2D-INTEGRATED SEISMIC INTERPRETATION AND RESERVOIR CHARACTERIZATION OF BADIN AREA SOUTHEREN SINDH MONOCLINE PAKISTAN

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CERTIFICATE

This dissertation submitted by ABDUL BASIT S/O MUHAMMAD SAEED is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the requirement for the award of M.Sc. degree in Geophysics.

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External Examiner ________________________

Dedication

This dissertation is dedicated to my mother ,father and siblings whose heart throb for me. I am what I am because of them and to them I owe all that I own.

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.

I am especially indebted to my dissertation supervisor Dr. Muhammad Gulraiz Akhter for giving me an initiative to this study.I want to pay thanks to Dr.Khalid Amin Khan for his support in my dissertation. His inspiring guidance helped me to complete this work in time. Besides my supervisor, I am thankful to my respectable seniors espacially Waqas Gondal, Class fellows and friends for thier cooperation and guidance during this research work. I would like to express my appreciation to my special friends especially Maarij Ahmed Siddiqui, Muhammad Zohaib, Karam Khan, Nasir , Munawar, Mubashir and Muhammad Altaf for their moral support during my work,i am blessed with these people they made my life.

I am extremely thankful to all of my teachers for their endless love, prayers and encouragement and my special appreciation to those who indirectly contributed in this research.

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ABSTRACT

This study pertains to the structural and Stratigraphy interpretation, attributes analysis, petrophysical analysis and estimation of rock physics of Badin area. The data used for this study consists of SEG –Y data, navigation data and well logs data. Badin area is prominent in the Lower Indus Basin for its hydrocarbon (oil and gas) structural traps.

The Seismic lines were acquired and processed by UTP. For interpretation of these seismic lines two reflectors and normal faults were marked by using the interactive tools of Kingdom software, polygon construction, two way time contour and depth contour are also the part of the seismic data interpretation. The marked horizons were identified using formation tops from wells and their depths were confirmed through correlation with synthetic seismogram from Density log (RHOB) and sonic log. From time and depth grids time and depth contour maps of the horizons that are marked were generated to understand the spatial geometry of the structures and the nature of geological structures as identified by the seismic section of the area. Normal faulting as identified on seismic sections confirmed that study area lies in extensional tectonic regime. The resulted seismic interpretation of these lines confirmed Horst and Grabben structures by normal faulting. Horsts or the elevated portions in the structure are suitable place for the accumulation of hydrocarbons.

Seismic attributes analysis of seismic section helps in identifying the different lithological boundaries and also confirmed the structural disturbance. Petrophysical analysis of Doti-01 well shows that is has good porosity as well as small quantity of shale in it, but the concentration of hydrocarbon is only 15 to 20 % in it.

Facies modeling is good tool for the confirmation of lithologies, with the help of facies analysis of Doti-01 well, I came to the result revealing sand as the reservoir lithology.

Contents

Chapter # 1
Introduction to the Study Area

1.1 Introduction

Hydrocarbon plays 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.

Pakistan has a high potential of hydrocarbons and consists of three major sedimentary basins (covering more than 2/3rd 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 Precambrain 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.

Seismic measurements can be used to gain knowledge about geological structures in the ground. The oil industry uses seismic measurements to locate oil-and gas reservoirs. Identification of subsurface structure, petrophysical analysis and estimation of rock properties are the most important tools to identify hydrocarbons (Link, 1991).

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

1.2 Location of study area

Study area is located in Badin district in Sindh province of Pakistan. The district is located between 24° 5’N to 25° 25’N Latitude and 68° 21’ E to 69° 20’ E Longitude and is bounded on the North by Hyderabad district, on the South by Arabian Sea & on the East by Mirpurkhas & Tharparkar districts and on the West by Thatta and Hyderabad districts Figure 1.1.

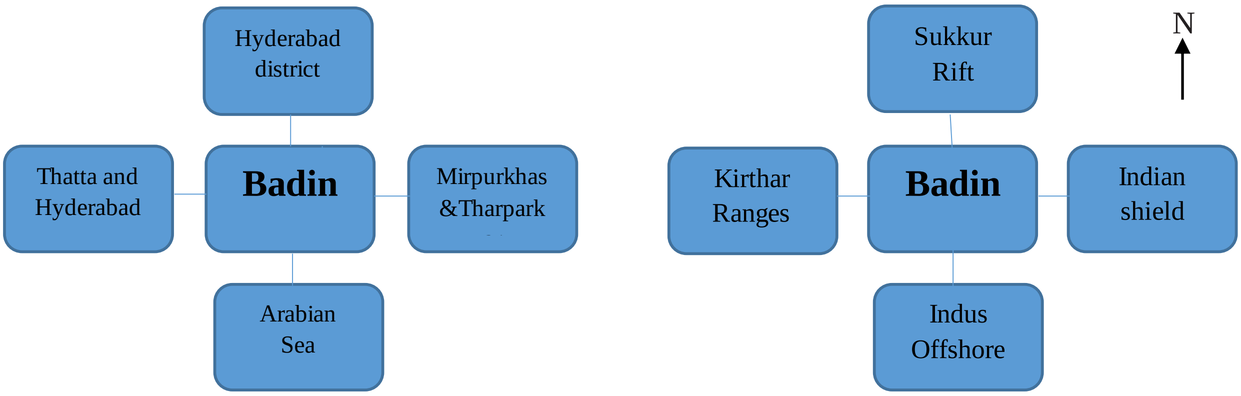


Fig 1.1 Boundaries of Study area.

The Indus Basin, which covers an area of 535,580 sq. km, is located on the northwest slope of the Indian Shield and includes the fold belt. It is divided into Lower, Middle, and Upper Indus Basin based on structural highs Figure 1.2. Badin Block is located in the Lower Indus Basin, approximately 160 km due east of Karachi city Figure 1.2. Geological boundaries of the area are: Indian shield in the east, Kirthar Ranges in the West, to the north it is bounded by the Sukkur Rift Zone and with the Indus Offshore platform being the southern extension Fig. 1.1.

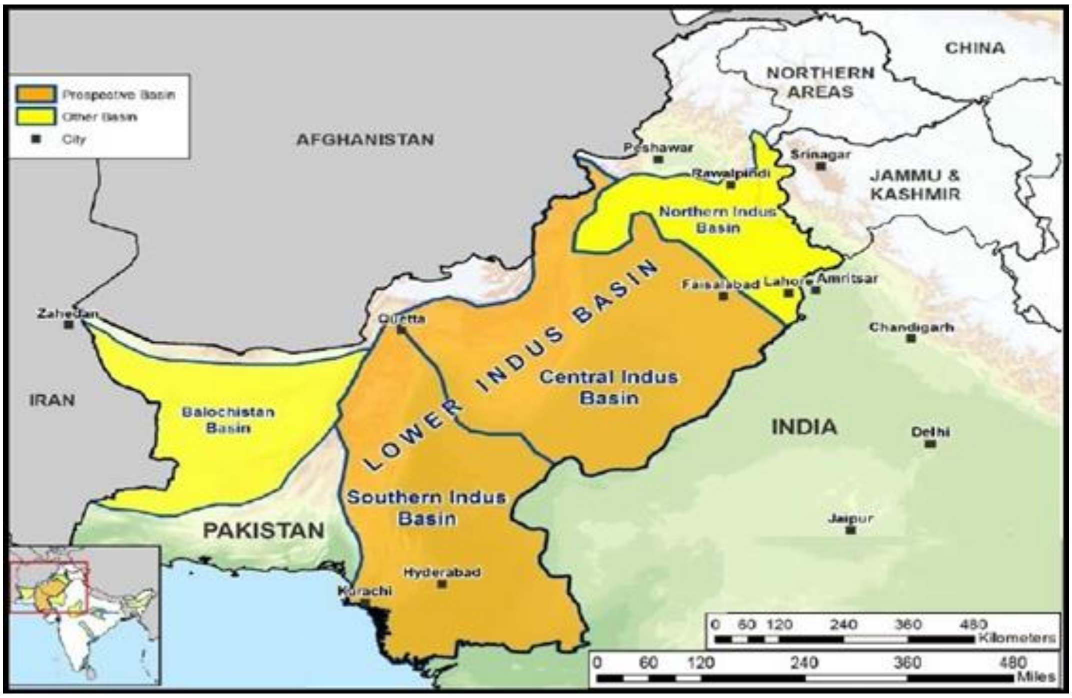


Fig 1.2 Location of Study area (Survey of Pakistan).

1.3 Generalized Structure

The study area is highly deformed and is characterized by extensional tectonic activities which are related to rifting phases experienced by the Indo-Pakistan plate. Thus the study of structural styles formed due to these tectonic activities is much important as the cretaceous rifting episodes had a profound effect on the formation and occurrence of hydrocarbons in Sindh Monocline. The Badin Rift Basin is located in the Thar platform area of the Lower Indus Basin.

The Badin Rift is characterized by a series of horst and graben structures present below the base Paleocene unconformity within the Cretaceous formation. These horst and graben structures were formed as a result of rifting between India and Seychelles during the Late Cretaceous.

1.4 Exploration History

The study area is the part of Southern Sindh Monocline. Sindh Monocline is an important hydrocarbon producing area of Pakistan from where a large number of hydrocarbon fields have been discovered in the tilted fault blocks. The Jabo Field is located in Southern Sindh Monocline Figure 1.5. The Jabo-01 exploratory well was drilled by UTP and completed in 1986 at TD of 2228 m TD at the top of Lower Goru and Gas was discovered. The Jabo-02 and Jabo-03 were completed in 2000 by UTP at TD of 2103m at the top of Lower Goru. Jabo-04 was drilled by BP** in 2002 at TD of 2103 m up to the Top of Lower Goru and produced Oil, Jabo-05 was drilled by British Petroleum in 2003 at TD of 2077 m up to top of Lower Goru and oil was discovered, Jabo-06 was completed BP in 2005 at TD of 2636m at the top of Lower Goru and Oil/ Gas was discovered, Jabo-07 was completed in 2007 by BP at TD of 2143 m and was decalared as abandoned, Jabo-08 was completed by BP in 2007 at TD of 2066 m up to top of Lower Goru and produced oil, Jabo-09 was drilled by BP in 2008 at TD of 2114 m up to top of Lower Goru and was declared as oil well, Jabo-11 and 12 wells were completed by BP in 2009 at TD of 2129 m and 2159m respectively and were declared as oil and gas wells, Jabo-13 was completed by BP in 2010 up to TD of 2082m to the top of Lower Goru and declared as oil and gas well, Jabo-14 was completed by UEPL*** in 2012 at TD of 2155 m up to the top of Lower Goru and was declared as oil well and according to Pakistan Energy Year Book 2013, Jab-15 was drilled by United Energy Pakistan Limited.

1.5 Base Map

A base map typically includes locations of concession boundaries, wells, Seismic survey points and other cultural data such as buildings and roads, with a geographic reference such as latitude and longitude or Universal Transverse Mercator (UTM) grid information. Geologists use topographic maps as base maps for construction of surface geologic maps. Geophysicists typically use shot point maps, which show the orientations of seismic lines and the specific points at which seismic data were acquired, to display interpretations of seismic data. Base Map of interest is given below in Fig. 1.3**.**

1.6 Software Tools

- SMT KINGDOM 8.6
- VAS
- Visual OIL
- Wavelets
- Surffer

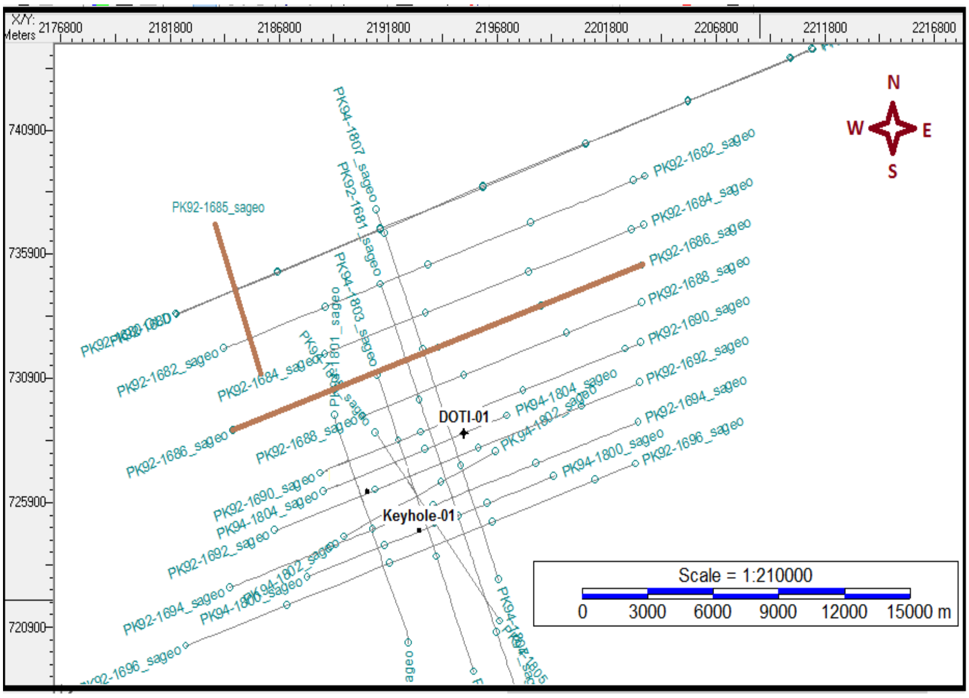


Fig 1.3 Base Map of Study area.

1.7 Technical Well Data

Technical Well Data			
Operator	**UTP**	**Province**	**Sindh**
Type	**Exploratory**	**Status**	**Gas/Cond**
Well Bore Name	**Doti-01**	**Source**	**Vibroseis**
Longitude	**068.702917**	**Latitude**	**024.889058**
Depth Reference Elevation(ft.):	**27**	**Total Depth(m)**	**1830.1600 m**
Depth Reference	**KB**		
List of Well Tops			
Formations	**Formation Age**	**Top(m)**	**Thickness(m)**
KIRTHAR-LAKI	**HOLOCENE**	**000222.5**	**483.1**
UPPER RANIKOT	**LATE PALEOCENE**	**000277.4**	**361.2**

LOWER RANIKOT	PALEOCENE	000461.7	115.8
KHADRO	EARLY PALEOCENE	000629.4	363
PARH LIMESTONE	LATE CRETACEOUS	000739.1	135.63
UPPER GORU	CRETACEOUS	000771.1	472.1
LOWER GORU	CRETACEOUS	001537.6	

Table 1.1 Technical well data of well Doti-01

1.8 Objectives of Study

Objectives of this research are as under:

- To interpret and identify the horizons using surface seismic and well information
- To interpret the structural styles and to find out the zone of interest
- To carry out the reservoir characterization of the area using wireline logs
- To map the prospective reservoir in the area

Chapter # 2
TECTONICS AND STRATIGRAPHY OF STUDY AREA

2.1 Tectonics of Pakistan

The Pakistani basins have acquired their primary structural and stratigraphic features from events associated with plate movements that occurred latest Paleozoic to the present. From Permian through Middle Jurassic time, the Indo-Pakistani plate was located in the Southern Hemisphere between the African, Antarctic and Australian plates and comprised part of southern Gondwana (Wandrey, 2004). The Lower Permian Tobra Formation tillites in the upper Indus Basin and other basal Permian glacial deposits on the Indo-Pakistani plate are indicative of much cooler paleoclimate (Shah et al, 1977). The Indo-Pakistani Plate has evolved through successive stages of plate tectonic events which are documented for the Eo-Cambrian onwards.

2.2 Tectonics of study Area

As the Study area is the part of Southern Sindh Monocline, Southern Indus Basin of Pakistan, is the divergent boundary of Indo-Pakistan plate formed during Early to Middle Cretaceous (130- 110 Ma) and resulted rifting. Due to this rifting the study area was deformed in a number of horst and graben structures. The cause of the formation of these structures was the northwest movement of Indian plate generated compression while the accompanying anticlockwise rotation produced tension. As a result of tension, the platform was split into horst and graben structures. The concentration of older reservoirs is more towards the east and northeast and the younger mature source rocks are to the west of the study area. The hydrocarbons in the grabens in the north-east (NE) and south-west (SW) of the monocline were subjected to higher temperatures due to deeper burial. Hence, extensional tectonics plays an important role in the occurrence and maturation of hydrocarbons in the study and nearby areas. Structuring and widespread deposition of sedimentary facies including organic rich source rock (Sembar Shale) and highly porous and permeable reservoir rock (Lower Goru) in the area provides the basic elements of the petroleum system. Grabens are main areas for the generation of hydrocarbons while faults are providing migration pathway for hydrocarbons from source to reservoir rocks. Faults are also providing the trapping mechanism for hydrocarbons. The tilted fault block traps were in existence at the time of hydrocarbon generation. Fault associated with the structural closures are responsible for trapping oil and gas in lower Goru sand stones in the study and nearby areas.

