# 2D Seismic Reflection Data Interpretation of Badin Area, Seismic Attributes and Petrophysical Analysis

**BY**

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**“WITH THE NAME OF ALLAH, THE MOST MERCIFUL AND THE MOST GRACIOUS”**

# CERTIFICATE

This dissertation submitted by **MUHAMMAD BILAL IJAZ** son of **IJAZ AHMED** 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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**EXTERNAL EXAMINER** __________________________

**DEDICATED**
**TO**

My Parents and

Friends

# 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 **Dr. MUHAMMAD TOQEER** 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 BILAL IJAZ**

# ABSTRACT

Badin area is a common example of extensional tectonics represented by Horst and Graben structures. In order to carry out the structural and stratigraphic interpretation of the Badin area, four seismic lines are interpreted. Two-way time and depth mapping helped in delineation of the structural trend and understanding the tectonics of the area. The major fault trend is NE-SW. There are indications of reactivation of faults. 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. Porosity calculations are made to find out the hydrocarbon saturation. The main constituents of petroleum system are present, proven by a number of oil and gas discoveries but there is still a requirement of advance techniques to improve seismic resolution and quality of interpretation.

# Contents

# Chapter 01

# INTRODUCTION

## 1.1 Introduction to the Study Area

Badin Block is not a geological entity nor is it different geologically from its adjacent parts. The district is placed 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. 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 area located to the west and northwest of Nagar Parker are the Tharparkar slope that dips westward and northwestward and where Indus basin most prolific hydrocarbon bearing territory is located. The main tectonic events which have controlled the structures and sedimentology of the Badin Block and also the Indus Basin are rifting of the Indian Plate from Gondwanaland (Jurassic or Early Cretaceous) which probably created NE-SW to N-S rift systems. Isostatic uplift or ridge push at the margins of the newly developed ocean probably caused uplift and eastwards tilting at the start of the Cretaceous. The disjointing of the Madagascar and Indian plates in the mid to Late Cretaceous which may have caused some sinistral strike-slip faulting in the region, hotspot activity and thermal doming at the Cretaceous-Tertiary boundary. This in turn caused uplift, erosion, extrusion of the Deccan flood basalts and probably the NNW-striking normal faults. Too far from Badin Block to the western edge of the Indian Plate at the time of Paleocene-Eocene the emplacement of the Bela Ophiolites may have caused gentle folding, Eocene passive margin conditions caused structural quiescence and carbonate deposition, Oligocene to present-day. The Himalayan collision caused sinistral transpression in the west of the Lower Indus Basin, with fold-thrust structures overprinted by sinistral flower structures but due to Badin Block distant location from the leading edge collision zone the impact is negligible in the structuration.

The syn rift and post rift deposition of the Lower Goru and Upper Goru formations was continued during early to middle Cretaceous time which can be observed as relatively thin presence of Upper Goru on the top of the fault blocks (horst blocks) whereas thicker in the lows (Graben). 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. In the recent years, the Indus basin of Pakistan is being extensively studied to evaluate the unconventional hydrocarbon potential (Zaigham and Mallick, 2000).

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 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. The most significant styles seen are rifting, overprinted by shear modification, and subsequently modified by doming.

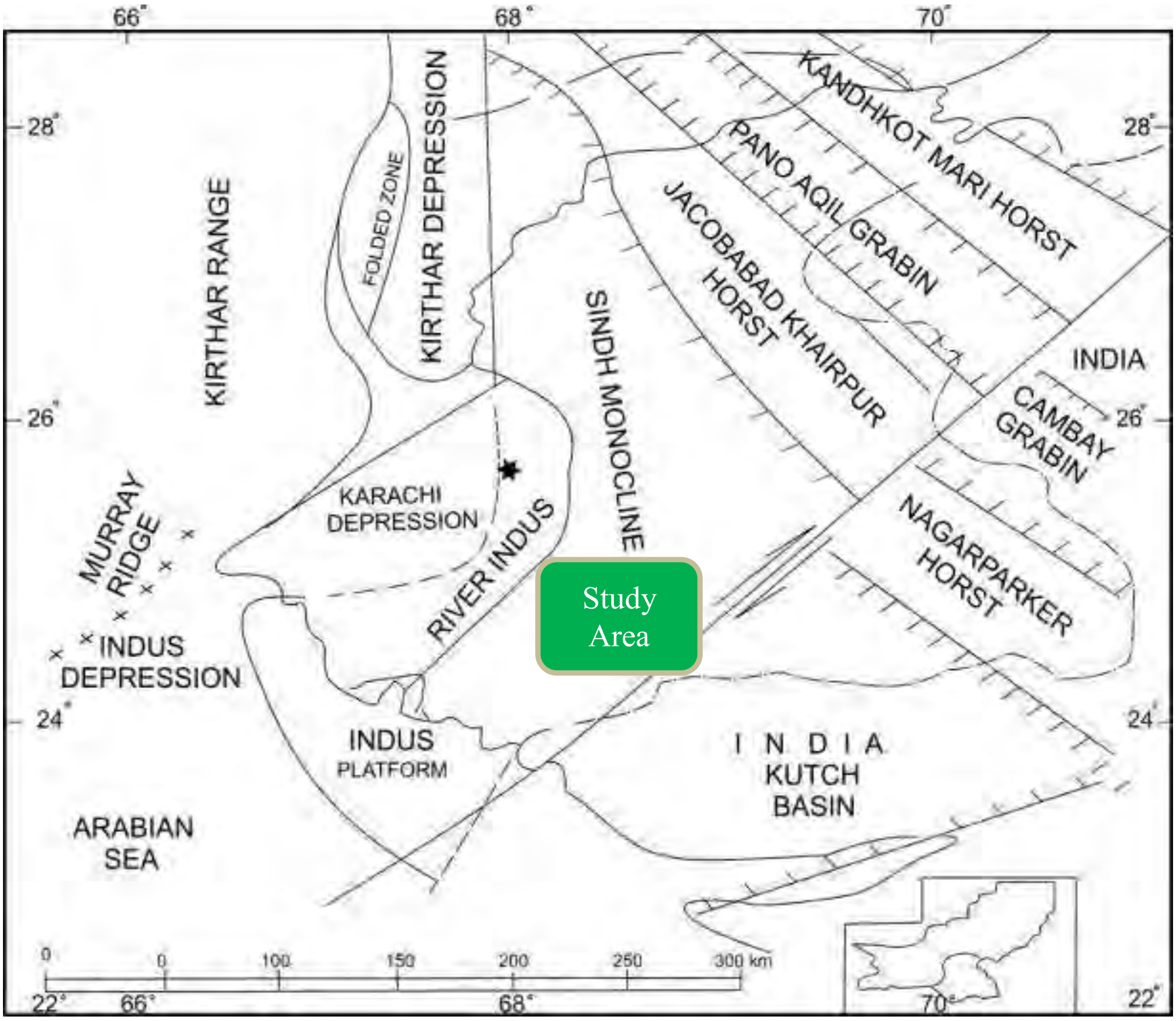

Figure 1.1 Tectonic map of Lower Indus Basin showing the study area. (after Ehsan et al ,2018)

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 W and N 50 W (Kemal et al., 1991). Commonly, faults are arranged in en-echelon 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. The under filling of structures can be attributed to upward leakage across extensive structures and redistributed hydrocarbon (Kemal et al., 1991).

## 1.2 Exploration History

Exploration in the Lower Indus Basin started in 1939 by Burmah Oil Company (BOC) near Karachi. In 1948 second well was drilled on the Lakhra structure by BOC. Aeromagnetic surveys were conducted by Standard Vacuum Oil Company (SVOC) in 1955 and by Oil & Gas Development Company (OGDC) in 1962-63. Surveys were carried out by SVOC in 1954-56, Oil Company (SOC) in 1957-59, Pakistan Petroleum Ltd (PPL) in 1949 and 1956-60, Pak Hunt Ltd in 1957-59, Tide Water Oil Company in 1959-60, OGDC in 1966-75 and Pakistan Texas Gulf in 1975. In May 1981, a joint venture of Union Texas Pakistan, Occidental of Pakistan Inc., and OGDC discovered oil at Khaskheli within the Badin Block. With this discovery, the Lower Indus Basin became the second largest oil producing sub basin of Pakistan, after Pothwar (Kemal et al, 1999)

## 1.3 Base Map

The base map is important component of interpretation, as it shows the spatial position of each picket of seismic section. For a Geophysicist a Base map is that which shows the orientations of seismic lines and specify points at which seismic data were acquired or simply a map which consist of number of dip and strike lines on which seismic survey is being carried out . A base map typically includes location of lease and concession boundaries, wells, seismic survey points and other cultural data such as buildings and roads with geographic reference such as latitude and longitude. Geophysicist typically use shot points maps, which show the orientation of seismic lines and shot points at which seismic data were required, to display interpretation of seismic data.

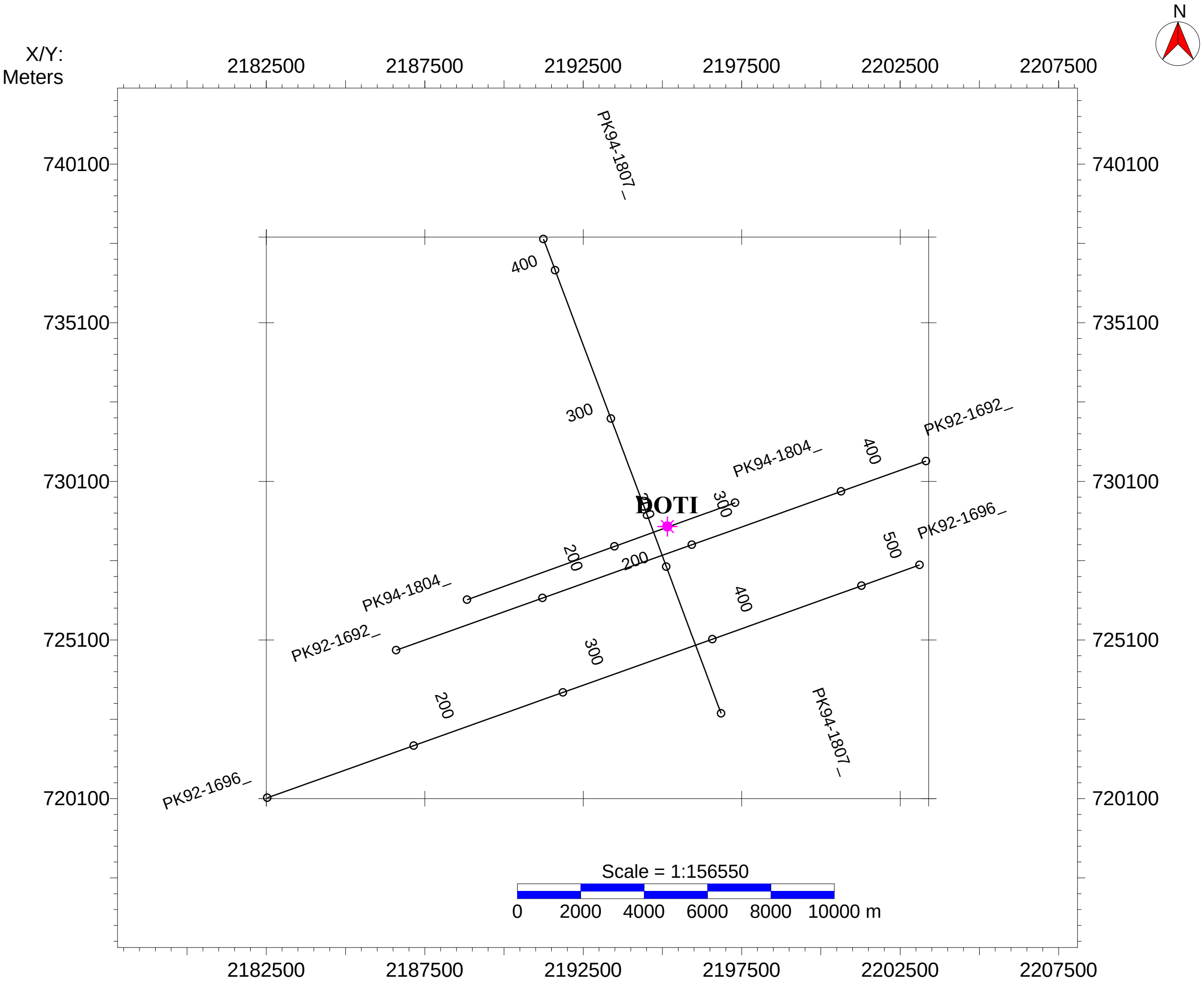

Figure 1.2 Base map of the study area

## 1.4 Data Formats

Seismic reflection data which consist of following formats.

