2D Seismic Reflection Data Interpretation of Badin Area Integrated with Reservoir Characterization along with 1D Forward Modeling, Seismic Attributes, and Petrophysical Analysis.

BY

MUDASSIR MEHMOOD KHAN

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Department of Earth Sciences

Quaid-i-Azam University

Islamabad

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

CERTIFICATE

This dissertation submitted by **MUDASSIR MEHMOOD KHAN** Son of **DILASA KHAN** 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.

Recommended By

Dr.MUMTAZ SHAH

______________________ (Supervisor)

Dr. Mona Lisa _________________

(Chairperson Department of Earth Sciences)

External Examiner ___________________

Department of Earth Sciences, Quaid-i-Azam University Islamabad, Pakistan

Dedicated To

Jo, who made me the person, I am today**.**

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. MUMTAZ SHAH** for giving me an initiative to this study.

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MUDASSIR MEHMOOD KHAN

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, two 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 Dot-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 oil and gas discoveries but there is still a requirement of advance techniques to improve seismic resolution and quality of interpretation.

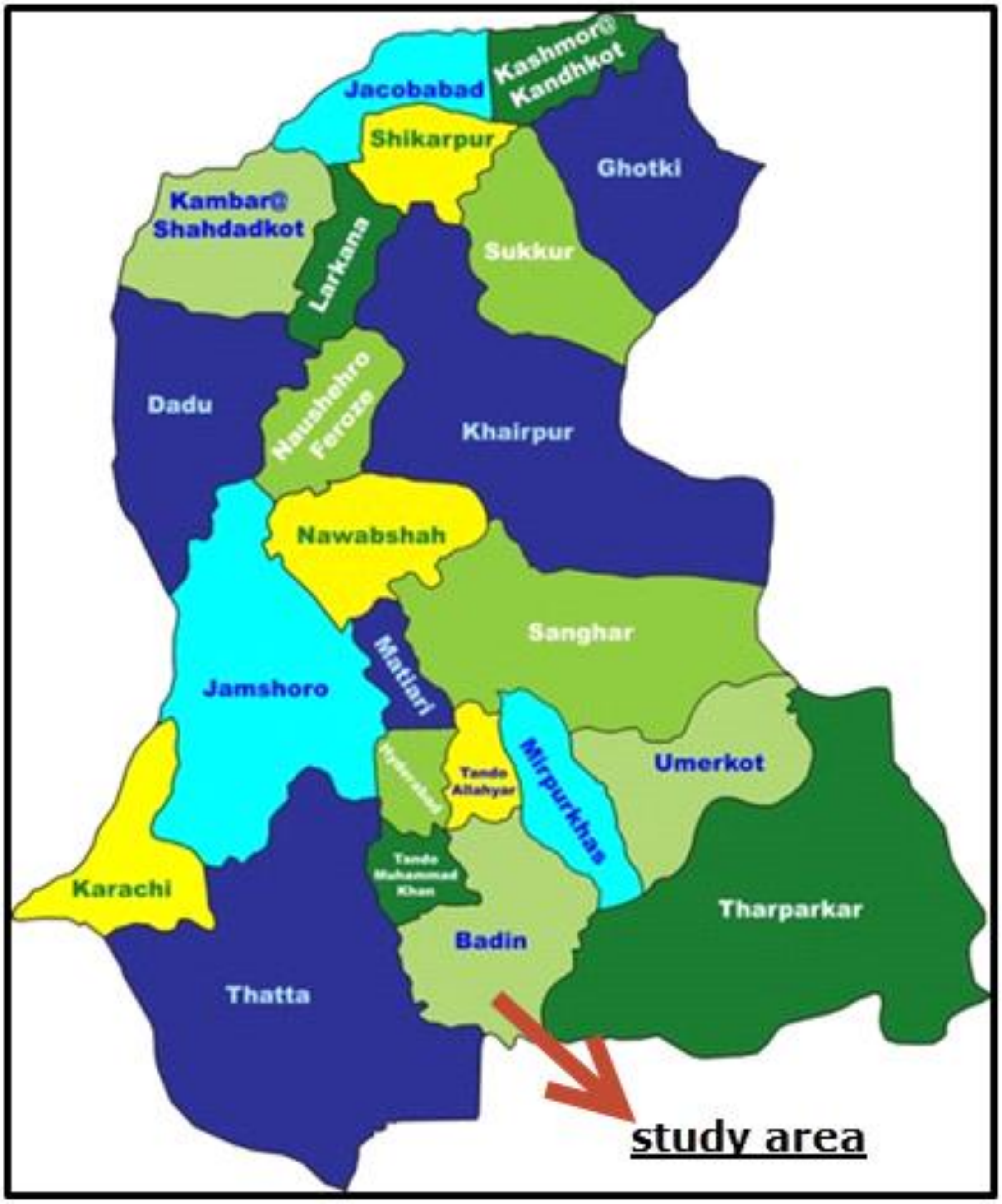
Contents

1 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, on the South by Arabian Sea & Rann of Kutch, on the East by Mirpurkhas & Tharparkar districts and on the West by Thatta and Hyderabad districts Due to oil and gas fields the area becomes distinctive amongst others but indeed has its extremely important petroleum geology . 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 ridgepush 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. The oldest sediments have been reported in the well Marvi -1 (Total depth 17000 ft, drilled by Union Texas in 1997)



1.2 Structural Setting and Tectonic History

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 (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. The under filling of structures can be attributed to upward leakage across extensive structures and redistributed hydrocarbon (Kemal *et al.*, 1991). Numerous plays and prospects of hydrocarbon are associated with the Cretaceous system, consequently the Indus basin is attractive to petroleum exploration companies in Pakistan (Sheikh and Naseem, 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. A summary of seismic lines and wells used in the study are given in Table below.

Sr.No.	**Line Name**	**Line Direction**	**Nature**	**Wells**
1	Pk92-1692	NE-SW	DIP	
2	Pk92-1696	NE-SW	STRIKE	
3	Pk92-1804	NE-SW	DIP	DOTI-01
4	Pk92-1807	NE-SW	DIP	

The lines under study PK94-1804, PK94-1807 and Pk92-1696 along other line is shown above table.

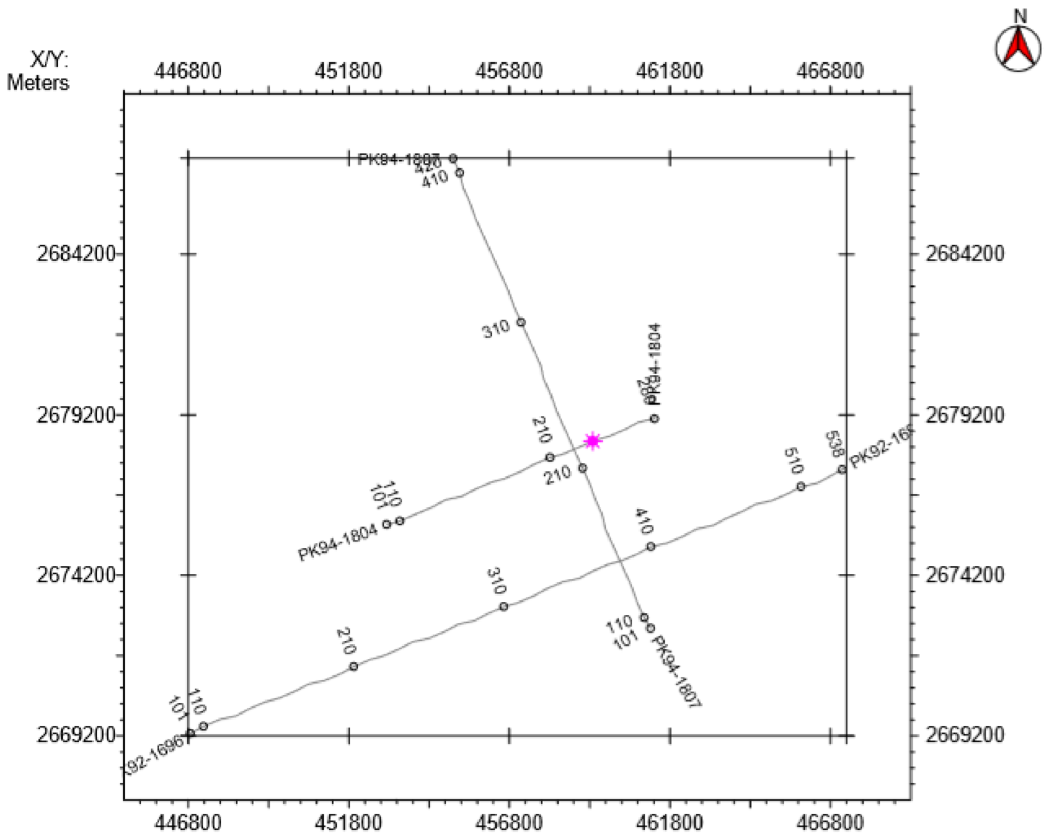


Figure 1-2 Seismic Lines and Location of Wells on Base map of Badin Area

1.4 Data Formats

Seismic reflection data which consist of following formats;

- SEG-Y (Seismic Data format)
- LAS (Well Log Data format)
- 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

- Structural Interpretation
- Stratigraphic Interpretation
- Well correlation
- Seismic attribute analysis.
- Rockphysics and Petrophysics
- Base Map enhancement

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 carried.