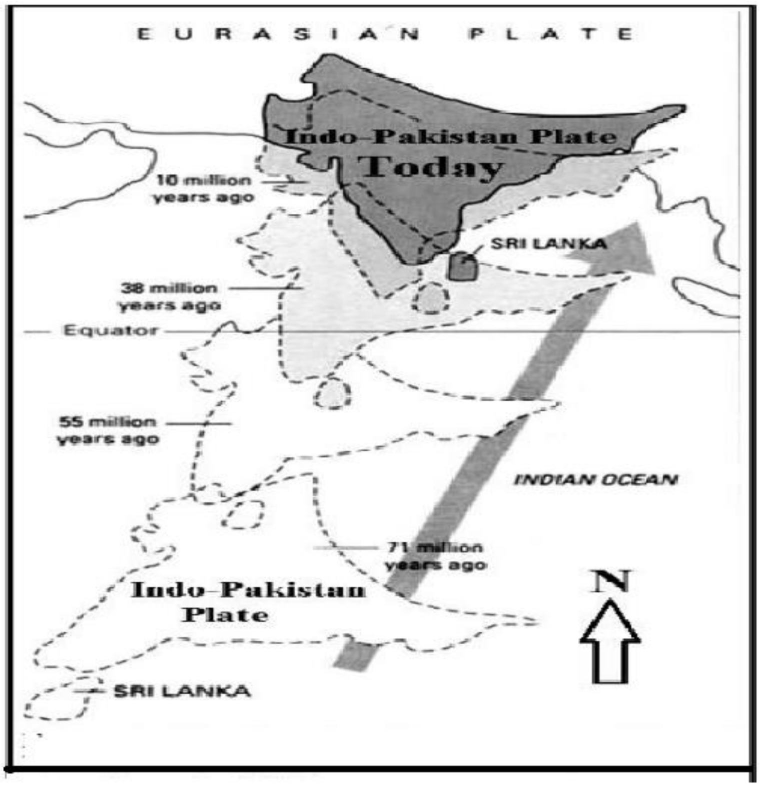


Fig.2.1 Present position of Indo-Pakistan Plate Since 70my.

The information about the geology of an area plays an important role for precise interpretation of seismic data, because some velocity effects can be generated from formation of different ideologies and also different velocity facts can be generated some lithological horizons. So as if we don't know geological formations in area we don't recognize the different reflections appearing in the seismic section.

2.3 Stratigraphy in the Study Area

It is very critical to have knowledge about the stratigraphy of the area for the hydrocarbons prospecting, by this knowledge it is determined that what are the source, reservoirs and seals rocks of the area. The lithological setting and stratigraphic sequence of the study area is given below Figure 2.3.

2.4 The top lower Goru unconformity

Regional studies show that the Lower Goru Formation is unconformably overlain by the Upper Goru Formation which mainly consists of marl and calcareous claystones, with occasional interbeds of siltstone and limestone. The unconformity can be identified based on resistivity images and openhole logs Figure. 2.3. The low-angle dip magnitude and azimuth remain constant over the unconformity but there is a difference in the frequency of computed dips. This is the result of well bedded (Upper Goru Formation) contrasting against a poorly bedded formation (top of Lower Goru Formation). The variable thickness of A Sand without faults is further supportive of the unconformity.

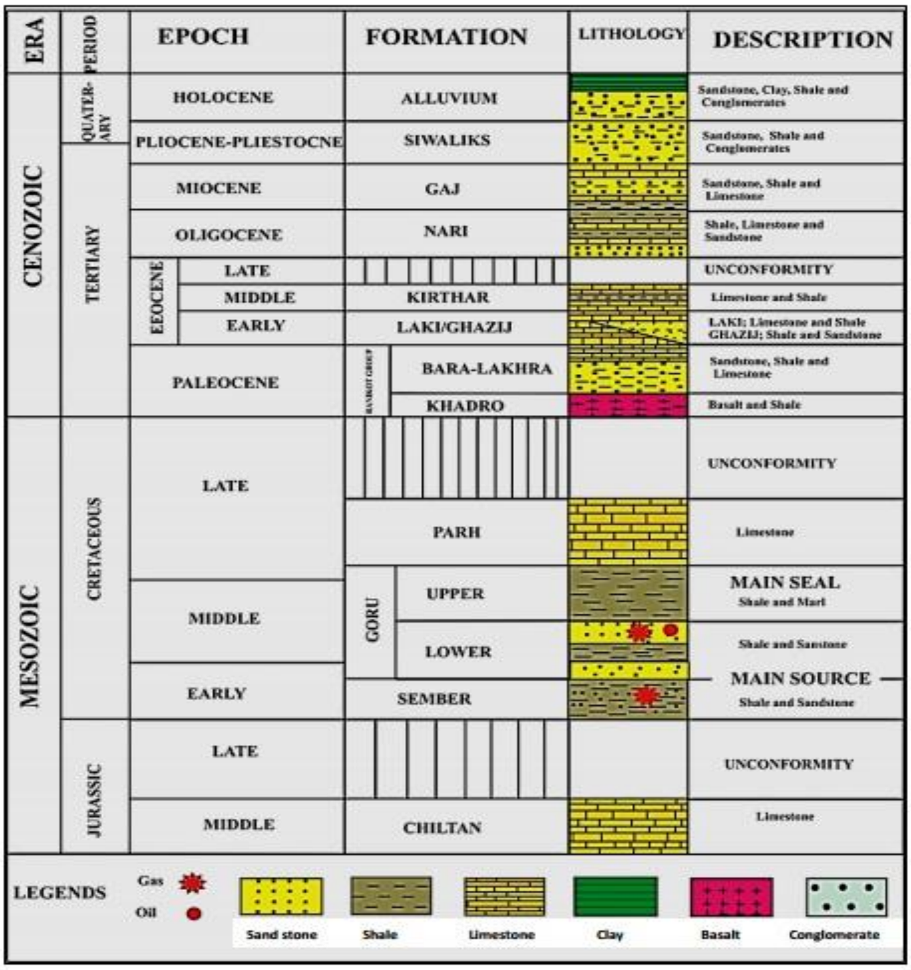


Fig 2.3 Generalized stratigraphy of the area (Khan et al,2012).

2.5 Petroleum play of study area

In geology a petroleum play or simply a play is a group of oil field or prospects in the same region that are controlled by the same set of geological circumstances. The Petroleum System consists of a mature source rock, migration pathway, reservoir rock, trap and seal appropriate relative timing of formation of these elements and the processes of generation migration and accumulation are necessary for hydrocarbons to accumulate and be preserved (Stoneley,1995).

Lower Indus basin is main hydrocarbons producing basin of the Pakistan 37% hydrocarbons of the Pakistan are extract from the lower Indus basin (Kadri, 1995)

2.5.1 Source Rock

Sembar Formation of Early Cretaceous age is a proven as major source rock in Lower Indus Basin and Intra Lower Goru Shales of Cretaceous age also has source rock potential. Sembar is mainly composed of clastic rocks, primarily shale followed by sandstone and siltstone with minor limestone. Sembar is considered to have been deposited on a broad shelf, gently sloping westward off the Indian shield. Shale of goru and Mughal kot formations both are widespread and thick. They contain abundant organic matter and generally exhibit the good source rock characteristics (Kadri, 1995).

2.5.2 Reservoir Rock

Reservoirs are rocks having hydrocarbon bearing potential. Hydrocarbons are trapped in these rocks after migration. Lower Goru Sands are reservoir rocks in Badin. Ranikot sandstone is also a good reservoir rock. The pub sandstone along with the sand horizons within Mughal kot formation is the potential reservoir rock for the entire study area. The main reservoir rocks are the sand of cretaceous age (lower goru formation). The goru formation is dominantly shale and mudstone frequently calcareous. Sand is rare in upper part with increasing tendency toward the base where it has developed into a producing reservoir. On the basis of its lithological content it has been divided into lower Goru and upper Goru, petroleum potential of lower Goru sand is very good as it contains all the hydrocarbons in Sindh monocline (Kadri, 1995).

2.5.3 Seal Rock

Seals act as a barrier for the flow of hydrocarbons. In the Lower Indus Basin Upper Goru and Intra Lower Goru Shales of Cretaceous age provide seal for the Lower Goru reservoir sands (Kadri, 1995).

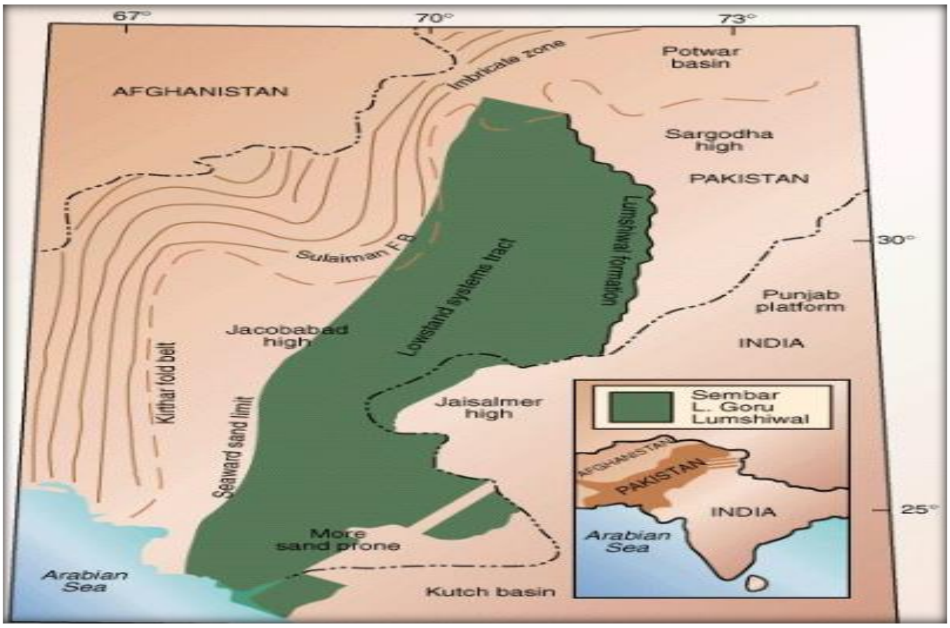


Fig 2.4 Petroleum play of Lower Indus basin (Stoneley, 1995).

2.6 Stratigraphy in the Study Area

It is very critical to have knowledge about the stratigraphy of the area for the hydrocarbons prospecting, by this knowledge it is determined that what are the source, reservoirs and seals rocks of the area.

2.6.1 Goru formation

Goru formation (early cretaceous) consists of interbedded limestone, shale, marls, sandstone and siltstone. The environment of deposition is shelf to shallow marine. Different parts of this thick formation have enough reflectivity indexes to produced very clear reflections. Goru formation is divided into two parts (Kadri, 1995).

2.6.2 Upper Goru

It is comprised of marl calcareous clay- stone occasionally with inter-beds of silt and limestone (Kadri, 1995).

2.6.3 Lower Goru

It is consists of basal sand unit, lower shale, middle sand unit (which is a very good reservoir rock) upper shale and upper sand (Shah, 1977).

2.6.4 Parh limestone

This formation consists of hard thin to medium bedded limestone with subordinate calcareous shale and marl intercalations. Environment of deposition is shallow marine (Shah, 1977).

2.7 Ranikot formation

Ranikot formation is considered to be a good source rock for the gas reservoir in the area. It also act as a seal rock (Shah, 1977).

2.8 Kirthar formation

Kirthar formation (middle Eocene) is mainly fossiliferous 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 (Shah, 1977).

Chapter # 3
Seismic Data Interpretation

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).

The acquisition and processing of reflection seismic data usually result in a seismic image of acoustic impedance interfaces. If these interfaces are assumed to follow lithological boundaries, then the seismic image is actually an image of subsurface geological units and the structures they form. The goal of seismic interpretation is to recognize possible geological patterns in the seismic image (Dobrin, 1960).

An interpreter of seismic data may have good hold in both geology and geophysics. It is the ingenuity and in-depth understanding of an interpreter to extract geologic significance from aggregate of many minor observations. For example, down dip thinning of the reflection might be result from normal increase velocity with depth or thinning of the sediments or flow of the shale or salt may develop illusory structure in the deeper horizon (Sheriff, 1991).

3.2 Qualitative interpretation

The primary aim of the qualitative interpretation of the seismic data is to map the subsurface geology. Qualitative interpretation is conventional or traditional seismic technique that include the marking of laterally consistent reflectors and discontinuities characteristics like faults of various types and there mapping on different scales (space and travel time). The geometry on the seismic section is precisely interpreted in view of the geological concept to detect the hydrocarbons accumulation. The structure and stratigraphic architecture of the petroleum is determined and on behalf of the geometric features the location of the well is established.

3.2.1 Stratigraphic analysis

Stratigraphy analysis involves the delineating the seismic sequences, which present the different depositional units, recognizing the seismic facies characteristic with suggest depositional environment and analysis the reflection characteristic variation to locate the both stratigraphy change and hydrocarbon depositional environment (Bachrach et al, 2004).

3.2.2 Structural analysis

In structural analysis main emphases is on the structural traps in which tectonic play an important role. Tectonic setting usually governs which types of the structure are present and how the structural features are correlated with each other's, so tectonic of the area is helpful in determining the structural style of the area and to locate the traps. Structural traps include the faults, folds anticline, pop up, duplex, horsts and grabben structures etc (Sheriff, 1991).

3.3 Quantitative interpretation

Seismic quantitative interpretation technique as compared to the traditional seismic interpretation technique is more useful. In which the physical variation of the amplitude is considered to predict the hydrocarbons accumulation. Various alterations in these techniques have contributed to the better prospects evaluation and reservoir characterization. Particularly the unconventional seismic interpretation techniques widen the exploration areas. They validate hydrocarbons anomalies and make prospect generation easier. The most important of these techniques include post-stack amplitude analysis (bright-spot and dim-spot analysis), off set-dependent amplitude analysis (AVO analysis), acoustic and elastic impedance inversion, and forward seismic modeling (Bachrach et al, 2004).

3.4 Seismic Interpretation Workflow

Procedure followed for seismic data interpretation is given in Fig 3.1. Base map is prepared by loading navigation data and SEG-Y in software SMT kingdom. Horizons of interest are marked manual and also by auto-tracking mode. Initially horizons are identify with the help of synthetic seismogram, which is generated by using well data. In this process faults are identified and also marked. Faults polygons are generated and horizons are contoured to find out structural highs and lows. Then time and depth contours are generated.

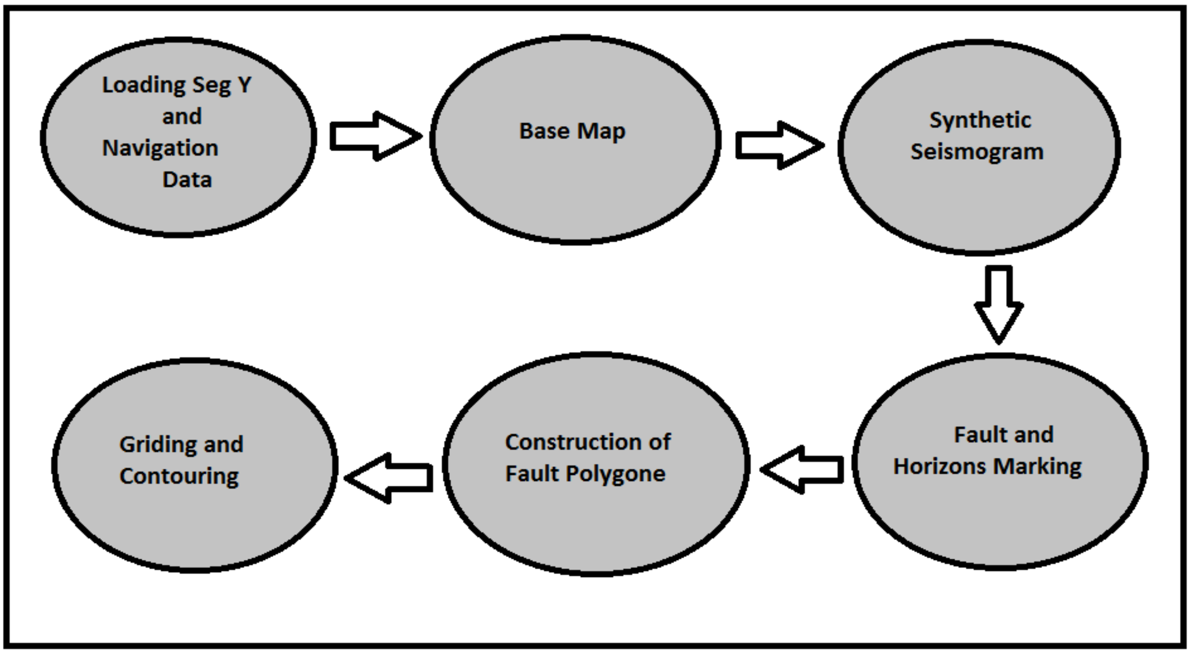


Fig 3.1 Workflow for seismic data interpretation

3.5 Synthetic Seismogram

Synthetic seismograms are artificial seismic traces use to establish correlations between local stratigraphy and seismic reflections. To produce a synthetic seismogram a sonic log is needed. Ideally, a density log should also be used, but these are not always available. With the help of Doti-01 well, we construct the synthetic seismogram Fig 3.3 in order to mark the horizons.

Synthetic seismograms provide a crucial link between lithological variations within a drill hole and reflectors on seismic profiles crossing the site. In essence, they provide a ground-truth for the interpretation of seismic data. Synthetic seismograms are useful tools for linking drill hole geology to seismic sections, because they can provide a direct link between observed lithologies and seismic reflection patterns (Handwerger et al., 2004). Reflection profiles are sensitive to changes in sediment impedance, the product of compression wave velocity and density. Changes in these two physical parameters do not always correspond to observed changes in lithologies. By creating a synthetic seismogram based on sediment petro-physics, it is possible to identify the origin of seismic reflectors and trace them laterally along the seismic line (Handwerger et al., 2004).