1. SEG-Y (Seismic Data format)
2. LAS (Well Log Data format)
3. Navigation

All data sets used were provided by Directorate General of Petroleum concession (DGPC), Government of Pakistan upon the request of Chairperson Department of Earth Sciences, Quaid-i-Azam University Islamabad.

## 1.5 Software Tools and Applications

SMT Kingdom 8.6

1. Structural Interpretation

2. Stratigraphic Interpretation

3. Well correlation

4. Seismic attribute analysis

5. Petro-Physics

## 1.6 Analysis of Workflow

The Interpretation was carried forward using different techniques and steps with each step involve different processes which were performed using the software tools as mentioned above. Simplified workflow used in the dissertation is given in figure1.3, which provides the complete picture depicting how the dissertation has been done.

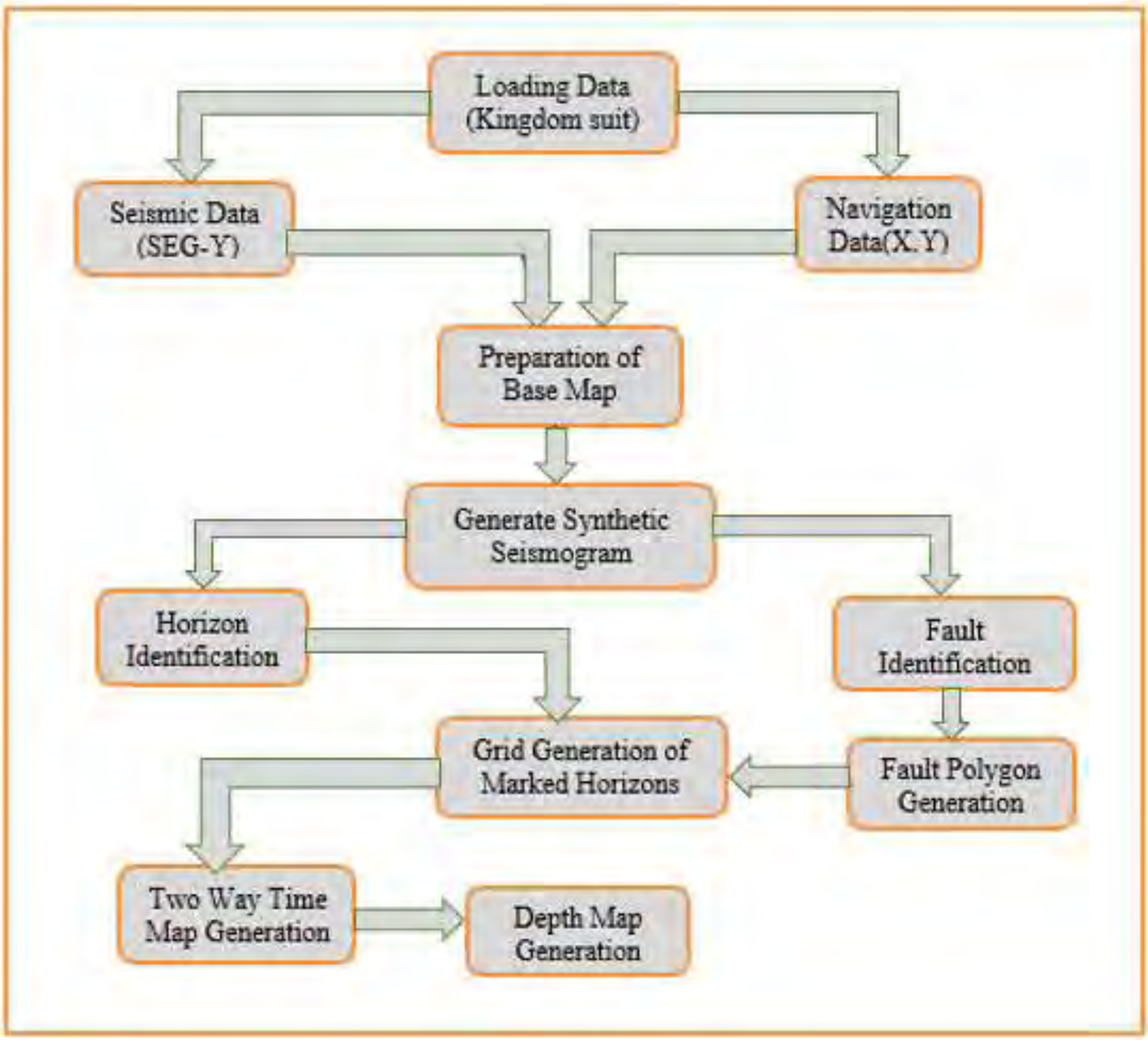

Figure 1.3 Workflow analysis of Seismic Interpretation

## 1.7 Objectives

The main objectives of this dissertation based on interpretation of seismic section are:

1. Structural interpretation to find out the structural traps and horizons of interest.
2. To generate time, depth contour map of the selected reflectors.
3. Seismic attribute analysis to confirm the interpretation.
4. Petro physical analysis of reservoir formations to identify the net pay zone.

## Chapter 02

# GENERAL GEOLOGY AND STRATIGRAPHY

## 2.1 Indus Basin

The Indus Basin belongs to the class of basins. 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 et al, 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 Pothwar 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 (Kazmi A. H. & Jan, M.Q, 1977).

## 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 Badin district 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 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). 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.

## 2.4 Division of the Lower Indus Basin

Lower Indus Basin is divided in to two classes. We are mainly focused on Southern Indus basin.

1. Central Indus Basin
2. Southern Indus Basin

### 2.4.1 Southern Indus Basin

The southern Indus basin extends approximately between 24$^{o}$N to 28$^{o}$N Longitude and 66$^{o}$ to 71$^{o}$ E Latitude. It is characterized by several structural features. It is characterized by several structural highs

1. Thar Platforms
2. Karachi Trough
3. Kirthar Foredeep
4. Kirthar Fold Belt

### 2.4.2 Central Indus Basin

Central Indus Basin may be divided into following broad tectonic divisions from east to west (Kadri, 1995)

1. Punjab Platform
2. Suleiman Depression
3. Suleiman Fold Belt

The basin is separated from Upper Indus Basin by the Sargodha High and Pezu uplift in north. It is bounded by Indian shield in the east, marginal zone of Indian Plate in the west, and Sukkur rift in the south. It is the Sargodha High in fact which is considered to be a divide between Upper Indus Basin & Lower Indus Basin. The Southern & Central Indus Basins are separated by Jacobabad & Mari- Kandhkot highs together termed as the Sukkur Rift (Kadri, 1995).

The oldest rocks exposed in this basin are of Triassic age (Wulgai Formation) while the oldest rocks penetrated through drilling are of Precambrian Salt Range Formation. The depth to the basement is about 15000 meters in the Trough areas. Precambrian shield rocks are evident along the rim of the Indian Plate (Kadri, 1995).

## 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 (Chaman 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 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. (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. 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 (Zaigham, N. A., Mallick, K. A., 2000).

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 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 (Powell, 1979).

## 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. 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 .From 80 M.A ago India moved at an average rate of about 16 cm/year relative to Australia and Antarctica. The rate of movement varied between 15 and 25 cm/year.

Two broad geological divisions of this region the Gondwanan and the Tethyan domains are discussed. In this scenario Pakistan is unique since it is located at the junction of these two diverse domains. The northern most and western regions Pakistan fall in Tethyan domain and present a complicated geology and complex crustal structure (Powell, 1979).

Based on 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.

1. Indus Platform and fore deep
2. East Baluchistan fold-thrust belt
3. Northwest Himalayan fold-thrust belt
4. Kohistan-Ladakh magmatic arc
5. Karakoram block
6. Kakar Khoarasan flysch basin and Makran accretionary zone
7. Chagai magmatic arc
8. Pakistan Offshore

## 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 interbeds of black siltstone and nodular rusty weathering argillaceous limestone beds. In the basal part pyritic and phosphatic nodules and sandy shales are developed locally. Rock unit is glauconite. And it is proven a good source rock. This rock unit is widely distributed in Suleiman and Kirthar ranges. Its Lower contact with various Jurassic formations such as Mazar Dirk formation, Chiltan limestone and Shirinab formation is disconformable while the upper contact is generally gradational with the Goru formation. The Sembar formation is correlated with Chichali Formation of the Kohat-Pothwar Province. This rock unit is richly fossiliferous, and the most common fossils reported are the belemnites, Mullucs and others and the age given is Early Cretaceous. (Kemal *et al.,* 1991).

### 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.

Based on lithology Goru Formation is divided in two parts

1. Lower Goru
2. Upper Goru

#### 2.8.2.1 Lower Goru

The lower Goru is the main reservoir rock within the area. It is based on following lithologies

1. The Basal Sand unit
2. Lower Shale
3. Middle sand unit (which has a good reservoir potential)
4. Upper Shale
5. 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 Kirthar and Suleiman Province. The lower contact with the Sembar formation is conformable and is locally reported unconformable. The upper contact is transitional with the Goru formation may be correlated with the Lumshiwal Formation of the Kohat-Pothwar Province. The formation contains foraminifers and bivalves and age given is Early Cretaceous (Powell, 1979).

### 2.8.3 Parh Limestone

The Parh limestone is a 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 (Suleiman and Kirthar 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 are dominant. No macrofossils are known. Age given is Late Cretaceous (Kemal et al., 1991).

### 2.8.4 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, grey to brown gypsiferous shale with interbeds of fossiliferous limestone. The formation is widely distributed in Kirthar 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. The age given to the formation is Early Paleocene (Powell, 1979).

## 2.9. Structural Setting in the Badin Block

Badin Rift Basin is in Thar platform area of Lower Indus Basin. It is the Sargodha High in fact which is a dividend for Upper Indus Basin & Lower Indus Basin. 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.

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° W and N 50° W (Kemal *et al.,* 1991). Commonly, faults are arranged in echelon 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.