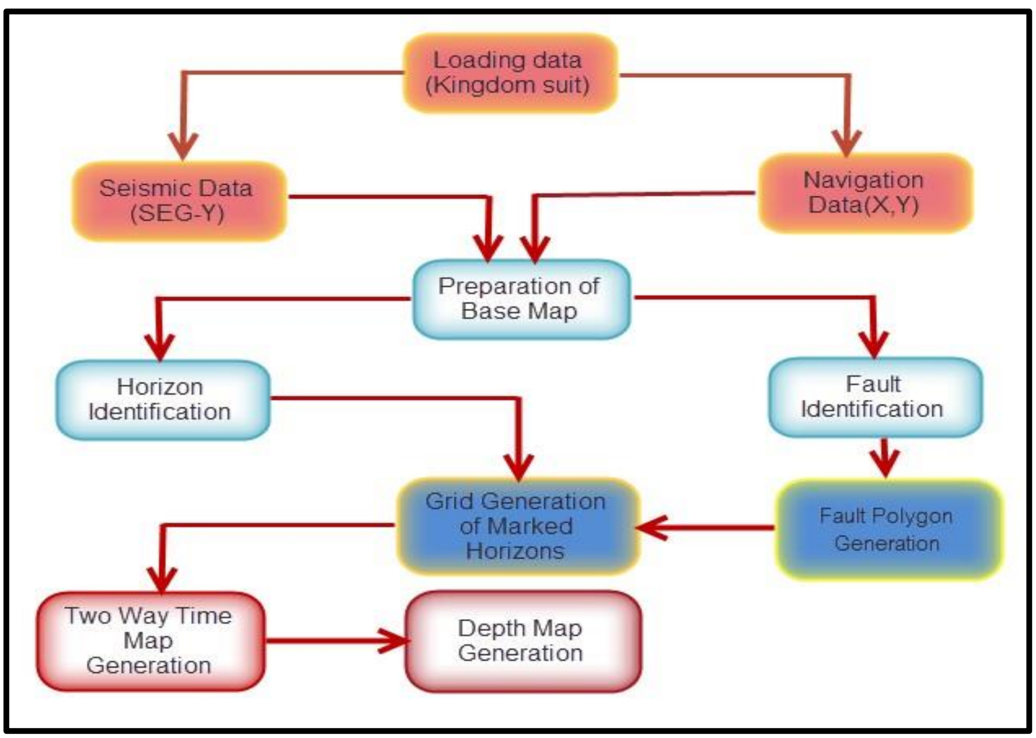


Figure 1-3 Work flow analysis of Seismic Interpretation

1.7 Objectives

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

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

2 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, 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 Potwar 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. F.K Bender et al, 1995.

2.3 Geology of the Area

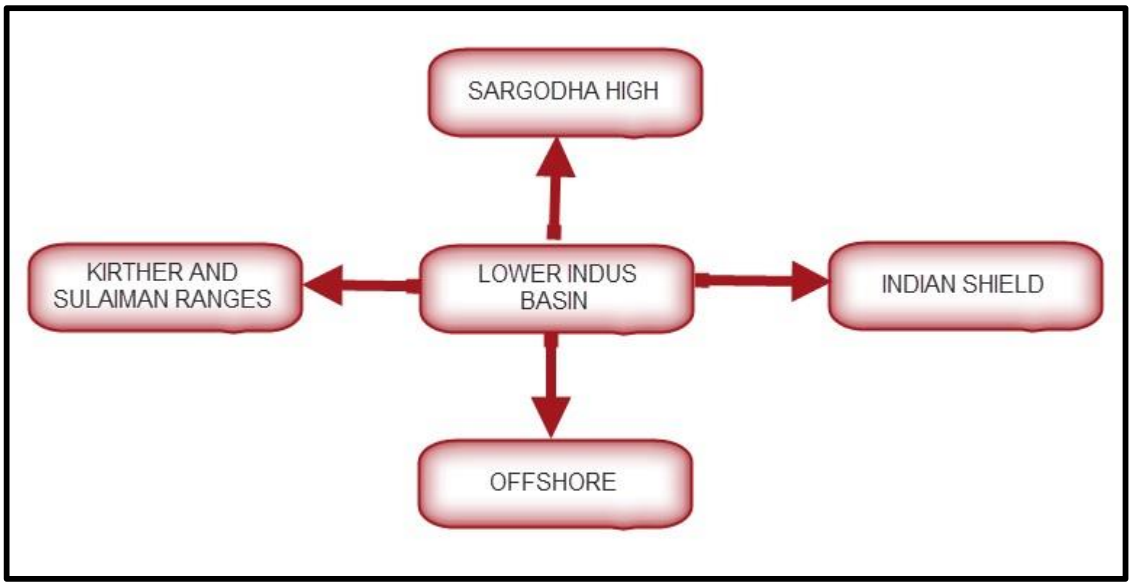
Pakistan is divided into many basins in which Indus basin is a major basin divided into two parts. Northern and north-eastern part of the basin is known as upper Indus basin and the southernmost part of the Indus basin is known as Lower Indus basin, Badin Block is the part of this basin. The is situated 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

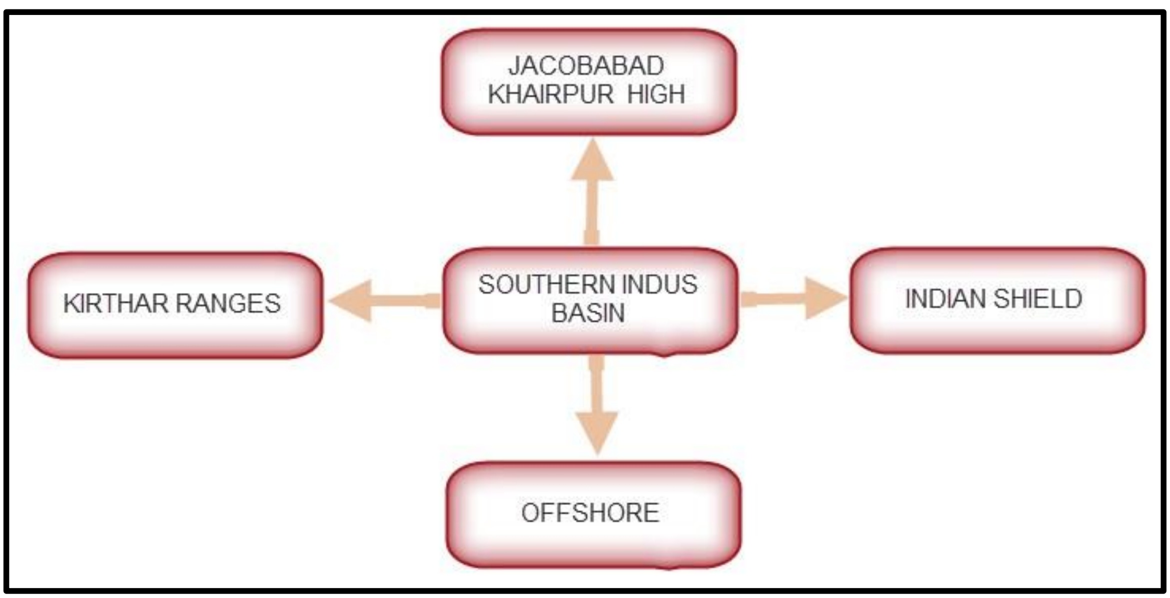
My Study area belongs to Southern Indus Basin. So I will mainly focus on southern Indus Basin, its geology, tectonics and other aspects.

2.4.1 Southern Indus Basin

The southern Indus basin (550 × 220 km) extends approximately between 24°N to 28°. Longitude and 66° to 71° 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.

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 anomaly 22 (50 m.y.) 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.

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

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 nodularrusty 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 Sulaiman and Kirther ranges. Its Lower contact with various Jurassic formations such as Mazar Drik 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-Potwar 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 (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 (Gilbert Killing et al).

- 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 (Gilbert Killing et al). The Goru Formation is widely distributed in the Kirther and Sulaiman Province. The lower contact with the Sembar formation is conformable and is very locally reported unconformable by Williams (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 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 (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.Vredenberg (1909a) 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 interbeds of limestone.

2.8.5 Khadro Formation

The basal part of the formation is comprised of dark coloured 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).