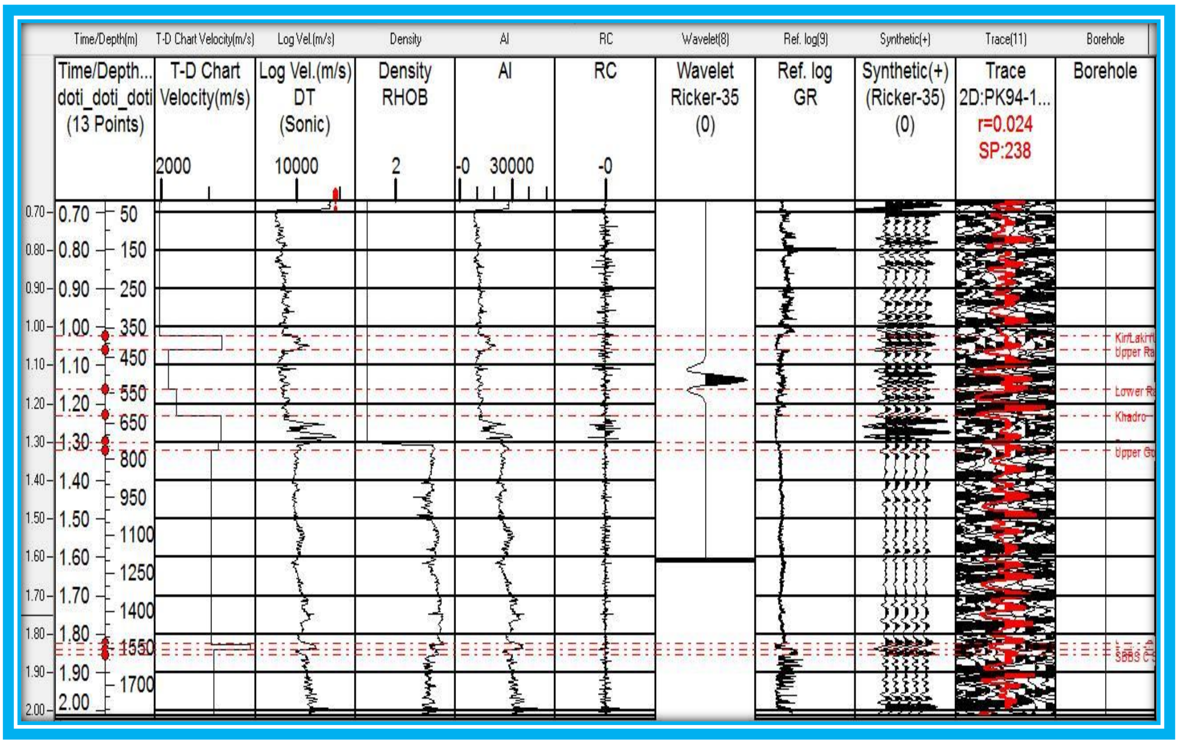


Fig 3.2 Synthetic seismogram of Doti-01 well

3.6 Picking of Horizons and Fault Identification

Primary task of interpretation is the identification of various horizons as an interface between geological formations. For this purpose, good structural as well as stratigraphic knowledge of the area is required. Thus during interpretation process, I mark both, the horizons and faults on the seismic section. Using well data of Doti-01, horizons are marked on dip lines PK94-1804 and PK92-1680 to PK92-1688. Doti-01 is drilled on shot point 239 of line PK94-1804 and ties all available dip lines and horizons are continued on all lines. Chiltan limestone horizon is marked on the basis of prominent reflections on all lines.

Finally, marked horizons are named as Chiltan limestone, Top of Lower Goru formation with the help of synthetic seismogram of Doti-01 well data on the dip line PK94-1804 as demonstrated in Fig 3.3.

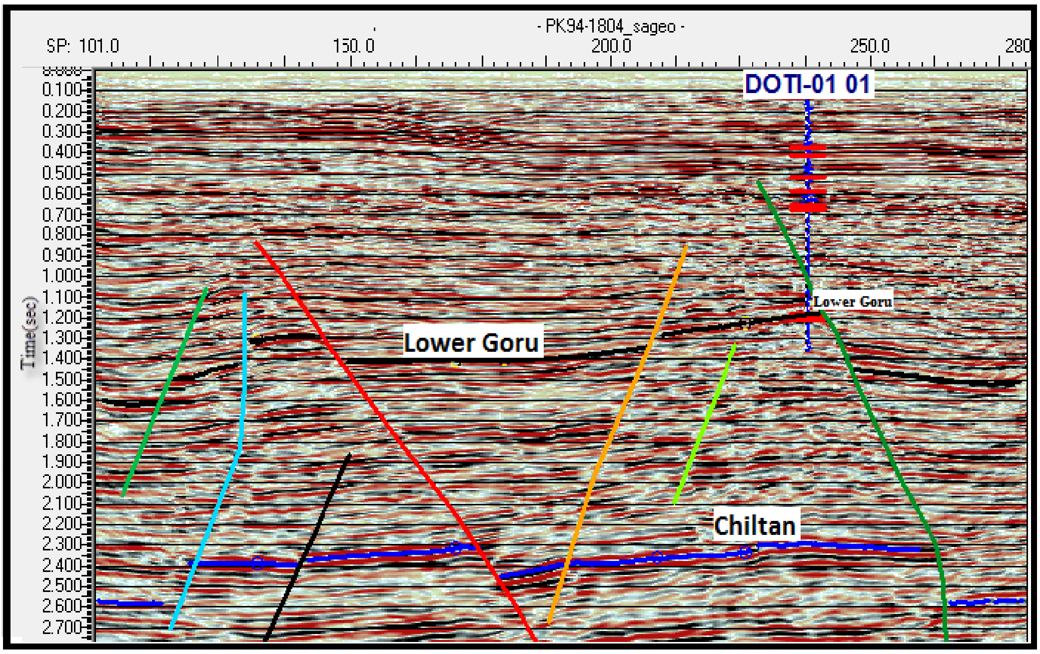


Fig 3.3 Synthetic Seismogram on Seismic section of line PK94-1804.

Study area lies in extensional regime dominated by normal faults and associated horst and graben structures. The identification of faults was difficult to some extent due to data quality. The average throw of the faults is observed to be about 15 – 20 ms. On the basis of discontinuity in time, nine normal faults have been marked on the seismic sections of the line PK92-1686 (Figure 3.4) forming the horst and graben features. Clues of normal faulting exist on all of interpreted seismic lines.

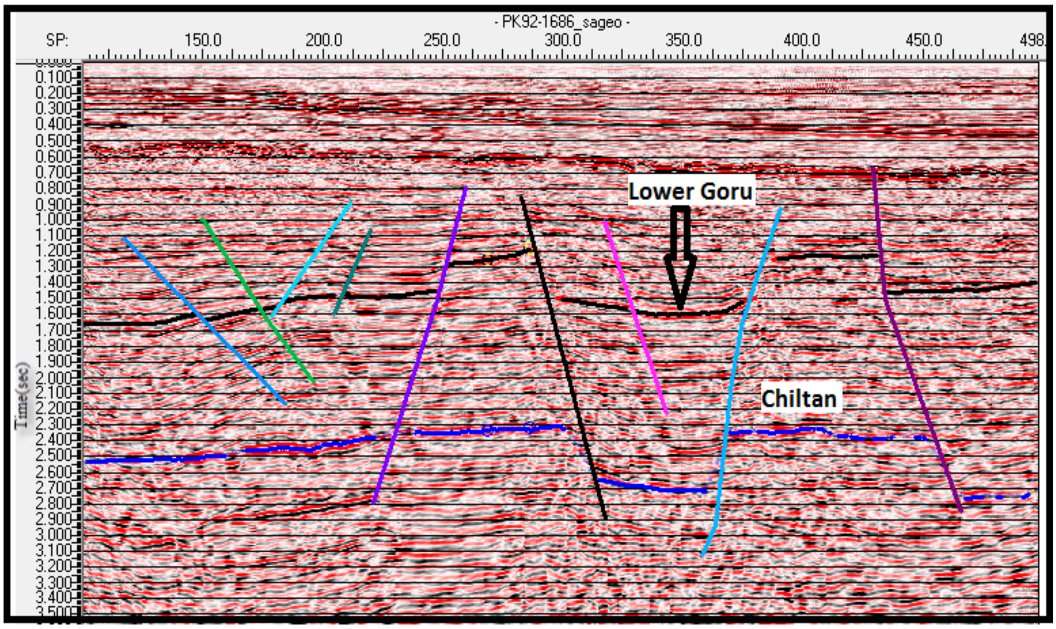


Fig 3.4 Normal faulting on Interpreted seismic dip line PK92-1686.

Here is the Seismic line shown on which seven faults are marked on the basis of continuity of reflectors and two formation Basal sand and Top of Lower Goru is marked with the help of synthetic seismogram. After marking Horizons and faults, we got good horst and graben geometry structures, which with matches our previous geological information.

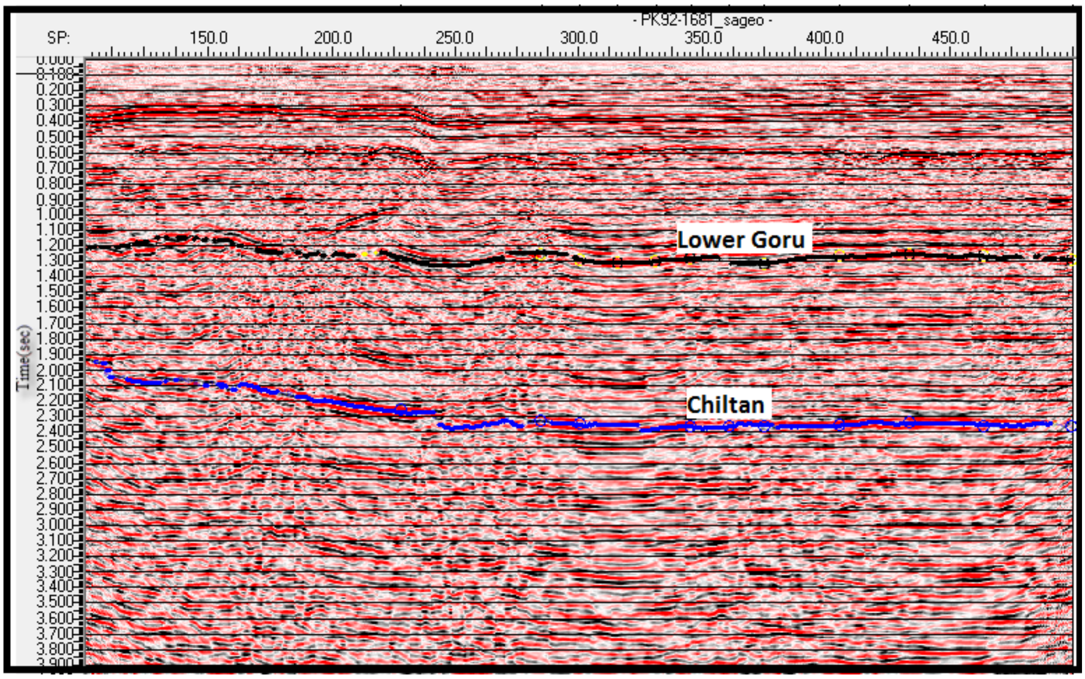


Fig 3.5 Interpreted Seismic Section of Strike line PK92-1681.

3.7 Construction of Fault Polygons

Construction of fault polygons are very important as far as time contouring of a particular horizon is concerned. Any mapping software needs all faults to be converted into polygons prior to contouring. The reason is that if a fault is not converted into a polygon, software doesn't recognize it as a barrier or discontinuity, thus making any possible closures against faults represents a false picture of the subsurface structures. Figure 3.6 formed at op of lower Goru level shows that after construction of fault polygons, the high and low areas on a particular horizon become obvious. Moreover, the associated dip symbols helps in giving information about the dip directions on a fault polygon .Fault polygons are constructed for all marked horizons and these are oriented in NW-SE direction.

Fault polygon formed at Top of Lower Goru level shown in Figure 3.7 shows alternate different color due to time change along both sides of polygon, showing normal faulting pattern.

3.8 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).

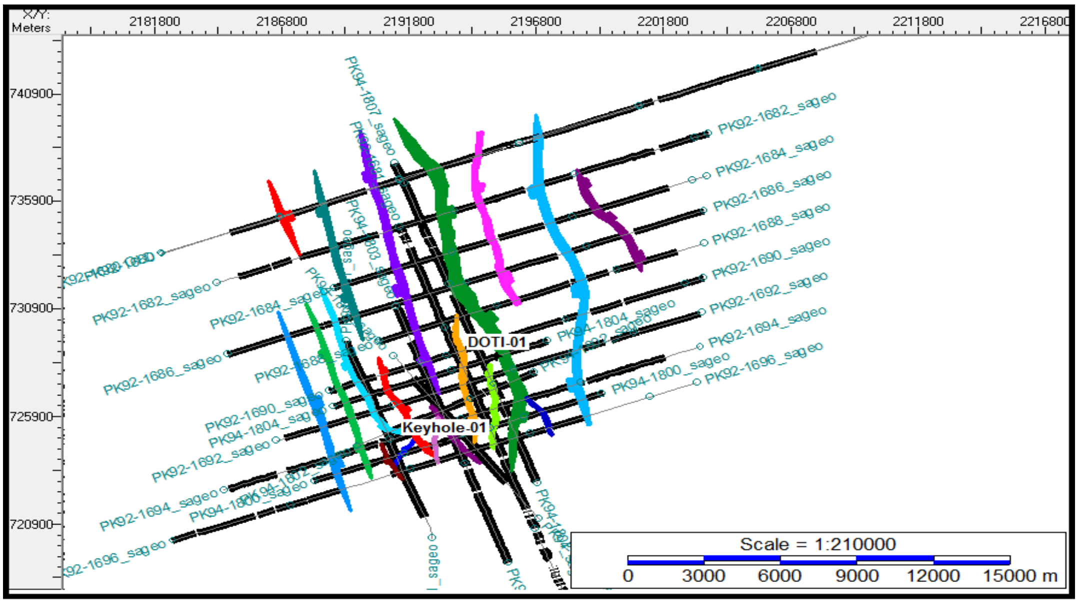


Fig 3.6 Fault polygon at Top of Lower Goru level.

3.8.1 Time Contour Maps

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.

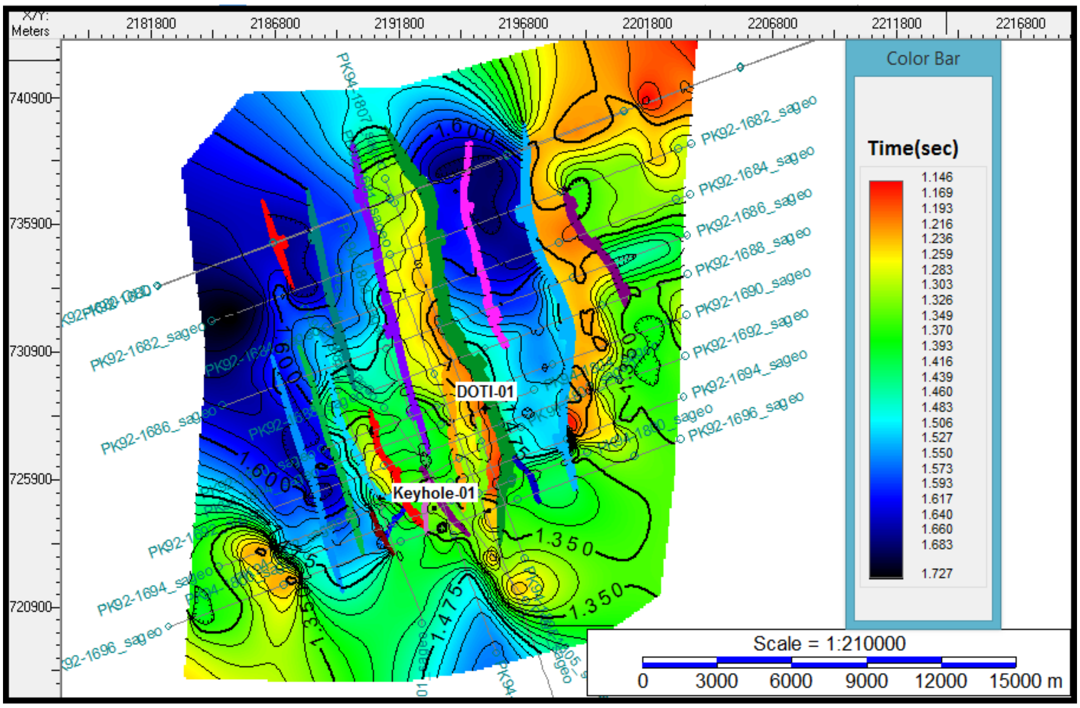


Fig 3.7 Time contour at Top of Lower Goru level showing change in time on the base map