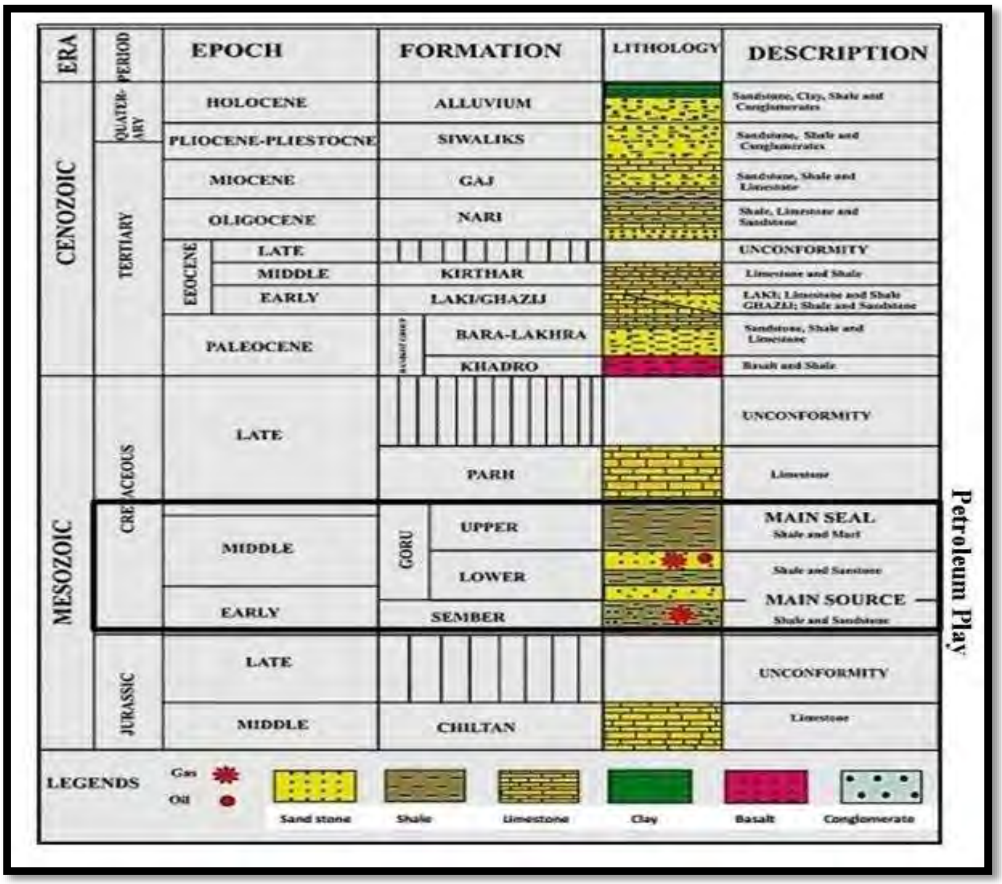

Figure 2.1 Generalized Stratigraphy of Study Area (Modified after Zaigham, 2000).

## 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 several 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 disconformity form the prevalent play types (Zaigham and Mallick, 2000).

### 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.

1. Upper Goru Formation
2. Lower Goru Formation (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. 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 (Zaigham and Mallick, 2000).

### 2.11.2 Reservior 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. 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 (Zaigham and Mallick, 2000).

### 2.11.3 Source Rock

The shales of the Cretaceous Sembar Formation are the principal source rock of the Lower Indus Basin. 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 .Oil produced from the Lower Goru sands has originated from the Sembar Formation. Sembar Formation 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. 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 .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).

# Chapter 03

# SESMIC INTERPRETATION

## 3.1 Introduction

Interpretation is a technique or tool by which we try to transform the whole seismic information into structural or Stratigraphical 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 in 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, 1960). There are two main approaches for the interpretations of a seismic section are:

1. Stratigraphical Analysis
2. 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 both, the 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 kilometer. The study area lies in intense extensional regime, so general structure is normal related i.e. horst and graben structure.

## 3.4 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. Ideally, a density log should also be used, but these are not always available hence we can also use 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 drill hole geology to seismic sections because they can provide a direct link between observed lithologies and seismic reflection patterns. 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).).

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. Compute a Ricker wavelet as a digital filter with increment of two millisecond.
9. Two-way travel time: using a frequency in Hertz (15.5 Hz frequency is used in this study).
10. Convolve the reflection coefficient log with the Ricker wavelet to generate the amplitudes of the synthetic seismogram.

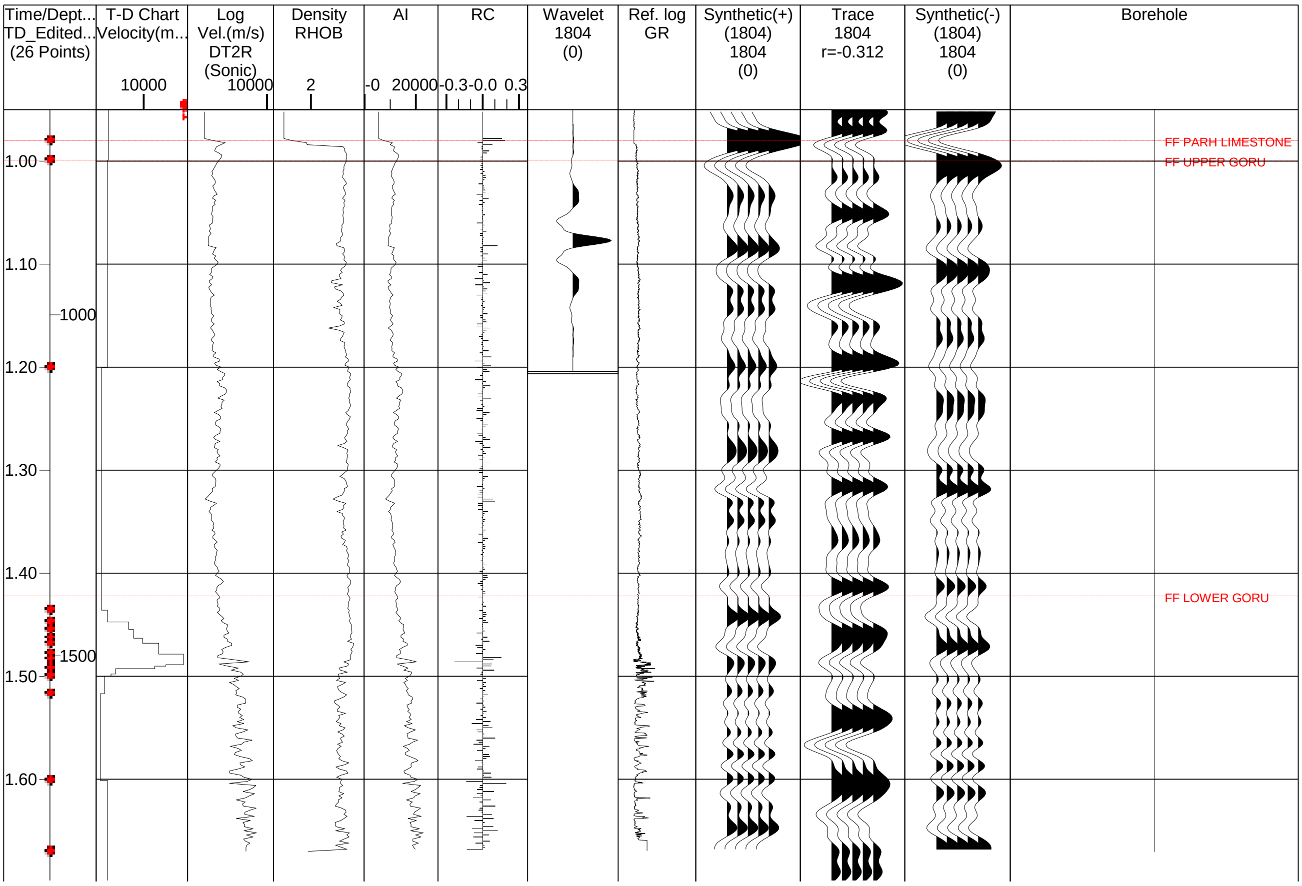

Figure 3.1 Synthetic Seismogram of DOTI-01

## 3.5 Marking of Seismic Horizons

Primary task of interpretation is the identification of various horizons as in interface between geological formations. For this purpose, good structural as well as stratigraphic knowledge of the area is required. Thus, during interpretation process marked both the horizons and faults on seismic section (McQuillan et al, 1984). Two horizons are picked. The horizons are named on the basis of well tops of the well DOTI-1. The lower and Upper Guru Formation which are showing high reflections seismic section making it easier to be picked.

## 3.6 Marking of Faults

Fault marking on real time domain seismic section is quite a hard work to do without knowing the tectonic study of the area. Faults are marked on the basis of unconformity of the reflections. This disconformity of the reflector shows that the data is disturbed here due to the passing of the fault. The Badin area is lying on continental regime thus we have normal faulting due to which Horst and Graben structures are formed. Faults in the area is due to the extension in the area of interest in Lower Indus Basin.

## 3.7 Seismic Time Section

The interpretation shows the alternatively horst and graben are formed between conjugate normal faulting. The fault having almost trend of the N-S. The main purpose was to show the favorable structure for petroleum accumulation. The horst and graben structures are considered good structural traps for the petroleum accumulation (Kadri, 1995).

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, PK94-1807, PK92-1696 and Pk92-1692 are show in the Figure 3.2, 3.3, 3.4 and 3.5. Reflectors are marked by tying with the line which is marked by using well top data of DOTI-01 well.

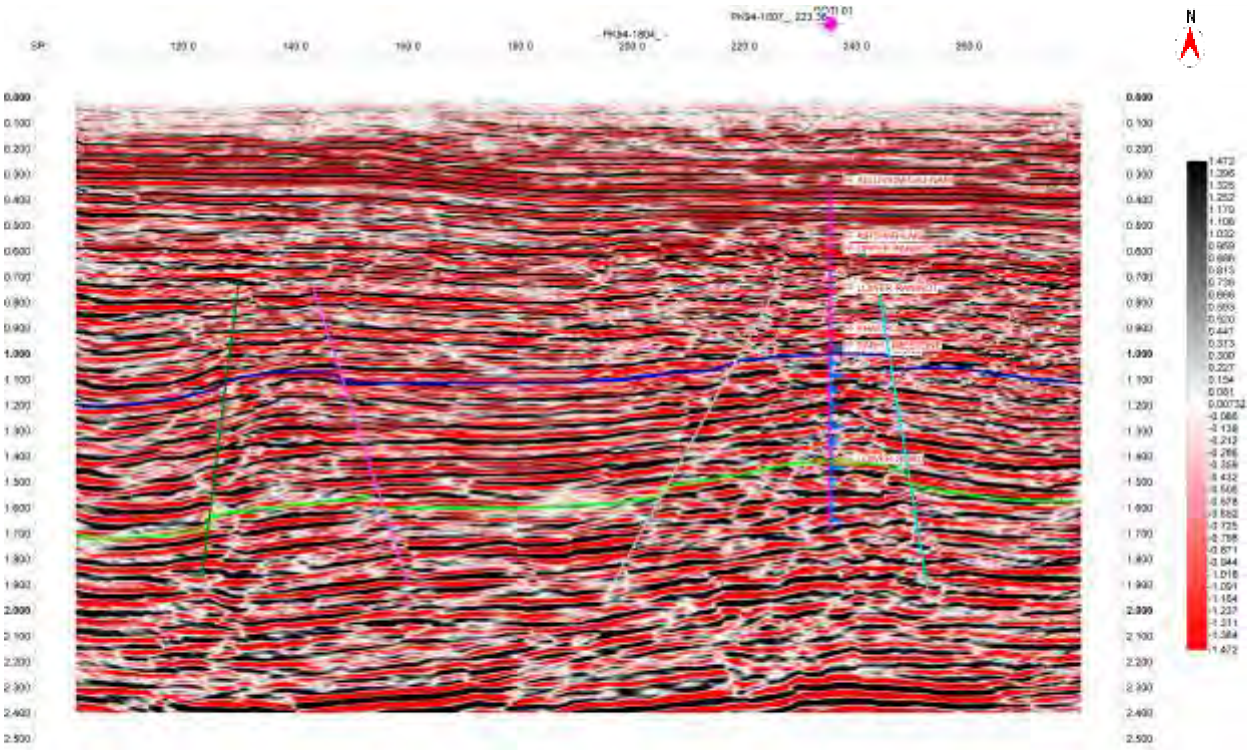

Figure 3.2 Seismic Time Section of Line PK94-1804

The line is oriented in NE-SW direction.