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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

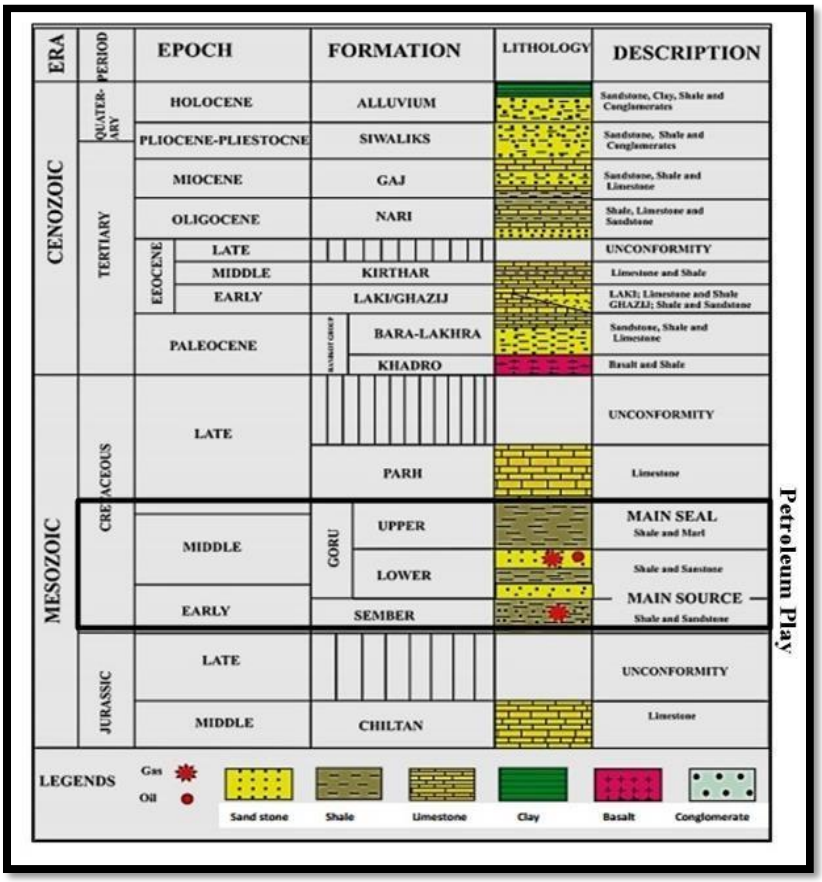


Figure 2-3 Generalized Stratigraphy of Study Area (Modified after Zaigham et al,2000).

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 (ECL, 1988).

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 (Fig. 2.6) 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 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 (Fig. 2.6) 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 (Fig. 2.5) 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 depocentre 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).

3 SEISMIC ACQUISITION AND PROCESSING

3.1 Introduction to Seismic Data Acquisition

Acquisition of seismic data, it is the very first step in the seismic exploration. It is the procedure through which seismic reflection data is acquired. With the help of modern electronics and computer industry, acquisition becomes very easy. Acquisition starts from shot and ends at recording the seismic events through various steps. Different energy sources are used to produce seismic waves and array of geophones are used to detect the resulting motion of earth. The data is recorded in digital as well as analogue form (Keary et al, 2002).Seismic surveys use low frequency acoustical energy generated by explosives or mechanical means. These waves travel downward, and as they cross the boundaries between rock layers, energy is reflected back to the surface and detected by sensors called geophones. The resulting data, combined with assumptions about the velocity of the waves through the rocks and the density of the rocks, are interpreted to generate maps of the formations. After identifying sedimentary basins, prospects or fields thought to contain hydrocarbons, an oil company will then contract with a seismic acquisition company to map the areas underground rock formations through seismic surveying .fundamental purpose of seismic data acquisition is to record the ground motion caused by a known source in a known location.

- First step in seismic data acquisition is to generate a seismic pulse with a suitable source.
- Second is to detect and record the seismic waves propagating through ground with a suitable receiver in digital or analogue form. Third is the registration of data on a tape recorder.

Prior to seismic data acquisition, control points in the area under study are established using the satellite and local ellipsoid datum. These control points are used to control the exact orientation of seismic lines.

3.2 Energy Sources

3.2.1 Energy sources are categorized into two groups

- Impulsive energy sources
- Non impulsive energy sources

3.2.2 Impulsive Energy Sources

The mechanism for generation of energy in this type is by exploding dynamite in a shot hole. Because of the impulsive nature of the seismic signal it creates and the convenient storage and mobility it provides for energy that can be converted into ground motion.
An important example of impulsive energy source is dynamite (Yilmaz, 2001).

3.2.2.1 Dynamite

It is commonly used to generate sources, used in seismic prospecting. Generally it is exploded inside a drilled hole at a depth ranging from few meters to several tens of meters. The deeper the charge the less intensive the generated surface waves are. It is advisable to place this charge below the weathering layer as it absorbs the high frequency components. Charge is usually sealed with water or mud to increase coupling with surrounding. Amounts of charge per shot point depend upon pattern of shooting (Telford, 2004).

3.2.3 Non Impulsive Energy Source

These sources involve mechanical impact upon the earth's surfaces or shaking of the surfaces with a mechanical vibrator. All sources of this type are so disposed in the field that signals received from impacts are applied to the earth over a linear distance comparable to what would be used for a line of shot holes at a shot point or over an area that would be used for two dimensional arrays of shot holes (Robinson & Corch, 1988).

3.2.3.1 Vibroseis

It is based on the use of a mechanical vibrator which is hydraulically or electrically driven to exert a force, on ground surface, of an oscillating magnitude Its energy is called as sweep (Al-Sadi, 1980).

Note the flat pad suspended under the middle of the truck. Once the truck reaches the specified point, this pad is used to raise the 20,000 kg truck entirely off the ground. The hydraulics then shakes the truck up and down on this central piston for a specified time and over a precisely controlled frequency band (e.g., eight 14 second sweeps from 10 to 56 Hz).

3.3 Acquisition Setup

The seismic acquisition setup involves the following;

- **The spread configuration**
- **Shooting types**
- **Shooting parameters**
- **Recording parameters**

3.3.1 The Spread Configuration

For acquisition of data and as well as to have quality of data high certain field operations are adopted. So the first step in this practice is the choice of spread type. The spread is defined as the lay out on the surface of, of the detectors which give recorded output for each source. Spread is made up of equal inter receiver distance and a defined offset. There is certain number of spreads called as basic spreads, which are used in seismic acquisition . These spreads are;

- **End on spread**
- **Inline offset spread**
- **Split Spread/Centre shooting**
- **Fan shooting**

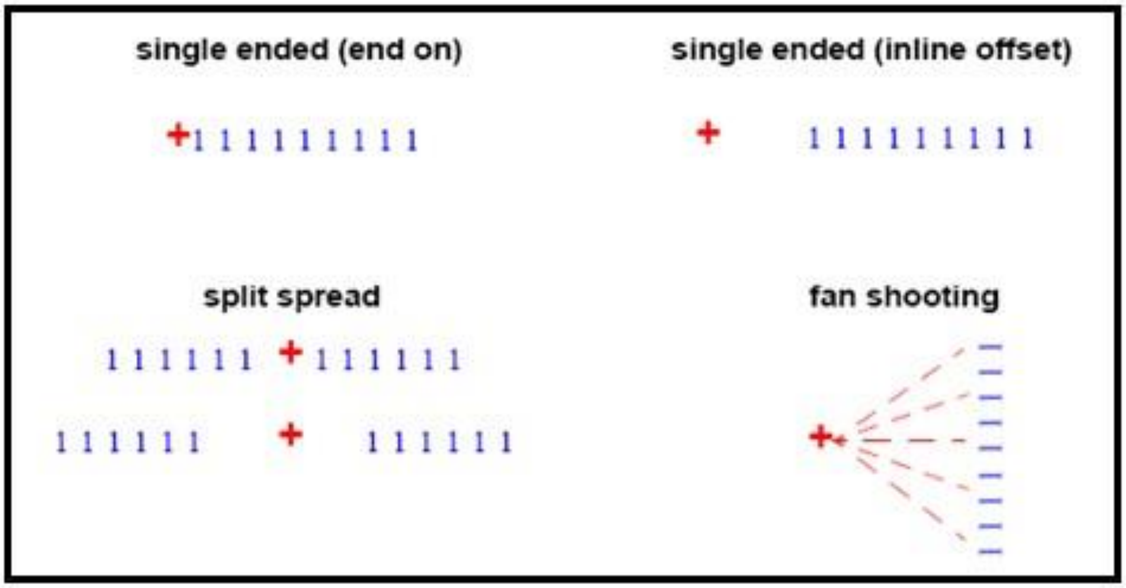


Figure 3-1 the basic spreads used in Seismic Acquisition.