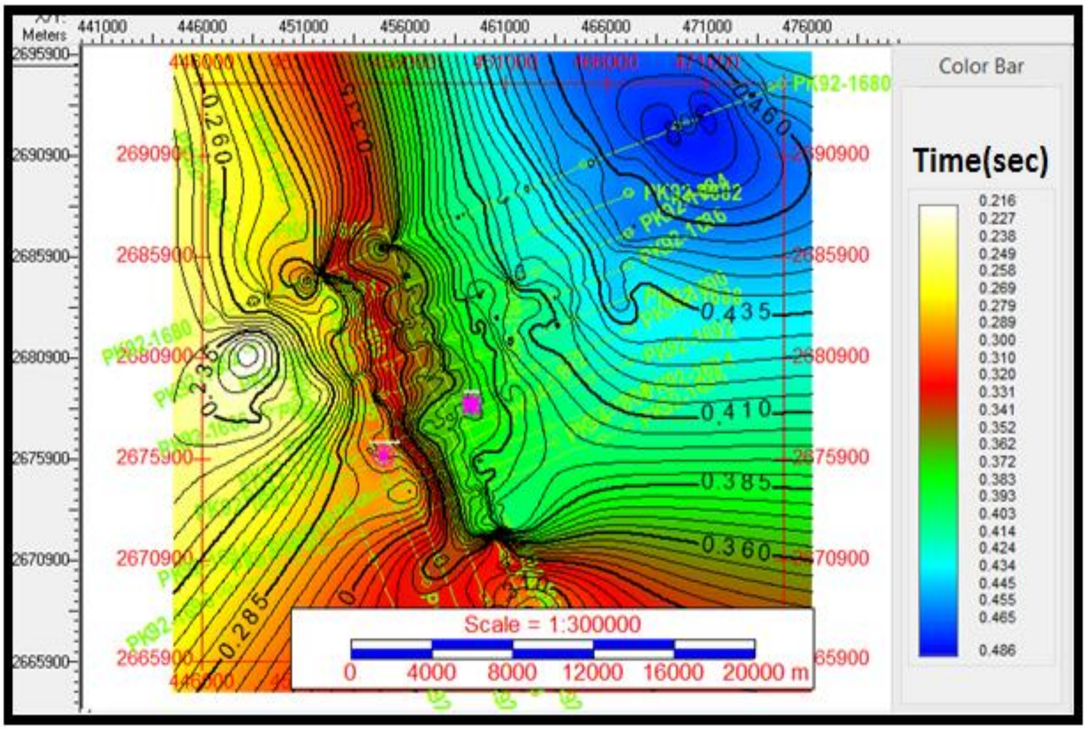


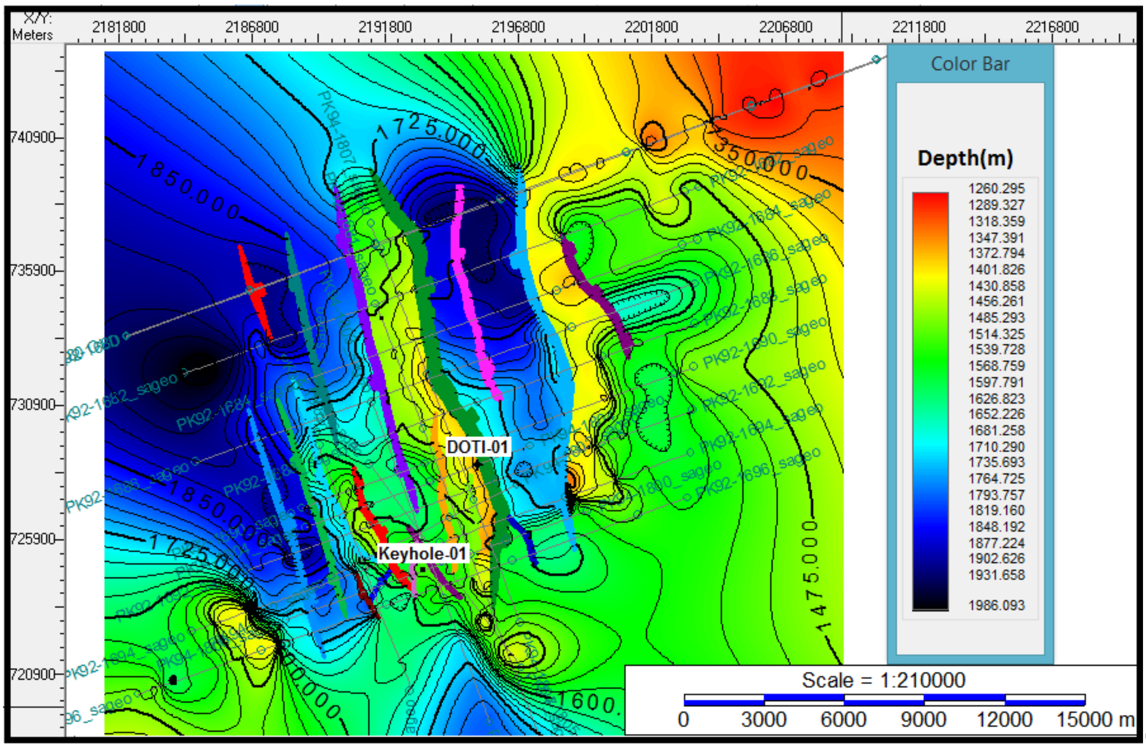
Fig 3.8 Time contour at Upper Ranikot level.

3.8.2 Depth Contour Maps

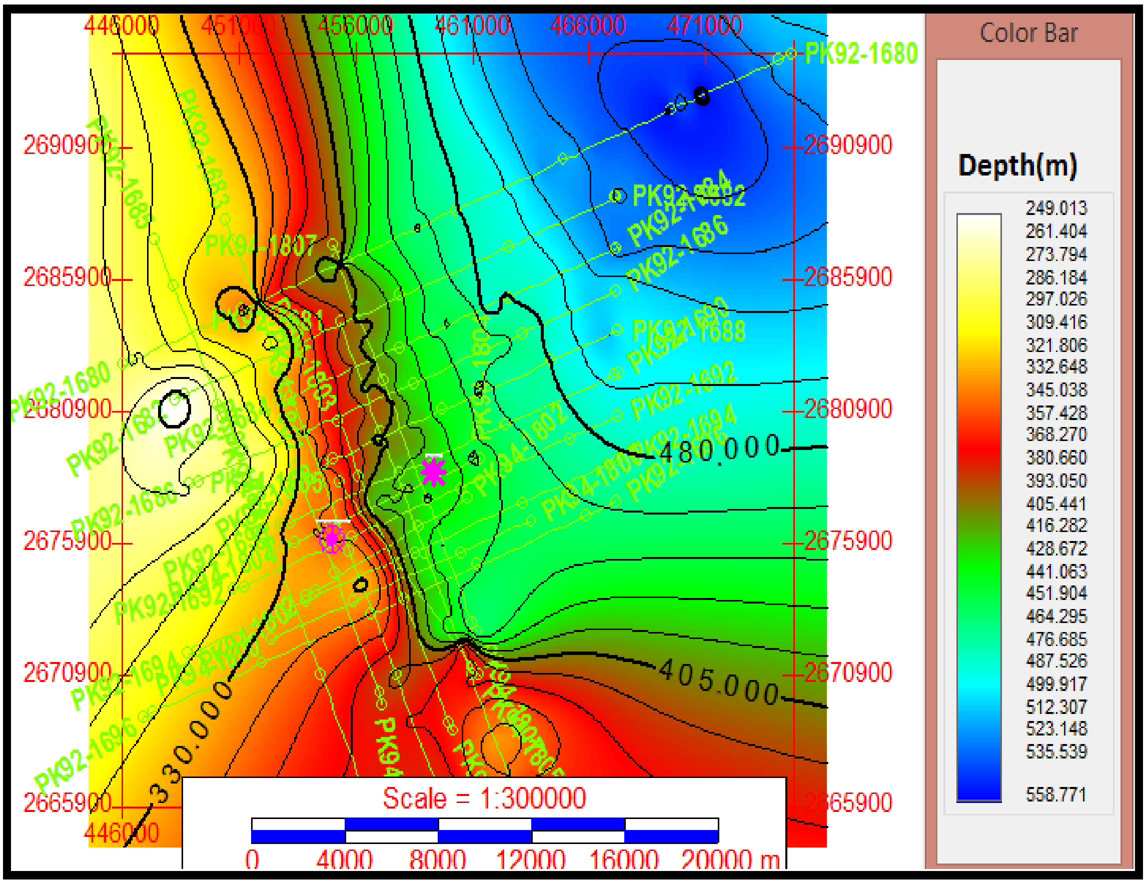
Depth conversion and depth contour maps are constructed to see the horizons in the subsurface at their true positions. Depth must be calculated from time to make a map that is more truly related to the subsurface shapes, because structure is a matter of depth. The idea of converting the times into depths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



(a)



(b)

Fig 3.9(a & b) Depth contour at Lower Goru and Upper Ranikot level.

Above Figure 3.9 shows the variation in color along both sides of the polygon. This alternate color variation is the sign of horst and graben geometry and time variation proves that it is normal faulting. Contouring also confirms the book shelf model.

As Lower Goru sand is recognize as a good reservoir rock of the Lower Indus Basin, depth contour map of this formation is constructed shown in Figure 3.9. Contour map confirms the horst and graben geometry in the area. The area with low value might be the good zone for the accumulation of hydrocarbons.

Chapter # 4
Attribute Analysis

4.1 Introduction

Seismic Attributes are all the information obtained from seismic data, either by direct measurements or by logical or experience-based reasoning. The study and interpretation of seismic attributes provide us with some qualitative information of the geometry and the physical parameters of the subsurface. It has been noted that the amplitude content of seismic data is the principal factor for the determination of physical parameters, such as the acoustic impedance, reflection coefficients, velocities, absorption etc. The phase component is the principal factor in determining the shapes of the reflectors, their geometrical configurations etc. The principal objectives of the attributes are to provide accurate and detailed information to the interpreter on structural, stratigraphic and lithological parameters of the seismic prospect (Taner, 1994).

We define the **"Seismic Attributes"** as all of the measured, computed or implied quantities obtained from the seismic data. Therefore Attributes include complex trace attributes, seismic event geometrical configurations, and their spatial and pre-stack variations. We generally compute attributes from the seismic data represented in time, rather than in depth. Therefore conventional CDP stack sections, DMO applied stack sections, pre-stack or post-stack time migrated sections are equally convenient for attribute computation. The attributes computed from the time migrated sections, due to their more accurate positioning of the reflectors (with respect to the CDP stack sections) may be more advantageous for interpretation purposes. The depth migrated sections, all time related information, such as the frequency, changes to wave numbers and wave-lengths. It should be noted that, to get the most expected results from seismic attributes, the data has to be processed with care. Special care must be directed to shaping source signatures, removing effects caused by the receiver plantation and array, near surface distortions, time, amplitude and phase distortions.

4.2 Types of Seismic Attributes

Attributes can be computed from pre-stack or from post-stack data, before or after time migration. The procedure is the same in all of these cases. Attributes can be classified in many different ways. Several authors have given their own classification. Here we give a classification based on the domain characteristics of the attributes (Taner, 1994).

4.2.1 Pre-Stack Attributes

Input data are CDP or image gather traces. They will have directional (azimuth) and offset related information. These computations generate huge amounts of data; hence they are not practical for initial studies. However, they contain considerable amounts of information that can be directly related to fluid content and fracture orientation. AVO, velocities and azimuthal variation of all attributes are included in this class (Taner, 1994).

4.2.2 Post-Stack Attributes

Post-stack attributes are derived from the stacked data. The Attribute is a result of the properties derived from the complex seismic signal. Azimuth related information. Input data could be CDP stacked or migrated. One should note that time migrated data will maintain their time relationships, hence temporal variables, such as frequency, will also retain their physical dimensions. For depth migrated sections, frequency is replaced by wave number, which is a function of propagation velocity and frequency. Post-stack attributes are a more manageable approach for observing large amounts of data in initial reconnaissance investigations (Taner, 1994)

These attributes may be sub-classified on the basis of the relationship to the geology.

4.2.3 Physical Attribute

Physical attributes relate to physical qualities and quantities. The magnitude of the trace envelope is proportional to the acoustic impedance contrast; frequencies relate to bed thickness, wave scattering and absorption. Instantaneous and average velocities directly relate to rock properties. Consequently, these attributes are mostly used for lithological classification and reservoir characterization (Taner, 1994).

4.2.4 Geometric Attribute

Geometrical attributes describe the spatial and temporal relationship of all other attributes. Lateral continuity measured by semblance is a good indicator of bedding similarity as well as discontinuity. Bedding dips and curvatures give depositional information. Geometrical attributes are also of use for stratigraphic interpretation since they define event characteristics and their spatial relationships, and may be used to quantify features that directly assist in the recognition of depositional patterns, and related lithology (Subrahmanyam, 2008).

4.3 Attribute Analysis of Line PK92-1686

4.3.1 Envelope of Trace (Reflection Strength/ Instantaneous Amplitude)

- The Trace Envelope is a physical attribute and it can be used as an effective discriminator for the following characteristics.
- Mainly represents the acoustic impedance contrast, hence reflectivity
- Bright spots, possible gas accumulation
- Sequence boundaries
- Thin-bed tuning effects

- Major changes in depositional environment
- Unconformities
- Major changes of lithology
- Spatial correlation to porosity and other lithological variations
- Indicates the group, rather than phase component of the seismic wave propagation (Subrahmanyam 2008).

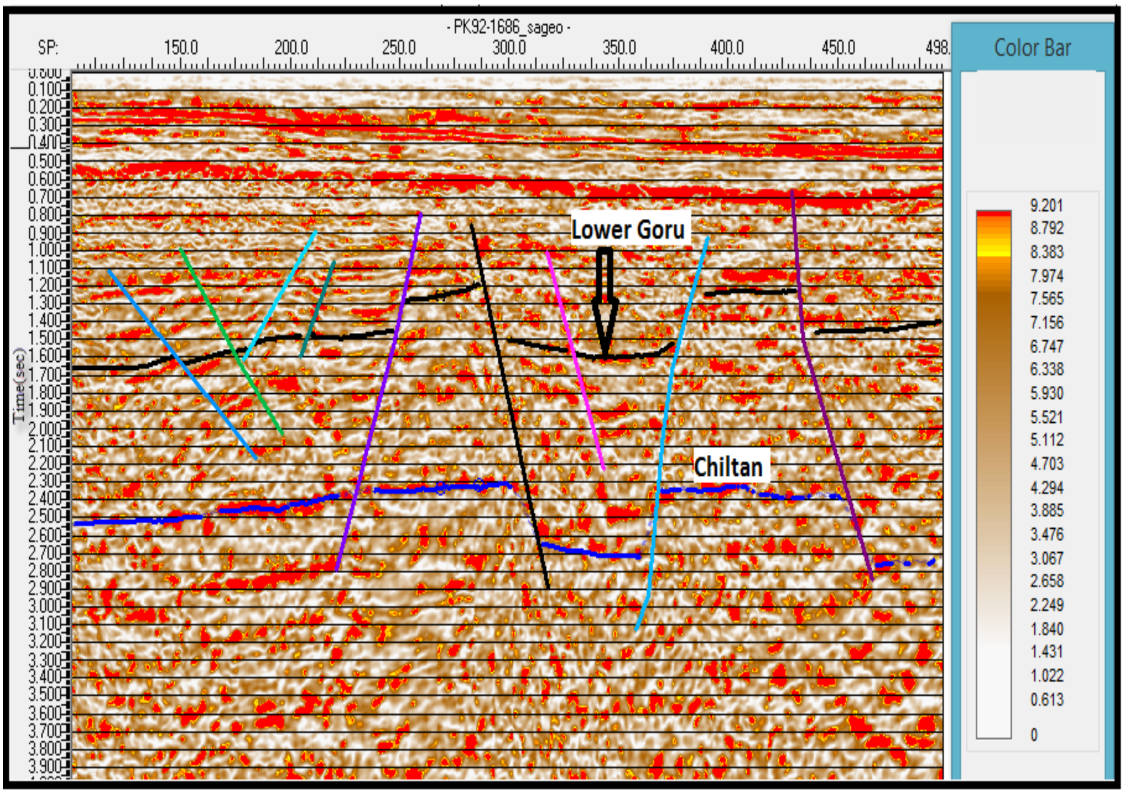


Fig 4.1 Envelope Attribute Map of PK92-1686.

A thick package indicates the maximum reflection strength corresponding to the source, reservoir and seal rocks shown in Figure. It also shows spatial patterns representing changes in the limestone thickness and breakage due to the faults.

4.3.2 Instantaneous Phase

Phase attribute is also a physical attribute and can be effectively used as a discriminator for geometrical shape classifications. The phase information is independent of trace amplitudes and relates to the propagation of phase of the seismic wave front.

- Detailed visualization of bedding configuration
- It can be used to highlight interface in sections with high decay of amplitudes and even highlight deeper horizons which are not visible in the normal amplitude sections
- Instantaneous phase is the best indicator of lateral continuity
- Shows discontinuities
  (Subrahmanyam, 2008).

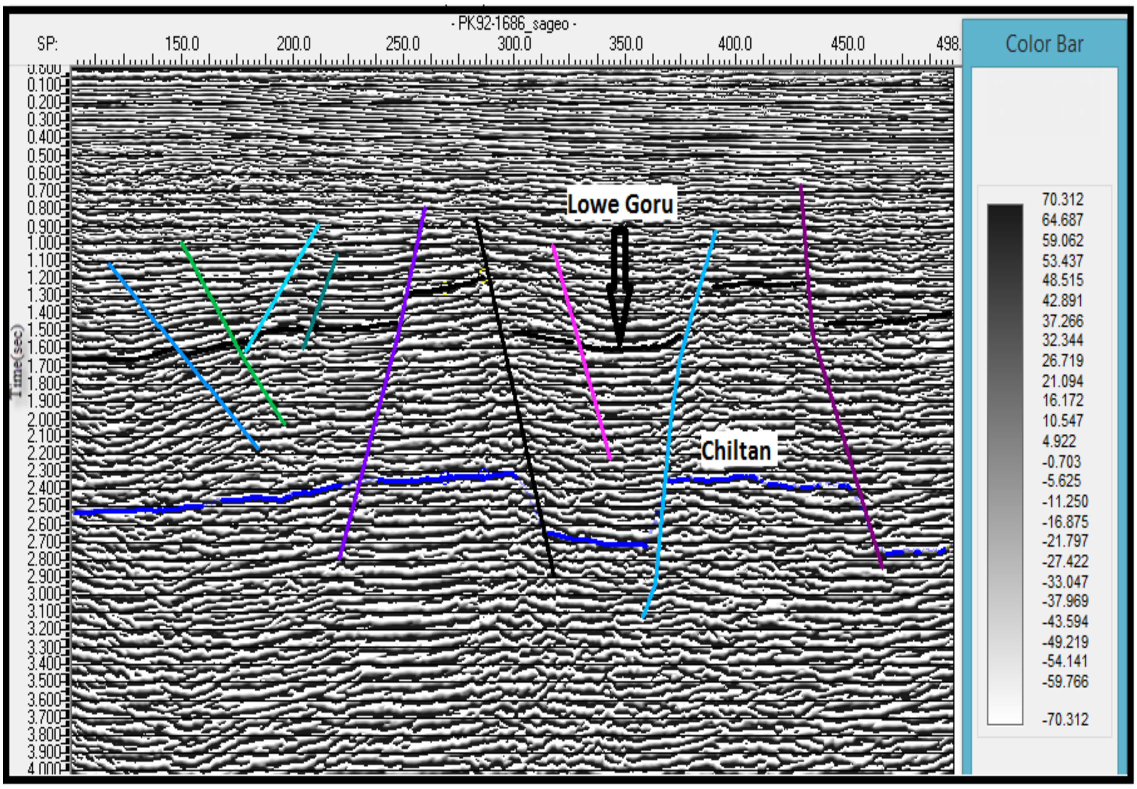


Fig 4.2 Phase Attribute Calculated For Seismic Line PK92-1686.