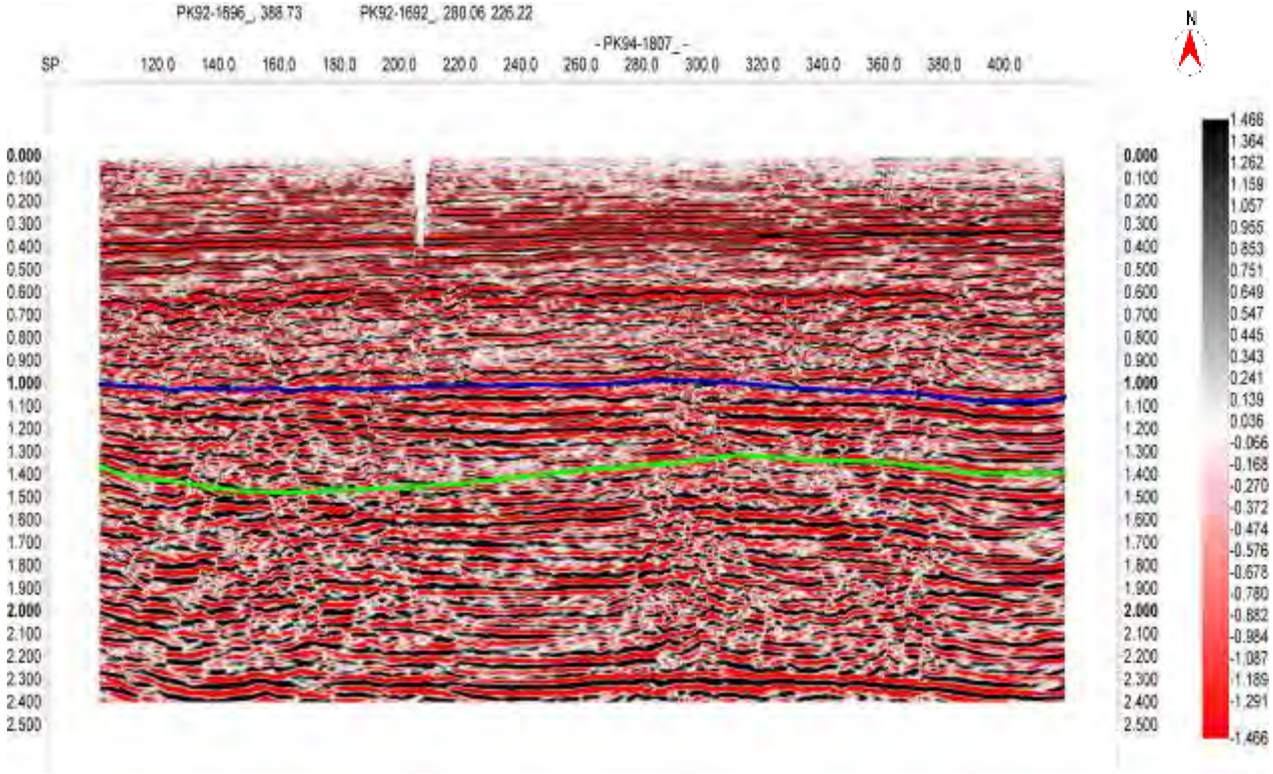

Figure 3.3 Seismic Time Section of Line PK94-1807

The line is oriented in NW-SE direction.

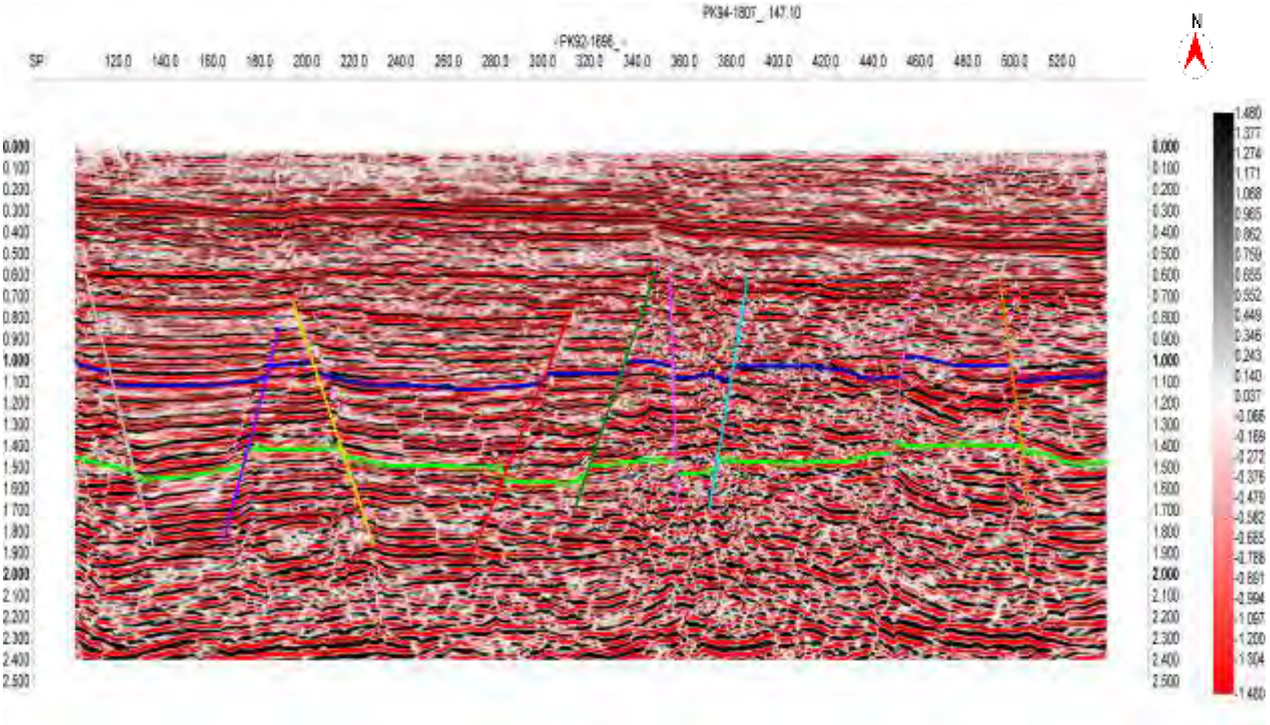

Figure 3.4 Seismic Time Section of Line PK92-1696

The line is oriented in NE-SW direction.

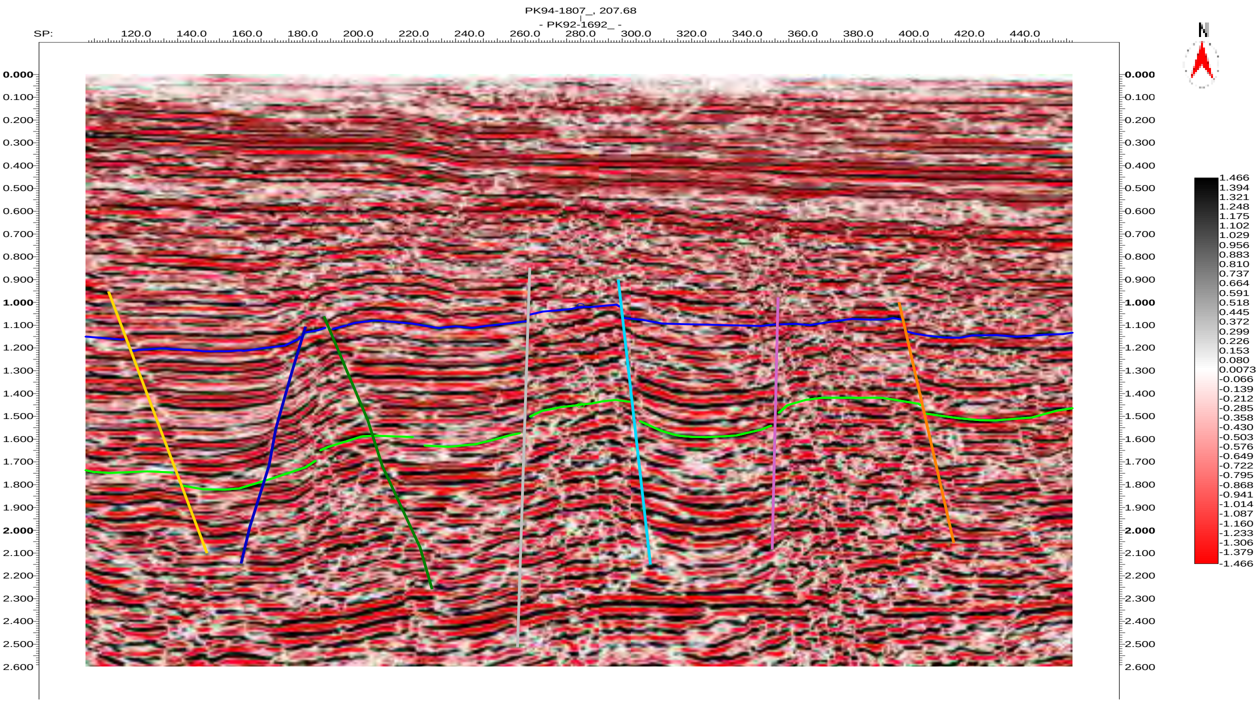

Figure 3.5 Seismic Time Section of Strike Line PK92-1692

The line is oriented in NE-SW direction.

## 3.8 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 direction on a fault polygon if dip symbols are not drawn. Fault polygons are constructed for all marked horizons. At Lower Goru after the construction of the fault polygons the high and low areas on a particular horizon become obvious.

