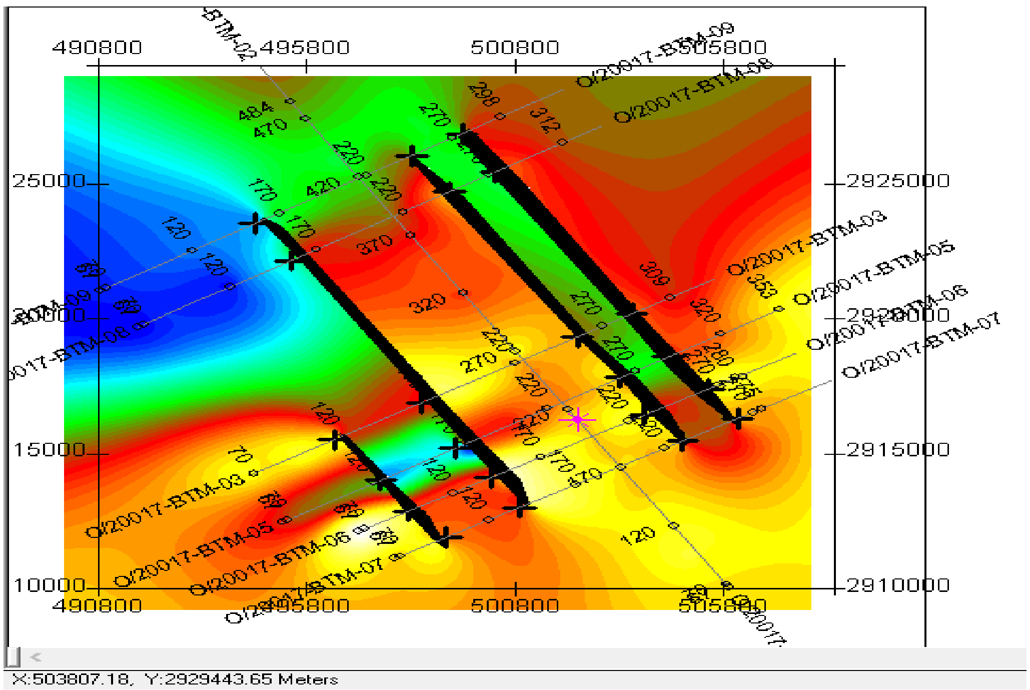


Figure 11 Time Contour of Lower Goru showing alternate horse and graben.

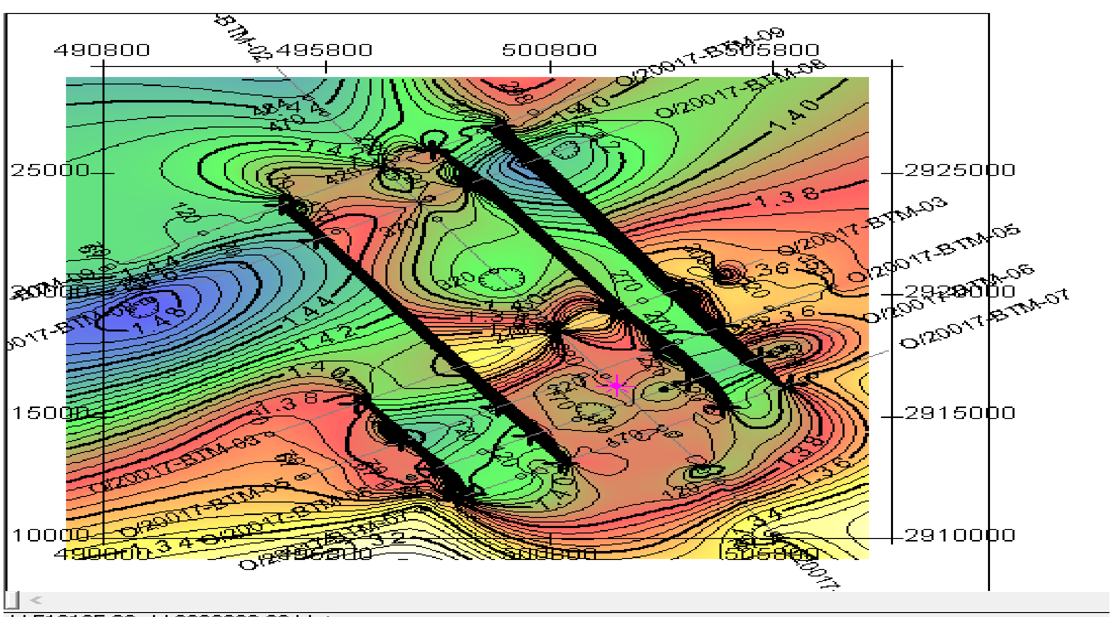


Figure 12 Time Contour of Upper Goru showing alternate horse and graben.

3.9-DEPTH CONTOURS:

In this Figure 13 and 14 shows horst structures at shallow depth and well is drilled in that area of contour. The depth contour of a horizon is formulated by velocity model aided time to depth conversion of time contour map of that horizon. It depicts the regional trend of a horizon's top surface and distinguishes structural lows and highs in the study domain.