The interpreted horizons lie over the zero phase regions indicated by white color. This attribute further confirms the interpretation as the input data is zero phase. It can be observed in comparison to amplitude based sections that the instantaneous phase shows much deeper horizons. The phase attribute in Figure show the lateral continuity.

4.3.3 Instantaneous Frequency

Instantaneous frequency attribute relates to the centroid of the power spectrum of the seismic wavelet. The instantaneous frequency attribute responds to both wave propagation effects and depositional characteristics, hence it is a physical attribute and can be used as an effective discriminator (Subrahmanyam, 2008).

Its uses include:

- Hydrocarbon indicator by low frequency anomaly. This effect is sometimes accentuated by unconsolidated sands due to the oil content of the pores
- Fracture zone indicator, since fractures may appear as lower frequency zones
- Bed thickness indicator. Higher frequencies indicate sharp interfaces such as exhibited by thinly laminated shale, lower frequencies are indicative of more massive bedding geometries, e.g. sand-prone lithology
- Instantaneous frequency can indicate bed thickness and also lithology parameters.

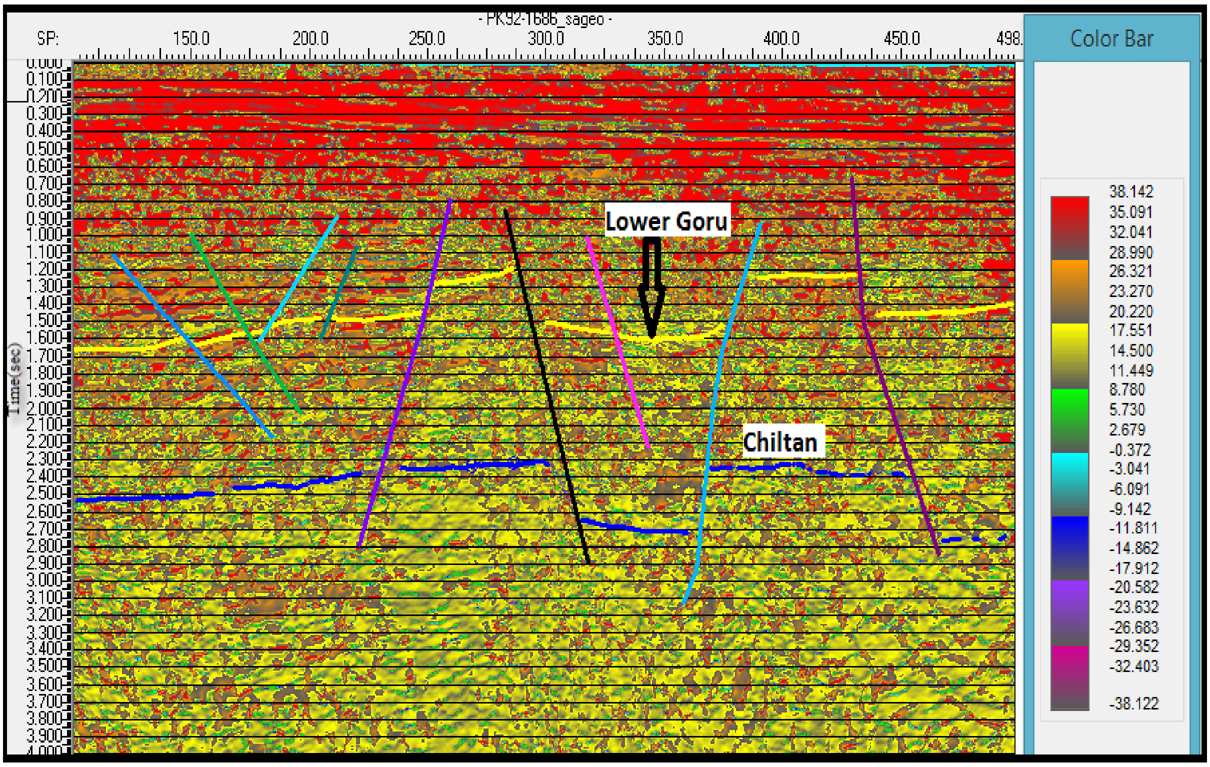


Fig 4.3 Frequency Attribute Calculated For Seismic Line PK92-1686.

Another piece of information we can extract from the seismic data are the locations where instantaneous frequencies jump or exhibit a negative sign. These sign reversals are caused by closely-arriving reflected wavelets. Therefore, the time derivative of the phase function will contain the indicators for thin beds, in the form of large variations of instantaneous frequency. Its smooth variation will relate to bedding characteristics (Subrahmanyam, 2008). Fig 5.3 shows the instantaneous frequency attribute of line PK92-1686.But the above applied attribute is not satisfied in the area.

A seismic attribute is a quantitative measure of a seismic characteristic of interest. Good seismic attributes and attribute-analysis tools mimic a good interpreter. Attribute developments tracking the breakthroughs in reflector acquisition and mapping, fault identification, bright-spot identification, frequency loss, thin-bed tuning, seismic stratigraphy, and geomorphology. Complex seismic trace attributes have become important qualitative and quantitative measures for geophysical exploration. Attributes have made it possible to define seismic data in a multidimensional form and neural network technology enables us to unravel the complex nonlinear relationships between seismic data and rock and fluid properties. Recently published case histories clearly show that multiple attributes overcome the failures associated with single attribute usage.

Chapter # 5
Reservoir Characterization Using Wireline Logs

5.1 Introduction

Mostly geological and geophysical studies are done to identify the hydrocarbons in the sub surface. Hydrocarbons reservoir are marked and characterized with the help of mud logging and wire line log data at meter scale. Doti-01 well have been selected for reservoir characterization in this study.

Sandstone units of Lower Goru (lower part of Lower Goru Formation) are the primary objective in this well but proven reservoirs of gas are the thin layers of sands within the unit of Lower Goru Formation. Basal part of Lower Goru have good porosity results but barren for hydrocarbons accumulation and presence. Flow chart of reservoir characterization is given in the Fig 5.1 which is showing the traditional and contemporary approaches to reservoir studies.

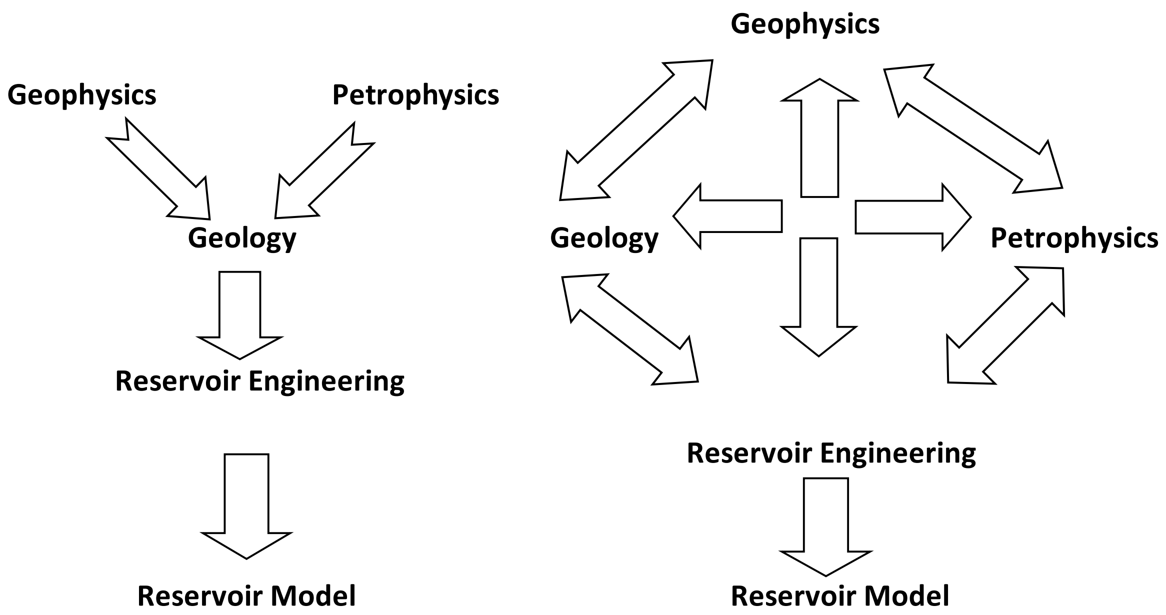


Fig 5.1 Flow chart of reservoir characterization.

5.2 Well logging

Well logging is the process of recording various physical, chemical, electrical, or other properties of the rock/fluid mixtures penetrated by drilling a well into the earth. In its most usual form, an oil well log is a record displayed on a graph with the measured physical property of the rock on one axis (horizontal axis) and depth (distance from the surface) on the other axis (vertical axis). More than one property may be displayed on the same graph. None of the log actually measure the physical properties that are of the most interest, such as how much oil or gas is in the ground, or how much is being produced. Such important knowledge can only be derived, from the measured properties listed above, using a number of assumptions which, if true, will give reasonable estimates of hydrocarbon reserves. Thus, analysis of the log data is required. The art and science of log analysis is mainly directed at reducing a large volume of the data to more manageable results, and reducing the possible error in the assumptions and in the results based on them. When log analysis is combined with other physical measurements on the rocks, such as core analysis or petro-graphic data, the work is called petrophysical analysis. The results of the analysis are called map able reservoir properties. The petrophysical analysis may be ‘calibrated” when the porosity, fluid saturation, and permeability results compare favorably with core analysis data. Further confirmation of petrophysical properties is obtained by production tests of the reservoir intervals.

5.3 Raw log Curves

Acquired well log data is displayed in the form of raw log curves of Doti-01. These logs include Caliper, Gamma Ray, Resistivity (Letro-log Deep, Letro -Log Shallow), Density, Sonic and Neutron etc Fig 5.2.

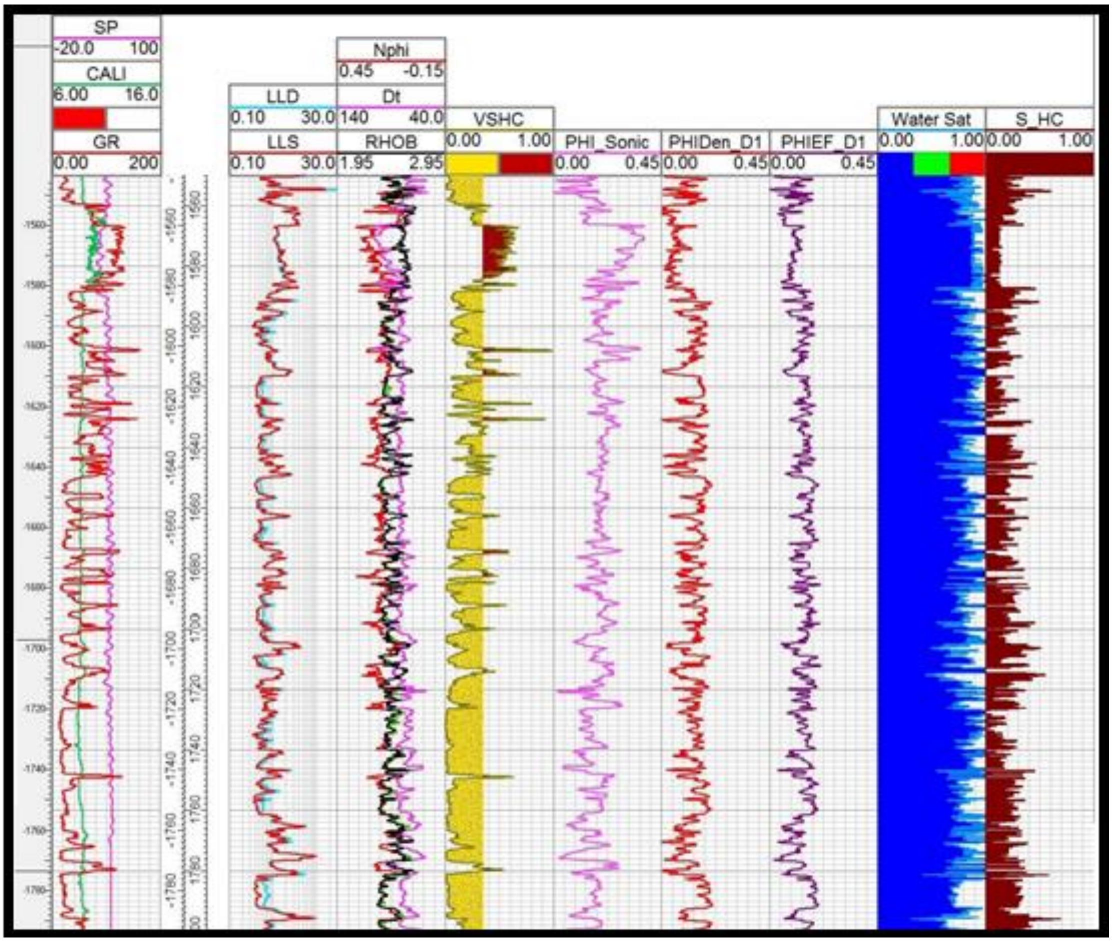


Fig 5.2 Raw log curves of Doti-01 well.

5.4 Petrophysics

Petrophysical analysis is the detailed analysis of a carefully chosen suite of wire-line services provide a method of inferring or deriving accurate values for the hydrocarbons and water saturations, the permeability, the porosity, and the lithology of the reservoir rock (Dewar, 2001).

- Petrophysics uses all kinds of logs, core data and production data; and integrates all pertinent information
- Petrophysics aims at obtaining the physical properties such as porosity, saturation and permeability, which are related to production parameters
- Petrophysics is generally less concerned with seismic, and more concerned with using wellbore measurements to contribute to reservoir description
- Petrophysics can provide things like porosity, saturation, permeability, net pay, fluid contacts, shale volume, and reservoir zonation
- Petrophysics is the interest of Petroleum Engineers, Well Log Analysts, Core Analysts, Geologists and Geophysicists

5.5 Petro physical interpretation

Petro physical interpretation is the process of using borehole measurements to evaluate the characteristics of sub-surface formation. These measurements maybe grouped together into four categories:

1- Mud Log
2- Core Analysis
3- Wire line Logs
4- Productivity Test; DST (Drill Stem Test) & production testing.

All these measurements and data have their own significance and special applications; over the less, they all have co objective of evaluating the formation for;

1- Identification of reservoir
2- Estimation of hydrocarbons in place
3- Estimation of recoverable hydrocarbon

The work flow of petrophysical analysis is shown in Fig 5.4.

5.5.1 Marking the Zone of interest

Based on regional and previous study following formation (Lower Goru formation) is taken as zone of interest in working well i.e Doti-01.

Here in these zones the value of GR Is comparatively low showing that shale volume is low and volume of sand is high ,also the caliper log is smoth in these zones indicates it is not a lose material. On the basis of GR log, caliper log and previous work we can easily mark these zones.

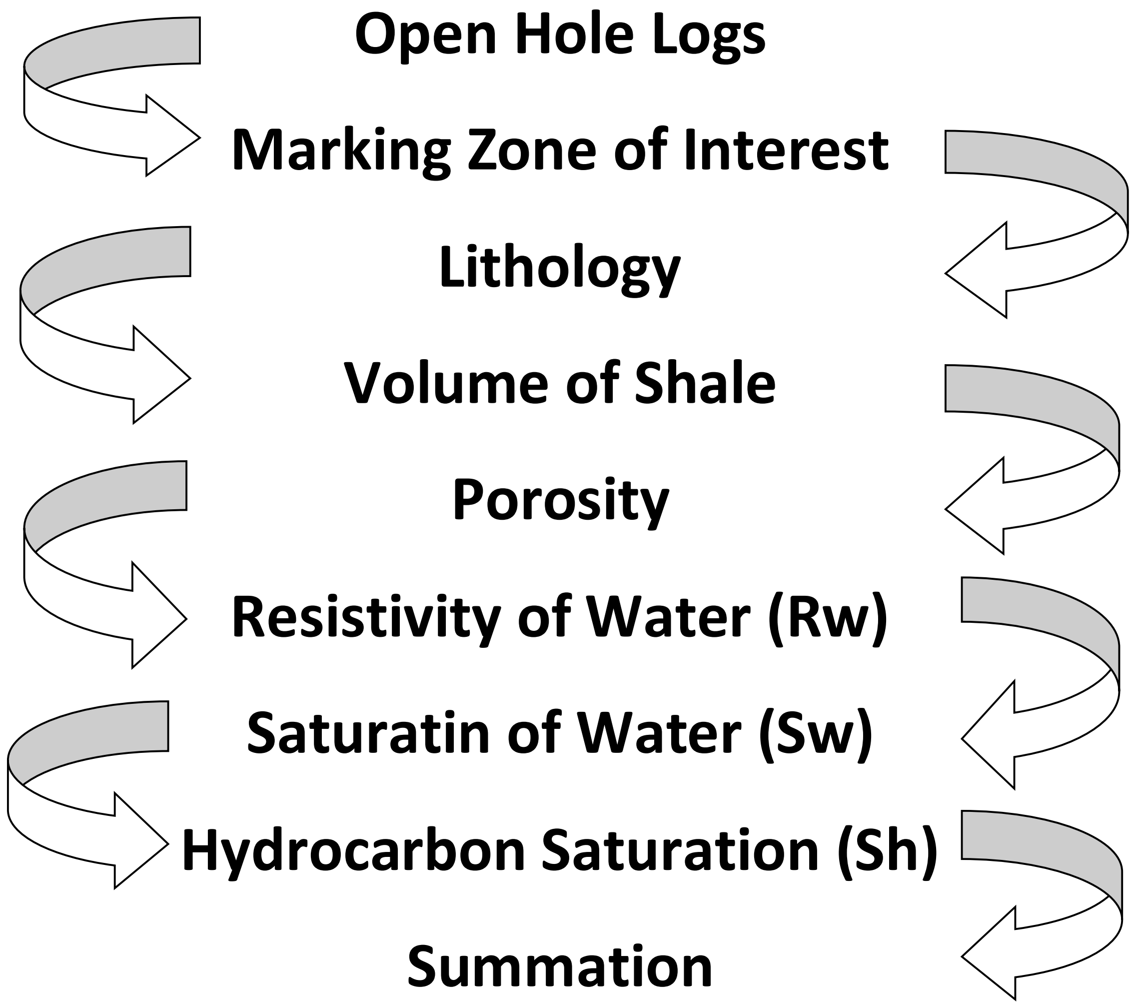


Fig 5.3 Work flow adopted for petrophysical interpretation of wells.