Along with these basic spreads, another technique called as Fan shooting can also be used. In this technique, geophones are arranged in an arc, fanning out in different directions from the source. Fan shooting is used in Transmission method. Transmission method differs from normal refraction method in the sense that it does not involve critical incidence of waves over the interface. In Transmission method, source and detector are on opposite sides of the investigated interface. Other techniques used in transmission method in velocity logging (well shooting, continuous velocity logging (CVL) and up hole survey fan shooting is used for determination of the dimensions of velocity anomalous structures (AlSadi, 1980).

3.3.2 Shooting Types

There are different types of shootings used in the field. These types are:

- Symmetric shooting (In this type the number of channels on sides of source is same.)
- Asymmetric shooting (In this the number of channels on sides of source is not same)
- End shooting (The source is at one end of the spread)

- Roll along/Roll out shooting (In roll along method receivers are added in the spread while shooting in the source along the spread. Roll-out shooting is one in which the receivers are removed from the spread while shooting out along the spread.

3.3.3 Shooting Parameters

- Shooting parameters include:
- Source size
- Number of holes
- Shot at or between the pickets.
- The shooting parameters are set by determining the following parameters:
- Maximum offset ~depth deepest zone of interest
- Minimum offset ~ not greater than shallowest section of interest
- Maximum array length is determined by the minimum apparent velocity of reflections
- Charge size determined by ambient noise late on the record
- Line orientation (up-dip, down-dip)

3.3.4 Recording Parameters

- The recording parameters include:
- Group Interval
- Group Base
- Number of Channels
- Number of Geophones in a Group
- Geophone Array(Linear or Weighted)
- Sample Rate
- Record Length
- Coverage (Folds)
- Zero Offset and Common Offsets

3.4 Detection and Recording of Seismic Waves

After using energy sources, through which energy is supplied to earth, there comes the stage of detection and recording of seismic waves. In seismic detection it is necessary to detect vibration amplitude as small as 10-8 inches. Seismic equipment of adequate sensitivity, large dynamic range, and suitable frequency response is the aim of all development programs taking place in the field of seismic detection. Geophone is the most important detecting instrument used. (Al-Sadi, 1980)

3.4.1 Geophones

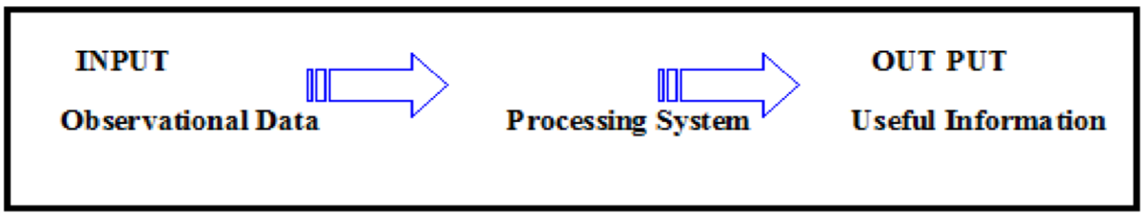
The receiver used for the detection of ground vibration is called a geophone or a seismometer. It is used for seismic surveying on land, and it can also be operated on the ocean floor if mounted in a suitable container. Mechanism is that the motion of a coil around a magnet induces electric current to flow in the coil. The strength of that current depends on the speed of the motion. The response of geophones to vibration of different frequency can be tested with a device called a shake table. The frequency of vibration that stimulates the strongest geophone response is recognized as the natural frequency of the geophone. It is found from the highest point on the response curve. Geophones commonly have natural periods in the range of 5 to 40 Hz. The smaller, more compact ones ordinarily have higher natural frequencies. The geophone is in a class of instruments that we call harmonic oscillators (Robinson & Cotuch,1988).

3.5 Introduction to Seismic Data Processing

Data Processing is sequence of operations which is carried out according to a pre-define program to extract useful information from a set of raw data. It can be said “as an approach by which the raw data recorded in the field is enhanced to the extent that it can be used for the geological interpretation” (see figure 5.1). Data processing is to convert the information recorded in the field into a form that mostly facilitates geological interpretation (Al. Sadi , 1980).Seismic data processing strategies and results are strongly affected by field acquisition parameters. Additionally, surface conditions have a significant impact on the quality of data collected in the field. Lack of seismic reflected events on seismic section is not the result of a subsurface void of reflectors. Rather it is caused by low signal-to-noise ratio (S/N) resulting from energy scattering and absorption in the medium of propagation.

3.6 Processing in General

Data Processing is a sequence of operation, which are carried out according to the predefined program to extract useful information from a set of raw data as an inputoutput system (Al. Sadi, 1980). Processing may be schematically shown as;



3.7 Processing Sequence

The seismic data processing sequence can be broadly defined in five categories.

- Data Reduction
- Geometric Corrections
- Data Analysis and Parameter Optimization
- Data Refinement
- Data Presentation

3.8 Aim and Purpose

The basic aim and purpose of data processing is to produce a perfect seismic section by applying a sequence of correction. Actually the seismic reflections from the depth are generally week and need to be strengthened by digital processing of field data (Robenson & Coruh, 1988).This approach involves the sequence of operation for improving signal to noise ratio(Dobrin &Sovit, 1988).The seismic field recorder generally records the data on magnetic tape. These tapes are then transferred to the data processing centre. Where the seismic data is processed. Processing seismic data consists of applying a sequence of computer program.

3.9 Data Reduction

Data reduction is done by certain processing operations as discussed below.

- Demultiplexing
- Geometry Definition
- Correlation
- Header Generation
- Display
- Editing and Muting
- Amplitude Adjustment

3.9.1 Geometery Defination

The layout of receivers for each shot record the location of all shots along the line, and all such field information must be described in detail to the computer for the geometryspecification step .Most geometry programs can access the digitized base-map file. Computer access is particularly necessary for processing crooked lines in which sources and receivers are not uniformly distributed along a straight traverse. The geometry program must calculate a source-receiver mid-point based on the two ground locations. All relevant geometric information is retained in the trace headers on the tape so that each trace is uniquely and accurately located. Later programs will time shift or filter as a function of ground location, offset, and/or other spatial coordinate(s) and time.

3.9.2 Correlation

Correlation is simply the measurement of similarity or time alignment of two traces. Since correlation is a convolution without reversing the moving array, a similar frequency domain operation also applies to correlation. (Yilmaz, 2001).

There are two types of correlation

1. **Cross Correlation**
2. **Auto Correlation**

3.9.2.1 Cross Correlation

Cross correlation measures how much two time series resemble each other. It is not commutative; output depends upon which array is fixed and which array is moved. As a measure of similarity, cross correlation is widely used at various stages of data processing (Yilmaz, 2001). For instance traces in a CMP gather are cross correlated with a pilot trace to compute residual static's shift. It is the fundamental basis for computing velocity spectra.

3.9.2.2 Auto Correlation

Cross correlation of a time series with itself is known as auto correlation. It is a symmetric function. Therefore only one side of the auto correlation needs to be computed (Yilmaz, 2001).

3.9.2.3 Vibroseis Correlation

The signal generated by a Vibroseis is not a short pulse but rather a sweep lasting some seven to ten seconds. The sweep is transmitted through earth and reflected signal. Each reflection is a near duplicate of a sweep itself, so the reflections in Vibroseis record overlap act are indistinguishable. To make it useable reflections are compressed into wavelets through cross-correlation of data with original input sweep. After correlation each reflection on record looks similar to impulsive source data. This involves cross correlation of a sweep signal (input) with the recorded Vibroseis trace. The sweep is a frequency modulated Vibroseis source signal input to the ground (Yilmaz, 2001). There are two types of sweep

- Up Sweep (When frequency of the Vibroseis source signal increases with time)
- Down Sweep (When frequency of the Vibroseis source signal decreases with time)

3.9.2.4 Importance of Vibroseis Correlation

For Vibroseis source, we have a sweep (a train of waves) rather than a short pulse/source wavelet whereas most seismic impulsive sources generate a very short pulse which can be used directly to examine subsurface structure Vibroseis sweep lasts for several seconds depending upon the sweep time. So in case of Vibroseis source all reflected and refracted signals on a Vibroseis seismogram overlap one another extensively. Even after Demultiplexing of the Vibroseis seismogram it is impossible to recognize the reflections. So Vibroseis correlation procedure is applied.(Robinson & Coruch,1988).Vibroseis correlation enables us to extract from each of the long overlapping sweep signals on Vibroseis seismogram, a short wavelet much like those obtained with seismic impulsive source.

3.9.3 Editing and Muting

Raw seismic data contains unwanted noise and sometime dead traces due to instrumental reasons. Thus the quality of data recorded is first observed by visual examination of raw field traces. Data may be affected by following reasons

- Polarity reversals in data
- Poor traces as well as poor bits

To remove polarity reversal, trace with reverse polarity is multiplied with it that becomes a trace with the polarity. Therefore editing is a process of removing or correcting traces, which in their original recorded taken, may cause stack deterioration (Rehman,1989).

