# 2D Seismic Data Interpretation of Badin Area Integrated with Petro physical Analysis and Facies Modelling.

**BY**

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**“With The Name of ALLAH, the Most Gracious & the Most Merciful**

# CERTIFICATE

This dissertation submitted by **MUHAMMAD SAMI UL HAQ** son of **EHSAN UL HAQ** 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 BS degree in Geophysics.

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# DEDICATED

# TO

My Parents and

My respected supervisor

Prof. Dr. Mona Lisa

# ACKNOWLEDGEMENT

First praise is to Allah, the most Beneficent, Merciful and Almighty, on whom ultimately we depend for sustenance and guidance. I bear witness that Holy Prophet Muhammad (PBUH) is the last messenger, whose life is perfect model for the whole mankind till the Day of Judgment. I thank Allah for giving me strength and ability to complete this study.

I am especially indebted to my honorable supervisor **Prof. Dr. Mona Lisa** for giving me an initiative to this study.

I specially acknowledge the prayers and efforts of my whole family, specially my parents for their encouragement, support and sacrifices throughout the study. I also wish to thank the whole faculty of my department for providing me with an academic base, which has enabled me to take up this study I pay my thanks to the employees of clerical office who helped me a lot and all those their names do not appear here who have contributed to the successful completion of this study.

**Muhammad Sami Ul Haq**

# ABSTRACT

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

1-D modeling is done for the Doti-01 well and zone of interest is the Lower Goru. Petro physical analysis is performed to find out the hydrocarbon saturation .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.

# Contents

# CHAPTER NO. 1: INTRODUCTION

## 1.1 Introduction

Seismic methods are the most important and commonly conducted geophysical survey technique used in the Oil and Gas exploration industry. 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, petro physical analysis and estimation of rock properties are the most important tools to identify hydrocarbons. The conditioning and analysis of log data for quantitative interpretations is often simply categorized as rock physics. Rock physics represents the link between qualitative geologic parameters and quantitative geophysical measurements (Avseth, 2005).

Investigation of the Earth's interior using geophysical methods, involves taking measurement at a near the surface of the Earth for analysis that can expose both vertical and lateral variations of the physical properties of the Earth's subsurface (Plummer, 2014).

In order to know the quantity of hydrocarbon accumulation in reservoir rocks (sandstone, limestone, dolomite etc), some basic petro physical parameters must be evaluated. These include storage and flow properties (porosity, permeability, fractional flow), fluid identification, interaction of surface forces existing between the rock and contained fluids (capillary pressure), measurements of pressure, stress conditions, electric conductivity of fluid-saturated rocks etc. These properties and their relationship are used to recognize and access hydrocarbon reservoirs, source rock, cape rock, and aquifers (Kemal,A 1992)

Seismic attributes all of the measured, computed are implied quantities obtained from the seismic data. Seismic attributes extract information from seismic reflection data that can be used for quantitative and qualitative interpretation (Chopra, 2007).

Facies analysis is the identification of subsurface lithology. Horizontal wells are rarely cored, a method is needed to indirectly derive the facies distribution within the formations penetrated by those wells (Saggaf and Nebrija, 2000). The uses of litho-facies identification and analysis have a greater importance in terms of clues towards the interpretation of depositional environments of sedimentary rocks. A succession of sedimentary strata should be described first in terms of distinct litho-facies units reflecting different processes of all the depositions. Then the facies can be grouped in the litho-facies associations, which can be interpreted according to depositional environments on the basis of the combination of physical, chemical and biological processes which have been identified from analysis of the facies (Sahito et al, 2013).

Study area is located in East of Badin district in Sindh province in Pakistan. The district is placed between 24° 5’N to 25° 25’N Latitude and 68° 21’ E to 69° 20’ E Longitude. The study area is the part of southern Sindh monocline, southern Indus basin of Pakistan. Geological boundaries of the area are Indian shield in the East and Kirthar ranges in the West, to the North it is bounded by the Sukkur rift zone and with the Indus off shore platform being the southern extension (Memon, 1999).

The Badin Block is the part of the Lower Indus which is located to the southern eastern part of Pakistan. The Nagar parker Granite in the extreme Southeastern corner of Pakistan is the exposed part of the Indian craton. The fossils fauna found in the Goru Formation in Badin Block suggest that deposition took place in varied condition, i.e., from continental, transitional, deltaic, shallow marine to deeper marine conditions. The reported thickness of combined Goru Formation (Upper and Lower Goru) 2000ft to 7500ft. The oldest sediments have been reported in the well Marvi -1 (Total depth 17000 ft, drilled by Union Texas in 1997)

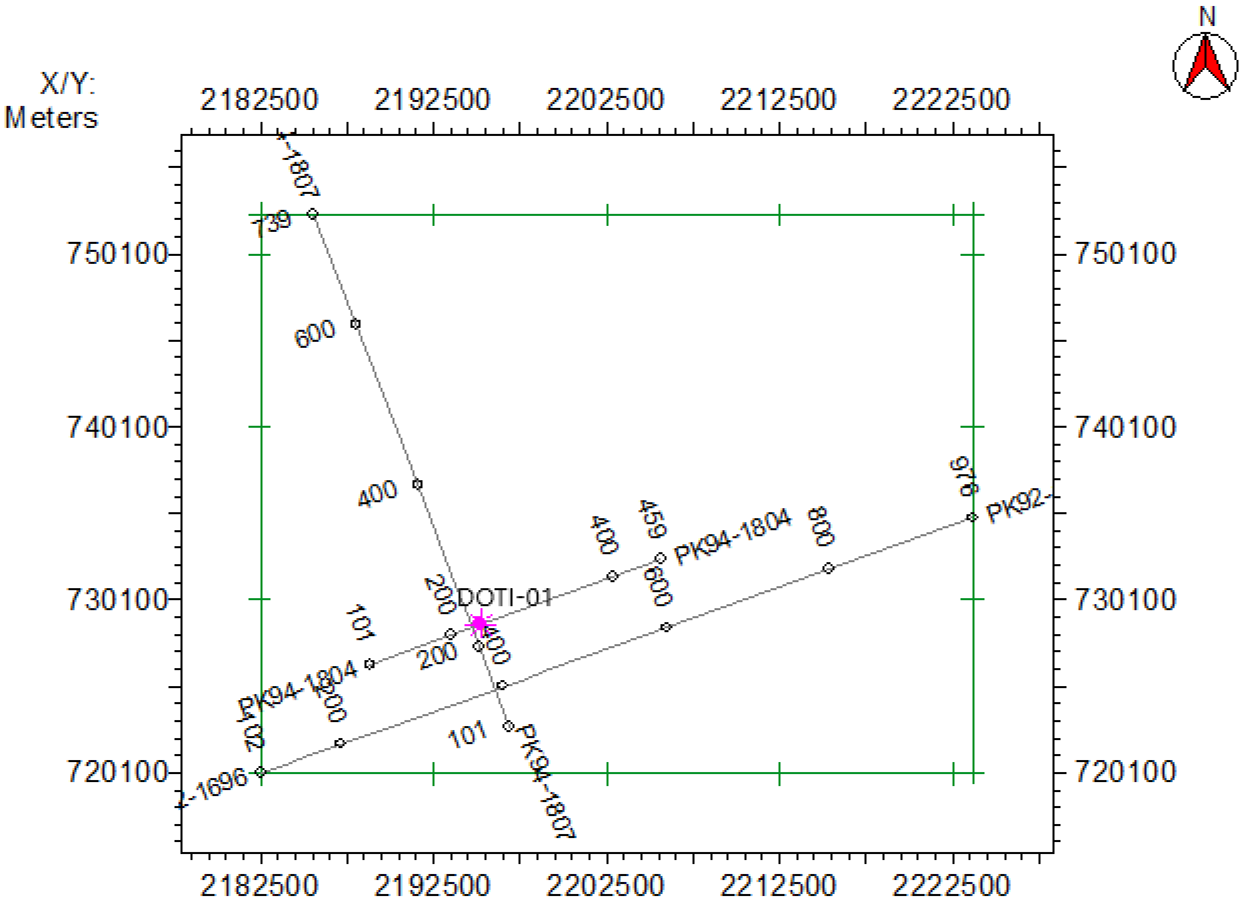
(igdsindh)

## 1.2 Base Map

For a geophysicist, a base map is that which shows the orientation of seismic lines and specified points at which seismic data were carried out. It is a map which shows typical location of wells and seismic survey points as well as some surrounding infrastructure like building or roads. Its significance is the representation of locations with respect to geographic reference.

Two dip and one strike line is selected in the area.

The Dip lines are PK92-1696 and PK94-1804, and one strike line PK94-1807is selected. Well under study is DOTI-1.




## 1.3 Data Formats

Seismic reflection data which consist of following formats;

➢SEG-Y (Seismic Data format)

➢LAS (Well Log Data format)

➢Navigation

## 1.4 Processing Objective

Processing phenomenon generally fall into one of the following categories:

1- Enhancing signal at the expense of noise

2- Providing velocity information

3- Collapsing diffractions and placing dipping events in their true subsurface locations (Migration).

## 1.5 Workflow Analysis

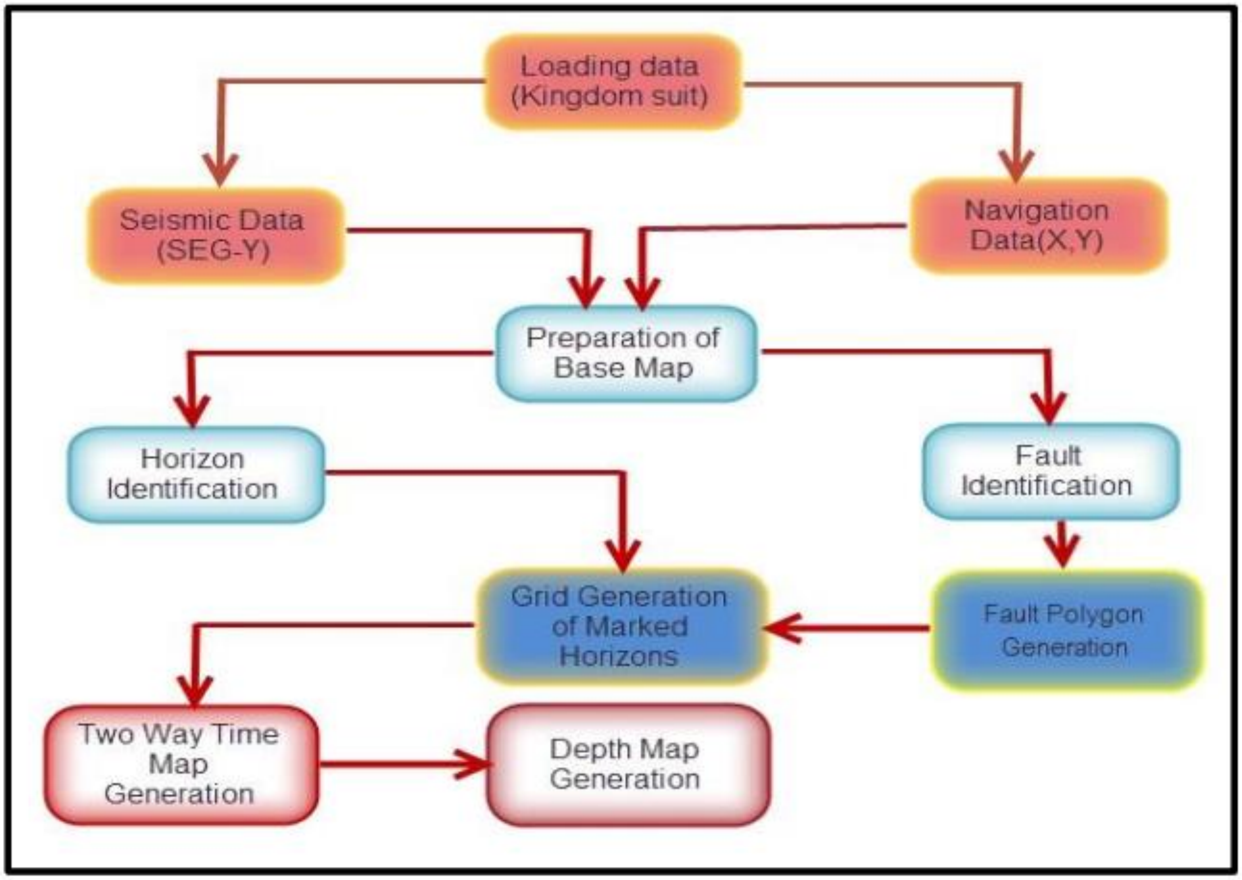



**Figure Workflow analysis of seismic interpretation**

## 1.6 Aims and Objectives

The following are the objectives of this study:

1- Introduction of the Badin area.

2- This dissertation is primarily focused on seismic interpretation of the study area, which includes marking of horizons, fault picking and construction of time and depth contour maps.
3- To find the petro physical properties of reservoir zone by using well data and identification of reservoir lithology.
4- Seismic attribute analysis for the confirmation of the horizon marking.
5- Facies Analysis to discriminate the shale and sand.

## 1.7 Previous Work:

Badin concession has been a prolific producer of hydrocarbons for more than 30 years. Various Petroleum Exploration companies in the Badin area have had an exploration success rate of about 43%, resulting in approximately 1.65 Tcf (trillion cubic feet) of gas and 225 MM bbls (Million Barrels) of oil found in almost 60 fields. The vast majority of the production is from the middle sand and basal sand unit of the Lower Goru Formation (Ahmed, S., 1999).

Petroleum Exploration activities were started by Union Texas Pakistan in the Badin Block in 1977. The first major oil discovery took place in early 1980"s at Khaskheli, near Badin where several large and small oil and gas fields have been discovered since then. Till the end of June 1999 a total of 52 discoveries were made of which 21 are classified as oil fields with gas caps in 5 of these fields and 31 are considered gas fields with significant oil rigs in 10 of these fields (Kazmi et al., 1979).