5.5.2 Lithological interpretation from Wireline logs

Lithological interpretation has been done by direct and indirect methods. Seismic data gives regional picture of the depositional behavior of the area and facies changes, well logs are also method interpreted and give indirect lithology of the formations. Mud logging is also a way of direct method to interpret the subsurface lithology like the outcrop. Indirectly, the penetration rate of the drill bit into the formation may be compared to a sonic log or gamma ray log and a good interpretation of bed boundaries has been made from it. However, in general, like well logs, the drilling rate involves too many variables, such as weight on the bit, bit wear, pump rates and so on, for it to be as accurate boundary indicator. The mud log interpretation of lithology should not be used to interpret boundaries on the well logs. So, the lithological interpretation must be made on the composite document showing all details of logs. Often the GR, SR, Sonic, Density and resistivity logs are used for this purpose (Rider, 2002).

GR is the index log used for lithological interpretations and gives rise to the petrophysicals, sedimentological and sequence stratigraphical interpretation. If a zone has a high potassium content coupled with a high gamma ray response, the zone is not shale. Instead, it could be a feldsparhic, glauconitic, or micaceous sandstone (Schlumberger, 1974).

The gamma ray log is a record of a formation's radioactivity. The simple radiations emanates from naturally occurring uranium, thorium and potassium. The simple gamma ray log gives the radioactivity of the three elements combined, while the spectral gamma ray log shows the amount of each individual element contributing to this radioactivity.

The geological significance of radioactivity lies in the distribution of these three elements. Most rocks are radioactive of some degree, igneous and metamorphic rocks more so than sediments. However amongst the sediments, shale has by far the strongest radiations. It is for this reason that the simple gamma ray log has been called the "shale log" although modern thinking shows that it is quite insufficient to equate gamma ray emission with shale occurrence. Not all shall is radioactive, and all that is radioactive is not necessary shale. The gamma ray log is still principally used quantitatively to derive shale volume. In its simple form, it can be used to correlate to suggest facies and sequences and, of course, to identify lithology (shaliness). The spectral gamma ray can be used additionally to drive a quantitative radioactive mineral volume and a more accurate shale volume. It can indicate dominant clay mineral types, give indications of depositional environment, indicate features and help to localize source rocks (Rider, 2002).

The density log is a useful lithology indicator, can be used to identify certain minerals, can help to assess sources organic matter content and may help to identify overpressure and fracture porosity (Rider, 2002).

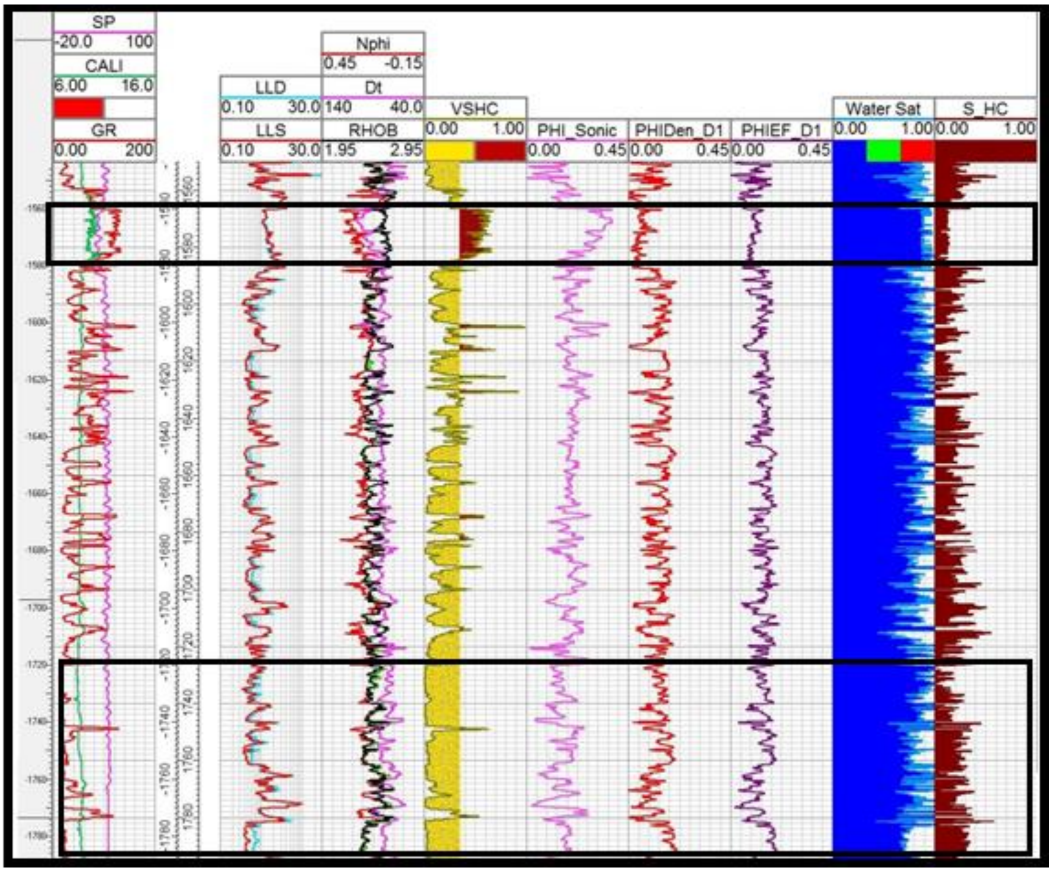


Fig 5.4 Demarcation the Zone of interest

5.5.3 Volume of Shale

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

$$Igr = \frac{GRlog - GRmin}{GRmax - GRmin}, \tag{1}$$

Where

I_{GR}= Gamma Ray Index,

GR_{log} = Gamma Ray log reading of the formation,

GR_{max} = Maximum gamma Ray log reading,

GR_{min} = Minimum gamma Ray log reading

Then by using the following formula volume of shale is computed

$$V_{sh} = 0.0883[2(3.7*I_{GR}) - 1], \tag{2}$$

It must be noted that when the shale volume is zero lithology must be clean sand (Schlumberger, 1974). GR log is the most widely used method to determine the volume of shale. In the quantitative evaluation of shale content, it is assumed that radioactive minerals are absent in clean rocks and are compared to shaly rocks.

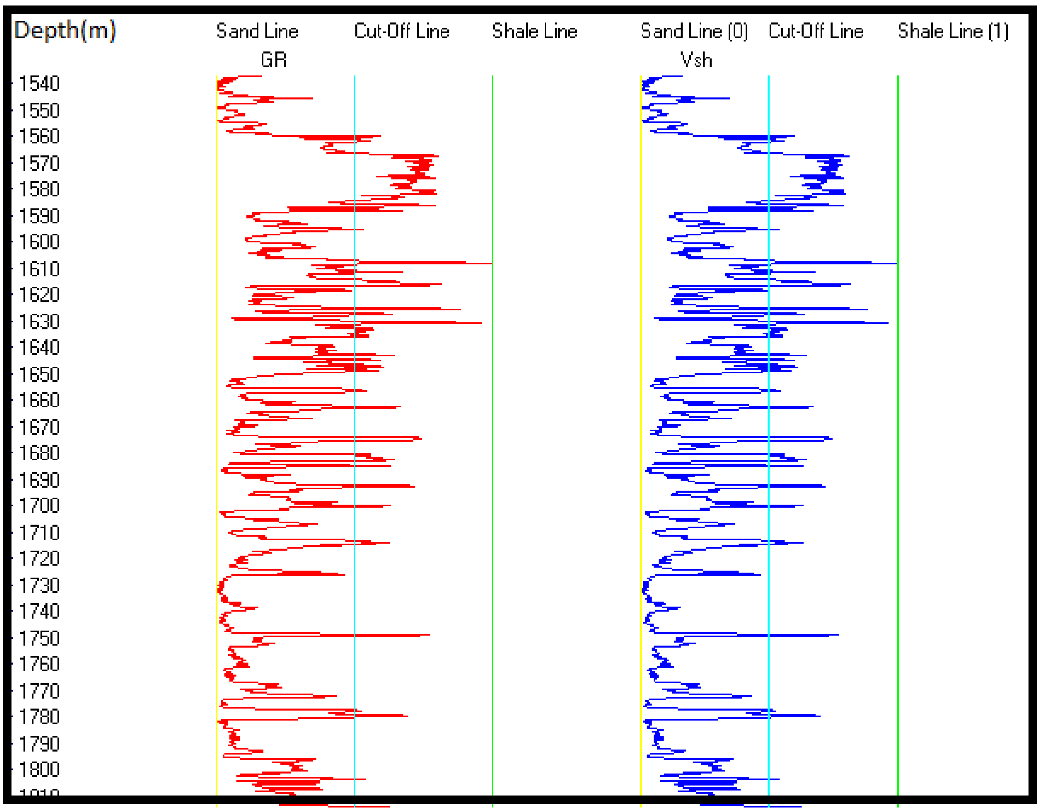


Fig 5.5 Volume of Shale with depth.

In reservoir portion volume of shale is present in small amount but as we go deep there are some small packages of shale is present but mostly the sand is clean and have little amount of shale in it.The average percentage of shale in this is portion is 16-20% Table 5.1.

5.5.4 Porosity

Porosity is defined as the ratio of the volume of void spaces to the total volume of the rock. Velocities have an inverse relation with the porosity, so that for small values of velocities the porosity value is high. The porosity is represented by (Φ).

After the cutoff of shale and demarcation of reservoir, porosity is conducted through which the hydrocarbons will move towards the borehole. But diagenetic processes are particularly important in hydrocarbons reservoirs, because they effect the development of porosity and permeability. Porosity and permeability of sandstone depends largely upon primary depositional process and sediment texture (slat, 2006). Well consolidated sandstones may have 10 to 15% porosity; unconsolidated sands may have 30%, porosity (Schlumberger, 1974).

Porosity	Percentage
Excellent	25-30%
Very Good	20-25%
Good	15-20%
Fair	10-15%
Poor	5-10%
Very Poor	<5%

Table 5.1 Porosity Values. Table retrieved from: http://web.ead.anl.gov

Porosity Calculations

The density log is a continuous record of a formation's bulk density. This is the overall density of a rock including solid matrix and the fluid enclosed in the pores. Geologically, bulk density is a function of the density of the minerals forming a rock (i.e. matrix) and the volume of free fluids which it encloses (i.e. porosity). For example sandstone with a no porosity will have a bulk density of 2.65/cm3, the density of pure Quartz. At 10% porosity the bulk density is only 2.49g/cm3, being the sum of 90% quartz grains (density 2.65g/cm3) and 10% water (density 1.0g/cm3).

The density log is used to calculate acoustic impedance. It is a useful lithology indicator, can be used to identify certain minerals, can help to assess source organic matter content and may help to identify overpressure and fracture porosity (Riser, 202).

Neutrons emitted from radioactive source, collide and lose energy (billiard ball effect). Primarily depends on hydrogen concentration or index, detect either epithermal neutrons, thermal neutrons, capture gamma rays or combination (Rider, 2002).

The use of neutron to probe formation has had a long history in well logging. The first neutron device appeared shortly after World War II. The initial application was to determine formation porosity. Currently, in addition to logging tools that detect neutrons in order to determine formation hydrogen content, there are tools which use pulsed neutrons to analyze the absorption rate of the emitted neutrons, and gamma rays spectroscopy tools which detect neutron-induced gamma rays to produce a limited chemical analysis of formation. The key to understanding the responses of these tools in the interactions that are exploited. Unlike gamma rays sources, which come from naturally occurring or easily produced isotopes, neutron sources used in logging are the result of deliberate nuclear reactions. The neutron log is used to measure porosity. It is an excellent discriminator between gas and oil. It can be used geologically to identify gross lithology, evaporates, hydrated minerals and volcanic rocks. When combined with the density log on compatible scales, it is one of the best subsurface lithology indicators (Rider, 2002).

The porosity values as computed from various sources showed reasonable agreement with each other. Different porosities calculated are

1- Neutron Porosity
2- Density Porosity
3- Average Porosity
4- Effective Porosity

Neutron Porosity

Neutron logs are porosity logs that measure the hydrogen concentration in a formation. In clean formations (i.e., shale-free) where the porosity is filled with water or oil, the neutron log measures liquid filled porosity (φ_N, PHIN, or NPHI).

The neutron porosity shows increasing behavior with depth. Neutron log reading gives the direct estimation of porosity.

Density Porosity

Formation bulk density (ρ_b) is a function of matrix density, porosity, and density of the fluid in the pores (saltwater mud, freshwater mud, or hydrocarbons). To determine density porosity, the matrix density and type of fluid in the formation must be known. The formula for calculating density porosity is:

$$\mathbf{\Phi D = \frac{\rho m - \rho b}{\rho m - \rho f}}, \qquad \mathbf{(3)}$$

Where

ρ_m = density of matrix (gm/cm^3)

ρ_f = density of fluid (gm/cm^3)

ρ_b = log Response in zone of interest

Density porosity shows almost constant behavior with depth. At some points the density porosity approaches to zero but overall it shows constant behavior Fig 5.7.

Sonic porosity

The sonic log is a porosity log that measures interval transit time (Δt, delta t, or DT) of a compressional sound wave traveling through the formation along the axis of the borehole. Interval transit time (Δt) in microseconds per foot, µsec/ft (or microseconds per meter, µsec/m) is the reciprocal of the velocity of a compressional sound wave in feet per second (or meters per second). The interval transit time (Δt) is dependent upon both lithology and porosity.

Therefore,a formation’s matrix interval transit time must be known to derive sonic porosity by the following formulas:

$$\Phi S = \frac{\Delta T - \Delta Tmat}{\Delta Tf - \Delta Tmat}, \quad (4)$$

Where

Φ_S = sonic porosity µs/ft

ΔT= Log response

ΔT_{mat}= Transit time in matrix

ΔT_f= Transit time in fluids

Fig 5.6 shows the sonic derived porosity behavior with depth. Opposite to density porosity sonic derived porosity shows decreasing behavior with depth. It slightly decreases with depth.

Average Porosity

Average porosity can be calculated by using the following formula

$$PHIA / \Phi = [(PHID)^2 + (PHIN)^2/2]^{1/2} \quad (5)$$

Where

PHIA/ **Φ** : Average Porosity

PHID/ **ΦD**: Density Porosity

PHIN/ **ΦN**: Neutron Porosity

Effective Porosity

Effective porosity is calculated with the help of following formula

$$PHIE = PHIA * (1 - V_{sh}) \quad (6)$$

Where

PHIE: Effective porosity

PHIA: Average porosity

V_{sh} : Volume of shale

Effective porosity is used to calculate the saturation of water in the reservoir zone in the wells. The interconnected pore volume or void space in a rock that contributes to fluid flow or permeability in a reservoir. Effective porosity excludes isolated pores and pore volume occupied by water adsorbed on clay minerals or other grains. Overall effective porosity slightly increasing with depth in reservoir portion Fig 5.6.

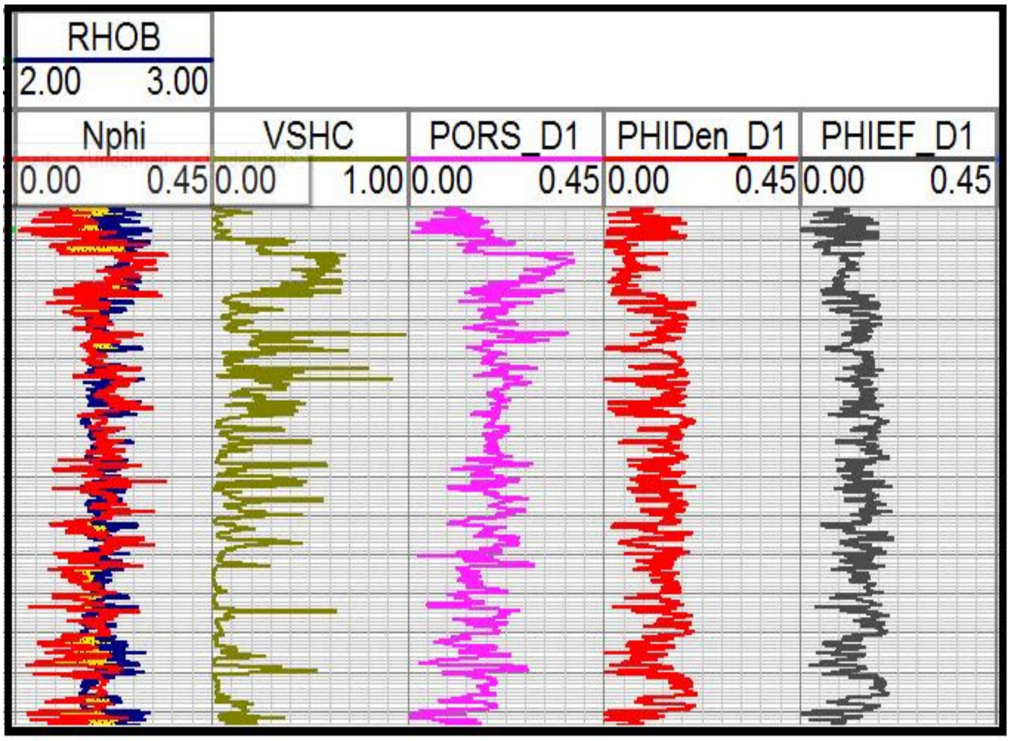


Fig 5.6 Neutron, Density, Sonic and Effective Porosities respectively.