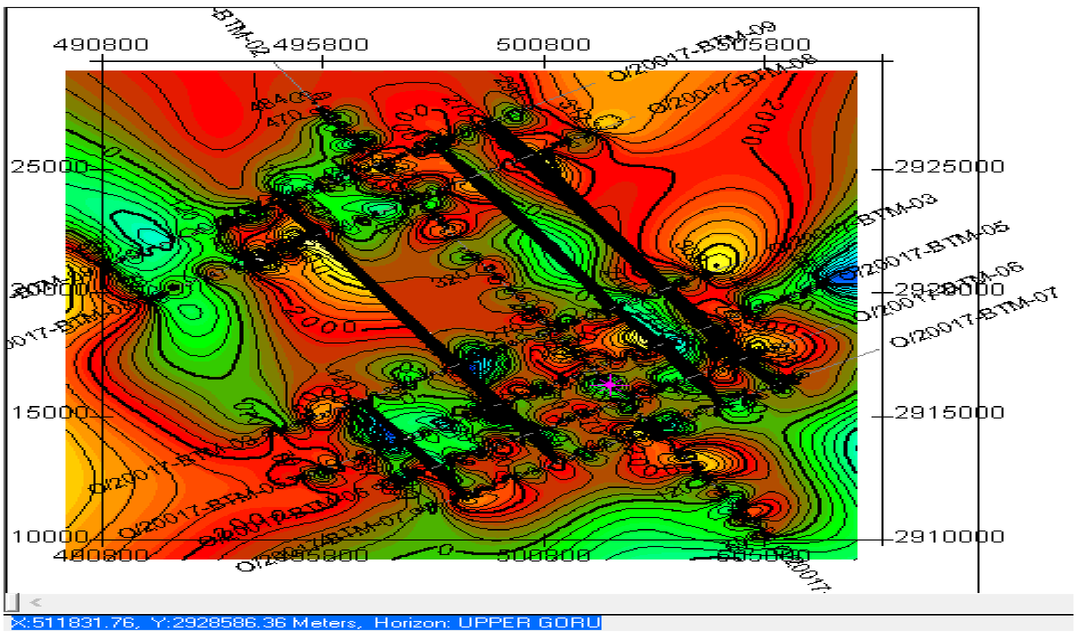


Figure 13 Depth Contour of Lower Goru showing alternate horse and graben.

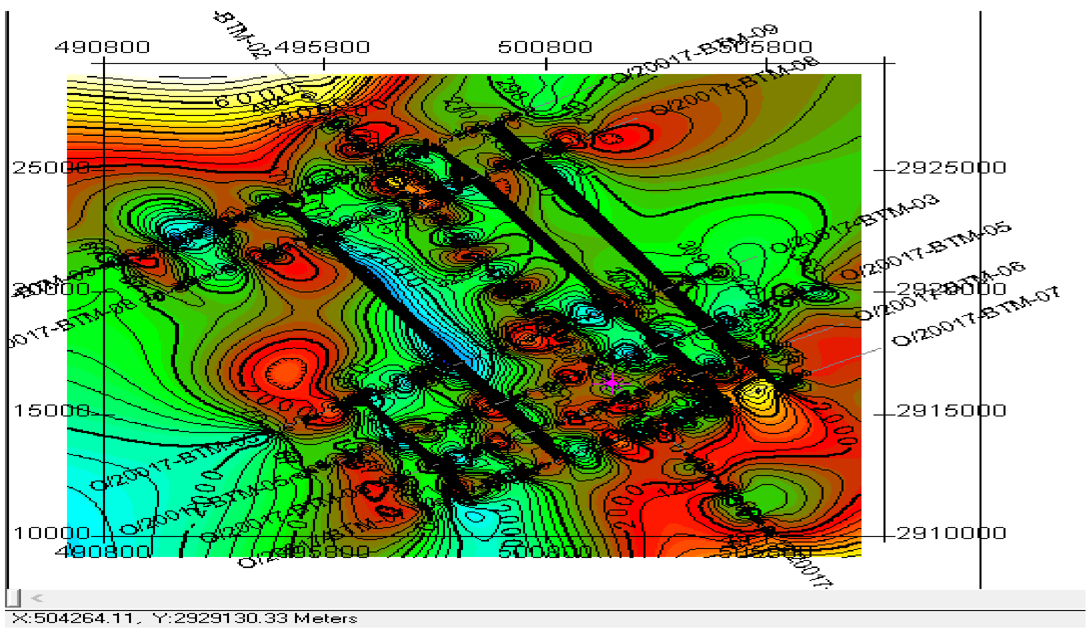


Figure 14 Depth Contour of Upper Goru showing alternate horse and graben.

CHAPTER 4

4.1-SEISMIC INVERSION:

Seismic inversion is essentially a very simple procedure. In a seismic inversion the original reflectivity data, as typically recorded routinely, is converted from an interface property (i.e. a reflection) to a rock property known as impedance, which itself is the multiplication of sonic velocity and bulk density.

Another way to look at seismic inversion is to consider it as the technique for creating a model of the earth using the seismic data as input. It can be considered as the opposite of the forward modeling technique, which involves creating a synthetic seismic section based on a model of the earth. Geophysical inversion involves mapping the physical structure and properties of the subsurface of earth using measurements made on the surface of earth.

4.2-DETERMINISTIC INVERSION:

In a deterministic inversion the missing low frequency is introduced to the inversion, thus giving the appearance of trends. However, in effect, the missing low frequency trend is simply modelled and added to the relative impedance result, so a deterministic inversion is really just a modelled trend plus a relative impedance. The result can look like it has strong vertical and lateral trends present but great care must be taken when interpreting this data because these trends are not from seismic reflections but are from a smoothly interpreted model.

Deterministic inversion without model is essentially identical to the relative inversion, hence the general statement that:

Deterministic Inversion = Relative inversion + Model

4.3-SIMULTANEOUS INVERSION:

Pre-stack seismic data contains additional information about the rock properties of the earth and these can be inverted for, using several different methods. A common one is simultaneous pre-stack inversion, a form of seismic inversion which inverts for several rock property parameters simultaneously using the pre-stack gather (or partial stacking of this data, such as angle stacks). Usually simultaneous pre-stack inversion is a deterministic inversion, so as noted above great care must be taken with the results to ensure that what is interpreted is seismic data and not the model. After pre-stack simultaneous inversion it is often safer to filter the model out of the results using a high pass filter.