# CHAPTER NO 2: GENERAL GEOLOGY AND STRATIGRAPHY

## 2.1 Indus Basin

It is the largest sedimentary basin of Pakistan. The basin is oriented in NE-SW direction. Basement is exposed as outcrop at two places, one in NE as Sargodha High and second in SE as Nagar Parker High. It comprises of normal to moderate and some steeply dipping structures. The compressional regime of the tectonic plates resulted the basin into Upper, Middle and Lower Indus basin.

## 2.2 Regional Geology

Pakistan has the northwest boundary of the Indian plate. The subduction of Indian plate under the Eurasian plate developed compressional thin-skinned tectonic features since Eocene time on the northern part of Indian plate. The continued compressional forces and subduction of Indian plate since Cretaceous produced the mountain ranges of the Himalaya and the chain of foreland fold and thrust belts as thick sheets of sediments thrusted over the Indian craton (Kemal, 1991). In Northern Pakistan, the Himalayan trend can be divided into four major divisions. On the north of Main Karakoram Thrust (MKT) Karakoram and Hindukush Mountain ranges lies. Kohistan block is on the south of MKT and on the north of Main Mantle Thrust (MMT). Swat, Hazara and Kashmir lies between the MMT and Main Boundary Thrust (MBT). The outlying Potowar Plateau, bounded on the south by the Salt Range Thrust (SRT) is the foreland folds and thrust belts of Pakistan which is equivalent to the Sub-Himalaya (Pennock et al, 1989). Kazmi and Jan (1997) named the Northwest Himalaya as the Northwestern Himalayan Fold and Thrust belts, in their tectonic zones of Pakistan.

Oligocene to present-day Himalayan collision caused sinistral transpression in the west of the

Lower Indus Basin, with fold-thrust structures overprinted by sinistral flower structures (Bannert, D. 1995).

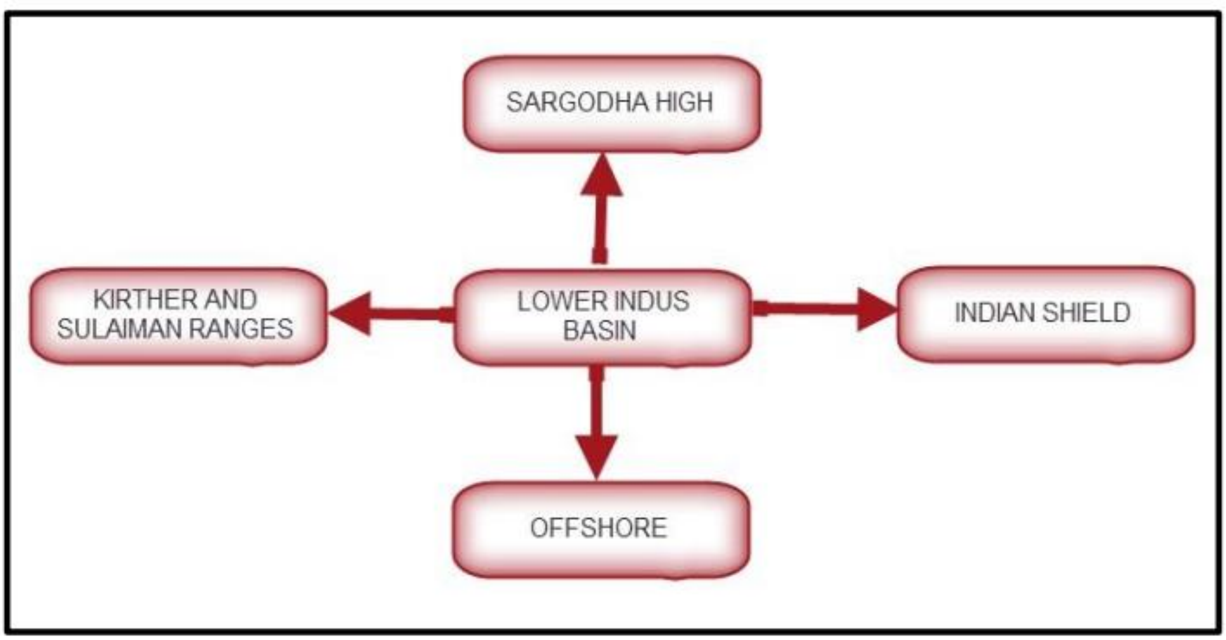
## 2.3 Geology of the Area

Pakistan is divided into many basins in which Indus basin is a major basin divided into two parts. Northern and north-eastern part of the basin is known as upper Indus basin and the southernmost part of the Indus basin is known as Lower Indus basin, Badin Block is the part of this basin. The is situated between 24°-5'to 25°-25' north latitude and 68° 21' to 69° 20' east longitude It starts from south of Khairpur High and extends into the Arabian Sea. Petroleum exploration started in back in 1950’s in the Lower Indus basin. The first gas discovery was Sari-Hundi in Kirthar Range; district Dadu whereas first major oil struck in early 1980's at Khaskheli, near Badin where several large and small oil and gas fields have been discovered since then. The Lower Indus basin can be divided into areas where Neogene to Cretaceous rocks are exposed along Kirthar Range, and into the areas where no surface geology exposed or minor at lesser extent geological units of Neogene to Pleistocene are cropping out. Badin Block are areas nearby all are without surface geological expression.

In Badin area, early Cretaceous Sembar Formation is considered as the principal source rock whereas clastics of the Early Cretaceous age Lower Goru Formation is the main reservoir. Traps in the Badin area is generally tilted fault blocks associated with normal faults developed during Late Cretaceous and Early Paleocene rift phase.

Badin area and northern part of Sindh province also fall in Indus Basin where Lower Goru Sands (Lower Cretaceous) are the main reservoir for oil and gas. In all these areas, Sembar shales are considered as the source rock. Habib Rahi limestone (Eocene) is the gas reservoir in the giant Mari Field. Ghazij shale is the cap rock for SML while Lower Goru shale provides cap rock for Pab. The intraformational shale within Lower Goru provides the seal.

The cap rock is invariably all the time is impermeable marl and shale sequence of Upper Goru Formation whereas the Early Paleocene volcanic flow, known as Deccan basalt, believed to be the reason for providing increasing temperature to the underlying sediments including source rock (Sembar and Goru) which help to generate hydrocarbon from the source and the process of the oil expulsion started to take place. A.H Kazmi et al, 1997.



## 2.4 Division of the Lower Indus Basin

Lower Indus Basin is further divided in to two classes:

- Central Indus Basin
- Southern Indus Basin

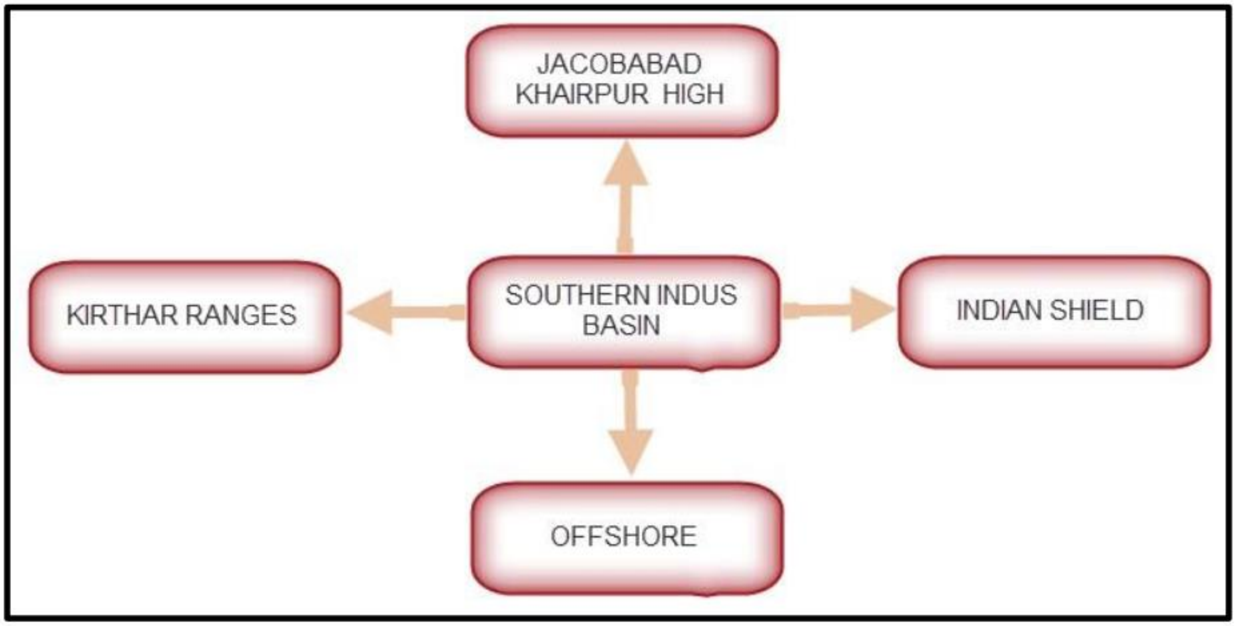
My Study area belongs to Southern Indus Basin. So I will mainly focus on southern Indus Basin, its geology, tectonics and other aspects.

### 2.4.1 Southern Indus Basin

The southern Indus basin (550 × 220 km) extends approximately between 24$^{o}$N to 28$^{o}$N Longitude and 66$^{o}$ to 71$^{o}$ E Latitude (V.N. Qadri and S.M. Shoaib, 1986). It is characterized by several structural Highs.

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

### 2.4.2 Boundaries of Southern Indus Basin




## 2.5 Geological Description of Southern Indus Basin

In the present plate tectonic setting, Pakistan lies between northwestern corner of the Indian plate, the southern part of the Afghan craton, and the northern part of the Arabian Oceanic plate. The eastern part of the Pakistan was affected by Tertiary plate convergence, having intense collision between the Indo-Pakistan subcontinent and the Afghan craton in the North West (Chamman Transform Fault). The western part of the country affected by the Tertiary convergence between the Arabian Oceanic plate and the Afghan craton (Chagai Arc and the Makran Flysch Basin), and between a segment of Arabian Oceanic plate and the western rifted margin of the Indo-Pakistan subcontinent.

The western margin of the subcontinent (eastern part of Pakistan) is characterized by a broad NS trending sedimentary basin (southern Indus Basin) having thick. Tertiary sequences underlain by Quaternary sediments. It had been relatively tectonically stable during the Mesozoic, but the intensity of shallow Tertiary folding increasing westward and becomes more pronounced in the strongly folded and faulted area of axial fold and thrust belt (N.A Zaigham, 2000)

## 2.6 History of Geological Evolution of Southern Indus Basin

Zaigham and Malik proposed a structural model for the evolution of southern Indus Basin. This corresponds to the initial rifting of the super continent Gondwanaland, probably during the Paleozoic (Smith & Hallam 1970; Powell, 1979). The divergent phenomena includes the formation of Basaltic magma in the upper part of the Asthenosphere, causing broad tectonic up warp and thinning of the overlying Lithosphere, probably resulting from plastic flow in the lower part and extensional faulting in the upper part. The thinning of Lithosphere continued and resulted in the collapse of the tectonic up warp over the magma blister and subsequently the process of sea floor spreading began with basaltic magma upwelling to the earth surface at oceanic Lithosphere.

Extensional forces broke the upper brittle crust into blocks separated by active faults during sea floor spreading. It appears that stretching of initial rifted stopped at some geological time during very late Paleozoic to very early Mesozoic (Ahmed & Zaigham, 1993). The stretched crust remained as Indus basin failed rift in sediments started to accumulate.

The third step represents subsidence of the stretched continental crust and simultaneous accumulation of the Mesozoic and Tertiary sediments in the Indus basin.

## 2.7 Regional Tectonics of the Study Area

### 2.7.1 Northward Drift of the Indian Plate and Opening of the Indian Ocean

The Indo-Pakistan subcontinent separated from the Gondwana motherland about 130 million years ago (Johnson et al. 1976). It has been estimated that between 130 M.A and 80 M.A. India moved northward at a rate of 3 to 5 cm/year (Johnson et al. 1976). From 80 M.A ago India moved at an average rate of about 16 cm/year relative to Australia and Antarctica (Powell 1979). According to Patriat and Achache (1984), before second anomaly (50 Ma) this rate of movement varied between 15 and 25 cm/year (fig 2-1)

Two broad geological divisions of this region the Gondwanian and the Tethyan domains are discussed. In this scenario Pakistan is unique inasmuch as it is located at the junction of these two diverse domains. The southeastern part of the Pakistan belongs to Gondwanian domain and is sustained by the Indo-Pakistan crustal plate. The northern most and western regions Pakistan fall in tethyan domain and present a complicated geology and complex crustal structure.

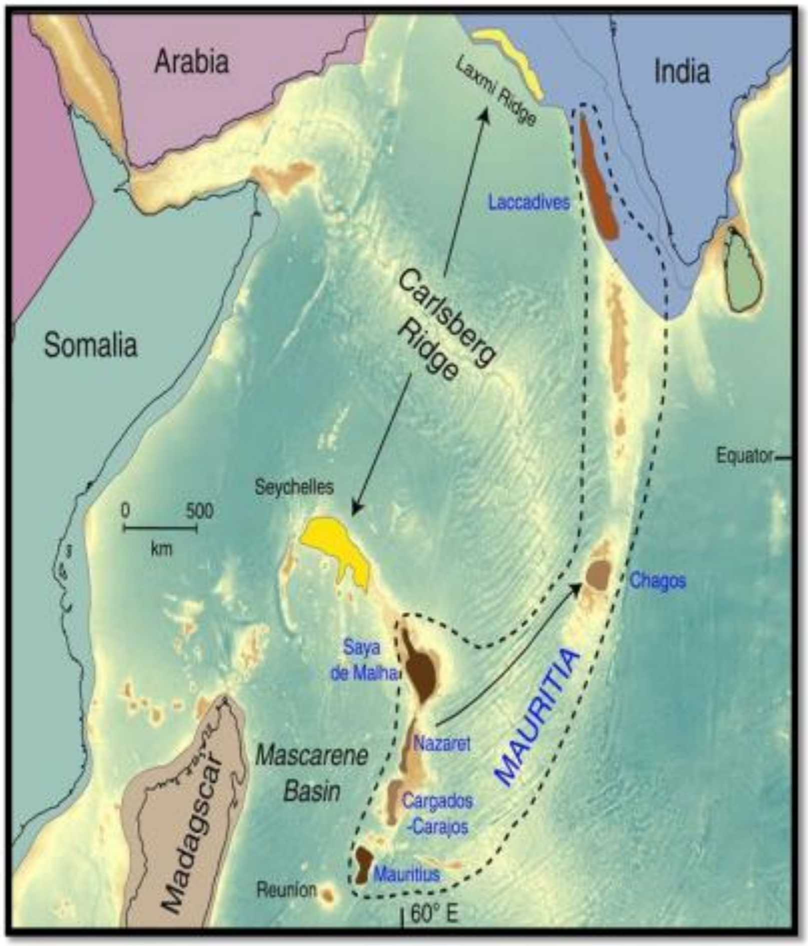



**Figure: Separation of Seychelles from Indian Plate (modified after Kemal, 1992)**

On the basis of plate tectonic features, geological structure, orogenic history (age and nature of deformation, magmatism and metamorphism) and lithofacies, Pakistan may be divided into the following broad tectonic zones see (fig 2-2).