After doing this all the contributing traces per each CDP are gathered together. Each trace in one CDP is identified by its shot point and receiver numbers .The CDP-gathers may be displayed as such for direct inspection and checking of edited data.

3.9.4 Muting

Trace- muting is a special type of data editing. This term is applied for process of zeroing the undesired part of a trace. In order to avoid stacking non-reflection events (such as first arrivals and refraction arrivals) with reflection, the first part of the trace is normally muted before carrying out the stacking process .This is occasionally referred to as first break suppression (Al-

Sadi,1980).Muting is useful to remove useless information from the processing stream in a way that first identifies the information to be removed and then blanked. Muting is categorized as Initial Muting, to remove first arrivals; usually done later in processing, and Surgical Muting, to remove air waves or ground roll energies.

3.10 Geometric Correction

In order to compensate for the geometric effects, we have to apply certain corrections on the recorded data .These corrections are called as geometric corrections (Dobrin, 1988). These corrections are applied on the traces gathered during trace editing and muting .The geometric corrections are

- **Static correction**
- **Dynamic correction**

3.10.1 Static Correction

Static correction compensates the effect of weathered layer and elevation effect due to unleveled surface .So static correction is of two types

- Elevation correction
- Weathering correction

For land data, elevation corrections are applied at the stage of development of field geometry to reduce the travel times to a common datum level (Yilmaz, 2001).This level may be flat or floating along the line.

3.10.2 Dynamic Correction

Dynamic correction compensates the effect of offset of receiver from the source .It is also related to the shape of the subsurface interfaces .It is also of two types.

- Normal move out correction (NMO).
- Dip move out correction.

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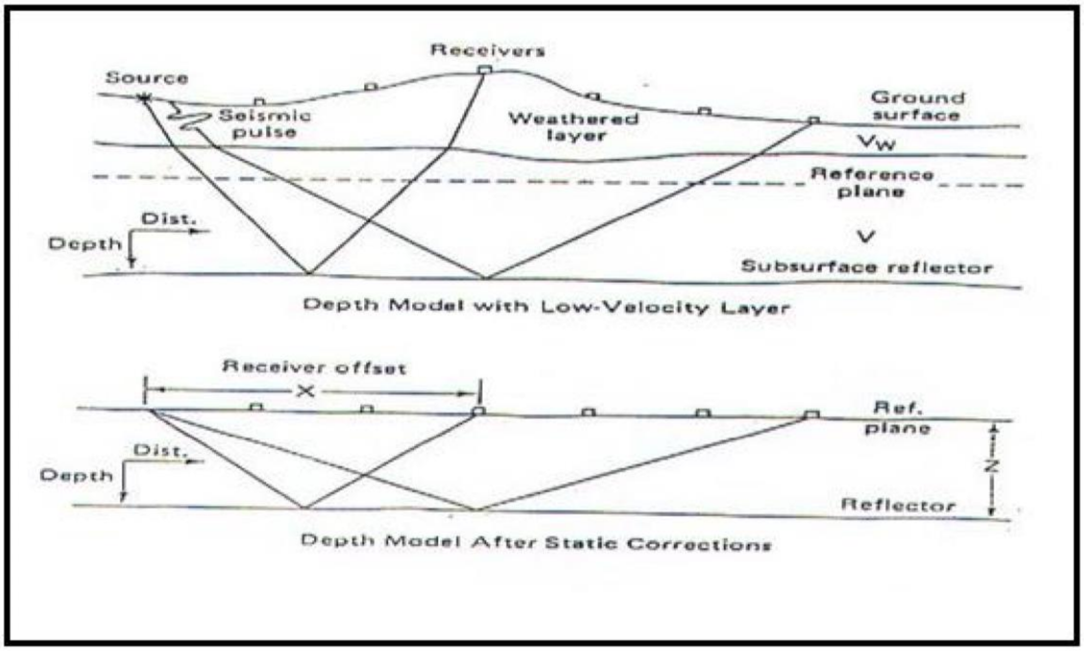


Figure 3-4 Diagrammatic representation of static and dynamic corrections.

3.10.3 Trace Gathering

Traces are routinely gathered into groups having some common elements.

- Common Source Point Gather.
- Common Depth Point Gather.
- Common Receiver Point Gather.
- Common Offset Gather.
- Common Mid Point Gather.

The concept of various types of Trace Gathers is shown in the Figure 3-10 as fallow:

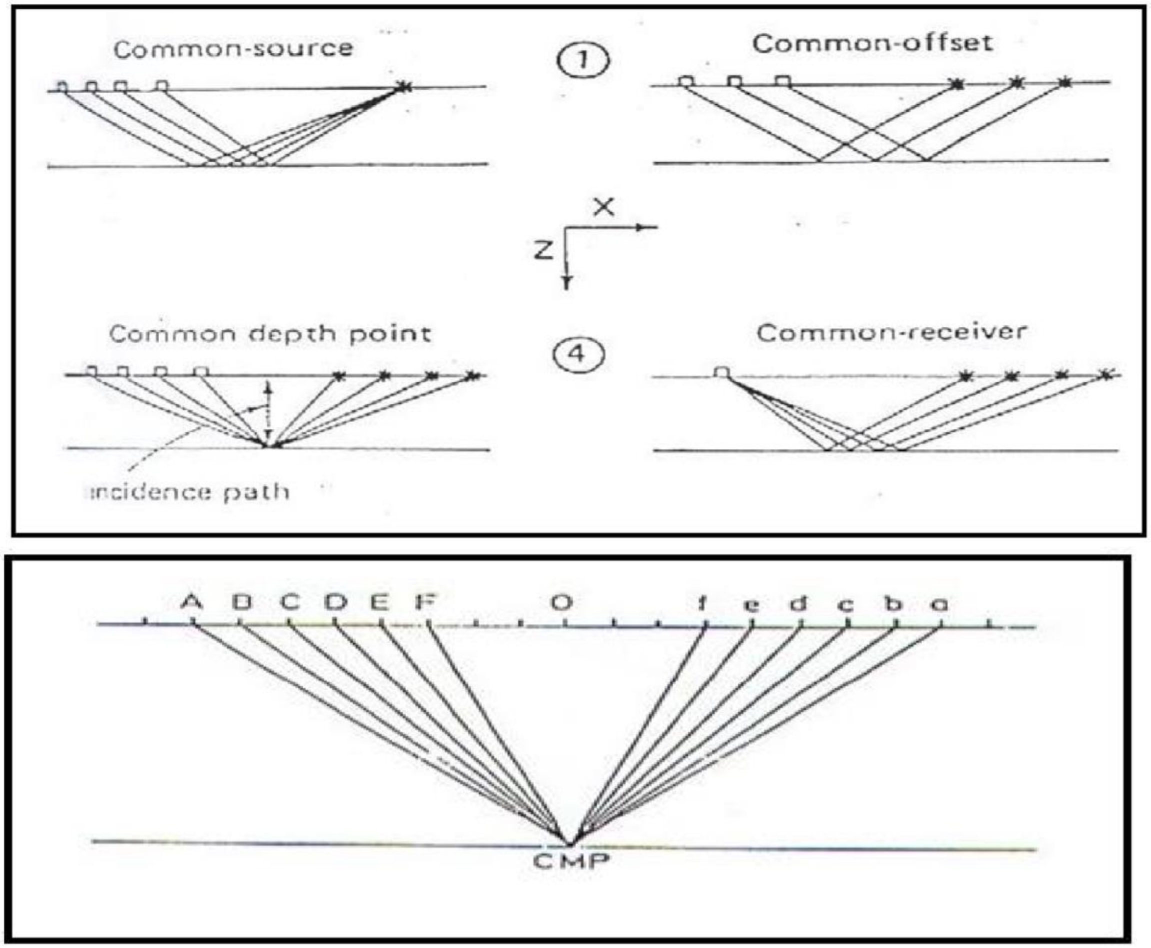


Figure 3-5 Diagrammatic representation of different trace gathers.

The classical shooting pattern involves the procedure of a fixed shape spread, which moves along a linear profile at a regular move up rate. Such a spread is made up of equal inter-trace distances and a defined offset (Yilmaz, 2001). This technique ensures CDP coverage of a fold, which increases as the move up rate decreases. Multifold coverage can be calculated in terms of number of recording channels N, the geophone interval (X) and (S), and source interval as;

Fold number = N X/2 S

The ability to combine seismogram traces to obtain multifold reflection vastly improve signal to noise ratio. CDP technique is most common for data acquisition now days.

3.11 Data Analysing and Parameter Optimization

There are three steps involved in the Data Analysis and Parameter optimization filtering.

- Deconvolution.
- Velocity Analysis.