5.5.5 Resistivity of Water

There are many methods to obtain water resistivity (Rw) and this most sensitive parameter in the computation of water saturation in developed fields water samples can be obtained and got analyzed from laboratories. In case of wild cat wells, usually water-bearing strata are not present on logs therefore it is necessary to compute it by indirect methods. Water samples recovered from the Repeat Formation Test (RFT) or Drill Stem Test (DST) have to be analyzed for their chemical compositions and measurements of resistivity at different temperatures, this is the most reliable method. Water resistivity (Rw) is calculate with the help of certain parameters like bottomhole temperature, water salinity (ppm) and static spontaneous potential.

5.5.6 Water and Hydrocarbon Saturation

Archie's Equation can be used to calculate the water saturation:

$$Sw = \frac{a}{\Phi m} X \frac{Rw}{Rt}, \qquad (7)$$

where

Sw = water saturation

Rw = is water resistivity (formation)

Φ= is porosity, m is (cementation factor) = 0.81, **a** (constant) = 1

Rt = LLD log response

Rw has been calculated with help of the following formula:

$$Rw = \Phi^2 \times R_t, \qquad (8)$$

Where
Φ = porosity in clean zone

R_t = Observed LLD curve in clean zone.

By using following relation hydrocarbon saturation (**S_{hc}**) can be found

$$S_{hc} = 1 - S_w, \qquad (9)$$

The calculated hydrocarbon saturation of reservoir is shown in Figure 5.7.

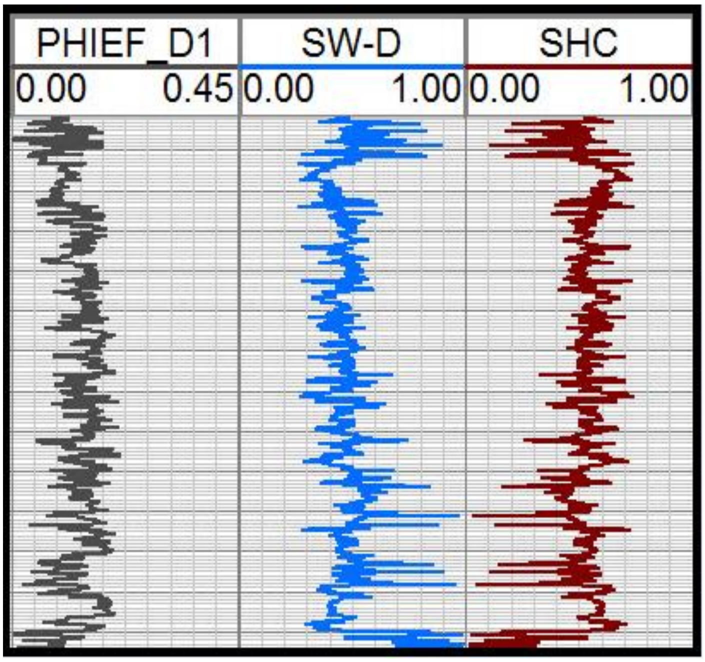


Fig 5.7 Effective porosity, water and Hydrocarbon Saturation.

Saturation of water is increasing but the hydrocarbon saturation is decreasing with the depth in reservoir. The all calculations about reservoir are given in Table 5.2.

5.6 Estimated Results

The calculations are done in reservoir portion and the calculated result are given in Table 5.2.

Well Name	Doti-01
Volume of Shale	16-18%
Total Porosity	15-18%
Effective Porosity	12-16%
Saturation of Water	80-85%
Saturation of Hydrocarbon	15-20%

Table 5.2 Estimated results of reservoir.

Chapter # 6
Facies Modeling and Regression Analysis

6.1 Introduction to Facies Modeling

In geology, Facies The observable attributes of a sedimentary rock body that reflect the depositional processes or environments that formed it. 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 figure 6.1 (Rais et al, 2012).

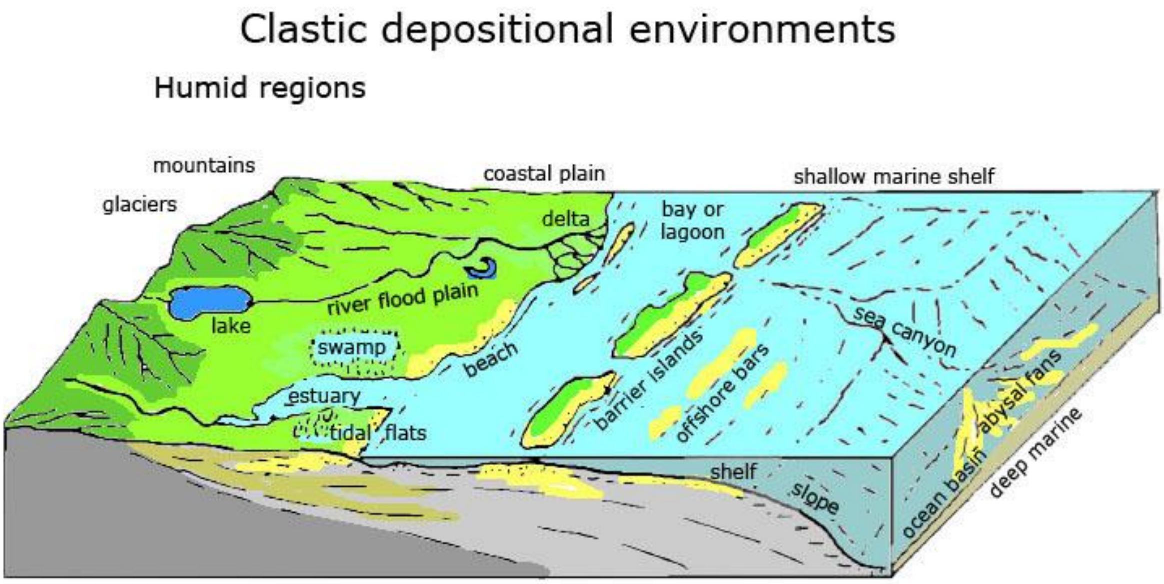


Figure 6.1 Major depositional environments. Picture retrieved from: Geology Cafe.com.

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. 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 (Rais et al, 2012).

6.2 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).

6.2.1 Facies Modeling (Interpretation) of Well Data

Cross plots

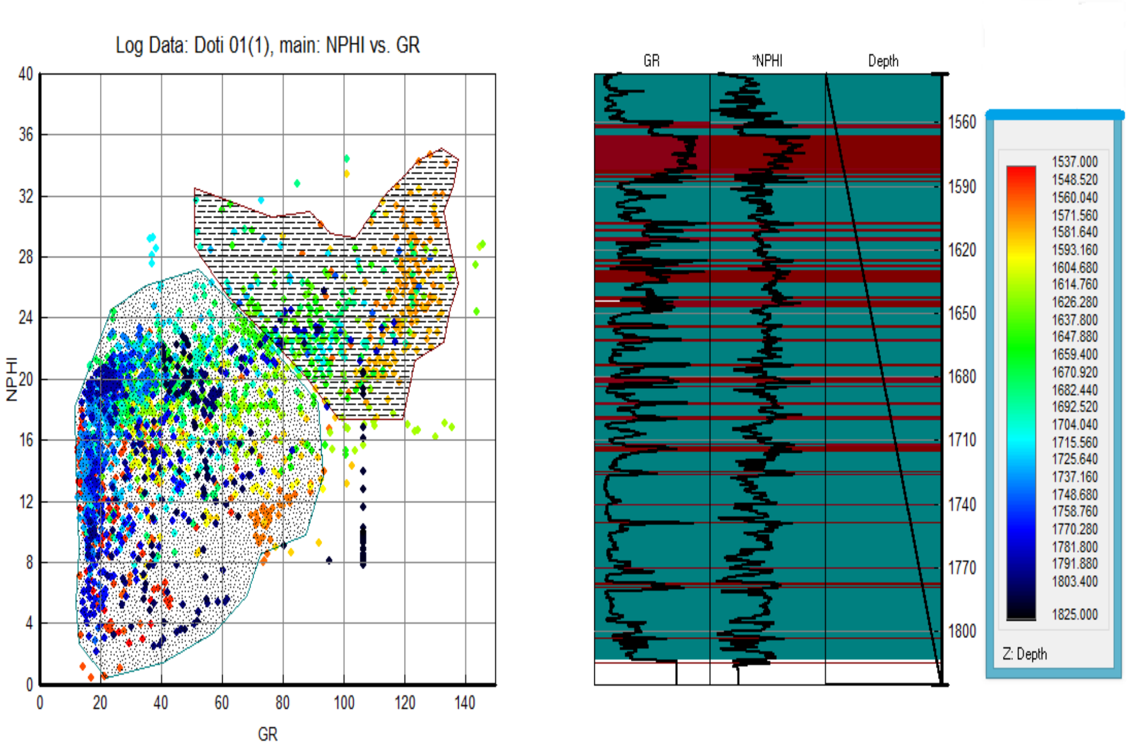


Figure 6.2 Gamma Ray versus Neutron PHI

The neutron log is measuring the hydrogen population of the formation. Therefore, it records a nearly constant response through sands and increases in Shales. Since the population of hydrogen is nearly the same in water, oil, and wet clay, the neutron log cannot distinguish between them. Hydrogen population is therefore no longer controlled by the pore distribution. The neutron log then measures increased hydrogen as the clay volume increases (Heslop, 2005).

High Gamma ray log and Neutron porosity log indicate the shale while the low response of both logs shows the existence of clean sand. Moderate Gamma ray log indicates the shaly sand around the shale sand boundary figure 6.2.

The cross plot between RHOB and DT in figure 6.3 shows that in our reservoir zone the major part of lithology is neither pure sand nor shale but it is shaly sand (Green colour shows the shaly sand**)** clean sand is slightly higher than shale and it has very small quantity of sandy shale.Sandy shale is minority.

Figure 6.4 shows that major lithology is shaly sand and it is interbedded with sand. In this cross plot sandy shale shows relatively higher quantity and it is spread unlike previous cross plot. Shale is very low in amount.

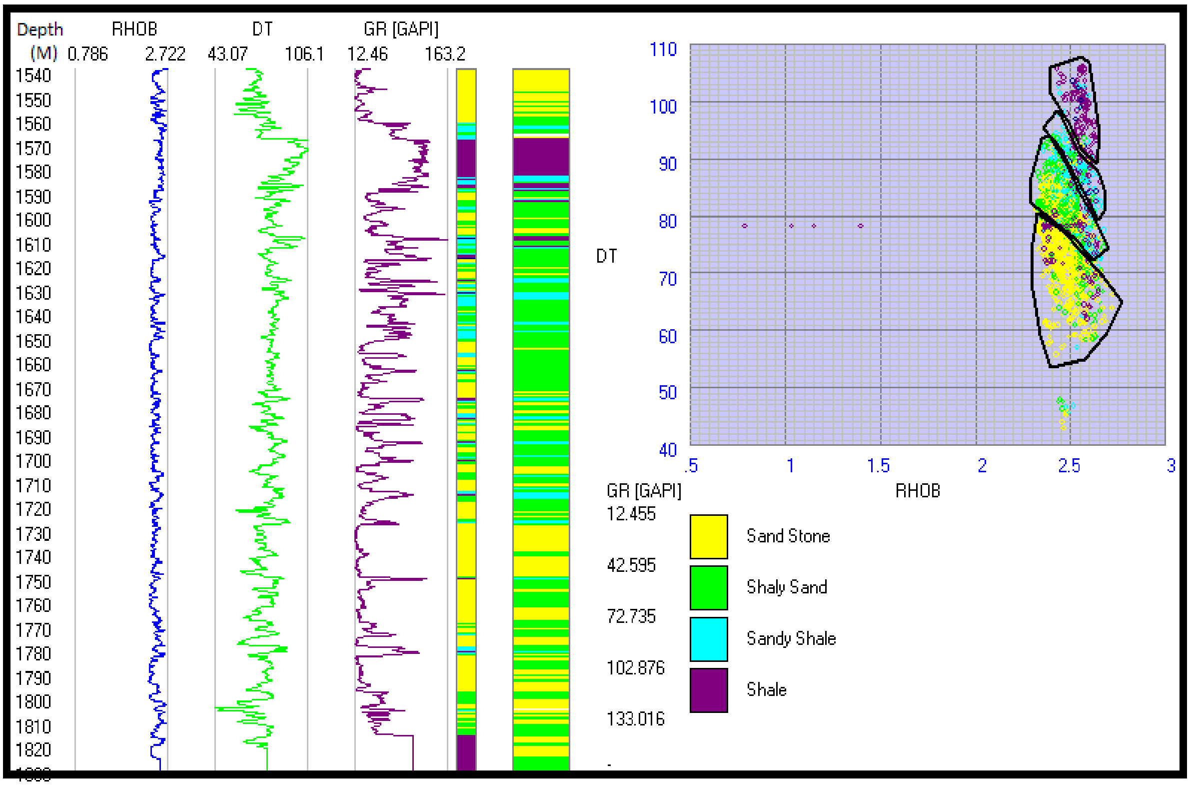


Figure 6.3 RHOB versus DT.

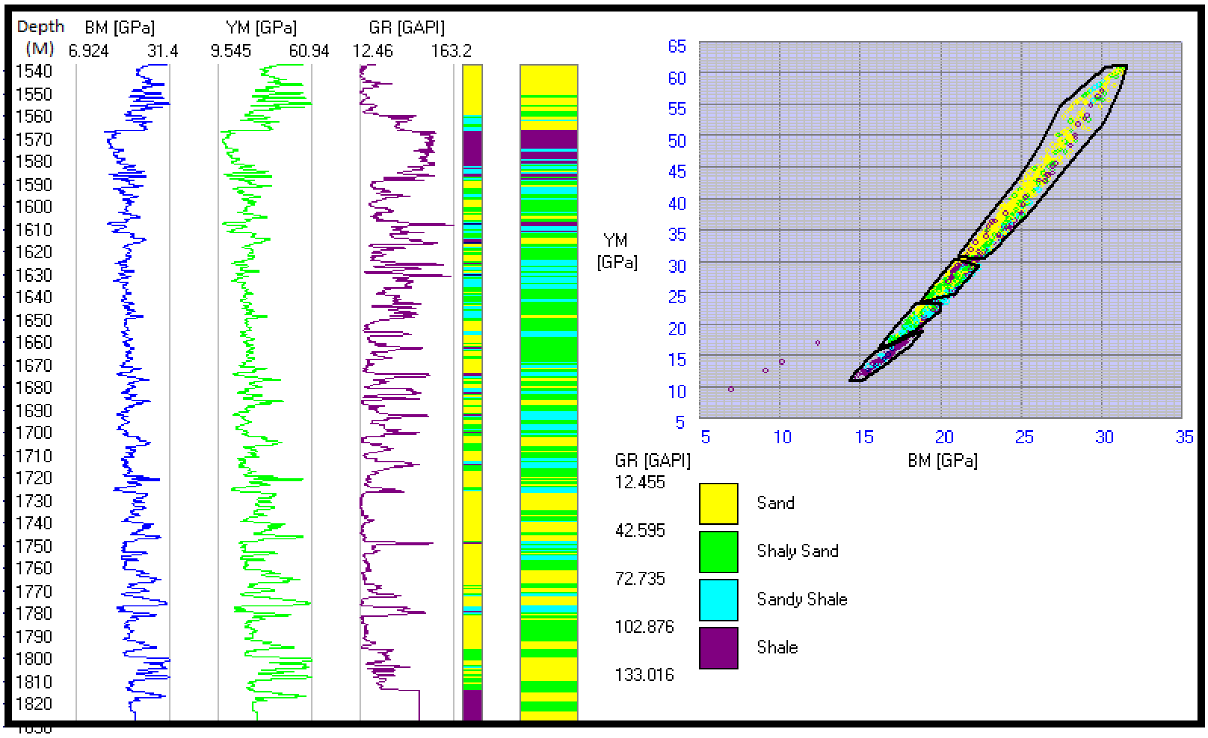


Figure 6.4 Bulk versus Young's Modulus.

Figure 6.5 shows similar behavior as shown in Figure 6.4.Clean sand and shale are relatively low in quantity but shaly sand shows large portion that it covers and sandy shale is interbedded and it is spread all over the reservoir.