- Indus Platform and fore deep
- East Baluchistan fold-thrust belt
- Northwest Himalayan fold-thrust belt
- Kohistan-Ladakh magmatic arc

- Karakoram block
- Kakar Khoarasan flysch basin and Makran accretionary zone
- Chagai magmatic arc
- Pakistan Offshore

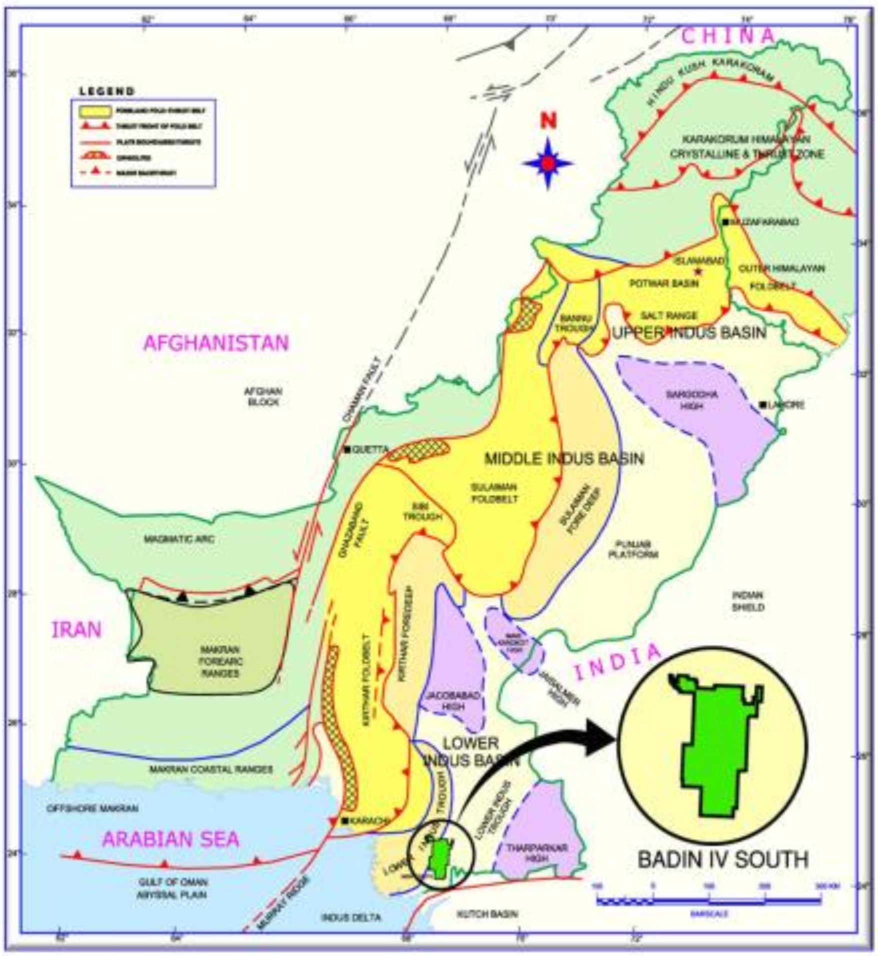



**Figure shows Geological Basins of Pakistan (modified after Kemal, 1992)**

## 2.8 Major Formation of the Area (Badin)

Following are the major formations of Badin Area: -

### 2.8.1 Sembar Formation

The Sembar formation consists of black silty shale with inter-beds of black siltstone and nodular rusty weathering argillaceous limestone beds. In the basal part pyritic and phosphoric nodules and sandy shales are developed locally. Rock unit is glauconitic. And it is proven a good source rock. This rock unit is widely distributed in Suleiman and Kirther ranges. Its Lower contact with various Jurassic formations such as Mazar Dirk formation, Chilian limestone and Shirinab formation is disconfirmable while the upper contact is generally gradational with the Goru formation. The Sembar formation is correlated with Chichali Formation of the Kohat-Potowar Province. This rock unit is richly fossiliferous and the most common fossils reported are the belemnites, Mollusca and others and the age given is Early Cretaceous (Shah, 1977)

### 2.8.2 Goru Formation

The Goru formation consists of interbedded sandstone, shale and siltstone. The limestone is grained, thin bedded, light to medium grey in color (Shah, 1977).

On the basis of lithology Goru Formation is divided in two parts

**Lower Goru**

**Upper Goru**

#### 2.8.2.1 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

#### 2.8.2.2 Upper Goru

The upper Goru sequence of middle to late cretaceous unconformable overlies the lower Goru formation which consists of mainly marl and calcareous claystone occasionally with inner beds of silt and limestone. The Goru Formation is widely distributed in the Kirther and Suleiman Province. The lower contact with the Sembar formation is conformable and is very locally reported unconformable by Woodward, J.E., (1959). The upper contact is transitional with the Goru formation may be correlated with the Lumshiwal Formation of the Kohat-Potwar Province. The formation contains foraminifers and bivalves and age given is Early Cretaceous (Shah, 1977)

### 2.8.3 Parh Limestone

The Parh limestone is lithologically very distinct unit. It is a hard, light grey, white, cream, olive green, thin-to-medium-bedded, lithographic and argillaceous limestone, with subordinate calcareous shale and marl intercalations. The formation is widely distributed in parts of the Axial Belt and Lower Indus Basin (Sulaiman and Kirther Province). The lower contact with the Goru formation is transitional and conformable, while the upper contact with the Mughal Kot formation is unconformable through most of its extent. The formation is correlated with the Kawagarh Formation of the Upper Indus Basin. The formation is richly fossiliferous. Forms (Globotruncana, Gumbelina) are dominant. No macrofossils are known. Age given is Late Cretaceous (S. M. Ibrahim Shah).

### 2.8.4 Ranikot Group

Blanford (1876) was the first to give the name Ranikot group. Vreden berg (1909) subdivided the Ranikot group into Lower Ranikot (sandstone) an Upper Ranikot (limestone).One division of Ranikot group suggests that it comprise of three formations which are Khadro formation, consists of olive, yellowish brown sandstone and shale with inter-beds of limestone.

### 2.8.5 Khadro Formation

The basal part of the formation is comprised of dark colored limestone with shale, followed by olive, grey to green, soft, ferruginous, medium grained fossiliferous sandstone an olive, gery to brown gypsiferous shale with interbeds of fossiliferous limestone. A number of basaltic lava flows are also present. The volcanics contain dark green and black basalt interbedded with mudstone, claystone and sandstone (Kazmi and Abbasi , 2008).The formation is widely distributed in Kirther fold belt and its thickness varies at different localities. Its lower contact is unconformable with Moro formation and Pab Sandstone, while its upper contact is conformable with Bara and Dungan formations in various parts of Kirther-Sulaiman fold belt. Khadro formation may be correlated with the lower part of the Rakhshani Formation of Chagai and Ras Koh area.Fossils reported from the formation include Corbula Globigerina pseudobulloides and G. triloculinoides and so many others. And age given to the formation is Early Paleocene (Kazmi and Abbasi , 2008).

## 2.9 Structural Setting in the Badin Block

Badin Rift Basin is located in Thar platform area of Lower Indus Basin. It is the Sargodha High in fact which is considered to be a divide for Upper Indus Basin & Lower Indus Basin (Kadri, 1995). The Badin Rift is characterized by a series of horst and graben structures present below the base Tertiary unconformity within Cretaceous and older strata. These horst and graben structures were formed as a result of rifting between India and Seychelles during the Late Cretaceous (Alam, 2002). The most significant styles seen are rifting, overprinted by shear modification and subsequently modified by doming. The major periods can be characterized as: Distal rift during the Late Jurassic & Early Cretaceous. Reactivation of Shear Modification during Middle Cretaceous. Inversion in Late Tertiary (Uplift and Doming).

Badin area was distal to main deformation locations in all three cases, and exhibits a provisional degree of deformation across the Badin. As a result the degree of deformation is relatively low, and progressively increases from East to West. The extensional tectonics during Cretaceous time created tilted fault blocks over a wide area of eastern Lower Indus sub-basin. Seismic reflectors, representing Cretaceous and older layers, are broken by a system of faults with normal dip separation. The Cretaceous faults generally strike between N 30$^{o}$ W and N 50$^{o}$ W (Kemal *et al.*, 1991). Commonly, faults are arranged in enechelon sets, aligned in zones that trend almost north south. The tilted fault block traps were in existence at time of hydrocarbon generation. Fault associated structural closures are responsible for trapping oil and gas in Lower Goru sandstone in Badin block redistributed.

## 2.10 Generalized Stratigraphy of the Study Area

Numerous plays and prospects of hydrocarbon are associated with the Cretaceous system, consequently the Indus basin is attractive to petroleum exploration companies in Pakistan.

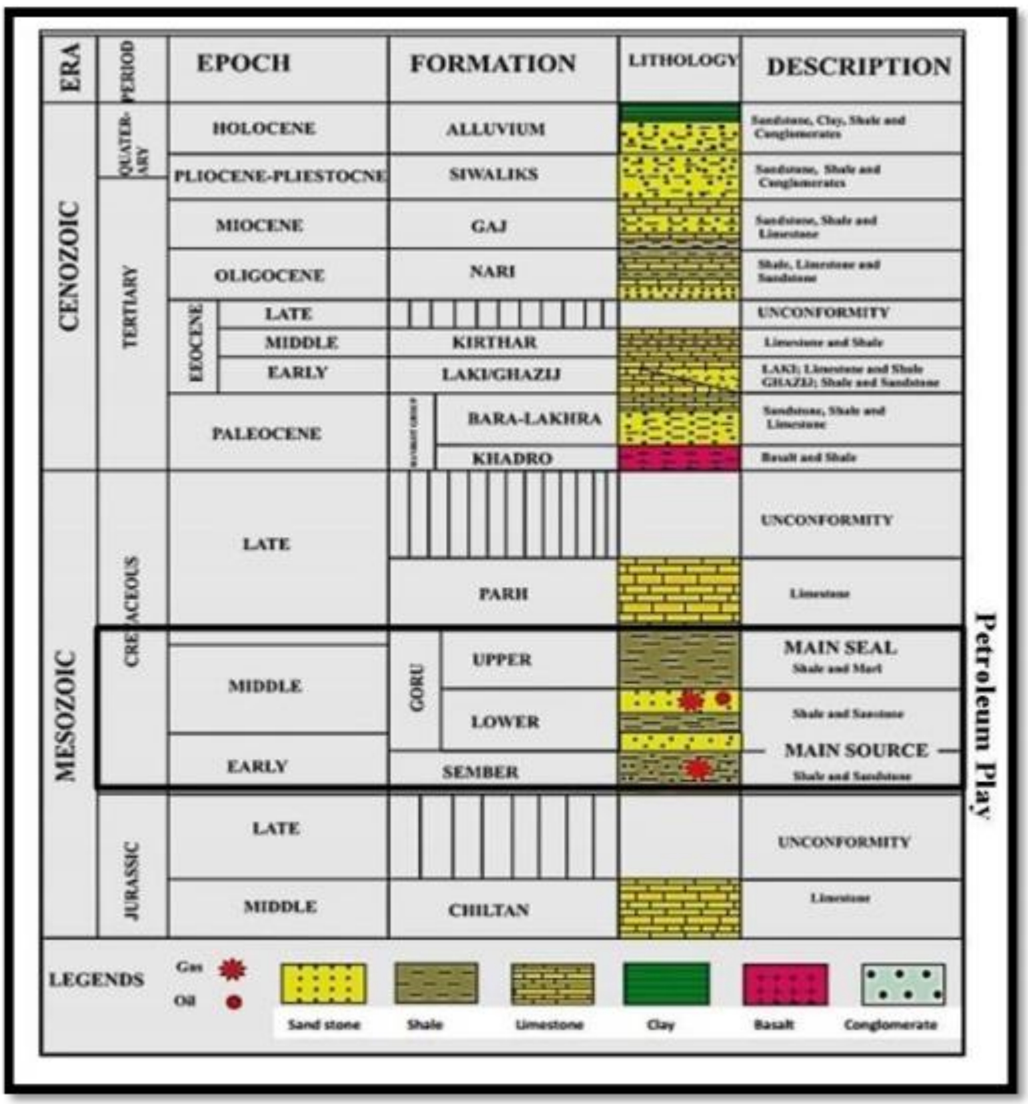



**Figure 2-3 shows Generalized Stratigraphy of Study Area (Modified after Zaigham et al 2000)**

## 2.11 Hydrocarbon Potential of the Area

Oil production has been established in the Lower Goru sandstones, in Layers I, II and III of Cretaceous age. Progressive rifting of the Indo-Madagascan plate commenced, as stretch troughs, early in the Cretaceous period. During the initial phase of the evolution of the rift system the Sember formation with significant organic content was deposited under restricted circulation. The formation, along with the basal shales of the Lower Goru formation, represents the major source of hydrocarbon in the Lower Indus Basin. With the evolution of the rift system into a more mature half graben stage, the extensional tectonics resulted in tilted fault blocks over the Thar slopes. The lithosphere during the evolution of the rift system underwent readjustments causing subsidence and uplifts .Coupled with the worldwide eustatic pulses, the changes in sea level influenced the depositional environments resulting in a sequence of delta-related sand bodies and marine shelf shale deposits. The tectono-eustatic oscillations also create a number of minor disconformities and marine transgressions. During mid-Cenomanian in one such marine submergence, “Badin shales” were deposited under more open marine environments and characterized by greater carbonate content (marls and thin limestone bands).After subsequent uplift, under very reservoirs in the region. Following a prominent depositional break, Turonian marine transgression created environments for pelagic sedimentation of the Upper Goru formation.