4.4-EEI INVERSION:

Stands for "Extended Elastic Impedance". An extended elastic impedance uses the angle gather information (the same information required by a pre-stack simultaneous inversion) and projects the data across new angles using standard AVO intercept and gradient analysis. The new angles required as output are chosen to correspond to rock or petro-physical quantities of interest, such as porosity or shale volume, usually by analyzing well log data. EEI uses a special angle term called Chi (χ) which can have a continuous projected range from -90º to +90º.

4.5-STOCHASTIC INVERSION:

Stochastic inversion (or geo-statistical inversion) is the technique of simulating possible rock property models using the seismic. This has many technical advantages for use in reservoir modelling and uncertainty analysis: it removes tuning effects, it models the uncertainty and it can be computed at fine scale; but these advantages must be weighed against its higher cost and the large data quantities that must be managed.

4.6-COLORED INVERSION:

A method was developed by Lancaster and Whit-comb (2000) which called Colored Inversion (CI). The CI method is a simple and fast technique to invert the band-limited seismic data to relative impedance and can be done by generating a single operator to match the average seismic spectrum to the shape of the well log impedance spectrum.

Colored Inversion enhances the seismic signal and aids the auto-picker. Often it can enhance features such as bed resolution, minor faulting, fracture zones and discontinuities due to channels and possibly the presence of hydrocarbons.

4.7-CALIBRATION OF DIFFERENT LOGS OF DATA SETS:

The sonic and density logs are one of the essential datasets used in this colored inversion package. The impedance log which is the product of velocity log and density log is used to calculate its spectral trend in the frequency domain from which an inversion operator can be derived. However before being used, the logs have to be calibrated with seismic data. This is because the resolution of the sonic log can be measured in centimeters whereas that of the seismic data is typically between 10 to 50 m. The log data must be averaged for the comparison between logs and seismic to be made.

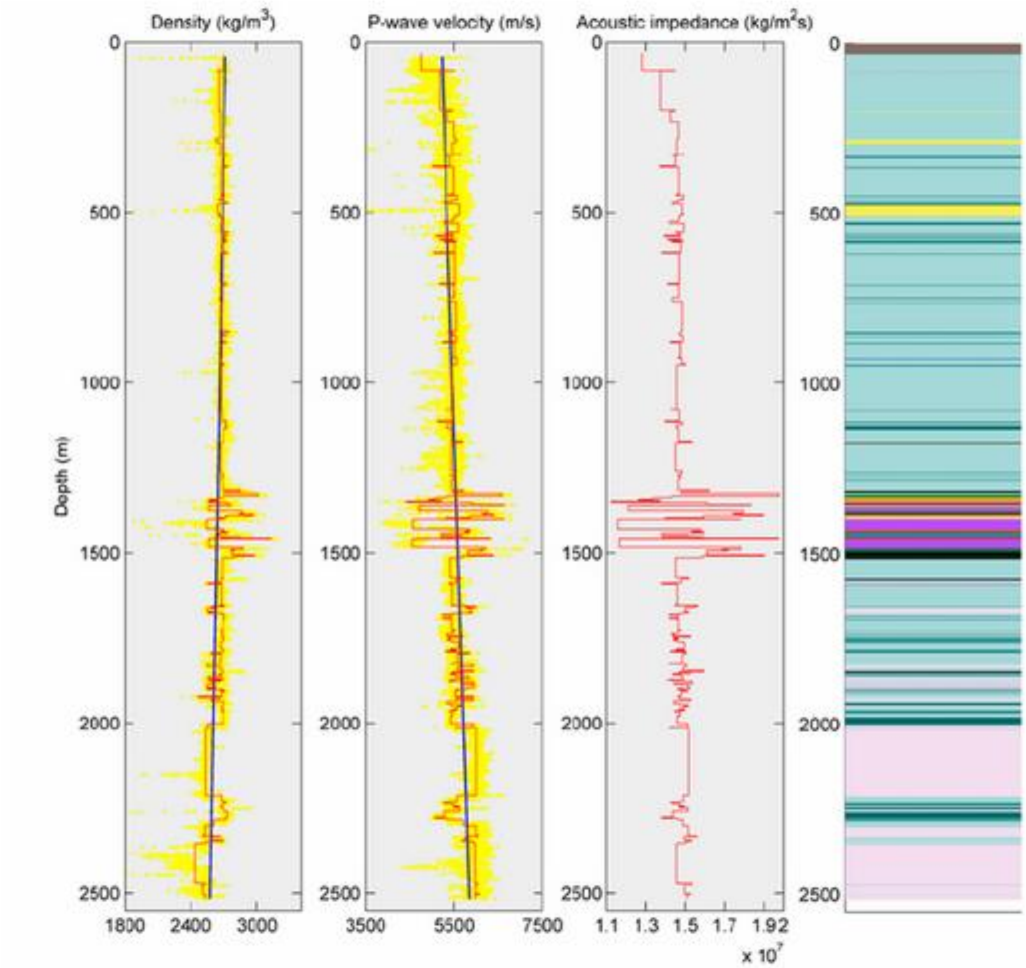


Figure 15 Density, Velocity, Acoustic impedance & Seismic data.