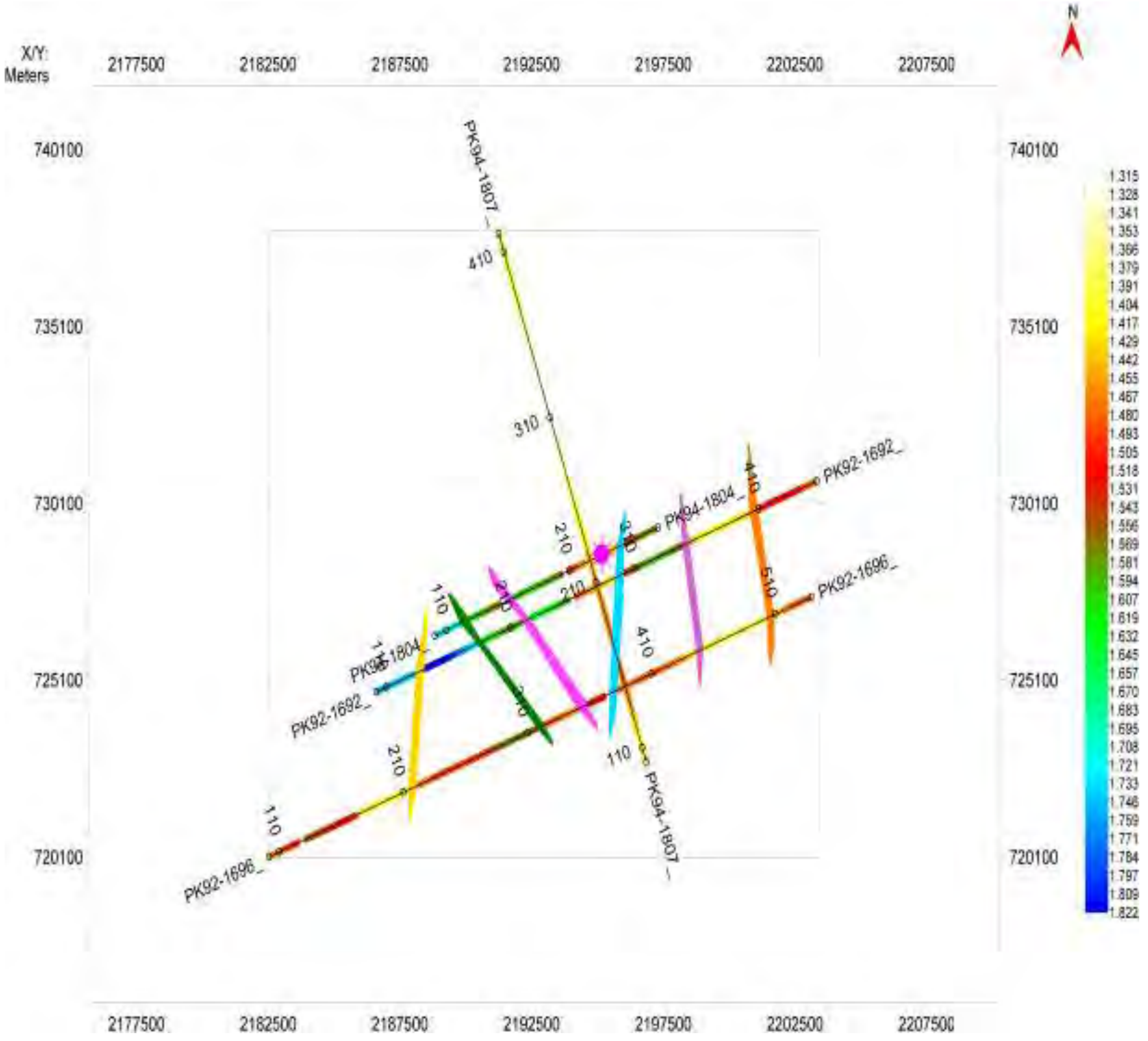

Figure 3.6 Fault Polygon constructed at Lower Goru

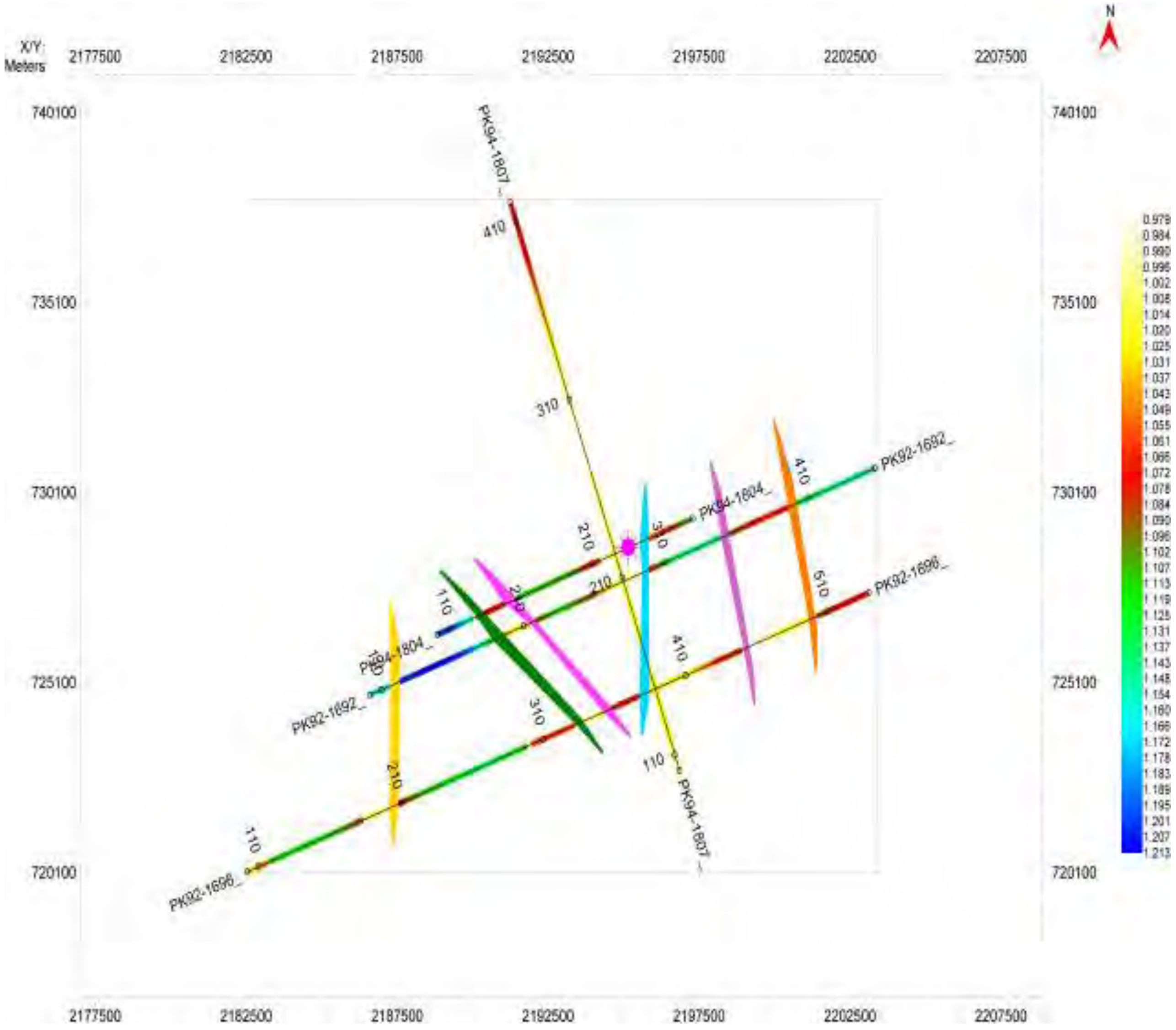

Figure 3.7 Fault Polygon constructed at Upper Goru

## 3.9 Contour Maps

The final products of all the seismic exploration are the contour maps, time or depth. Mapping is the part of the interpretation of the data, the one on which the entire operation depends for its usefulness. The contours are the lines of equal depth wandering about the map as dictated by the data (Coffeen, 1986). 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.

### 3.9.1 Time Contour Map of Lower Goru

In these time contour maps; the central parts indicate graben trending NW-SE shows deepest parts while the shallowest parts indicate horst. The two-way time contour maps have been generated using the Kingdom Software. Time contour map of Lower Goru is shown in figure 3.8.

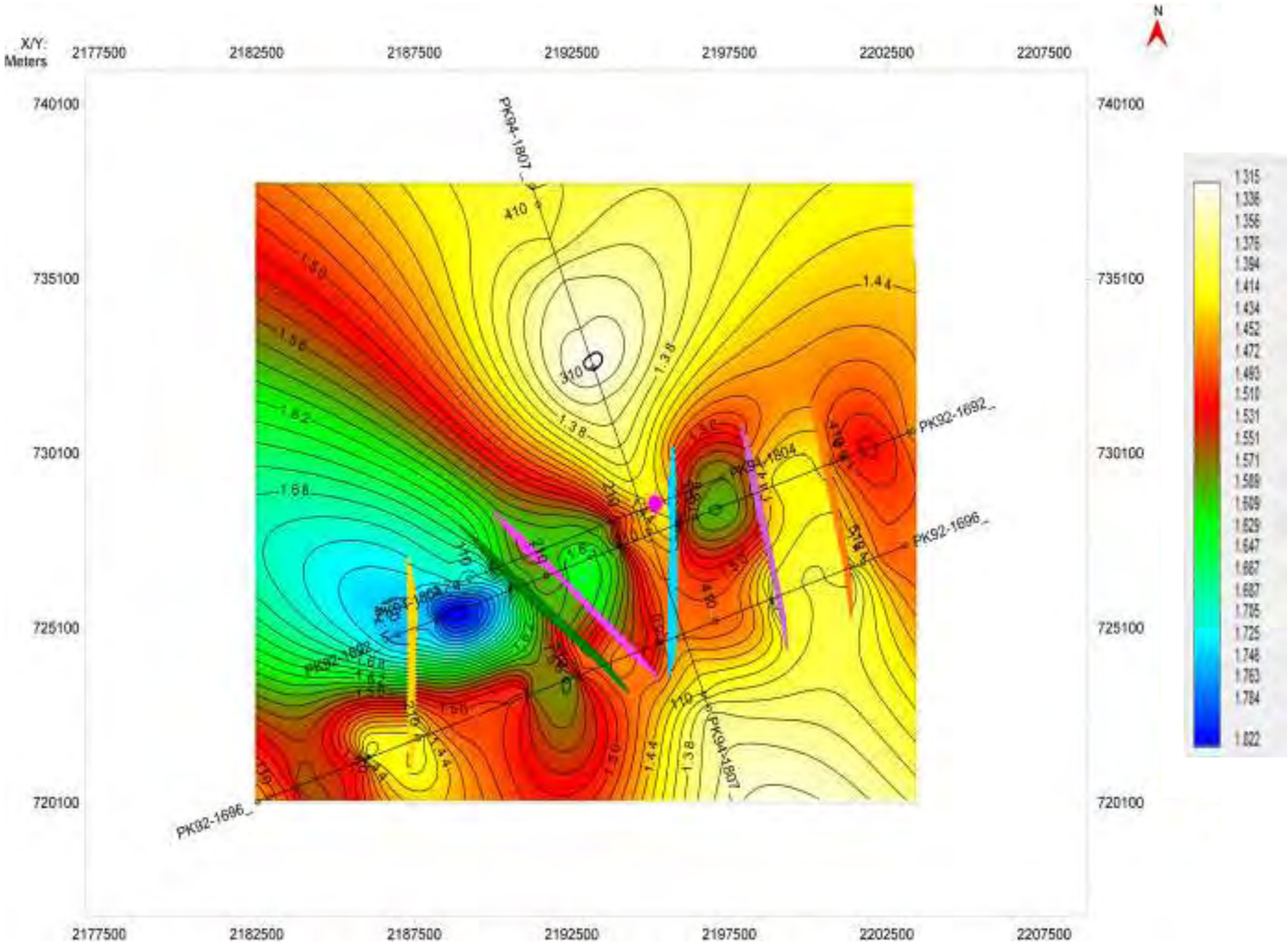

Figure 3.8 Time contour map of Lower Goru.

### 3.9.2 Time Contour Map of Upper Goru

The two-way time contour maps have been generated using the Kingdom software. Time contour map of Upper Goru is shown in figure 3.9.

### 3.9.3 Depth contour map of Lower Goru

The depth contour maps have been generated using the Kingdom software. In Time contour map of lower Goru, the yellow color shows the highest area and blue color shows deeper area.

The depth contour maps have been generated using the kingdom software. Depth contour map of Lower Goru is shown in figure 3.10.