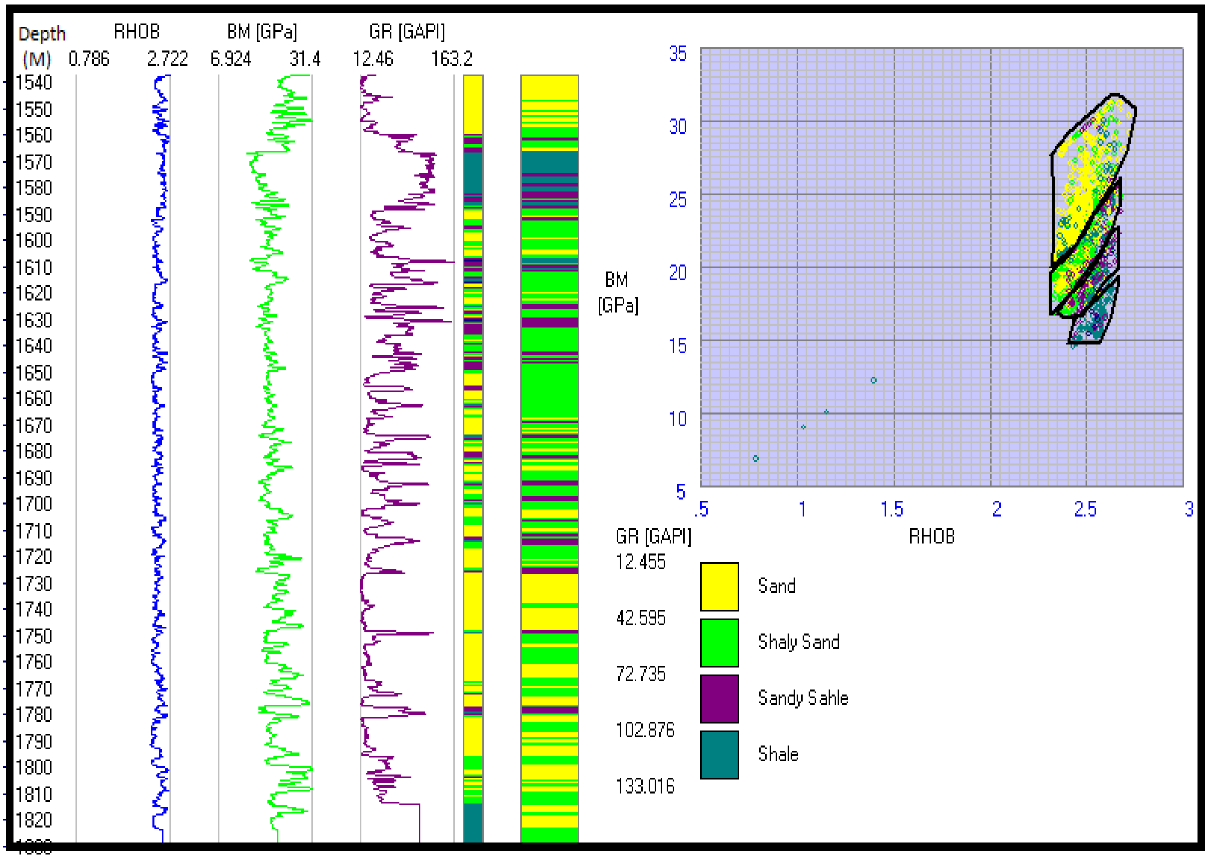


Figure 6.5 RHOB versus Bulk Modulus.

6.3 Regression Analysis

In statistical modeling, regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (or 'predictors'). More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed. Most commonly, regression analysis estimates the conditional expectation of the dependent variable given the independent variables – that is, the average value of the dependent variable when the independent variables are fixed. Less commonly, the focus is on a quantile, or other location parameter of the conditional distribution of the dependent variable given the independent variables. In all cases, the estimation target is a function of the independent variables called the regression function.

6.3.1 Regression Correlation Analysis

We can use the statistical technique to check the relationship between different logs and chose the best relationship holders out of them. The red and orange colours shows the strong relationship Figure 6.6.

Log-X	Log-Y	L.Corr.Coef	Equation
GR	RHOB	.30797	RHOB = 2.414 + 0.0009 GR
GR	DT	.52197	DT = 72.533 + 0.1295 GR
GR	SM	-.41313	SM = 14.464 - 0.0487 GR
GR	BM	-.37205	BM = 23.287 - 0.0328 GR
GR	YM	-.41865	YM = 35.913 - 0.1123 GR
GR	LC	-.0195	LC = 13.645 - 0.0003 GR
GR	Vp	-.49876	Vp = 4184.466 - 5.8538 GR
RHOB	GR	.30797	GR = -204.526 + 104.8620 RHOB
RHOB	DT	-.05917	DT = 91.791 - 4.9981 RHOB
RHOB	SM	.25969	SM = -13.845 + 10.4338 RHOB
RHOB	BM	.39448	BM = -7.675 + 11.8583 RHOB
RHOB	YM	.26501	YM = -29.705 + 24.2005 RHOB
RHOB	LC	.80674	LC = 1.555 + 4.9024 RHOB
RHOB	Vp	.10995	Vp = 2788.276 + 439.4009 RHOB
DT	GR	.52197	GR = -113.571 + 2.1042 DT
DT	RHOB	-.05917	RHOB = 2.518 - 0.0007 DT
DT	SM	-.94677	SM = 47.643 - 0.4504 DT
DT	BM	-.92747	BM = 47.761 - 0.3301 DT
DT	YM	-.95195	YM = 111.694 - 1.0292 DT
DT	LC	-.41488	LC = 15.999 - 0.0298 DT
DT	Vp	-.98518	Vp = 7575.141 - 46.6120 DT
SM	GR	-.41313	GR = 95.158 - 3.5012 SM
SM	RHOB	.25969	RHOB = 2.386 + 0.0065 SM
SM	DT	-.94677	DT = 103.064 - 1.9904 SM
SM	BM	.98373	BM = 12.805 + 0.7360 SM
SM	YM	.99949	YM = 2.972 + 2.2718 SM
SM	LC	.45859	LC = 12.805 + 0.0694 SM
SM	Vp	.98127	Vp = 2713.964 + 97.6012 SM
BM	GR	-.37205	GR = 144.387 - 4.2142 BM
BM	RHOB	.39448	RHOB = 2.180 + 0.0131 BM
BM	DT	-.92747	DT = 135.575 - 2.6060 BM
BM	SM	.98373	SM = -16.453 + 1.3148 BM
BM	YM	.98739	YM = -34.677 + 2.9996 BM
BM	LC	.61076	LC = 10.969 + 0.1235 BM
BM	Vp	.95627	Vp = 1133.968 + 127.1252 BM
YM	GR	-.41865	GR = 100.331 - 1.5610 YM
YM	RHOB	.26501	RHOB = 2.376 + 0.0029 YM
YM	DT	-.95195	DT = 105.797 - 0.8805 YM
YM	SM	.99949	SM = -1.295 + 0.4397 YM
YM	BM	.98739	BM = 11.811 + 0.3250 YM
YM	LC	.47892	LC = 12.674 + 0.0319 YM
YM	Vp	.98359	Vp = 2583.883 + 43.0425 YM
LC	GR	-.0195	GR = 68.569 - 1.0927 LC
LC	RHOB	.80674	RHOB = 0.653 + 0.1328 LC
LC	DT	-.41488	DT = 158.061 - 5.7666 LC
LC	SM	.45859	SM = -29.468 + 3.0320 LC
LC	BM	.61076	BM = -19.645 + 3.0213 LC
LC	YM	.47892	YM = -68.184 + 7.1971 LC
LC	Vp	.40531	Vp = 238.296 + 266.5396 LC
Vp	GR	-.49876	GR = 218.151 - 0.0425 Vp
Vp	RHOB	.10995	RHOB = 2.356 + 0.0000 Vp
Vp	DT	-.98518	DT = 160.071 - 0.0208 Vp
Vp	SM	.98127	SM = -26.335 + 0.0099 Vp
Vp	BM	.95627	BM = -6.316 + 0.0072 Vp
Vp	YM	.98359	YM = -57.104 + 0.0225 Vp
Vp	LC	.40531	LC = 11.241 + 0.0006 Vp

Fig 6.6 Suitable logs for regression analysis.

Vp and Shear Modulus

Figure 6.7 shows the regression correlation for Vp – Shear Modulus that shows almost 80% of linearity between them (most of the time as the Vp increases SM also increases in the reservoir interval), curvy behavior at the start and at the end showing slight deviation from linearity indicating the change in lithology and change in fluid respectively, dotted lines spotted and showing the possible variation occurred from linearity.

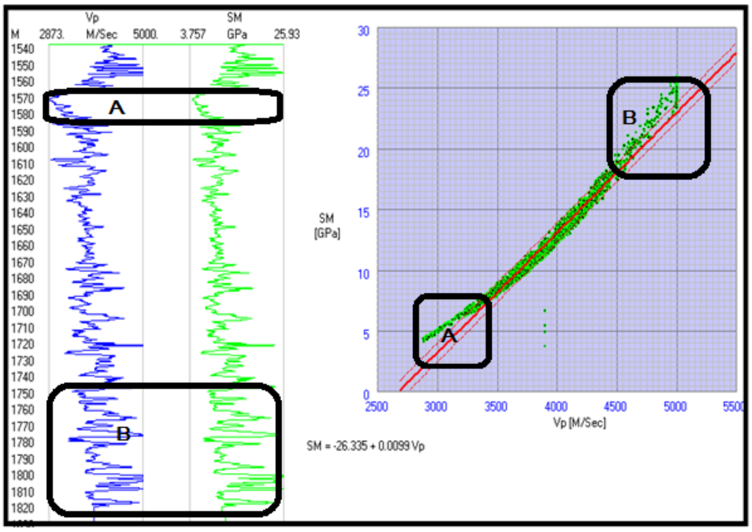


Fig 6.7 Regression analysis between Vp and shear Modulus.

Vp and Bulk Modulus

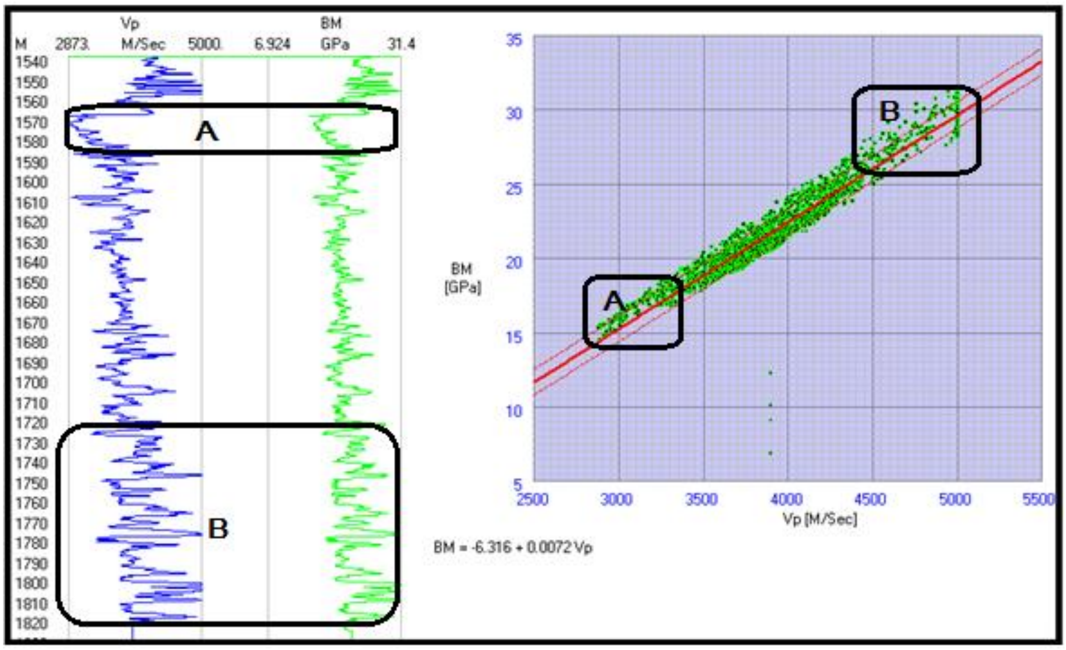


Fig 6.8 Regression analysis between Vp and Bulk Modulus.

The figure 6.8 shows the linear relationship between Vp and Bulk modulus in the reservoir interval of 1537m-1830m. By statistical analysis we can say that the data is closely clustered which is an indication of strong linear relationship, at the start and at the end showing slight deviation from linearity indicating the change in lithology and change in fluid respectively dotted lines showing the possible variation that can occur from linearity.

Vp/Vs and Poisson Ratio(Fluid type identification)

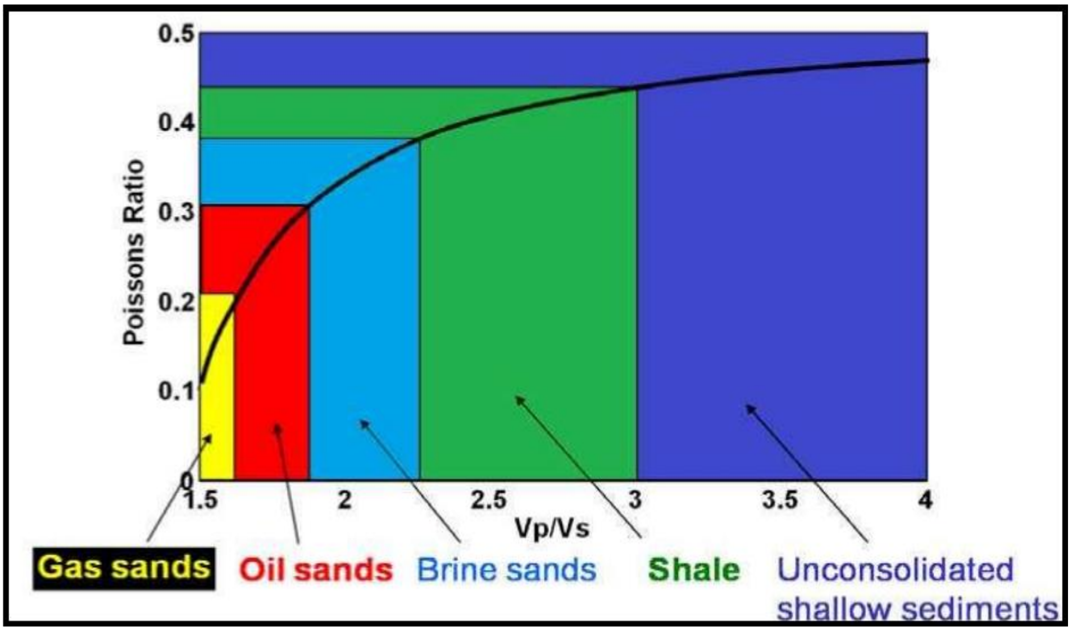


Fig 6.9 Fluid type identification Picture retrieved fromhttp://www.slideshare.net.

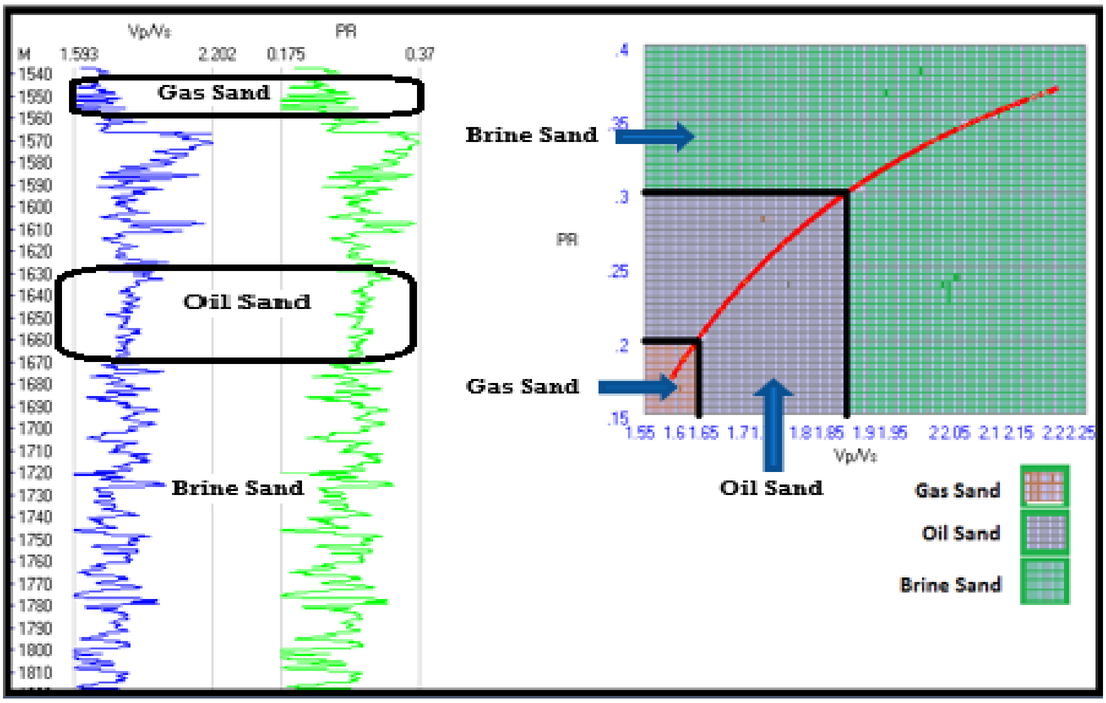


Fig 6.10 Regression analysis between Vp/Vs and Poisson Ratio.

Figure 6.9 shows the different fluids on the basis of standard ranges of Poison ratio and Vp/Vs ratio. Above figure 6.10 shows the slight deviation from the linear relationship showing slight curvy nature at the start and at end although clusterness of data shows that two parameters has strong relationship, at the start and at the end showing slight deviation from linearity indicating the change in lithology and change in fluid respectively Although dotted lines on the both sides of straight line shows the possible variation that can occur from linearity. On the basis of this cross plot we can differentiate between different kinds of fluid as marked in the figure.

It shows in the reservoir interval as the Vp/Vs increases so as the Poisson ratio and vice versa.

CONCLUSION

- Time and Depth contour shows that Horst and Graben structure formed in study area.
- Petrophysical results shows that Lower Goru have good porosity but it is mostly consists of water i.e 80-85%.
- Facies Modelling shows that lithology is mostly shaly sand.
- Fluid type identification shows that reservoir contain little bit of oil and largely consists of water.

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