4.8-INVERTED SEISMIC SECTION OF PHASE:

When the input seismic traces have been accurately zero-phased relative to the reflectivity sequence at wells, the colored inversion process requires a phase shift -90^0 to complete the match with the impedance log as well as the estimated amplitude spectral trend. There is an opportunity in the inversion package to apply a phase shift that will optimize the tie with impedance log traces, or the program can be requested to calculate the phase. The program estimates the phase rotation angle by comparing band-pass filtered impedance logs with the shaped seismic data assuming that ties are reasonably good. This phase value will be used to rotate the shaped seismic data to complete the colored inversion process.

A colored Inversion operator can be derived from either single well or multiple wells. The inversion process is a simple application of a filter operator to the input seismic data followed by a phase rotation of shaped traces. I had single well data available that is why I used one well to derive operator i.e. Fateh-01. When I apply operator then I have an inverted section which is shown below:

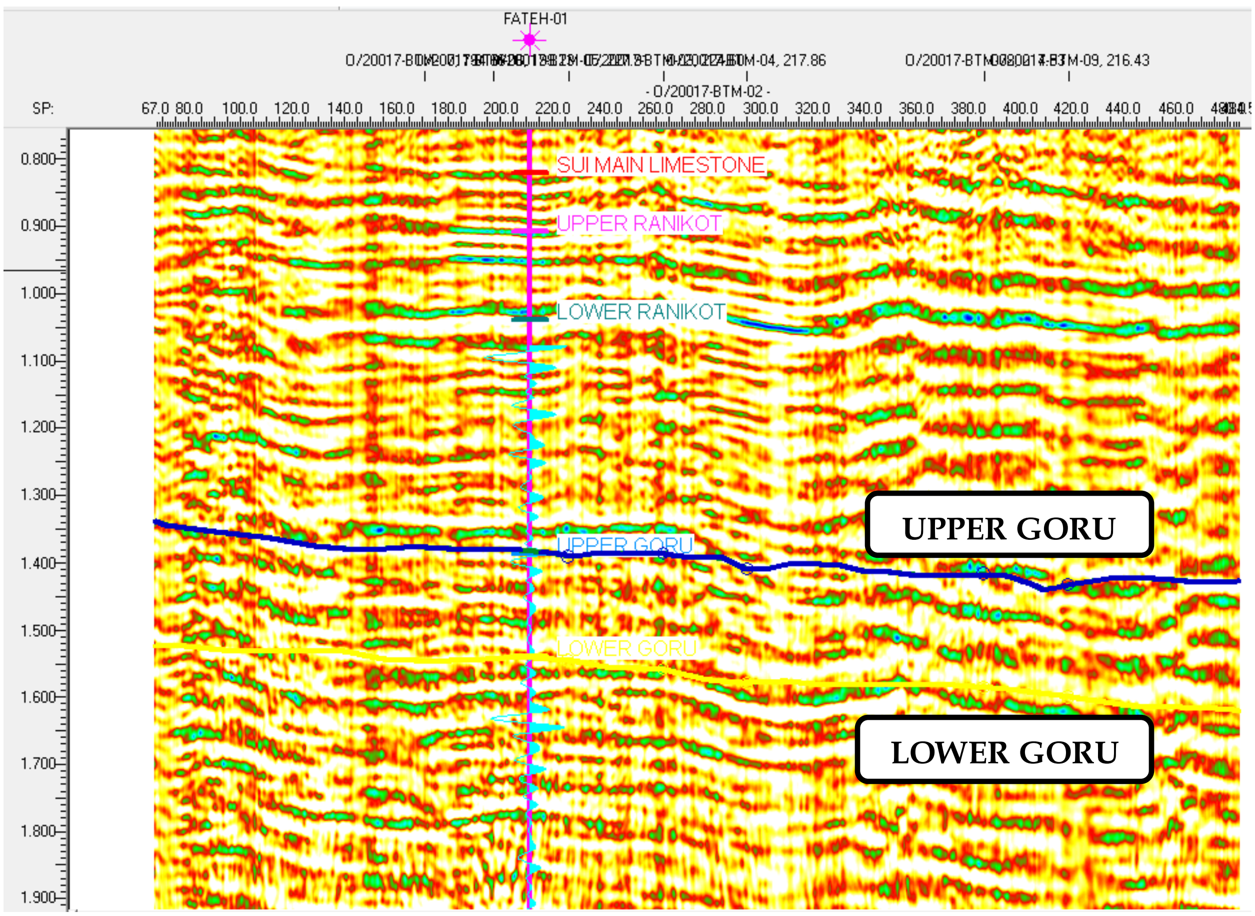


Figure 16 Inverted Seismic Section (Well Fateh-01)

CHAPTER 5

PETROPHYSICS:

5.1-INTRODUCTION:

"Petro-physics is the study of the physical and chemical properties that describes the occurrence and behavior of the rocks, its mineral compositions and fluids". To accurately characterize an oil or gas reservoirs, measurements such as resistivity and density are made, from which effective porosity, saturations and permeability can be quantified. It uses all kinds of logs, core and production data to obtain physical properties of reservoir such as volume of shale, porosity, water and hydrocarbon saturation which help in identifying probable zones of hydrocarbons.

5.2-PETROPHYSICAL ANALYSIS:

- A case study involving the well log interpretation of well Fateh-01 is carried out.
- To identifying and characterize a reservoir, not a single log is enough but a combination of multiple logs is employed.