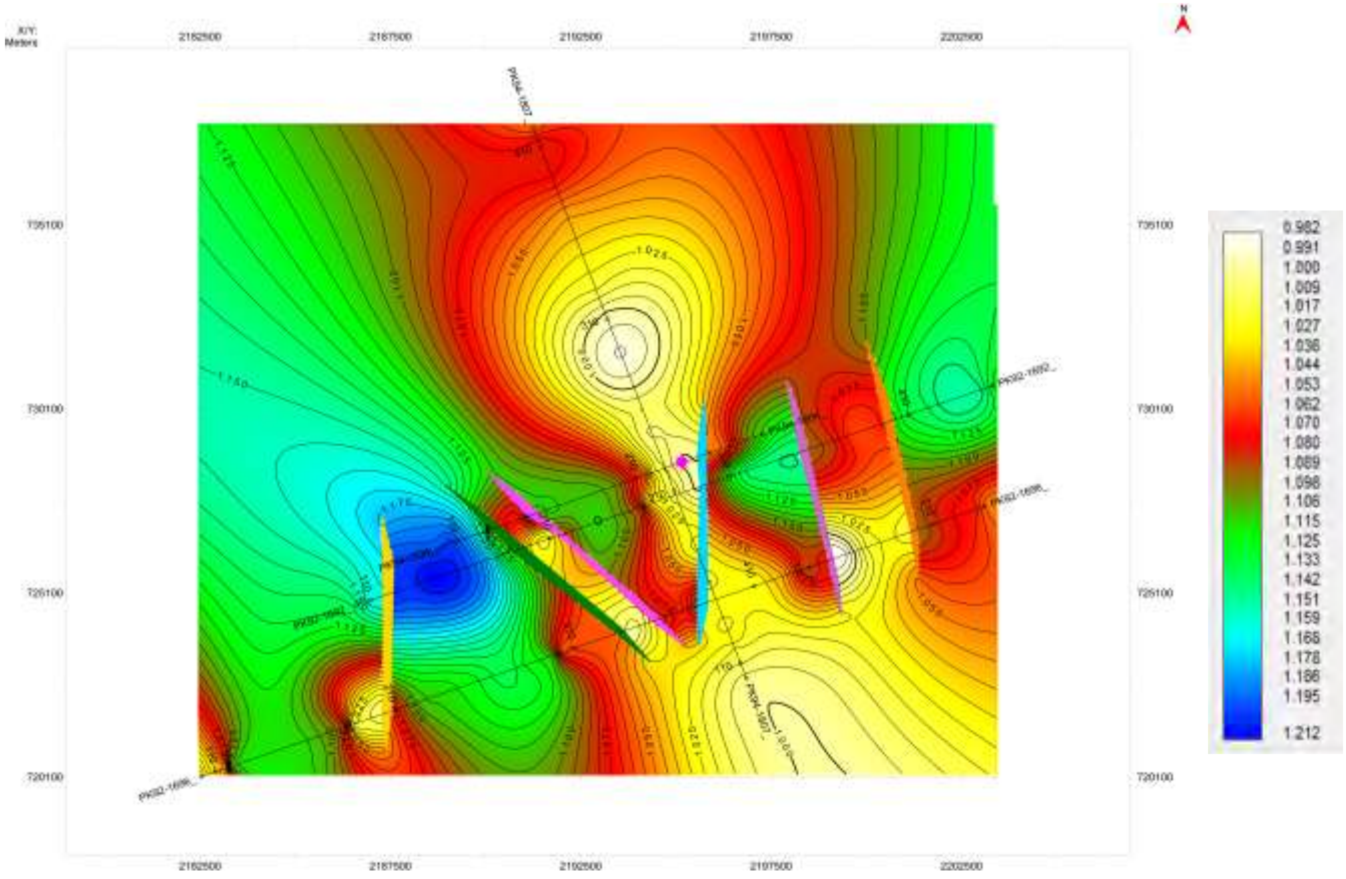

Figure 3.9 Time contour map of Upper Goru.

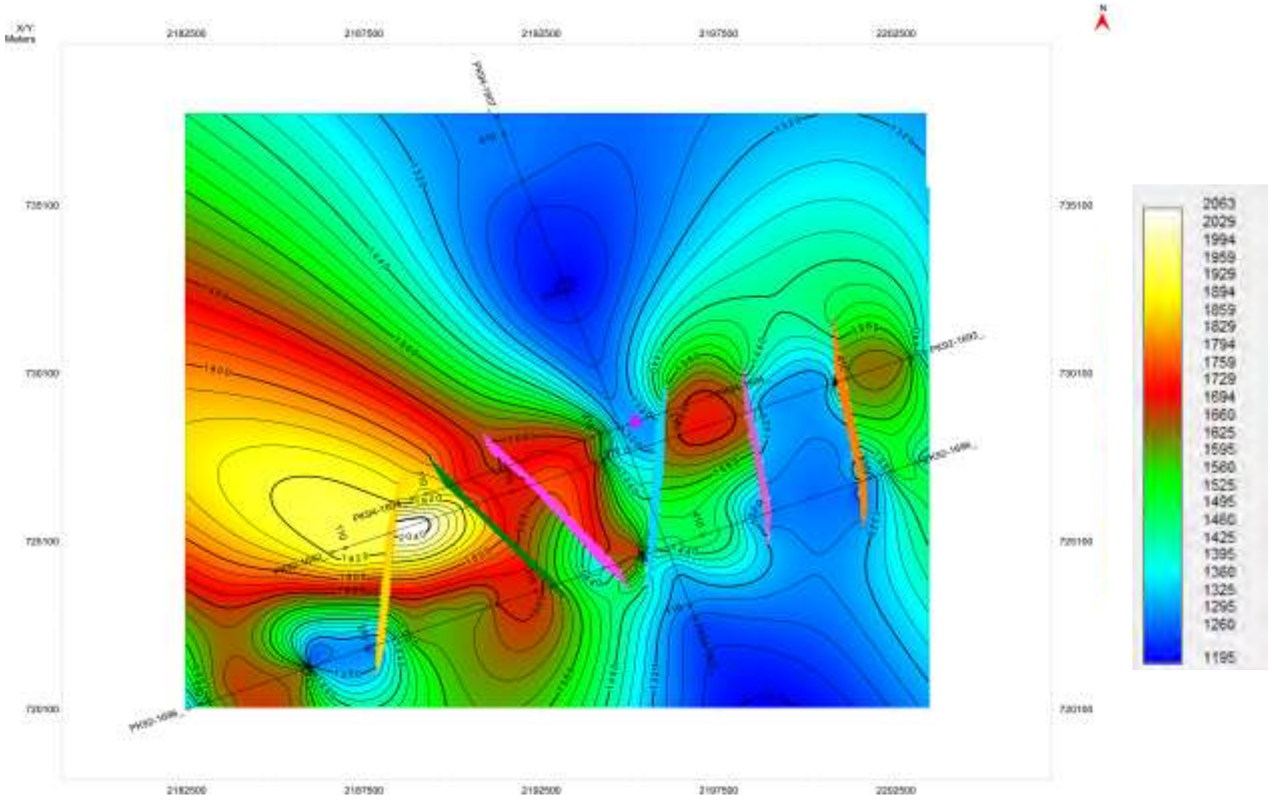

Figure 3.10 Depth contour map of Lower Goru

### 3.9.4 Depth Contour Map of Upper Goru

The depth contour maps show the horizon depth variation. It can easily be interpreted that horizon is forming horst and graben structures as the central portion between fault polygons is shallowest in depth than the surrounding area.

The depth contour maps have been generated using the kingdom software. Depth contour map of Upper Goru is shown in figure 3.11.

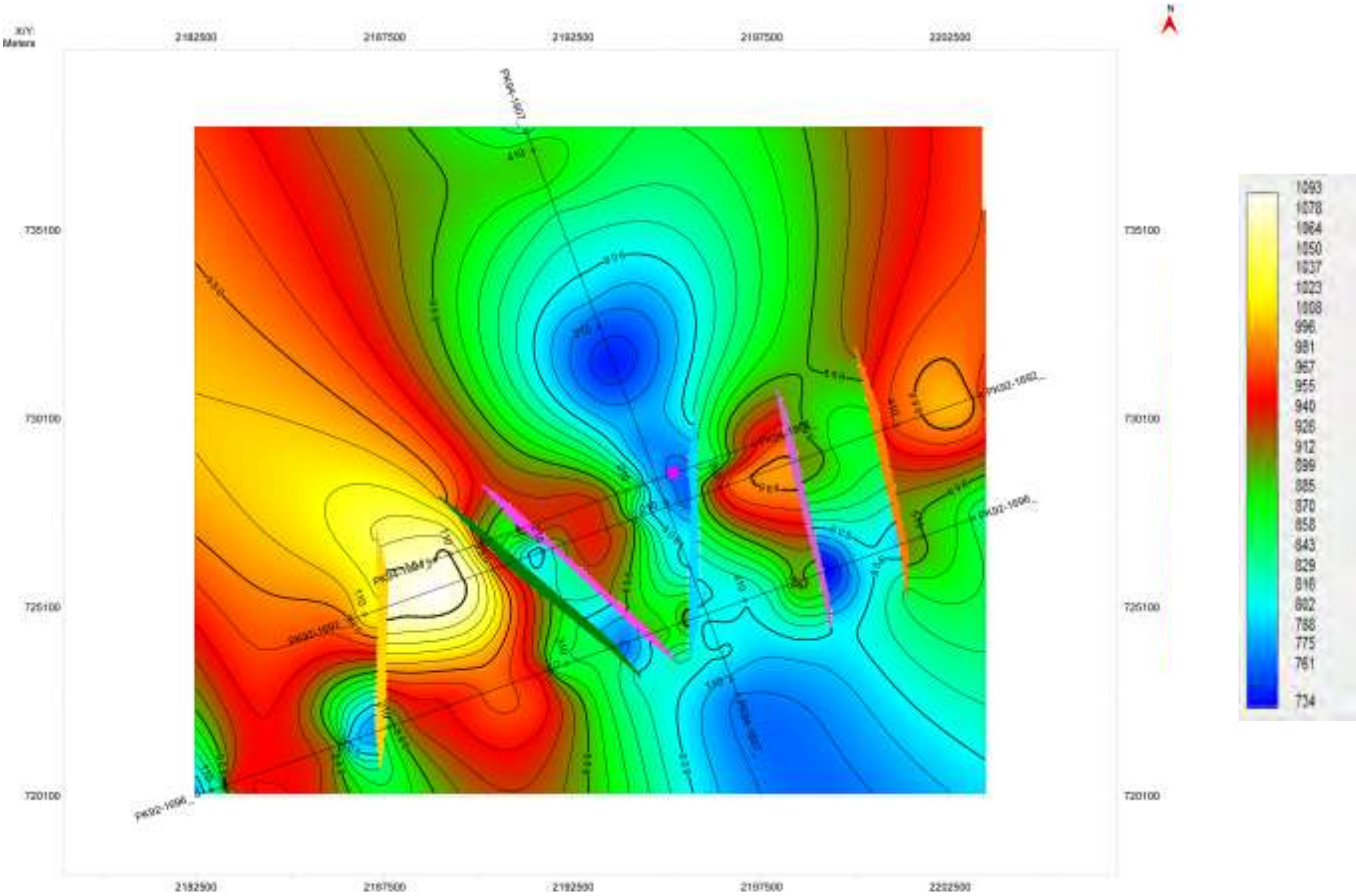

Figure 3.11 Depth contour map of Upper Goru

## 3.10 Conclusion

After all the interpretation it is concluded that in my study area there are horsts and graben structures. The horst and graben structures are formed in the result of the normal faulting which is discussed previously. Hence Horst is favorable structures formed as result of normal faulting for accumulation of hydrocarbon in the Badin area. This normal faulting is generated as the result of India and Seychelles during Late cretaceous.

Horst and Graben structures can act as a good structural trap in point of view of the petroleum play. From stratigraphic column discussed in previous chapter and the petroleum play in the study area, the Lower Goru formations has potential for hydrocarbons. Faults in the study area act as traps in most places.

# Chapter 04

# SEISMIC ATTRIBUTES

Seismic attributes are a set of properties computed from input seismic data in which the amplitude is the default attribute. Attributes can be calculated on the pre-stack as well as post-stack data. The most common post stack attributes are instantaneous attributes that are work out at each sample of seismic trace. The seismic energy is basically a mechanical energy which has two components kinetic and potential energy. Through experiments it has found that we can only measure the kinetic energy. Now to compute instantaneous attributes we need to calculate the imaginary potential energy component of seismic energy. The imaginary component is basically a $90^o$ degrees phase rotated version of the input seismic trace and therefore can be computed through the Hilbert transform (Tanner et al., 1994).