These plastic marls and shales provide the capping mechanism with a thickness approaching 1000 meters in the project area. Tilted fault blocks and horst draped by Upper Goru ductile lithologies, possibly, along the up dip truncation of Post-Badin shale sand bodies by a Turonian disconformities form the prevalent play types.

### 2.11.1 Cap Rock

The Goru Formation belongs to Early Cretaceous age and consists mostly of shaly facies in outcrops along the axial belt in the west of the Indus Basin. In the central part of the basin, along the Karachi trough and sub-Kirthar foredeep, it is too deeply buried for any well to penetrate. However most wells in the eastern area of the Lower Indus Basin on the Thar slope platform drilled into the Goru Formation, which is dominantly shales or mudstone, frequently calcareous. It is thin bedded where bedding is discernible and ranges in color from black to grey and maroon. Sand is rare in the upper part of the formation while increasing tendency of sands towards base, where it has developed into a producing reservoir. On the basis of its lithological content it has been divided into two units;

- Upper Goru Formation
- Lower Goru Formation (Dolan, 1990; Kadri, 1995).

The upper shale unit of the Goru Formation is termed as Upper Goru which is the main cap rock of the reservoirs both vertically and laterally existed in the Lower Goru Formation. The Upper Goru although contained shale, in fact consists of marl and its qualities of being a seal rocks are good unless faults run from the reservoir up through the Upper Goru. However the large faults are sealed at the base of Tertiary unconformity by the basalt flows (Ahmad and Malick, 1998). Upper Goru Formation rocks consist of marls, claystone and shales with minor siltstone. This formation gradually becomes less calcareous and is predominantly claystone as moving deep, but with minor interbedded siltstones. Toward the base of the section the Upper Goru once again is found to be limey with a number of dirty limestone stringers occurring. The Upper Goru unconformably overlies the Lower

Goru sands which are reached to Middle Cretaceous in age (Ahmad and Ashton, 1982).

### 2.11.2 Reservoir Rock

Lower Goru has characteristics of both source and reservoir but mainly is an excellent reservoir from Cretaceous age. The main oil productive reservoir rock units in the Lower Indus Basin are Lower Goru sandstones (Hussain et al., 1991). These sandstones were eroded from the Indian shield during Late Cretaceous rifting episodes and redeposited as a series of deltaic and barrier bar sandstones in both the Lower and Middle Indus Basins. The name Lower Goru has been applied to the lower sandy member of the Goru Formation. Stratigraphically, upper unit of the Lower Goru Formation is the documented oil and gas source rock unit in the Lower Indus Basin

### 2.11.3 Source Rock

The shales of the Cretaceous Sembar Formation is the principal source rock of the Lower Indus Basin (Hussain et al., 1991; Zaigham and Mallick, 2000,). The source rocks in the Cretaceous are restricted to the Thar platform where Goru contains approximately 15 meters of good gas bearing and the Sembar 75 meters of good gas and condensate bearing source rocks (Kadri, 1995). Oil produced from the Lower Goru sands has originated from the Sembar Formation. Kerogen type of the Sembar Formation varies throughout, OM principally originated from a mixed terrestrial and marine origin (Ahmad and Malick, 1998).

In the east of the Thar Platform, the Goru rocks are immature as they do not fall within the oil window thermal maturity. Sembar Formation, however, is mature and their thick sediments are capable of generating both gas and condensate. The maturity data suggests that most of the Badin oils have generated on the platform and migrated up dip via different pathways (Kadri, 1995; Malik et al., 1988). The eastern margin of the western Thar platform depicts the excellent coexistence of presence of oil window within organic rich Sembar shales (overlying Lower Goru sand reservoirs) and the availability of proper informational seals (Kadri, 1995). Sembar Formation (Early Cretaceous age) consists mainly of shale with subordinate amounts of siltstone and sandstone. The rock composition of Sembar Formation is mainly clastic, primarily shales followed by sandstones and siltstone with minor limestones. The sandstone, probably derived from the Indian shield, is more abundant near the eastern part of the Formation, decreasing to the west; shale and siltstone units are more abundant to the west. Based on the stratigraphic studies of the exploratory data from oil and gas fields, the Sembar Formation of the Upper Jurassic-Lower Cretaceous is the major hydrocarbon source for charging the oil and gas fields of the Lower Indus Basin and surrounding areas. Thus Sembar shales are the proven source rocks in the Lower Indus Basin (Zaigham and Mallick, 2000). The generation, migration and accumulation of both liquid and gaseous hydrocarbons have occurred in the Lower Indus Basin. Extensive geochemical studies show the Lower Cretaceous Sembar Formation to be the main source rock because it has organic richness, oil prone kerogen and thermal maturity (Quadri and Shuaib, 1986).

In the Lower Indus Basin a major depo center developed in response to rifting and fault block subsidence (Malik et al., 1988). The chances of Sembar sourced oil migration into the underlying Jurassic Formations against faults also appear to be relatively favorable (Kadri, 1995). The Sembar Formation was deposited over most of the Indus Basin under marine depositional environment and ranges in thickness from 0 to 260 meters (Iqbal and Shah, 1980). In another report, the Sembar Formation seems to have formed under open-marine environmental conditions (Quadri and Shuaib, 1986). The Jurassic sequence of Lower Indus Basin contained various lithological structures, where eastern part have clastic dominated marginal marine sediments, central part of pelagic deep water sediments and western part of high energy shallow water carbonates (Dolan, 1990). Chiltan Formation is present in the middle of Jurassic era and is typically a massive, thick bedded (dark in color) containing Pisolitic limestone beds locally. The texture varies from fine grained, sub lithographic to oolitic, reefoid and shelly (Zaigham and Mallick, 2000).

# CHAPTER NO. 3: SEISMIC DATA INTERPRETATION

## 3.1 Introduction

The main goal after the entire seismic investigation is the identification of prospect in the sedimentary basin and this would be done with the most imperative step that is interpretation. It is simply the ability to interpret the seismic reflection data in geological terms. Interpretation is a technique or tool by which we try to transform the whole seismic information into structural or Stratigraphic model of the earth. Since the seismic section is the representative of the geological model of the earth, by interpretation, we try to locate the zone of final anomaly. It is rare that correctness or incorrectness of an interpretation is ascertained, because the actual geology is rarely known in well manner. The test of good interpretation is consistency rather than correctness. Not only a good interpretation be consistent with all the seismic data, it also important to know all about the area, including gravity and magnetic data, well information, surface geology as well as geologic and physical concept (Sheriff, 1999).

The Seismic data interpretation is the method of determining information about the subsurface of earth from seismic data. It may determine general information about an area, locate prospects for drilling exploratory wells or guide development of an already discovered field (Coffeen, 1986). According to Badley (1985), such reflections and unconformities are to be mapped on Seismic section, which fully describe the geology and hydrocarbon potential of the area. If the Horizon of interest is not prominent and it is difficult in tracing it over the whole area, it is advisable to pick additional horizons above and or below the target horizon. This helps understanding the trend and behavior of the target horizon in the zones where its quality is not good enough to be picked with confidence. Final objective of interpretation is conversion of seismic section into a geological section which provides a somewhat realistic subsurface picture of that area, both structurally as well as stratigraphically (Badley, 1985). 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, 1999). Main purpose of the reflection is to reveal as clear as possible the structure and stratigraphy of the subsurface. Geologic meaning of the reflection is the indication of the boundaries where there is change in the acoustic impedance; to distinguish the different horizons with the seismic data we correlate the well information with the seismic data. Structure and estimate of the depositional environment, seismic velocity, seismic stratigraphy and the lithology is identified by using the best available seismic data (Dobrin &Savit, 1988). There are two main approaches for the interpretations of a seismic section are:

- Stratigraphical Analysis
- Structural Analysis

## 3.2 Stratigraphical 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 . The amplitude, velocity, frequency or the change in wave shape indicates hydrocarbon accumulation. Unconformities are marked by drainage pattern that help to develop the depositional environment. Reef, lenses, unconformity are example of stratigraphy traps (Sheriff, 1999).

## 3.3 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, etc. (Sheriff, 1999).

Seismic section can predict the structure that scale up to few tens of kilometers. A fault with throw less than ¼ of the wavelength of seismic wave will difficult to pick in the seismic section (Badley, 1985). The study area lies in intense extensional regime, so general structure are normal related i-e horst and graben structure.

## 3.4 Overview of the Area

Badin area is distal to deformation locations due to which the degree of deformation is relatively low but progressively increases when moving from East to West. Badin area is considered favorable for oil and gas whereas Western part of Lower Indus Basin and adjacent area is known for its gas potential.

Badin area lies in extensional regime, the structural traps are simple and shallow so seismic can display fair enough results on shallow depths. Good quality shallower data can help analyzing any structural feature in this region.

## 3.5 Methodology of Interpretation

The seismic lines selected for the interpretation are

1-**PK94-1807** Strike line

2-**PK94-1804** Dip line

3-**PK92-1696** Dip line

The following steps were followed for interpretation purpose.

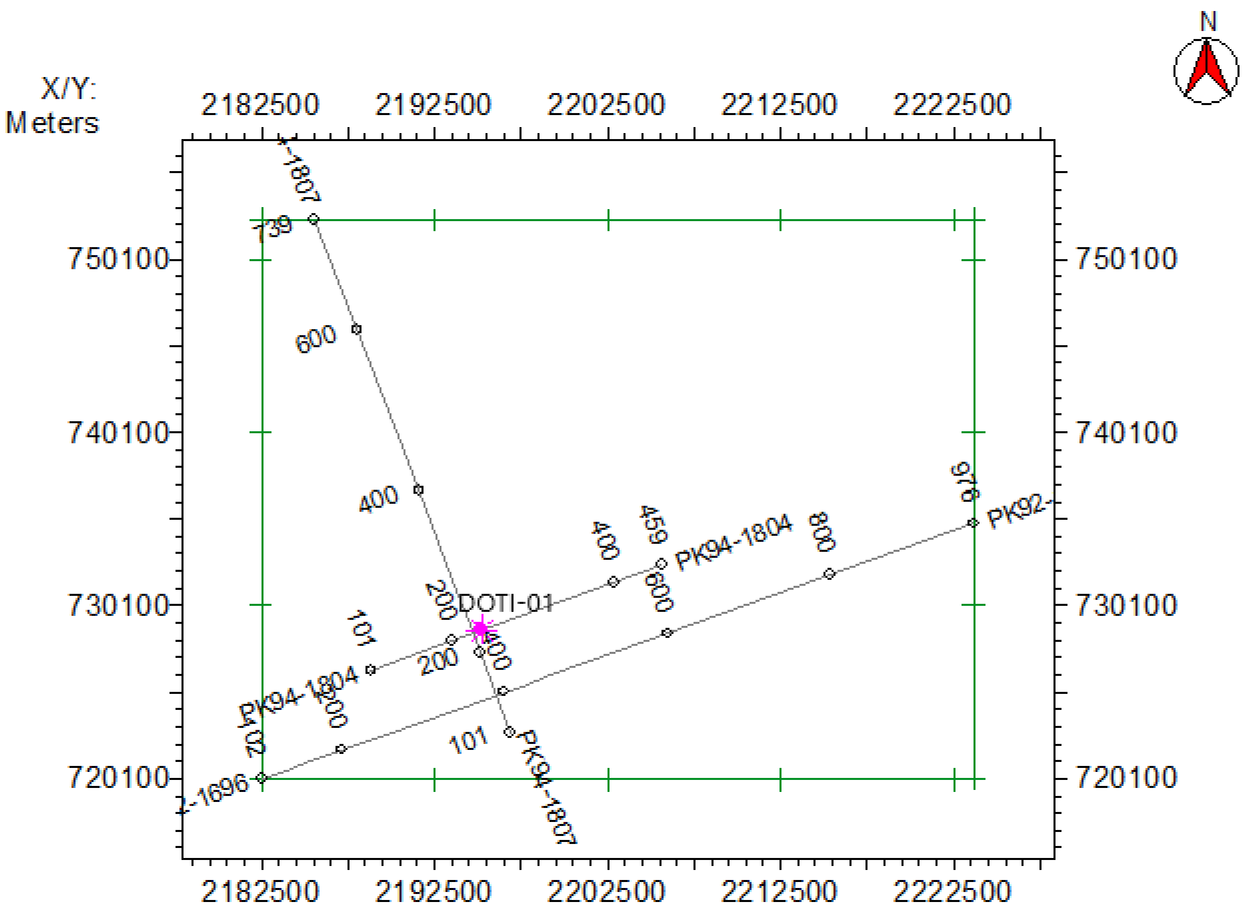
- Preparation of base map
- Generation of synthetic seismogram.
- Fault identification and marking
- Horizon marking

The interpretation was done on Kingdom which provides an interactive interface for marking horizons and faults, exporting horizon's time, velocity and depth data for contouring and for further analysis.

## 3.6 Base map Generation

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.

For interpretation we prepare base map first by using kingdom software. The base map of study area is as follows.




PK 94-1804 is selected for its importance due to the well presence. DOTI-01 can be seen near this dip line. It was used to mark horizons on other lines for a clear extension that minimized risk of any ambiguity in the interpretation.

## 3.7 Generation of 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 to compute density.

Ideally, a density log should also be used, but these are not always available hence we can also used the constant density for that area. With the help of Doti-01 the synthetic seismogram was constructed 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 borehole geology to seismic sections, because they can provide a direct link between observed lithologies and seismic reflection patterns (Cooper, A., 2004). Reflection profiles are sensitive to changes in sediment impedance, the product of compression wave velocity and density.