There are some logs which are discuss in below:

- Spontaneous potential log (SP),
- Gamma ray log (GR),
- Sonic log (DT),
- Caliper log (CALI)
- Later-log Shallow (LLS),
- Neutron log (NPHI),
- Density log (RHOB),

5.3-DIFFERENT LOGS & ITS UNITS:

The logs used in Petro-physical analysis which are run in Fateh-01 are:

Serial No.	Types of Logs	Acronym	Scale Used	Units
1	Neutron log	NPHI	0.15 to 0	PU
2	Caliper Log	CALI	1 to 16	Feet
3	Density Log	RHOB	2 to 3	gm/cm3

4	Spontaneous Potential Log	SP	-10 to 10	Mv
5	Gamma Ray Log	GR	0 to 150	APT
6	Sonic Log	DT	140 to 40	µsec/ft
7	Later-log shallow	LLS	1 to 100	Ω.m

Table. 5.1. Logs used & Their Scales

5.4-USES OF DIFFERENT WELL LOGS:

NAME	USES
DENSITY(RHOB)	Lithology interpretation, finding hydrocarbon bearing zone, porosity calculation, rock physics properties (AI, SI, σ, etc.) calculation, etc.
NEUTRON POROSITY(NPHI)	Finding hydrocarbon bearing zone, porosity calculation, etc.
GAMMA RAY (GR)	Lithology interpretation, shale volume calculation, calculate clay volume, permeability calculation, porosity calculation, wave velocity calculation, etc.
CALIPER(CALI)	Detect permeable zone, locate a bad hole**.**
SONIC (DT)	Porosity calculation, wave velocity calculation, rock physics properties (AI, SI, σ, etc.) calculation, etc.
SPONTANEOUS PONTENTIAL(SP)	Lithology interpretation, Rw and Rwe calculation, detect permeable zone, etc.
SHALLOW RESISTIVITY LLS	Lithology interpretation, finding hydrocarbon bearing zone, calculate water saturation, etc.

Table . 5.2. Uses of Different Logs in petro-physical

5.5-DIFFERENT TYPES OF LOGS:

5.5.1-SPONTANEOUS POTENTIAL LOG:

The SP log records the electric potential between an electrode pulled up a hole and a reference electrode at the surface. This potential exists because of the electrochemical differences between the waters within the formation and the drilling mud. The potential is measured in milli volts on a relative scale only since the absolute value depends on the properties of the drilling mud.

In shaly sections, the maximum SP response to the right can be used to define a “shale line”. Deflections of the SP log from this line indicate zones of permeable lithologies with interstitial fluids containing salinities differing from the drilling fluid. SP logs are good indicators of lithology where sandstones are permeable and water saturated. However, if the lithologies are filled with fresh water, the SP can become suppressed or even reversed. Also, they are poor in areas where the permeabilities are very low, sandstones are tightly cemented or the interval is completely bitumen saturated (i.e. oil sands).

5.5.2-CALIPER LOG:

Caliper Logs record the diameter of the hole. It is very useful in relaying information about the quality of the hole and hence reliability of the other logs. An example includes a large hole where dissolution, caving or falling of the rock wall occurred, leading to errors in other log responses. Most caliper logs are run with GR logs and typically will remain constant throughout.

- The decrease in the caliper is a good indicator of permeable lithology because mud cake only form when rock is permeable. Caving and washouts show loose lithology.
- Increase of borehole diameter indicates caving and washouts and decrease in borehole diameter refers to the formation of mud cake against the wall of borehole. , i.e. shale, therefore increase of borehole diameter refers to the presence of shale.

5.5.3-RESISTIVITY LOG:

Resistivity logs record the resistance of interstitial fluids to the flow of an electric current, either transmitted directly to the rock through an electrode, or magnetically induced deeper into the formation from the hole.

5.5.4-LATER-LOG SHALLOW (LLS):

Shallow later-log measure the resistivity of the invade zone (Ri). In water-bearing zone, the shallow later-log records a low resistivity because mud filtrate resistivity (Rmf) is approximately equal to mud resistivity (Rm).

5.5.5-SONIC LOG:

Sonic logs (or acoustic) measure the porosity of the rock. Hence, they measure the travel time of an elastic wave through a formation (measured in ΔT - microseconds per meter). Intervals containing greater pore space will result in greater travel time and vice versa for non-porous sections. They must be used in combination with other logs. Particularly gamma rays and resistivity, thereby allowing one to better understand the reservoir Petro-physics. The unit measure is the microseconds per foot or microseconds per meter.

5.5.6-DENSITY LOG:

Density logs measure the bulk electron density of the formation, and are measured in kilograms per cubic meter (gm/cm3 or kg/m3). Thus, the density tool emits gamma radiation which is scattered back to a detector in amounts proportional to the electron density of the formation. The higher the gamma ray reflected, the greater the porosity of the rock. Electron density is directly related to the density of the formation (except in evaporates) and amount of density of interstitial fluids. Helpful in distinguishing lithologies, especially between dolomite (2.85 g/cc) and limestone (2.71 g/cc), sandstone (2.65 g/cc).

5.5.7-NEUTRON LOG:

Neutron Logs measure the amounts of hydrogen present in the water atoms of a rock, and can be used to measure porosity. This is done by bombarding the formation with neutrons, and determining how many become “captured” by the hydrogen nuclei. Because shales have high amounts of water, the neutron log will read quite high porosities. Thus it must be used in conjunction with GR logs. However, porosities recorded in shale-free sections are a reasonable estimate of the pore spaces that could produce water.

5.6-DIFFERENT LOG TRACKS:

Specific arrangement of logs in different Tracks is followed during the presentation of logs. In Table.5.3, this arrangement of logs is shown. The Petro-physical analysis, which I performed in my dissertation, follows this track pattern.