3.11.1 Filtering

A filter is a system, which discriminates against some of its input. Seismic data always contain some signal information, which we want to preserve. Everything else is called noise, and we want to remove it. These systems, which are generally called filters work either by convolution in the time domain or by spectral shaping in the frequency domain. The common types of filters are the following:

- Low pass frequency filter.
- High pass frequency filter.
- Band Pass frequency filter.
- Notch filter.
- Inverse filter.

3.11.2 Deconvulation

It is the process by which the wavelet associated with the significant reflections is compressed and arbitrary energy that trails behind each reflection is largely attenuated .It is a filtering process designed to improve resolution and suppress multiple reflections. Deconvolution can be considered either in the time domain or in the frequency domain. In the time domain the object is to convert each wavelet with its reverberations and multiples, into a single spike. If we know the shape of the wavelet, we can design an operator which, when convolved with the seismic trace, with convert each wavelet into a single spike (Dobrin, 1988).It is a class of operations developed as a mean of partially reversing the effect of earth filter .When dynamite is blasted, spike is produced that is visible in the seismogram. Spike has very high frequency and short wavelength. When it travels through earth its amplitude decreases and it becomes a waveform, with lower frequency and greater wavelength. Thus earth is absorbing higher frequencies with time and depth. This behavior of earth is termed as hi-cut filter.Thus Deconvolution with a reverse process by which these higher frequencies are reproduced, called reverse filtering. Sometime- there are fake reflectors produced due to multiples which can cut by Deconvolution and deeper reflections become identifiable (Yilmaz,2001)

3.12 Velocity Analysis

Velocity in seismic processing is an important parameter, which controls the stacking quality. Thus the proper velocity value gives the optimum dynamic correction which leads to efficient stacking process. The seismic traces of a common depth point gather are basis for each velocity analysis. Before velocity Analysis suitable static correction and data enhancement procedures are applied to the data (Yilmaz, 2001).

A series of Normal Move Out corrections, each based on arbitrary constant velocity are then applied to each trace of data set. Then NMO corrected traces are stacked to produce a single output trace. This calculation is repeated for each constant velocity until the range of velocities applied extends from the minimum to maximum to be encountered in the area. The velocity increments may not be uniform but may be rather small for application of slower velocities, which yield large normal move out and large for higher velocities. A plot of velocities against record time for each analysis location represents the velocity function for that location. Velocity analysis is performed on selected CMP or CDP gathers. The out put from one type of velocity analysis is a table of numbers as a function of velocity vs. Two-way zero off set time also called as velocity spectrum. Numbers present in the table represent some measure of signal coherency along the hyperbolic trajectories governed by velocity, off set, and travel time.

The curve in each spectrum represents the velocity function based on picked maximum coherency values associated with the primary reflections. The pairs of numbers along each curve denote the time_ velocity values for each pick. These velocity time pairs are picked from these spectra based on maximum coherency peaks to form velocity functions at analysis locations. In areas with complex structures, velocity spectra (defined above) often fail to provide sufficient accuracy in velocity picks. In that case, the data on staked with a range of constant velocities (called as constant velocity analysis), and the constant velocity stacks themselves are used in picking velocities (Yilmaz, 2001).

3.13 Data Refinement

Processes described thus far are used to reformat, correct and diagnose data characteristics. In this step for data refinement the following procedures are carried out:

- **Stacking**
- **Migration**

3.13.1 Stacking

Once the necessary corrections have been applied, the data may be stacked. In the "corrected gather" the traces have been gathered into the depth order, both static and dynamics applied and the traces muted. All that remains to stack the data is to sum all the traces in each depth point, resulting in a single stacked traces being output for each depth point. Stacking is a data compression of one to two orders of magnitude. The signal-to-random noise ratio is increased through an N fold stack by N. after stack; the data are displayed at the surface location of the midpoint between source and receiver.

When all adjustments to the data have transformed the offset data into time and phase coincidence with the zero offset traces, the common midpoint CMP and CDP are both widely often interchangeably. With dipping reflectors, the CMP after conventional processing is not the CDP. The correct positioning of reflection point will be by migration (Dobrin & Savit, 1988). Stacking chart is shown in Fig 3-11.

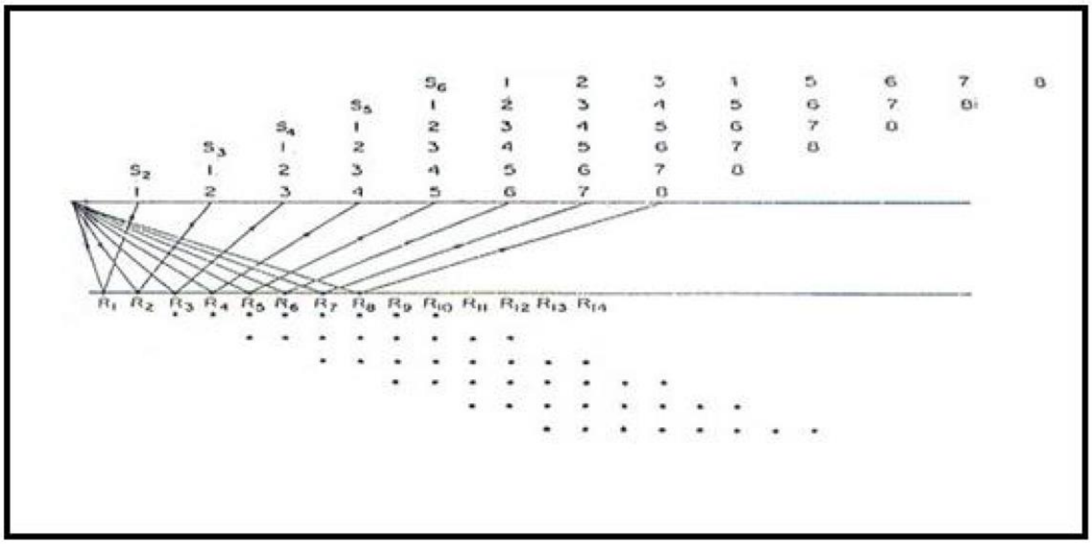


Figure 3-6 shows Stacking Chart

3.14 MIGRATION

Migration moves dipping reflectors into their true subsurface position and collapses diffractions, thereby delineating detailed subsurface features such as fault planes. So in this respect migration can be viewed as a form of spatial Deconvolution that increases the spatial resolution. Migration does not displace the horizontal events; rather, it moves dipping events in the up direction and collapses diffractions, thus enabling us to delineate faults.

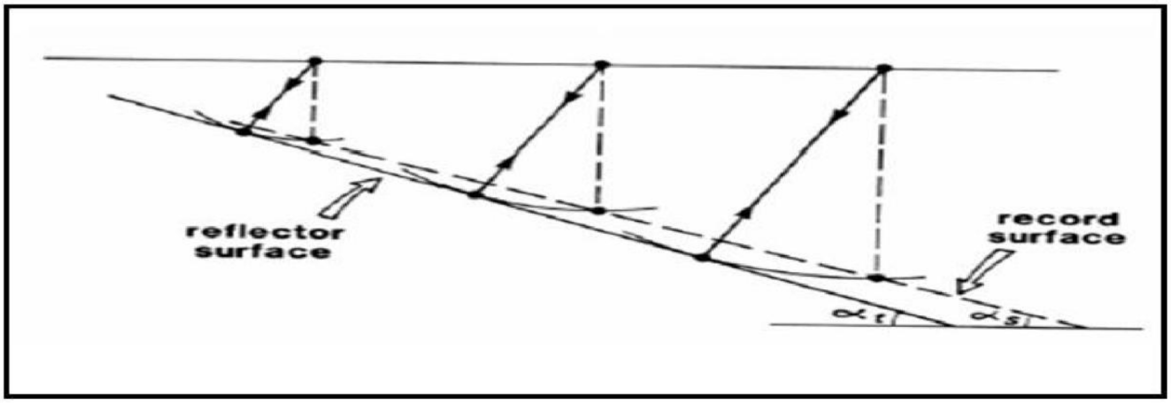


Figure 3-7 Seismic response form a dipping reflector, the recorded surface gives the apparent dip of the reflector surface.

Therefore, migration is a tool used in seismic processing to get an accurate picture of the subsurface layer. It involves geometric repositioning of recorded signals to show a boundary or other structure,where it is being hit by the seismic wave rather than where it is picked up Now, not only the position but the dip angle can incorrectly imaged by vertically plotting (Rehman, 1989).

3.14.1 Types of Migration

With respect to the stage when migration is applied on the seismic data during processing, there are two important types of migration

- **Pre-Stack Migration.**
- **Post-Stack Migration**

4 INTERPRETATION

4.1 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, 1988). There are two main approaches for the interpretations of a seismic section are:

- Stratigraphical Analysis
- Structural Analysis

4.2 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).