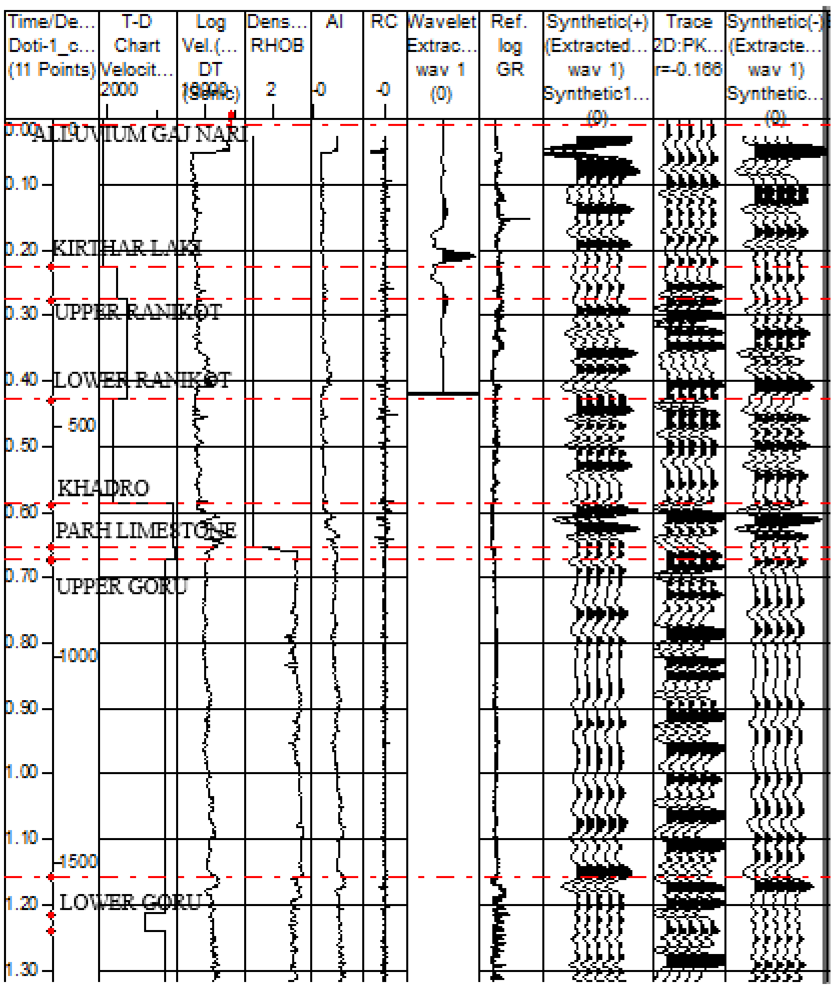
Changes in these two physical parameters do not always correspond to observed changes in lithologies. By creating a synthetic seismogram based on Sediment Petro-physics, it is possible to identify the origin of seismic reflectors and trace them laterally along the seismic line (Cooper, A.,2004)

The following steps are adopted during the Generation of the synthetic seismogram using the IHS Kingdom.

1. Load the Las file of the well in the software.
2. Open 1D forward modeling Project and select the well logs.
3. Integrate the sonic log to rescale from depth in meters to two-way travel time in seconds.
4. Compute velocity from sonic log for P and S waves.
5. Create a TD chart for the well from the velocity logs.
6. Compute Acoustic impedance log using velocity and density log.
7. Compute the reflection coefficients from the time-scaled velocity log.

8. Wavelet is extracted from seismic trace.

10. Convolve the reflection coefficient log with the obtained wavelet to generate the amplitudes of the synthetic seismogram.




**Previous Fig shows synthetic seismogram of Doti-1**

## 3.8 Marking of Seismic Horizons

The main (Prominent) reflections that are present on the seismic sections are marked, and then selected those reflectors that have good characteristics and continuity, and they can also be tracked well over the whole seismic section. In seismic section the depth was given in milliseconds, as it is the travel time of the wavelet. To pick up horizon, well tops are required. Well tops give the information about the depth of each formation in subsurface. So to mark horizon time depth chart was prepared.

There are difficulties in continuing the reflectors at the end of the seismic section and confusions arise where reflectors are mixed that may be due to sudden change in lithology, seismic noises, or poor data quality. The seismic data was interpreted using Kingdom which is used for interpretation.

The SEG -Y format data of seismic line **PK94-1804, PK94-1807** and **PK92-1696** is loaded by Kingdom software for interpretation. After loading data in kingdom software of lines using the interactive tools and applications of Kingdom Software prominent horizons are marked following the trend and continuity of the reflectors. The lines comprise normal faulting which shows a horst and Graben Geometry.

## 3.9 Seismic Time section

After marking seismic horizons and faults, the time of each reflector was noted at different vibrating points, and then the seismic time section is generated by plotting the two-way travel time of the reflectors and faults on y-axis against the shot points on x-axis. The seismic time section is simple; reproduction of an interpreted seismic section. The horst and graben structure present on the seismic sections may be a suitable place for the accumulation of hydrocarbons. Time section is the developed section of reflectors, which shows subsurface structure in time domain. Time section of the Lines PK94-1804, Pk92-1696 and PK94-1807 is shown in Fig.3-2 ,Fig3-3 and Fig3-4 respectively, reflectors are marked by tying with the line which is marked by using well top data of DOTI-01 well.

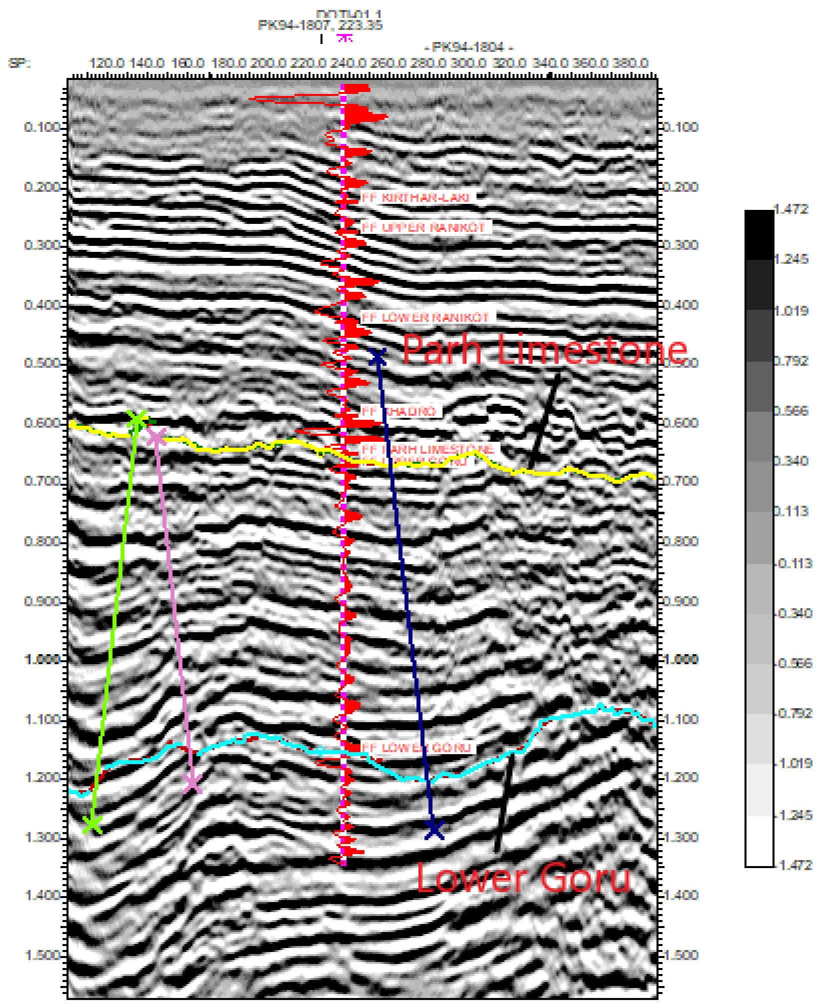



**Figure 3-2 Seismic Time Section of Line PK94-1804**

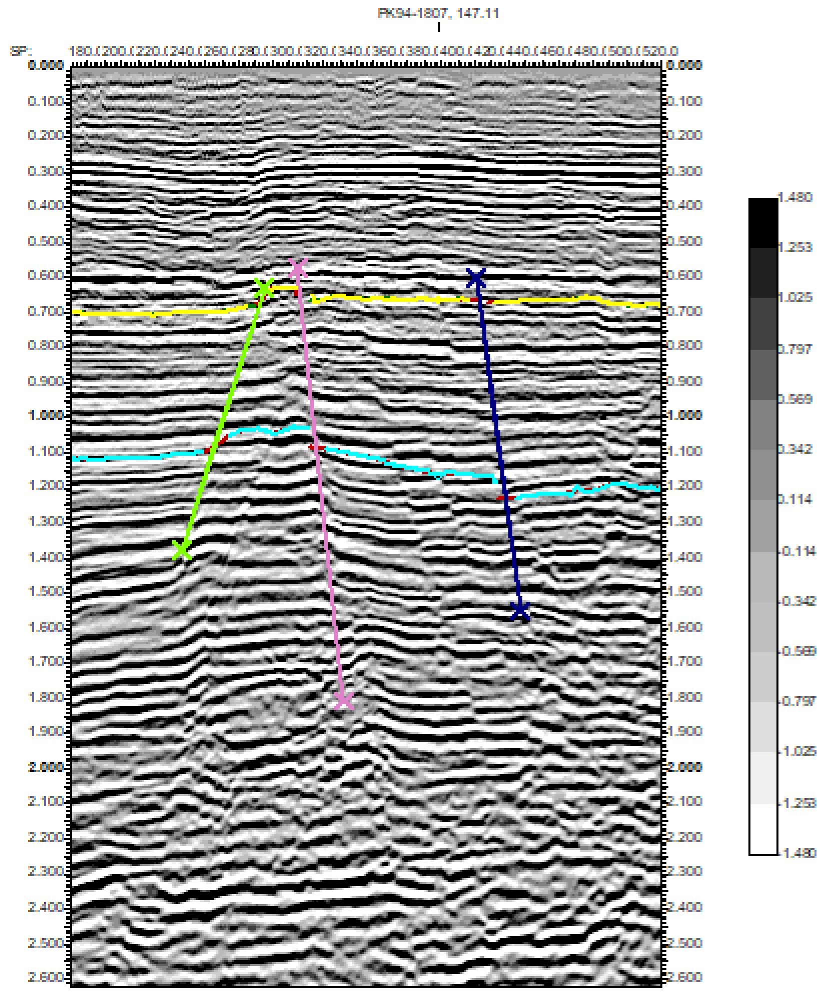



**Figure 3-3 Seismic Time Section of Line PK92-1696**

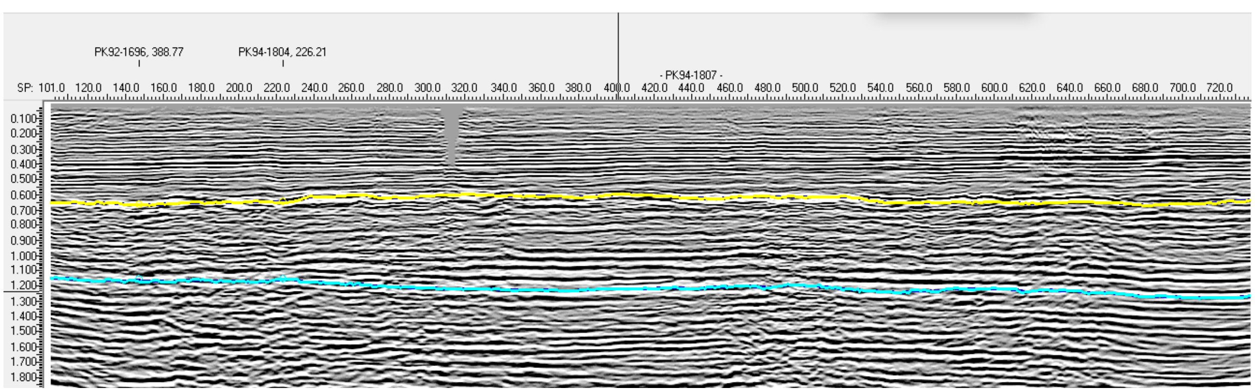



**Figure 3-4 Seismic Time Section of Line PK94-1807**

## 3.10 Fault Polygons Generation

A fault polygon represents the lateral extent of dip faults or strike faults having same trend. Fault polygons show the sub-surface discontinuities by displacing the contours. To generate fault polygons it is necessary to identify the faults and their lateral extent by looking at the available seismic data. If one finds that the same fault is present on all the dip lines, then all points on base map can be manually joined to make a polygon directions on a fault polygon if dip symbols are not drawn.

It is also often useful, when picking fault polygons, to see the intersections of faults with the displayed horizon. **Fault** exclusion **polygons** are a part of nearly every seismic interpretation workflow. They are commonly used in map presentations of seismic horizon interpretations and can even be used in the **fault** modeling process. The output is a surface that is gridded through the **faults** and **fault** exclusion **polygons**. The main reason to generate polygons is that if a fault is not converted into a polygon, the software doesn't recognize it as a barrier or discontinuities, thus represent a false picture of the subsurface.

Fault polygons are constructed for all marked horizons. Figure 3-4 shows polygon of Lower Goru and figure 3-5 shows polygon of Parh Limestone. At Lower Goru and Upper Goru level three fault polygons are generated.