## 4.1 Applications of Seismic Attributes

Uses of Seismic attributes include

1. To check seismic data quality identifying artifacts
2. Performing seismic facies mapping to predict depositional environments
3. Hydrocarbon play evaluation
4. Reservoir characterization

## 4.2 Types of Attributes

The default attribute of Seismic data is Amplitude. Attributes can be computed from pre- stack or from post-stack data, before or after time migration. The procedure is the same in all these cases. Attributes can be classified into many types but there are two broad classifications of the attributes (Tanner et al, 1994).

### 4.2.1 Geometrical Attributes

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 and Rao, 2008).

### 4.2.2 Physical Attributes

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 (Tanner et al 1994).

## 4.3 Envelope of Trace

Envelop trace also called reflection strength is a physical attribute is used to indicate impedance contrast, total instantaneous energy of the trace, it may represent the individual interface contrast or, more likely, the combined response of several interfaces, depending on the seismic bandwidth, also represent bright spots, unconformities, thin bed tuning, major changes in depositional environment, 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 and Rao, 2008).

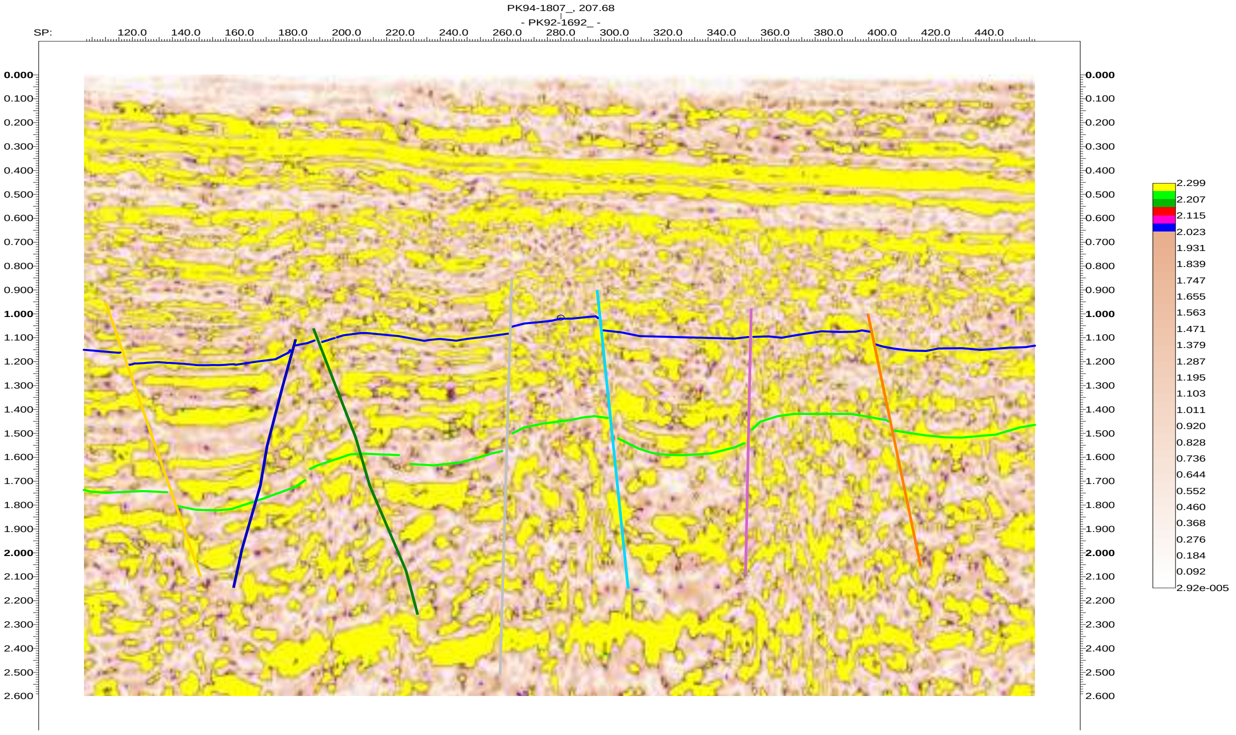

Figure 4.1 Envelop attribute of seismic line PK 92-1692

Strata above the upper Goru shows no breakage on applying that attribute so cretaceous faulting do not affect them. Both Horizons shows positive acoustic impedance contrast (black color) changing in thickness and faulting on applying that attribute. Figure 4.1 shows the trace envelop applied on line PK92-1692.

## 4.4 Phase Attribute

Phase is a physical attribute and used for the geometrical shape classification. It is independent of amplitude and depend on the propagation of the seismic wave front. This attribute gives information about the continuity and discontinuity, relates to the phase component of the wave propagation and can be used to compute the phase velocity. 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 (Subrahmanyam and Rao, 2008).

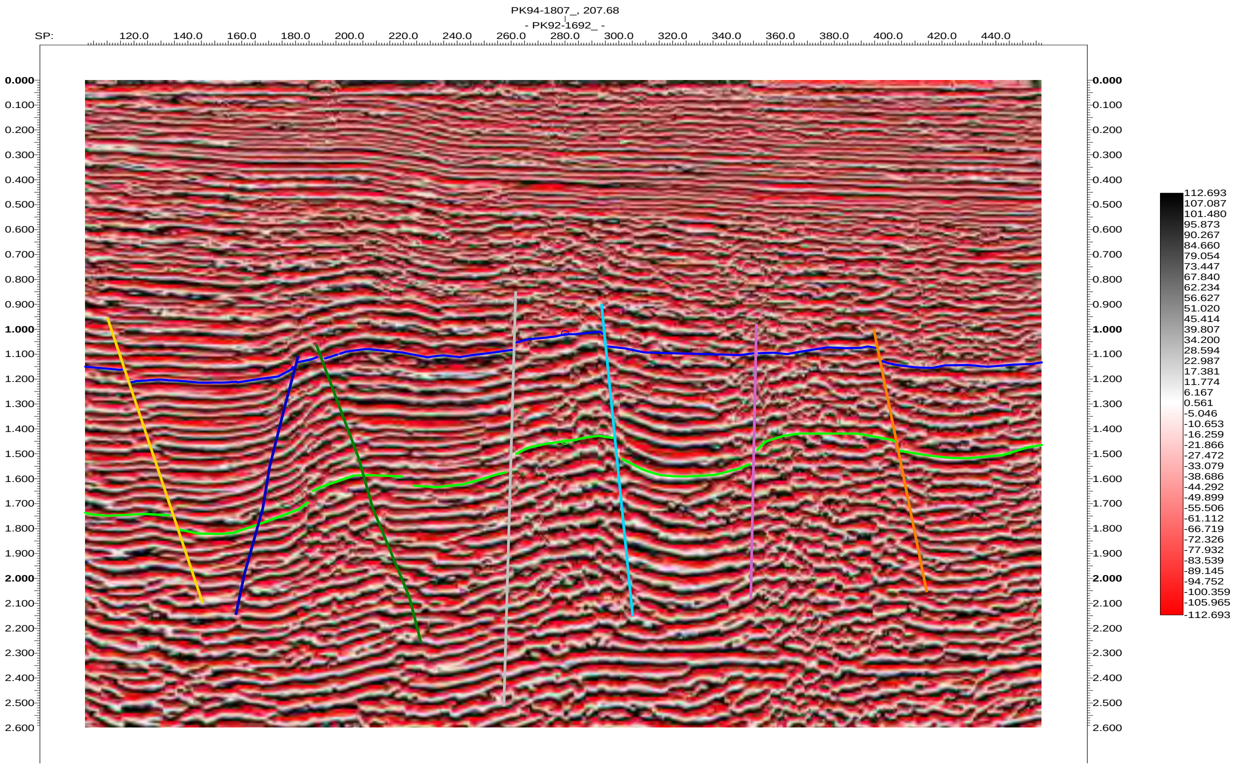

Figure 4.2 Phase attribute of seismic line PK 92-1692

Upper Goru formation is unaffected by Cretaceous faulting. It is highlighting the low amplitude reflectors. It shows continuity on applying phase attribute. This attribute satisfied the picking of horizons. Figure 4.2 shows phase attribute applied on seismic line PK92-1692.

# Chapter 05

# PETROPHYSICAL ANALYSIS

## 5.1 Introduction

Well logging is a tool to measure the subsurface properties of earth. The physical and the chemical properties of the rock explained existence and behavior of the rocks, fluids and soils .Petrophysics uses well logs (caliper, resistivity, GR, DT, RHOB, Neutron logs etc.) and all pertinent information is obtained by use these well logs. Every well log has its own importance, and these logs play very important role in quantifying the precise reservoir parameters such as porosity, permeability, net pay zone, fluid content and shale volume. Petrophysical interpretation generally has less concern for seismic while more concerned with using well bore measurements to contribute to reservoir description (Asquith et al, 2004).

## 5.2 Classification of Geophysical Well Logs

Geophysical well logs can be classified into three categories

1. Lithology logs
2. Resistivity logs
3. Porosity logs

## 5.3 Lithology Logs

Lithology log are mostly used to identify the boundaries between the permeable and nonpermeable formation, information about the permeable formations provide lithology data for the correlation with other well logs.

1. Caliper (CALI)
2. Spontaneous potential (SP)
3. Gamma Ray (GR)

### 5.3.1 Caliper (CALI)

Caliper logs measure the diameter of the borehole. It records the cavities where the well is caved in. Where there is the porous material, mud cake will be formed that cause the hole diameter to become smaller. Variation in the diameter of the borehole influence the record of the different logs. Therefore, it is important to consult with the caliper logs any artifacts (Croizé et al, 2010).

### 5.3.2 Gamma Ray Log

Gamma ray logs are lithology logs that are used to measure the natural radioactivity of a formation. The radioactive material's concentrations are present in shale, as shale has high gamma ray reading. Therefore, shale free sand and the carbonates have low gamma ray reading. Volume of shall can be calculated by the following formula:

$$I_{gr} = \frac{\mathrm{GR}_{log} - \mathrm{GR}_{min}}{\mathrm{GR}_{max} - \mathrm{GR}_{min}}$$

Where GRmin is minimum value and GRmax is the maximum value of the gamma ray, Igr is the gamma ray index and GRLOG represent the gamma ray log. Gamma ray logs are used to identify lithology, the volume of the shale and the correlation between the formations (Asquith et al, 2004).

## 5.4 Resistivity well log

Resistivity well logs give the thickness of the formation, accurate value for the true formation resistivity and information for the correlation purposes. All these logs are plotted on the logarithmic scale due to more variation in resistivity (0.2 to 1000 ohm) with depth. Resistivity logs are:

1. Deep laterolog (LLD)
2. Shallow laterolog (LLS)

Deep laterolog is the electrode logs and are designed to measure formation resistivity in the borehole filled with saltwater muds (Rmf). The effective depth of the laterolog investigation is controlled by the extent to which the surveying current is focused (Asquith et al, 2004).

Shallow laterolog measure the resistivity of in the invade zone (Ri). In water-bearing zone, the shallow laterolog records a low resistivity because mud filtrate resistivity (Rmf) is approximately equal to mud resistivity (Rm), (Asquith et al, 2004).

## 5.5 Porosity well logs

Porosity well logs provide the data through which the water saturation can be determine, provide the accurate lithologic and porosity determination and provide data to distinguish between oil and gas. Porosity well logs are:

1. Sonic/Acoustic (DT)
2. Neutron Porosity (NPHI)
3. Density (RHOB)

Sonic logs measure the interval transit time ($\Delta t$) of the compressional sound wave through the formation. The interval transit time is related to the porosity of the formation. The unit of measure is the microseconds per foot or microseconds per meter (Asquith et al, 2004).