TRACKS	LOGS
1	GR, SP, GALI
2	LLS,LLD,MSFL
3	RHOB,DT,NPHI
5	VSH
6	PHID
7	PHIT
8	PHIE

Table. 5.3. Logs used in Different Tracks

5.7-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 gamma ray index is the first step to determine the shale volume from gamma ray log (Schlumberger, 1974).

IGR = GR log –GR min/ GR max- GR min

IGR = Gamma ray index

GR log = Gamma ray reading of formations

GR max= Maximum gamma ray

GR min= Minimum gamma ray

The following formula is used to find volume of shale:

- Consolidated:

$$\mathbf{Vshale=0.33[2(2*I_{GR})-1]}$$

- Unconsolidated:

$$\mathbf{Vshale=0.883[2(3.7*I_{GR})}$$

5.8-CALCULATION OF RESISTIVITY OF WATER (RW):

The Resistivity of Mud Filtrate at Zone of Interest (Reservoir Formation) is calculated by the equation given below:

$$\mathbf{R_{mf2} = R_{mf1} * (T_1 + 6.77/ T_2 - 6.77)}$$

Where R_{mf1}=Resistivity of mud filtrate at surface temperature

T_1 =surface temperature

T2= formation temperature

$R_{mf2=}$ resistivity of mud filtrate at formation temperature

5.9-CALCULATION OF WATER SATURATION:

The fraction of pore spaces containing water is termed as Water Saturation (Sw) which is calculated by from the Archie's formula given by:

Sw = {Rw/ (RT*ϕm)} 1/n

Where

Rw= Resistivity of Water

R_t =True Resistivity

Φ =Porosity

m =Cementation factor

n = Wet ability factor

5.10-CALCULATION OF SATURATION OF HYDROCARBON:

The fraction of pore spaces containing Hydrocarbons is known as Hydrocarbon Saturation and mathematically given by the following equation;

$$\mathbf{S_{hc} = 1 - S_w}$$

Where

Shc= saturation oh hydrocarbon

Sw= saturation of water

5.11-PETRO-PHYSICAL RESULTS OF LOWER GORU FORMATION:

Log	Average	Average in percentage	Range
PHIE LG	0.062633	20.87768	0-0.3
VSH LG	0.600104	60	0-1
PHID LG	0.04005645	13.3521495	0-0.3
SHC LG	0.076463	7.646301	0-1

PHIT LG	0.16155	53.84993	0-0.3
SW LG	0.923537	92.3537	0-1

Table.5.4 Petro-physical results of Lower Goru Formation

CHAPTER 6

FACIES ANALYSIS:

6.1-CONCEPT OF FACIES:

In geology, a **facies** is a body of rock with specified characteristics which can be any observable attribute of rocks such as their overall appearance, composition, or condition of formation, and the changes that may occur in those attributes over a geographic area. It is the sum total characteristics of a rock including its chemical, physical, and biological features that distinguishes it from adjacent rock.

Facies based on petrological characters such as grain size and mineralogy are called **lithofacies**, whereas facies based on fossil content are called ***biofacies***.

6.2-TYPES OF FACIES:

*6.2.*1-SEDIMENTARY FACIES:

A sedimentary facies is a distinctive rock unit that forms under certain conditions of sedimentation, reflecting a particular process or environment. Sedimentary facies are either descriptive or interpretative. Sedimentary facies are bodies of sediment that are recognizably distinct from adjacent sediments that resulted from different depositional environments. Sedimentary facies reflect their depositional environment, each facies being a distinct kind of sediment for that area or environment.

6.2.2-WALTHER'S LAW OF FACIES:

Walther's Law of Facies, or simply Walther's Law, named after the geologist Johannes Walther (1860-1937), states that the vertical succession of facies reflects lateral changes in environment. Conversely, it states that when a depositional environment "migrates" laterally, sediments of one depositional environment come to lie on top of another. In Russia the law is known as **Golovkinsky-Walther's Law**, honoring also **Nikolai A. Golovkinsky** (1834-1897). A classic example of this law is the vertical stratigraphic succession that typifies marine transgressions and regressions.

6.2.3-METAMORPHIC FACIES:

The sequence of minerals that develop during progressive metamorphism (that is, metamorphism at progressively higher temperatures and/or pressures) define a *facies series*.

6.2.4-SEISMIC FACIES:

Seismic facies are mapable three-dimensional seismic units composed of reflection units whose parameters differ from adjacent facies units.

6.3- FACIES SCALES:

Facies can be defined on a variety of scales depending upon:

- The purpose of the study
- The time available to make the measurements
- The abundance of descriptive features in the studied strata.

6.4-FACIES SEQUENCES:

A facies model is an idealized sequence of facies defined as a general summary of a specific sedimentary environment based on studies of both ancient rock and recent sediments. Available information on a depositional environment is distilled to extract general information and generate an idealized environmental summary or sequence of facies.

Depositional or architectural elements are the recommended unit for sedimentological analysis for groundwater investigations because they are mapable units on a scale appropriate for groundwater models. Facies sequences are a series of facies whose transitions and relationships are geologically significant with respect to depositional environment. Hence, perhaps **'facies sequences'** should now be referred to as **'facies successions'**. A depositional element (e.g., shoreface) may occur in several geographic settings. A similar concept is the architectural element of Miall (1985), which are defined in terms of geometry, scale, and lithofacies assemblages.

6.5- FACIES MODELING:

In geology, These depositional environments are classified as terrestrial, continental slope, slope, and basin. The terrestrial environment includes lakes and stream deposits, continental slope environment includes coastal plain to shallowest marine and basin floor environment includes all deposits from shelf, slope and deep ocean. fig 17. Facies are the observable attributes of a sedimentary rock body that reflect the depositional processes or environments that formed it.