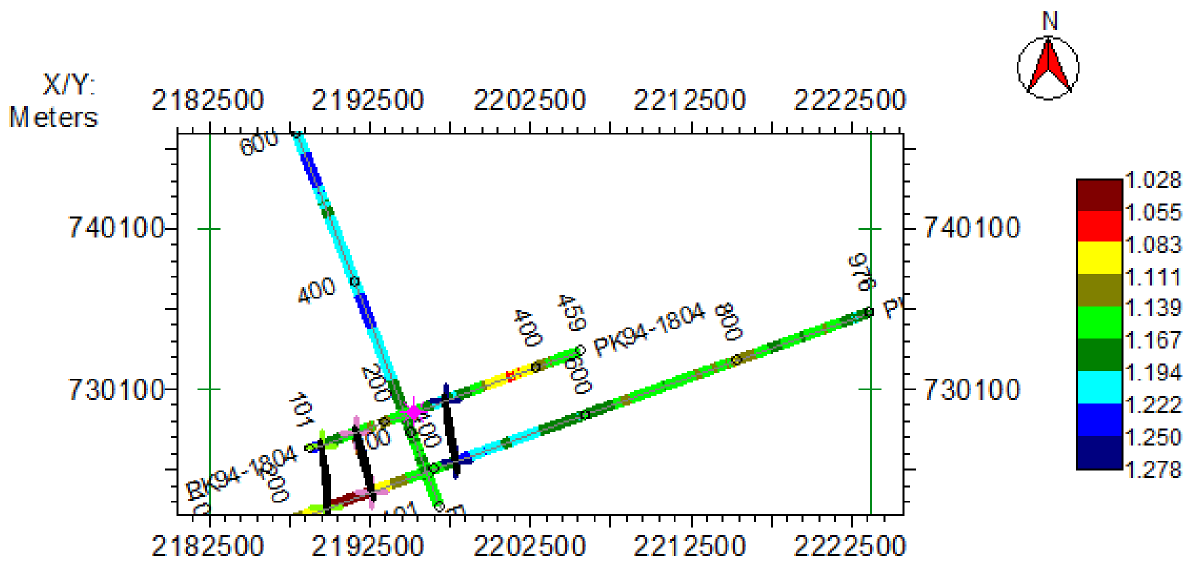



**Figure 3-4, polygon of Lower Goru**

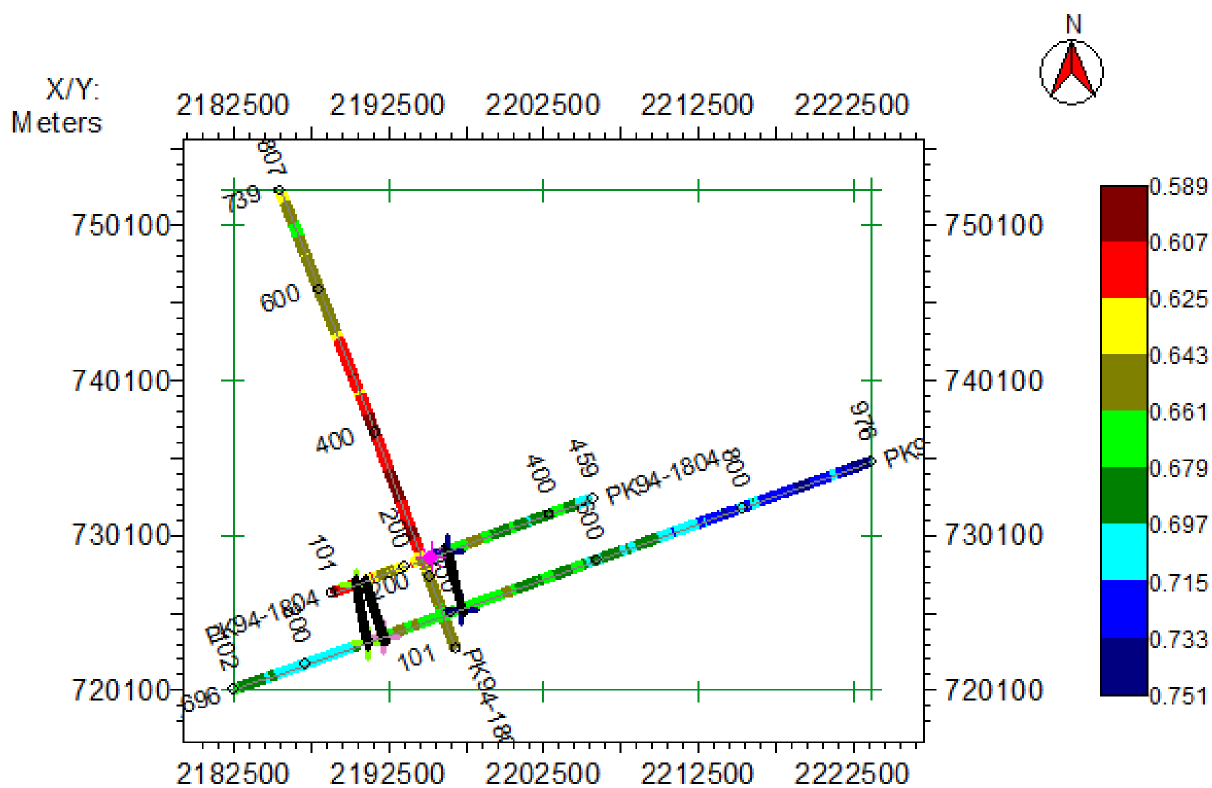


**Figure 3-5, polygon of Parh Limestone**

## 3.11 Contour Maps

Contouring is the main tool used in the seismic interpretation. After contouring it becomes obvious that what sort of structure is forming a particular horizon. The contour map of reflector is prepared. At the end of interpretation, I prepared time and depth contour maps. As mapping is the part of interpretation, so time and depth contour maps are necessary. Contouring represents the three-dimensional Earth on a two dimensional surface, the seismic data is contoured which provides 3-D layers of area. Later the time contour maps of Parh formation and Lower Goru formation are shown.

### 3.11.1 Time Contour Map of Lower Goru

In these time contour maps the central parts indicating Graben. The NE-SW in lower Goru shows deepest part on the color scale indicated by highest time while the shallowest parts indicating horst. As our well is lying away from the highs, so it is a non-producing well.

The two way time contour maps have been generated using the Kingdom Software. Time contour map of Lower Goru, as shown in the figure 4-7.

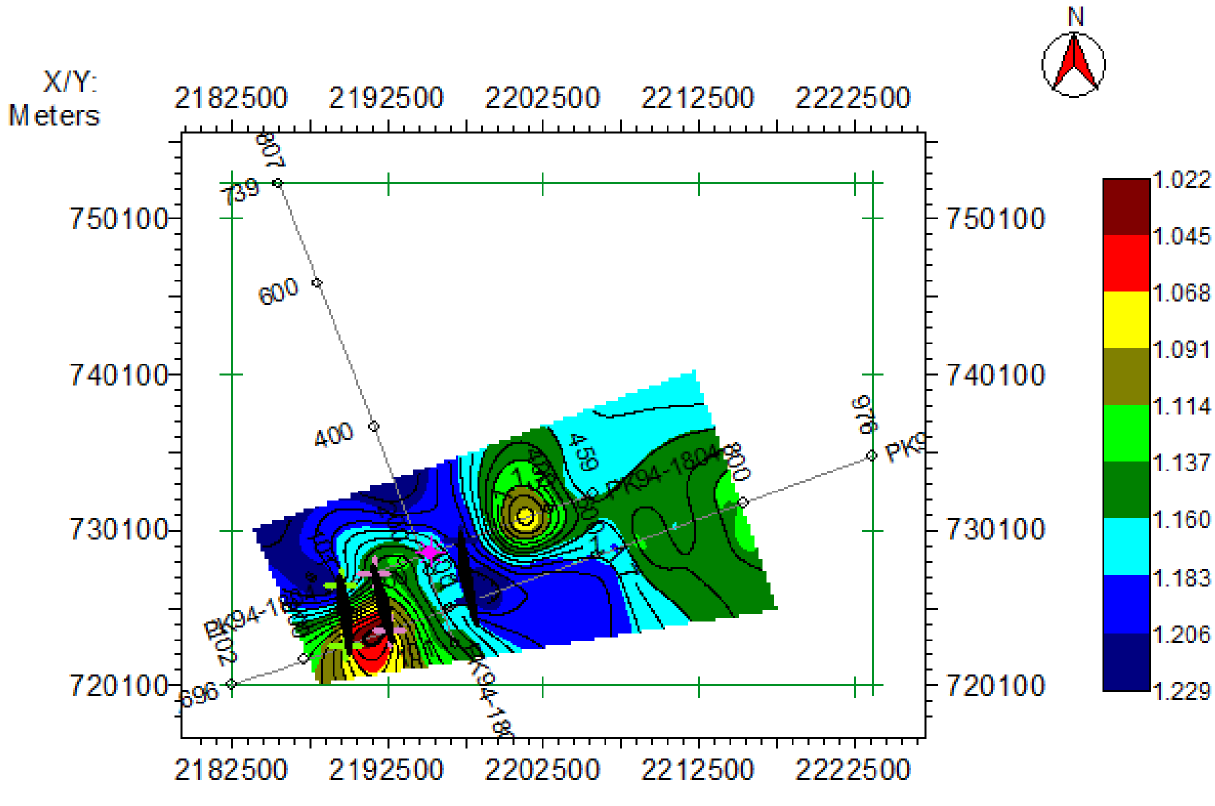



**Figure 4-7, Time contour map of Lower Goru**

### 3.11.2 Time Contour Map of Parh limestone

The two way time contour maps have been generated using the kingdom software. Time contour map of Upper Goru, as shown in the figure 4-8.

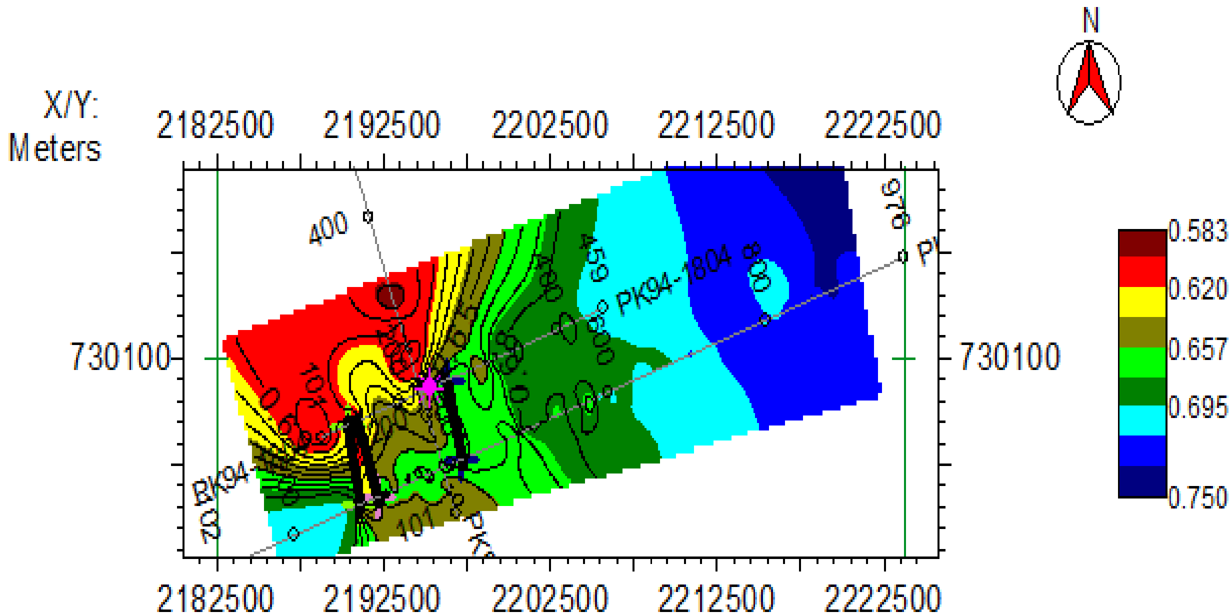



**Figure 4-8, Time contour map of Parh Limestone**

### 3.11.3 Depth Contour map of Parh Limestone

The depth contour maps show the horizon depth variation .Following are the figures of depth contour maps of Lower Goru and Parh formations. These depth maps shows that horizon is forming horst and graben structures. As from scale the N-E portion is deepest than the surrounding area between fault polygons. It is noticed that pattern of depth and time is same because of no variation in time and depth.