4.3 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.

4.4 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 used the constant density for that area. With the help of Doti-01 the synthetic seismogram was constructed shown in the (Figure 4-1) 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 groundtruth for the interpretation of seismic data. Synthetic seismograms are useful tools for linking drill hole geology to seismic sections, because they can provide a direct link between observed lithologies and seismic reflection patterns (Handwerger et al., 2004). Reflection profiles are sensitive to changes in sediment impedance, the product of compression wave velocity and density. Changes in these two physical parameters do not always correspond to observed changes in lithologies. By creating a synthetic seismogram based on Sediment Petro-physics, it is possible to identify the origin of seismic reflectors and trace them laterally along the seismic line (Handwerger et al., 2004).

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.

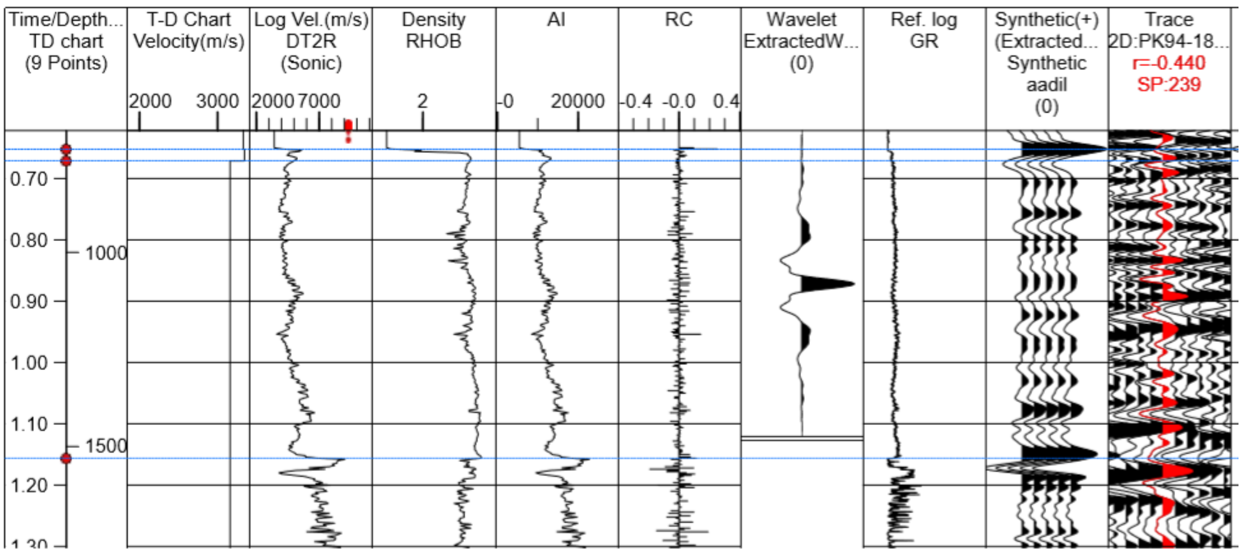
6. Compute Acoustic impedance log using velocity and density log.

7. Compute the reflection coefficients from the time-scaled velocity log.

8. Compute a first-order Ricker wavelet as a digital filter with two millisecond increments of

9. Two-way travel time; using a frequency in Hertz (35 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.



4-1 Synthetic Seismogram of DOTI-01

4.5 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 traced well over the whole seismic section.

There are difficulties in continuing the reflectors at the end of the seismic section and confusions are arrived where reflectors are mixed that may be due to sudden change in lithology, seismic noises, poor data quality or presence of salt in the subsurface at these locations. 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 strike slip nature and horst and Graben Geometry.

4.6 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, PK94-1807** and **Pk92-1696** is shown in Fig.4-2 ,Fig4-3 and Fig4-4 reflectors are marked by tying with the line which is marked by using well top data of **DOTI-01** well.