Porosity of the formation can be calculated by using the following formula

$$\emptyset_{s} = \frac{\Delta \mathrm{t}_{log} - \Delta \mathrm{t}}{\Delta \mathrm{t}_{f} - \Delta \mathrm{t}_{m}}$$

Where

- Øs represent the calculation that derived from the sonic log.
- Δtm is the interval transient time of the matrix.
- Δtlog interval transient time of formation.

The transient time of the fluid (salt mud=185 and fresh mud=189).the interval transient time of the formation depends upon the matrix material, its shape and cementation. If fluid (hydrocarbon or water) is present in the formation, transient interval time is increases and this behavior shows increase in porosity which can be calculated by using sonic log (Asquith et al, 2004).

Neutron log is the porosity log that measure hydrogen ion (HI) concentration in a formation (Asquith et al , 2004).In the shale free formations where the porosity is filled with the water, the neutron log is related to the water filled porosity (NPHI).In gas reservoir, porosity measured by the neutron log is low then the formation true porosity as the hydrogen ions concentration are less in gas reservoir then that of oil and water (Asquith et al, 2004).It is the one limitation of neutron log that is known as the Gas effect.

Density log is the porosity log that measure electron density of the formation, (Asquith et al, 2004).

Density log can be used to find out the correct porosity of the formation, if the matrix densities in the formation or rock type are known (Asquith et al, 2004). The rock type in my research work is sandstone and shale.

By using following mathematical relation, density porosity can be related as:

$$\emptyset_d = \frac{\rho_m - \rho_b}{\rho_m - \rho_f}$$

Where,

- Ød is the porosity derived from the density log.
- ρb is the bulk density of formation.
- ρm is the matrix density and for sandstone it is 2.65.
- ρf is the density of fluid (0.3 for Gas).

The main purpose of present petrophysics is to obtain calculation about porosity, saturation of water and hydrocarbon.

## 5.6 Average porosity calculation

Sum of the porosities that are obtained from the different logs divided by number of logs from which porosity is calculated. Here Lower Goru formation is reservoir of cretaceous age for which

the average porosity is calculated, to zone of interest reservoir, all the logs are interpreted.
The relation is given below through which average porosity is calculated.

$$\varphi_{avg} = \frac{\varphi_n + \varphi_d + \varphi_s}{3}$$

Where,

- ∅avg is the average porosity calculated from the available porosities.
- Φn is the neutron porosity.
- ∅d is the density porosity.
- ∅s is the sonic porosity.

## 5.7 Effective porosity (∅e)

This will define as “the ratio of the volume of interconnected pore spaces in a rock unit to the total volume of the rock by removing shale effect that rock unit”. The zone which rich in the shale, effective porosity will be zero. Effective porosity is used to mark the saturated zone. The effective porosity can be calculated by the following formula (Asquith et al, 2004).

$$\emptyset_e = \emptyset_{avg} * (1 - V_{sh})$$

Where,

- ∅e is effective porosity which is to be calculated.
- ∅avg represent the average porosity.
- Vsh represent volume of the shale.

## 5.8 Water Saturation (Sw)

Water saturation in the formation can be defined as “The percentage of the pore volume filled by water in the formation”. For water saturation we must have borehole temperature and resistivity of mud filtrate. So first we need to find resistivity of water in order to find the water saturation.

$$Ssp = -\mathrm{K} * \log \frac{R_{mf}}{R_{wf}}$$

For K.

$$K = 65 + 0.24 * T^{\circ}\mathrm{C}$$

We can find value of SSP from Sp log curve as SSP is the maximum deflection towards negative side, and Rmf is given resistivity of mud filtrate.

So the saturation of water in the formation can be calculated by the following Archie equation.

$$S_w = \sqrt[n]{\frac{F * R_w}{R_t}}$$

Where,

- F is formation factor which is

$$F=\frac{a}{\emptyset_m}$$

- Rw is the resistivity of water calculated from above formulation.
- Rt is the true formation resistivity.
- n is the saturation exponent.
- a is the constant and its value is 1 in case of sand.
- represents effective porosity.
- m is the cementation factor and it value is taken 0.81 for the sandstone.

## 5.9 Hydrocarbon Saturation (Sh)

Hydrocarbon saturation can be defined as “the pore in formation is filled with hydrocarbon”. It can be calculated by using the following mathematical relation.

$$S_h=1-S_w$$

Where,

- Sw is water saturation.
- Sh is hydrocarbon saturation.

## 5.10 Petrophysical Result

### 5.10.1 Well Log Interpretation

IHS Kingdom software is used for the analysis of well Doti-01.

1. As we know that we are looking for reservoir zone where hydrocarbon saturation is very important so for this, we need to interpret all logs in addition with other logs like porosity, water saturation, hydrocarbon saturation.
2. First of all, the crossover between NPHI and RHOB is important, but the crossover should be on the lower side for both log curves, as we know that hydrocarbon has less density but for hydrocarbon accumulation porosity is necessary so porosity should be little higher in case of hydrocarbon but overall the crossover should be on lower side.
3. Secondly, separation between LLD and LLS is very important for petrophysical interpretation, as the separation of LLD and LLS shows the accumulation of hydrocarbon. In resistivity we have 3 zones flushed, transition and uninvaded zone. So, in flushed and transition we have brine mud and in uninvaded zone its hydrocarbon that’s why we get separation in LLD and LLS.
4. In the third step we interpret Vsh which is calculated by linear method, Shale and sand is

being separated by applying 40% cut-off value. Below this cut-off value, there is sand and above this cut-off, there is shale.

5. Then after that interpretation of porosity logs are done whereas in reservoir zone porosity should be higher such that accumulation of hydrocarbon could possible, for this density porosity log, effective porosity, and total porosity logs are made.
6. Now the last step is the water saturation and hydrocarbon saturation, as the separation of LLD and LLS is an indicator of hydrocarbon but we can't conclude any result by interpreting one log, so we need to correlate two or more logs that is why water saturation log is incorporated and interpreted. As we know that hydrocarbon saturation is difference of water saturation by unity.

### 5.10.2 Zone of Interest

Zone A (1016 m – 1630 m). The thickness of this zone is 14 m. In track 1, GR log has low values whereas SP and Caliper is stable. In track 2, LLD and LLS shows separation and log has lower values. In track 3, RHOB and NPHI has crossover on lower side.  Vsh is on lower side, porosities are higher and water saturation log shows moderate saturation of water while hydrocarbon saturation is higher. All these conditions show their might be the presence of a reservoir potential zone in the area, which contain hydrocarbon as shown in given table.

| **Petrophysical property** | **Lower Goru** |
|---|---|
| **Volume of shale** | **15.7%** |
| **Water saturation** | **45%** |
| **Hydrocarbon saturation** | **55%** |
| **Density Porosity** | **10.7%** |
| **Total porosity** | **15.1%** |
| **Effective Porosity** | **12.7%** |

Table 1: Show the Petrophysical properties of lower Goru.

## 5.11 Petrophysical analysis

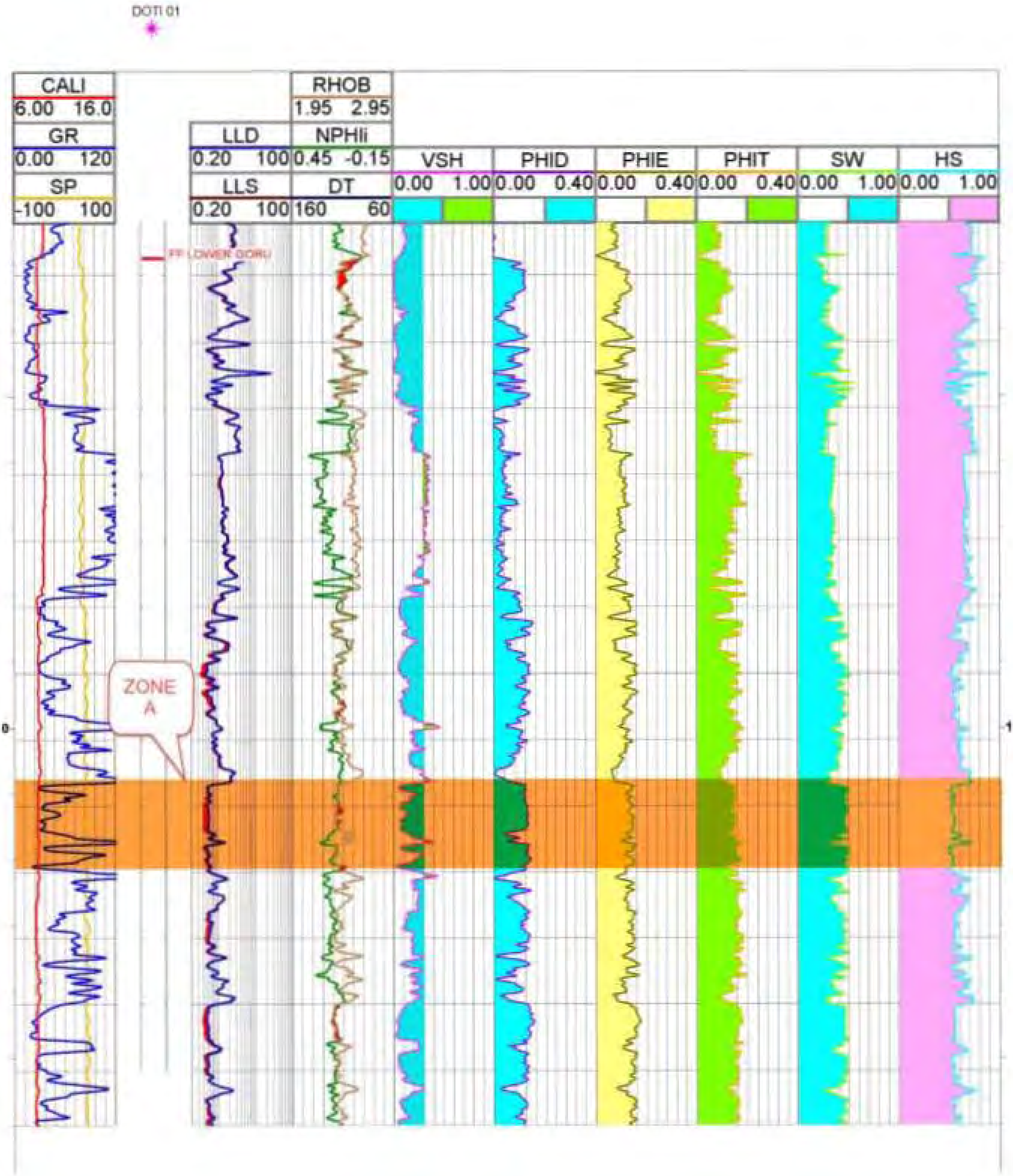

Figure 5.1 Petrophysical interpretation of well Doti-01

## Conclusions

- On the basis of seismic as well as well data reflector of geological importance were identified among which Lower Goru is acting as reservoir.
- The seismic interpretation revealed Horst and Graben structure in Badin area.
- Time and Depth Contour Maps help us to confirm the presence of Horst and Graben structure in area.
- Synthetic Seismogram was matched with the marked horizons and it has confirmed the structural interpretation.
- Seismic attribute analysis confirmed the structural interpretation like fault marking and horizon marking done on seismic lines. It also confirms the horst and graben structure in the extensional regime due to normal conjugate faulting.
- Petro physical analysis of the reservoir shows high hydrocarbon potential.
- The overall result indicates the economic importance of Lower Goru as a reservoir.

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