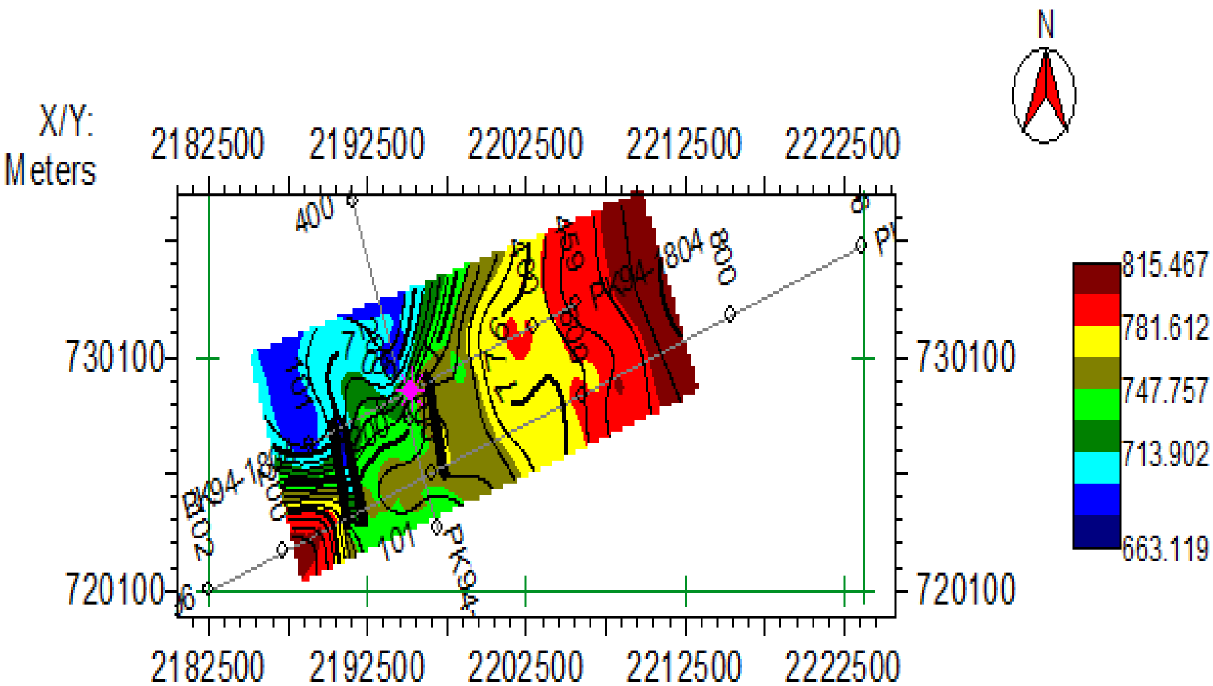



**Fig 4-9 Depth contour map of Parh Limestone**

### 3.11.4 Depth Contour map of Lower Goru

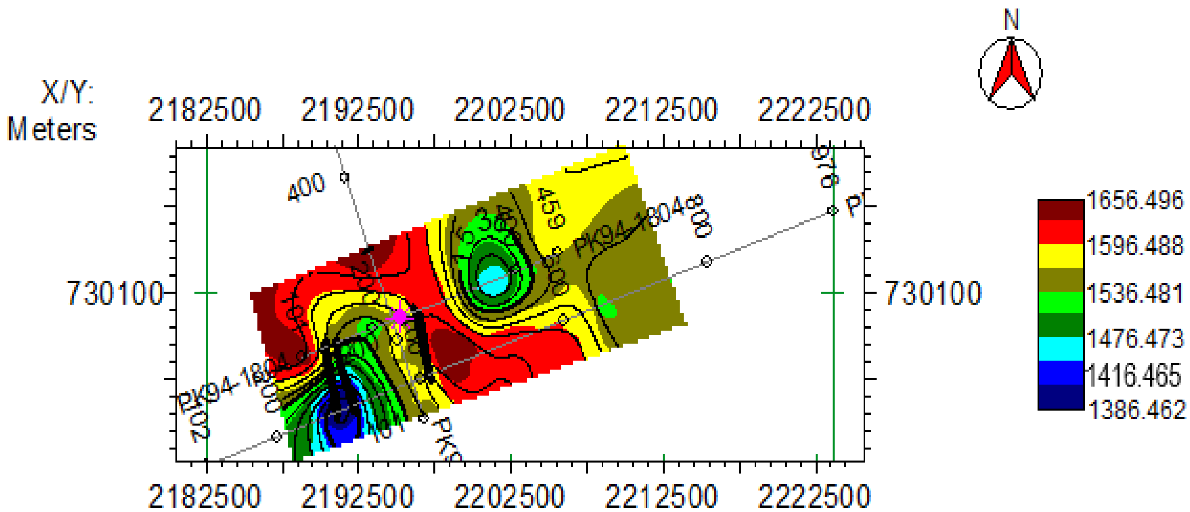



**Fig 4-10 shows Depth Contour map of Lower Goru**

## 3.12 Analysis and Conclusion

On the basis of general stratigraphic column present in the area and the formation tops of the Doti-01 well, five reflectors are named.

➢ Reflectors were named after correlation with the available well data on the line **PK94-1804, PK94-1807** and **PK92-1696.**

➢ Reflector 1 is named as Parh Limestone

➢ Reflector 2 is named as Lower Goru.

➢ The seismic section shows a system of conjugate normal faults, making Horst and Graben structures.

# CHAPTER NO. 4: PETRO PHYSICS

## 4.1 Introduction

### 4.1.1 General Information:

Doti-01 lies upon the seismic line PK 94-1804. It is exploratory but abandoned and dry well. Badin block consists of a total of 380 exploratory wells and 59 oil and gas condensate discoveries. In Lower Indus, so far more than 12 TCF (Trillion Cubic Feet) gas reserves and more than 100 trillion barrels Oil have been discovered in Lower Indus Basin whereas more than 90% oil production is from Badin area (Mozaffer et al., 2002). Well log interpretation is done on Top Lower Goru Formation. The purpose of study is to be able to identify the permeable zones, their fluid content and hydrocarbon saturation.

In well logging different types of logs are obtained with the help of a sonde. In early ages different sondes are used for different type of logging in the well but now a days we use only one sonde which has ability to do all type of logging both cased or uncased logging.

The well logs analysis was carried out by using the following wire-line logs of Doti-01 issued by DGPC:

- Density log
- Neutron log
- Resistivity log
- Gamma Ray log
- Sonic log

- Caliper log

## 4.2 Petro physics:

Petro physical 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).

- Petro physics uses all kinds of logs, core data and production data; and integrates all pertinent information.
- Petro physics aims at obtaining the physical properties such as porosity, saturation and permeability, which are related to production parameters.
- Petro physics is generally less concerned with seismic, and more concerned with using wellbore measurements to contribute to reservoir description.
- petro physics can provide things like porosity, saturation, permeability, net pay, fluid contacts, shale volume, and reservoir zonation.

## 4.3 Petro physical Analysis:

Electrical well logging was introduced to the oil and gas industry over half a century ago and since then, many improved and additional logging tools and devices have been developed and have been put in general use. The art of interpretation of the data advanced along with the advancements in well logging science. Today, the detailed analysis of a carefully chosen suite of wire-line services provides a method of inferring or deriving accurate values for the following:

- Hydrocarbons and water saturations
- Permeability indexes
- Porosity
- Lithology of the reservoir rock

## 4.4 Log Curves:

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

## 4.5 Method:

The following processing chart was used while interpreting the well logs:

- Marking zones of interest
- Calculating volume of Shale (GR Log)
- Calculating porosity
- Estimating resistivity of water ($R_w$)
- Estimating saturation of water (Sw)

### 4.5.1 Interest Zones:

The zones of interest are defined on the basis of source, reservoir and seal rock formations given in well tops of Doti-01 well. The zone of interest which is marked as follows:

Three zones are marked and their information is briefly given at the end of this chapter.

### 4.5.2 Shale Volume Calculation:

The volume of shale is calculated using GR log by given formula

$$I_{GR} = \frac{GRlog - GRmin}{GRmax - GRmin} \quad \text{(Rider, 2002)}$$

Following terminologies have been used in the above formula:

**IGR:** Gamma Ray Index

**GR log:** Gamma Ray reading at interested depth.

**GR max:** Maximum Gamma ray reading.

**GR min:** Minimum Gamma ray reading.

The lithologies are marked by Gamma Ray log deflections; it is a good indicator of shale. The shale and sand formations are identified by this log, but sometimes caliper and SP log information is also very important for strata characterization. Because of more shaly content in the reservoir patch with excessive volume of shale is not as good reservoir as compared to the rest of lithology. This is one of the probable reasons of the dryness of well Doti-01. It cannot produce economical amount of hydrocarbons.

### 4.5.3. Determination of Lithology:

Shales always have high GR values as compared to sandstones that has low GR value and low density –neutron value. Sandstone is permeable by all means so in order to differentiate between any of the sandstone we use Neutron-Density cross plot (Rider, 2002). The root mean square formula provides the best calculation:

| For Oil and Water bearing Formation | For gas bearing Zone |
|---|---|
| $\phi = \frac{\phi N + \phi D}{2}$ | $\phi = \sqrt{\frac{\phi N^2 - \phi D^2}{2}}$ |

(Rider, 2002)

**ϕN**: Neutron porosity

**ϕD**: Density porosity

### 4.5.4. Identifying the Fluids Present:

While studying the porosity pattern in any formation if we encounter large variation in resistivity in permeable formation of similar porosity, either there is water bearing formation or hydrocarbon bearing formation.

1. High resistivity likely hydrocarbons.

2. Low resistivity likely water

### 4.5.5 Porosity Determination:

The pore spaces which are not occupied by the rock fragments are named as porosity. Porosity is created due to inter granular spaces, voids formed by dissolution of grains as well as fracturing of rocks. The symbol used for porosity is "ϕ" and expressed either by percentage or in decimals.

It determines the ultimate volume of rock type that can contain hydrocarbons. The value and distribution of porosity, along with permeability and saturation are the parameters that dictates reservoir production and development plans. The porosity of the formation can be obtained from the bulk density if the mean density of the rock matrix and that of the fluid it contains known.

$$\phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad \textbf{(Rider, 2002)}$$

Following terminologies have been used in the above formula:

$\rho_b$: Bulk density of the Formation.

$\rho_{ma}$: Density of the rock matrix.

$\rho_f$: Density of the fluid occupying the pores.

$\phi$: Density porosity of the rock.

The following table shows Density values of Formations/Water types

| Formations/Water Type | Values |
|---|---|
| Saline Water | 1.1 g/cm$^3$ |
| Fresh water | 1.0 g/cm$^3$ |
| Sandstone | 2.65 g/cm$^3$ |
| Limestone | 2.71 g/cm$^3$ |

(Rider, 2002)

Porosities are added into neutron porosities, divided by 2 and a total porosity is found then volume of shale is subtracted by 1 and multiplied with total porosity to get effective porosity.

Density is calculated by using following methods:

- **Density Porosity:**

It is derived from density log using the following equation

Density Porosity = (Density Matrix - Density Log) / (Density Matrix- Density Fluid)

- **Neutron Porosity:**

It is directly obtained from Neutron log values.

The Average Porosity is obtained by taking the mean of the above two;

Average Porosity = (Density Porosity + Neutron Porosity)/2

Finally Effective Porosity is given by;

Effective Porosity = Average Porosity * Vmatrix

Where Vmatrix is Volume of Matrix given by 1- Vshale

## 4.5.6 Rw Calculation:

By using the Archie Method value of Rw was calculated. The value was found to be equal to 0.042 ohm-m.

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

**Rmf2 = Rmf1 * (T1 + 6.77/ T2 - 6.77)**

Where Rmf1 is Resistivity of mud filtrate at surface temperature, T1 is surface temperature.

T2 is formation temperature and Rmf2 is resistivity of mud filtrate at formation temperature (zone of interest).

## 4.5.7 Water Saturation:

Water saturation determines the ratio of water present to that of hydrocarbons in the reservoir. Archie equation is used to find the saturation of water and then it is subtracted by 1 to find the saturation of hydrocarbon.

**SW=(A*RW/(RT*(PHI^M)))^(1/N)**

Following terminologies have been used in the above formula:

**Sw:** Water saturation of the uninvaded zone.

**Rw** =water resistivity (formation)

**Φ(phi)** = effective porosity

**n**=2.05

**m** (cementation factor) = 2

**a** (constant)= 1

**Rt** = log response (LLD)

**Rw** has been calculated with help of the following formula:

**Rw= Φ2×Rt**

Where, **Φ** = porosity in clean zone

**Rt** =Observed LLD curve in clean zone

### 4.5.8 Hydrocarbon Saturation

Hydrocarbon saturation is calculated from the given formula

**Shc = 1-Sw**

Where,

Sw= Water Saturation

Shc= Hydrocarbon saturation

## 4.6 Log Interpretation Results on Lower Goru Formation:

The Lower Goru formation in Doti-01 starts from the depth of 1537m, and ends at 1822m.

By analyzing different well logs such as caliper log, Gamma ray log, Resistivity log, and neutron density cross over on SMT Kingdom, different zones of interest can be marked.

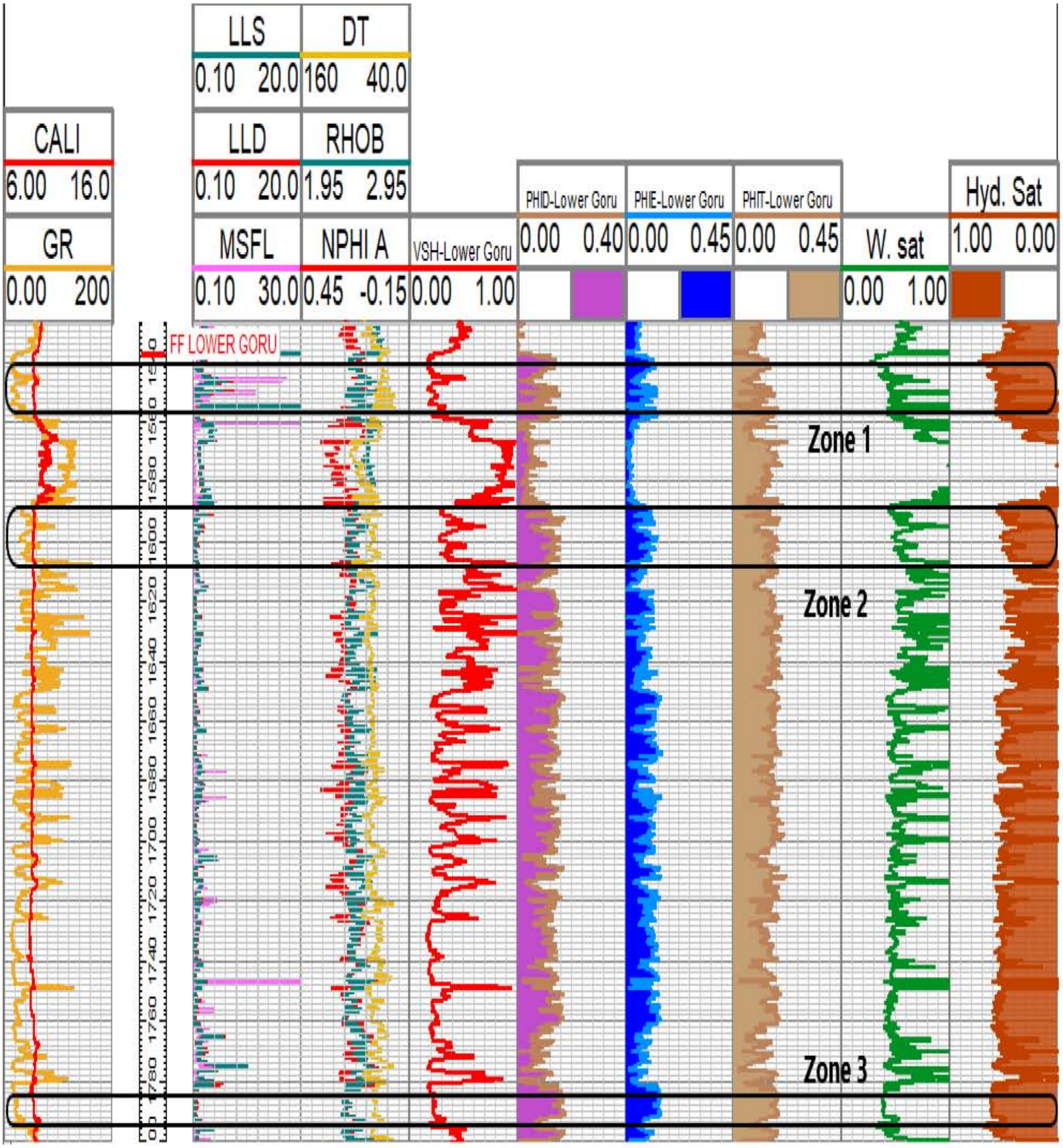
Following conditions should be fulfilled in order to mark zone of interest for hydrocarbons.