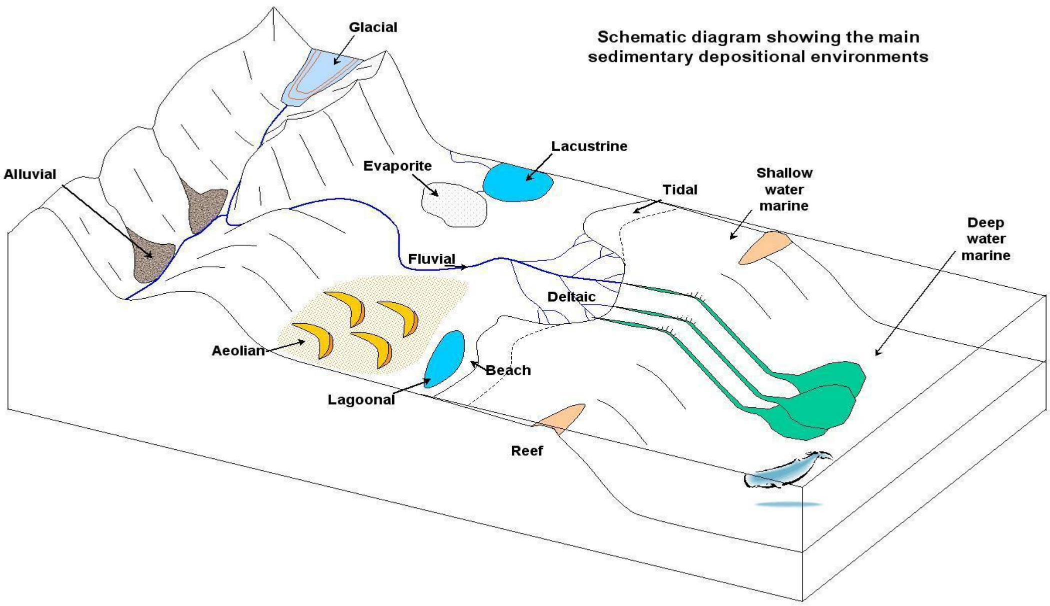


Figure 17 Diagram of major depositional environments

As a marine environment deposits, deep water submarine fan is a product of sedimentation of clastic sediments carried by water currents, mainly by density current that flow downslope under ambient sea water. Fluvial a type continental environment formed from influx of sediment in river system. Delta of transitional environment is deposited at mouth of river that caused coastline to swell into standing body of water.

6.6-CROSS PLOT OF NPHI AND RHOB:

When any two values are cross plotted, the resulting series of points shows the relationship between these two variables or define fields, using both x and y axis values and gives the both upper and lower limits of both variables. There are some types of well-logs cross plots exist:

- Cross-plots of compatible logs: Cross plot between those logs measures the same parameter. For example neutron porosity vs. density porosity logs.

- Cross-plot of incompatible logs: Cross plot between those logs does not measures the same parameters e.g. plot between RHOB, LLD and GR.

In fig. 29, there is a cross plot between NPHI and RHOB and GR is used as reference. Reference log is used for the identification of different lithologies. In fig.18 Blue portion indicates the presence of shale whereas green portion indicates the presence of sandy shale and red portion indicates sand.