1 There should be low value of Gamma Ray log, as low value represents clean lithology.

2 There should be positive cross over for density and neutron.

3 There should be significant difference between the resistivity values of LLS and LLD (Rider, 2002).

On the basis of the conditions mentioned above, I marked three zones of interest for sand reservoir in Doti-01 well in Lower Goru formation. The figure is shown on next page




### 4.6.1 Interpretation of marked zones:

In the marked zones, values of GR log are low, so it represents the clean lithology. Shaly content is also relatively so it indicates the presence of sand. There is a gap between MSFL and LLD, LLS logs, gap represents the presence of Hydrocarbons. There is a positive cross over between neutron and density log. It represents the presence of Hydrocarbons in these depths. All these conditions tells us the presence of Hydrocarbons in the marked zones but in less amount. Doti-01 is dry so percentage of water saturation is relatively high.

### 4.6.2 Result of petro physical analysis:

| **Zone** | **Depth Starts (m)** | **Depth Ends (m)** | **VSH Avg.** | **PHIE Avg.** | **PHID Avg.** | **Water Saturation** | **Hydrocarbon Saturation** |
|---|---|---|---|---|---|---|---|
| **Zone 1** | 1540 | 1558 | 23.5% | 8.02% | 8.79% | 52.2% | 47.8% |
| **Zone 2** | 1588 | 1606 | 39.69% | 8.7% | 11.83% | 57.94% | 42.1% |
| **Zone 3** | 1782 | 1796.87 | 24.42% | 11.65% | 13.18% | 41.08% | 58.91% |

# CHAPTER NO. 5: FACIES MODELLING

## 5.1 Introduction

### 5.1.1 Sedimentary facies

“A rock or stratified body distinguished from others by its appearance or composition.”

Sedimentary facies are bodies of sediment that are recognizably distinct from adjacent sediments that resulted from different depositional environments. Generally, geologists distinguish facies by the aspect of the rock or sediment being studied.

### 5.1.2 Walther’s Law of facies

Walther's Law of Facies, 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. A classic example of this law is the vertical stratigraphic succession that typifies marine transgressions and regressions.

## 5.2 Facies modelling

It is used for the act of modelling a reservoir using knowledge of the facies, which make up the reservoir and the depositional environments that the facies represent. The depositional characteristics will suggest rules concerning the geometries of the facies and the possible relationships between facies especially where the facies have been related to each other within a stratigraphic sequence or a cyclothem. Facies modelling is an important component of geostatistical reservoir characterization and facilitates construction of superior reservoir models for complex reservoirs.

Facies is a distinctive kind of sedimentary deposit, which was deposited in a distinctive setting. Sedimentary facies reflect the depositional environment and original composition that have resulted into the present characteristic of the rock units.

A facies model is a general summary of the specific sedimentary environment. This involves the distillation of the facies and facies successions in several related environmental settings into a widely applicable model.

Facies modelling helps in understanding sedimentary features characterize a particular environment and the lateral and vertical distribution of facies within sedimentary deposits.

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.

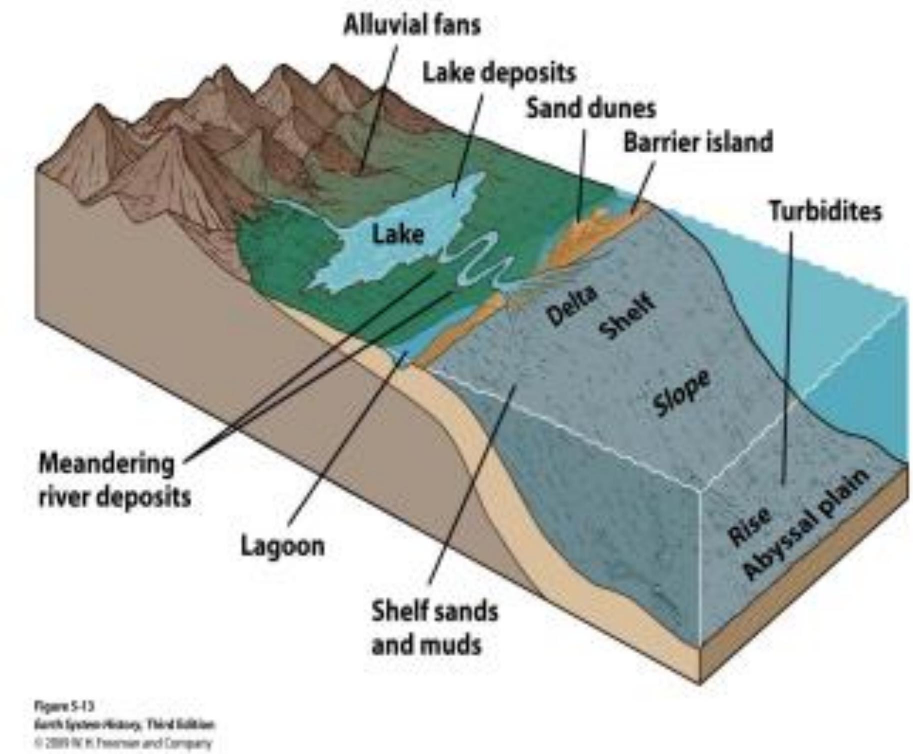



**Figure from Earth system history, third edition by W.H Freeman and company**

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.

## 5.3 Facies Analysis

Fundamental to all subsurface geologic studies is an analysis of depositional facies. Development of a facies classification scheme is a challenging interplay between capturing enough information for environmental interpretation yet remaining simple.

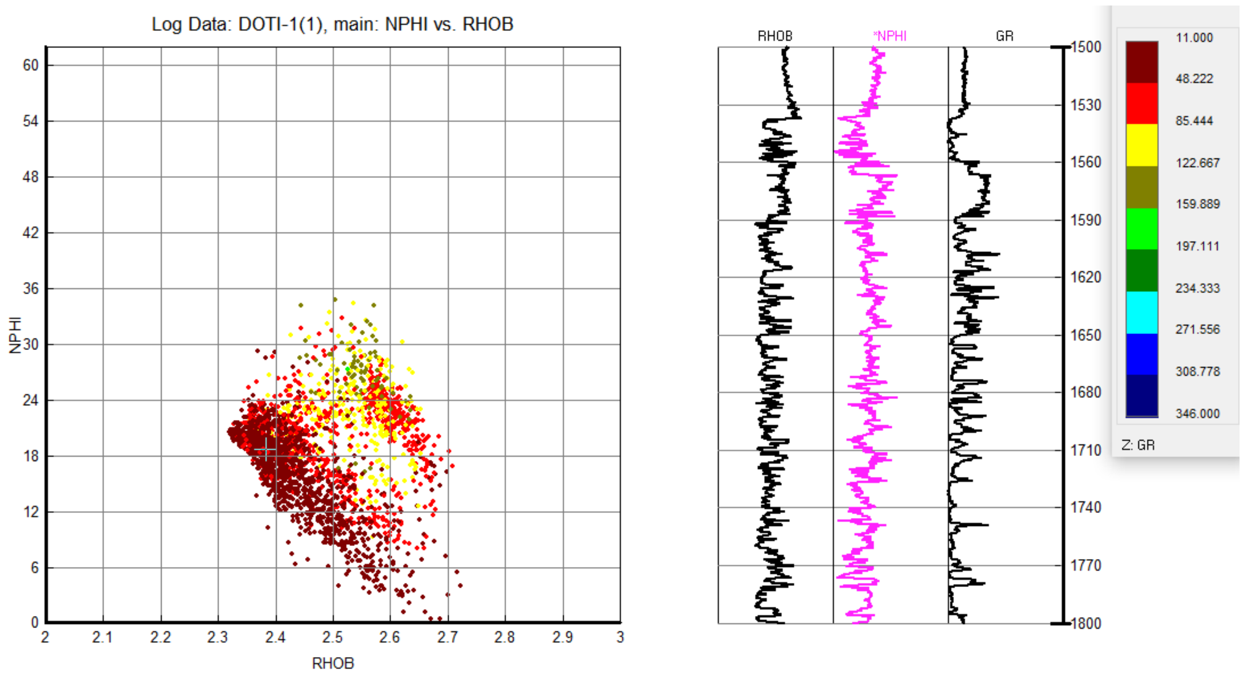
"Every facies of a deposition shows well-defined petrographic, geognostic and paleontological properties which can be clearly differentiated from the properties of other facies in the same geological period." The necessity for interdisciplinary studies is clearly expressed in this definition given by Amanz Gressly in 1838. In facies analysis paleontological, sedimentological, geological, and geochemical data provide the basic information about the sedimentary environment, the lithogenesis, and the biotopes of organisms preserved as fossils. (Homewood, P. W. (1997))

## 5.4 Facies modelling of well data

### 5.4.1 NPHI and RHOB cross plot:

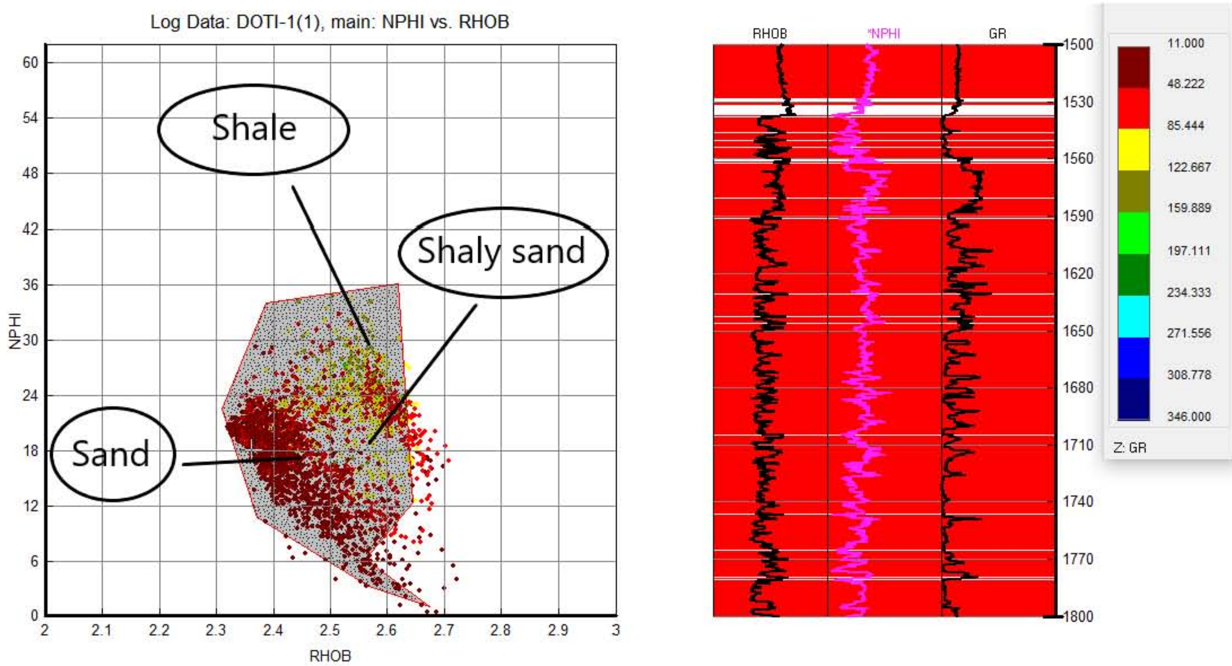
For facies modelling, cross plot of NPHI and RHOB is extracted by taking GR as reference log. Neutron-porosity log is taken at y-axis, Density at x-axis and Gamma ray was plotted on z-axis. Hydrogen concentration is best measured by NPHI, zone with excess of shale has high hydrogen concentration and not much deviation could be seen in front of sand. NPHI is quite indistinguishable in Oil, water and clay due to identical concentration of hydrogen in all of them. So, Neutron log has recorded higher level of hydrogen with increasing volume of clay.

At the same time, density has shown a slightly decreased value in sandstone than the fixed matrix value of 2.65 g/cm$^3$. Whereas, reservoir zone of Lower Goru Sandstone shows values lower than 2.5 g/cm$^3$, a strong indication for the presence of hydrocarbons. 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 below shows the lithology model for Doti-o1 well.




## **Figure shows cross plot of both NPHI and RHOB with GR as Reference log.**

The figure below shows the marked regions of shale, shaly sand and sand.


Log Data: DOTI-1(1), main: NPHI vs. RHOB
NPHI
RHOB
Shale
Shaly sand
Sand
60
54
48
42
36
30
24
18
12
6
0
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
RHOB
*NPHI
GR
1500
1530
1560
1590
1620
1650
1680
1710
1740
1770
1800
11.000
48.222
85.444
122.667
159.889
197.111
234.333
271.556
308.778
346.000
Z: GR

# Conclusions

1- Seismic data interpretation of study area reveals the involvement of extensional and shear tectonics in the structural geology of the area.

2- Petro-physical interpretation results showed that Zones of interest in Lower Goru Formation has conductive properties with low values of LLD and LLS as compared to MSFL. Petro physical analysis showed Lower Goru as a desirable reservoir.

3- Results of seismic interpretation, well log interpretation and facies analysis point to the dryness of well Doti-01.

4- Time and Depth contour maps of Lower Goru help us to confirm the presence of horst and graben structure in the given area. This structure acts as a trap in the area, which is best for hydrocarbon.

5- Synthetic seismogram helped in checking the credibility of Time and Depth contour by observing values at the well and endorse stratigraphic interpretation.

6- Geological structure of the area is confirmed and further studied with the help of interpretation.

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