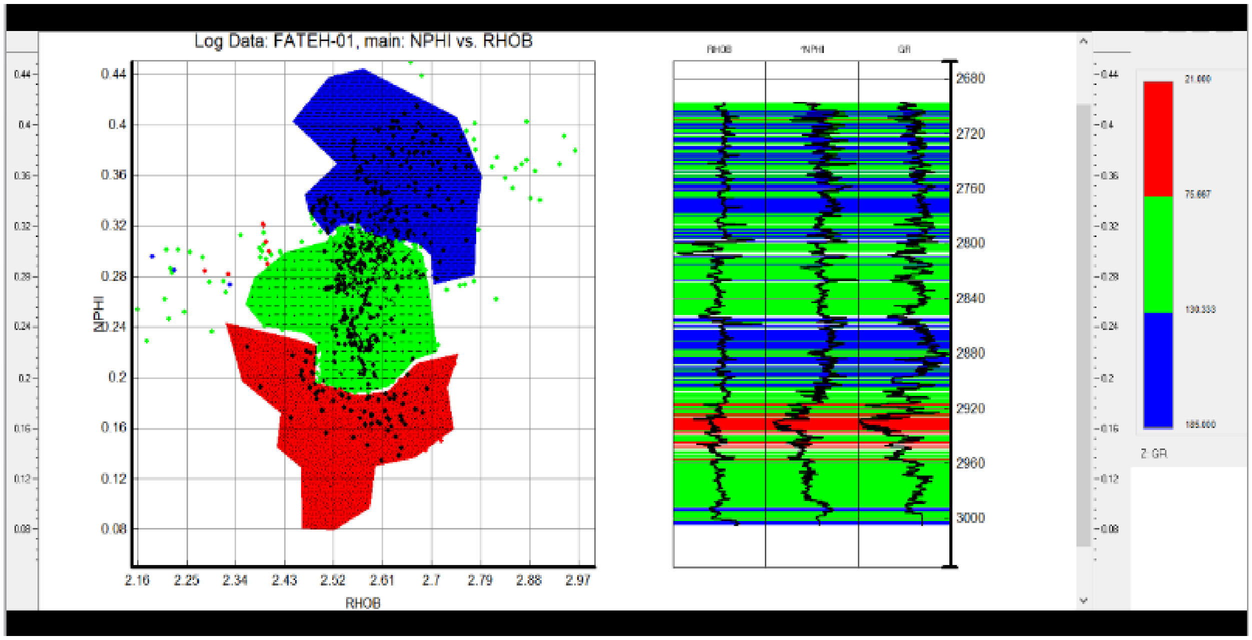
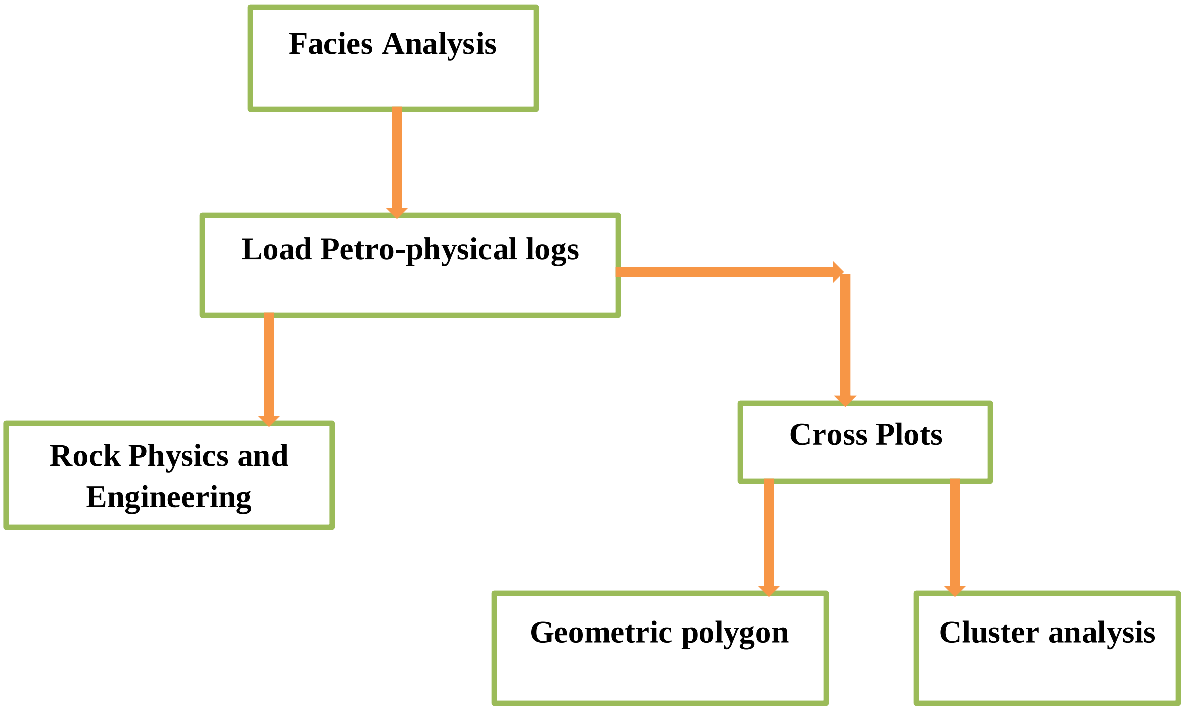


Figure18.Facies model showing clustered points of different lithologies (Well Fateh-01)

6.7-FACIES ANALYSIS:

Fundamental to all subsurface geologic studies is an analysis of depositional facies. Development of a facies classification scheme is a particular challenging interplay between capturing enough information for environmental interpretation yet remaining simple. Particularly important is the characterization of facies such that their recognition criteria relate to critical environmental thresholds such as sea level, normal wave base, and storm wave base. These physical environmental zones regulate sedimentary textures and biotic assemblages. A good understanding of paleoecology always strengthen the interpretation and such studies should be included as part of all depositional facies studies. Depositional textures in turn affect porosity-permeability in carbonates. The vertical and lateral organization of facies is an exercise essential to sequence stratigraphic interpretations (Lau 1990). The work flow for facies analysis is shown in below:



Workflow of facies Analysis

6.8-LIMITATIONS OF FACIES MODELS:

Limitations of facies models is that:

- Facies characteristics and distributions are a complex function of the interaction of numerous variables within a depositional environment.
- Sedimentary deposits are a continuum rather than consisting of a fixed number of discrete facies models.
- With respect to fluvial deposits, we noted that numerous facies models have been proposed, which reflect fixed points on a multidimensional continuum of variables.
- Facies modeling is based on the recognition that there is system and geologists can identify and agree upon a limited number of depositional environments and systems.
- Geological deposits have both apparently random and regular or predictable elements.

7-CONCLUSIONS:

After applying seismic and well data on the study area and using different software tools I concluded that:

- The seismic interpretation revealed Horst and Graben structure in the Bitrism area.
- Time and Depth contour maps help us to confirm the presence of Horst and Graben structure in the given area. Surface contour map of Lower Goru gives the real shape of sub-surface structure, which is horst and graben. This structure acts as a trap in the area, which is best for hydrocarbon.
- Synthetic Seismogram was matched with the marked horizons and it has confirmed the structural interpretation.
- Petro physical analysis of the reservoir shows a high hydrocarbon potential.
- Study area is in extensional regime having step faulting along with horst and graben structures.
- Both the wells drilled in study are in horst block. According to interpretation both are not on the crustal part of structure.
- Time sections on which two clear reflectors were marked i.e Upper Goru Formation and Lower Goru Formation.
- Both the wells in the study area are abandoned. Petro physical analysis gave one of the probable reason for uneconomical condition of well is the wet reservoir.
- A dominant lithology of our reservoir confirm shale in facies analysis. i.e Lower Goru Formation.
- The overall results indicate the economic viability of Lower Goru as a reservoir.

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