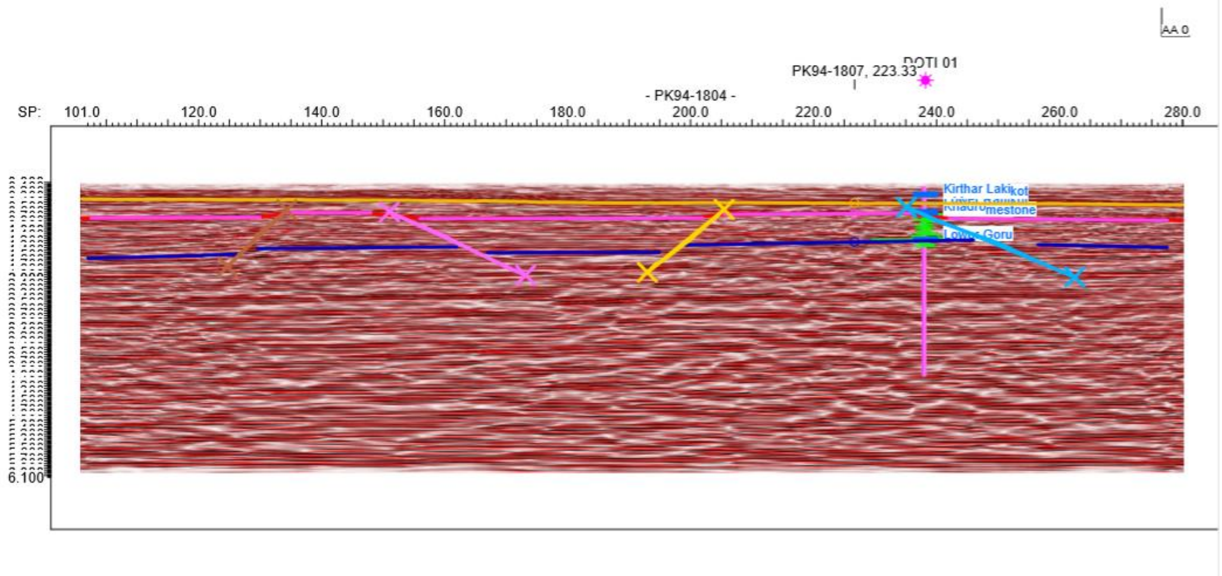


Figure 4-2 Seismic Time Section of Line PK94-1804

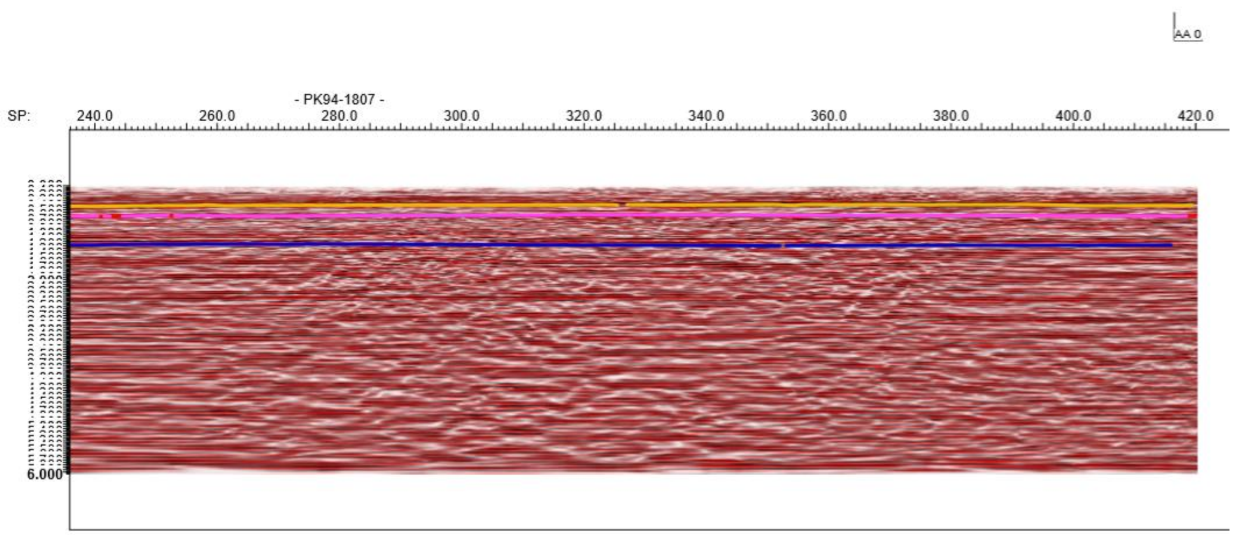


Figure 4-3 Seismic Time Section of Line PK94-1807

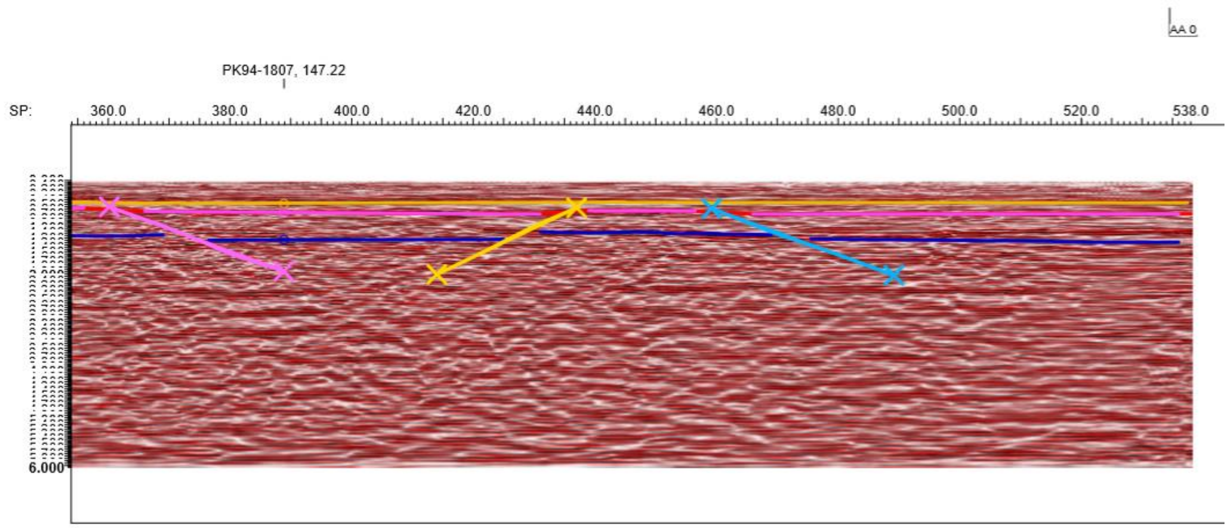


Figure 4-4 Seismic Time Section of Strike Line PK92-1696

4.7 Fault Polygones 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. Fault polygons are constructed for all marked horizons. Figure 4-4 shows polygon of Lower Goru and figure 4-5 shows polygon of Upper Goru. At Lower Gour and Upper Goru level five fault polygons are generated.

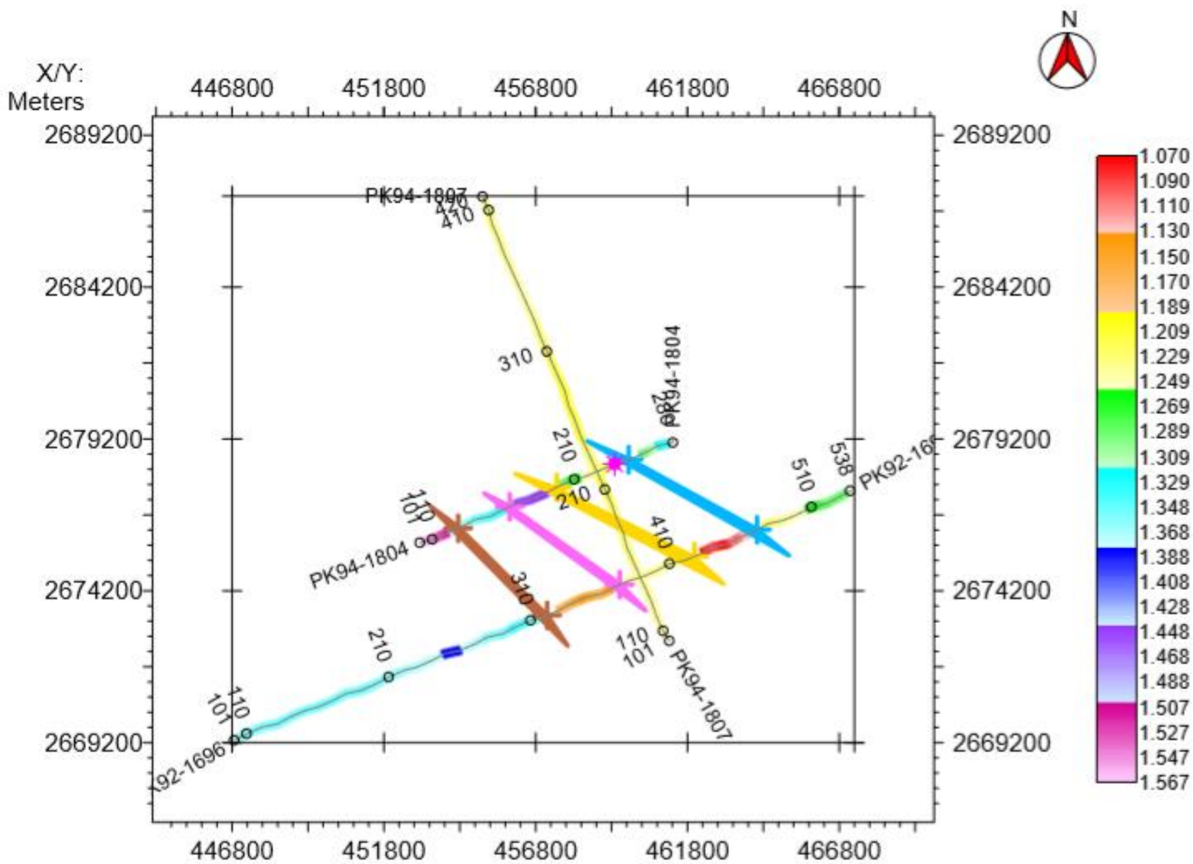


Figure 4-5 Fault Polygon constructed at Lower Goru.

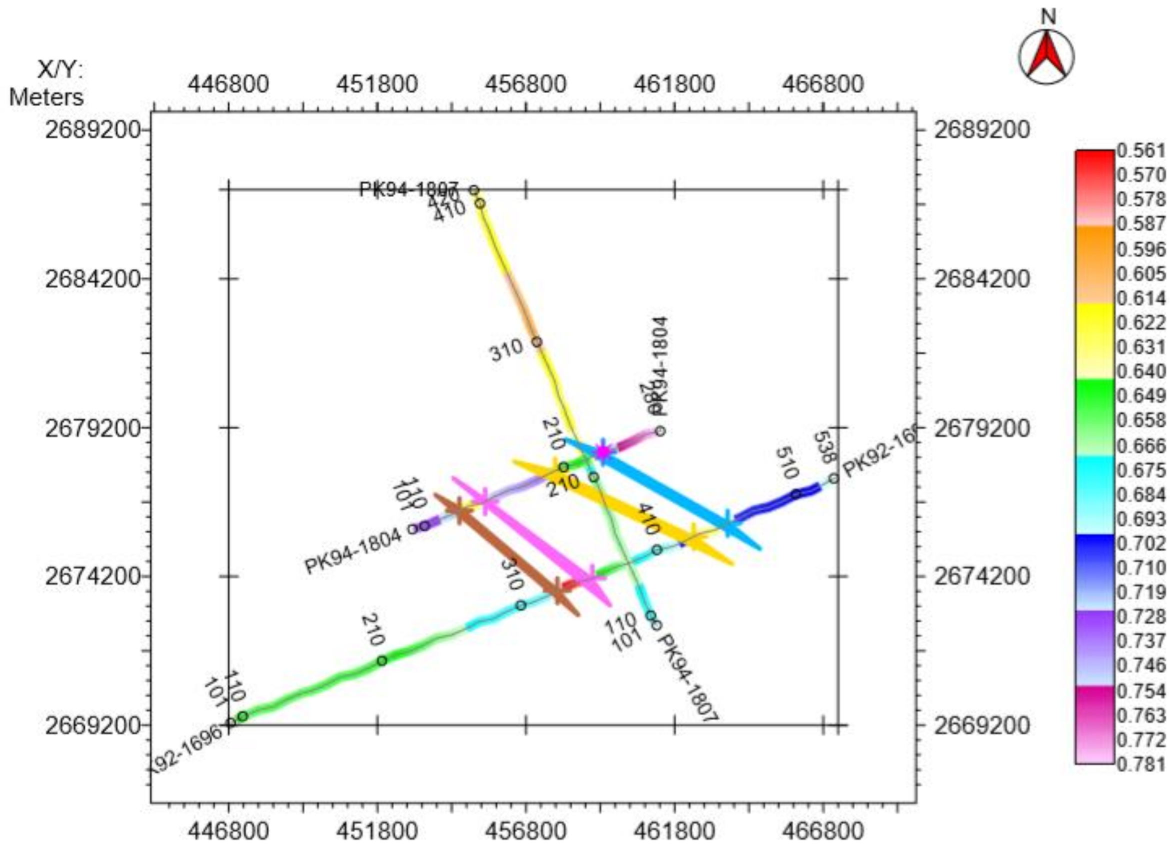


Figure 4-6 Fault Polygone constructed at Parh limestone

4.8 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.

4.8.1 Time Contour Map of Lower Goru

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

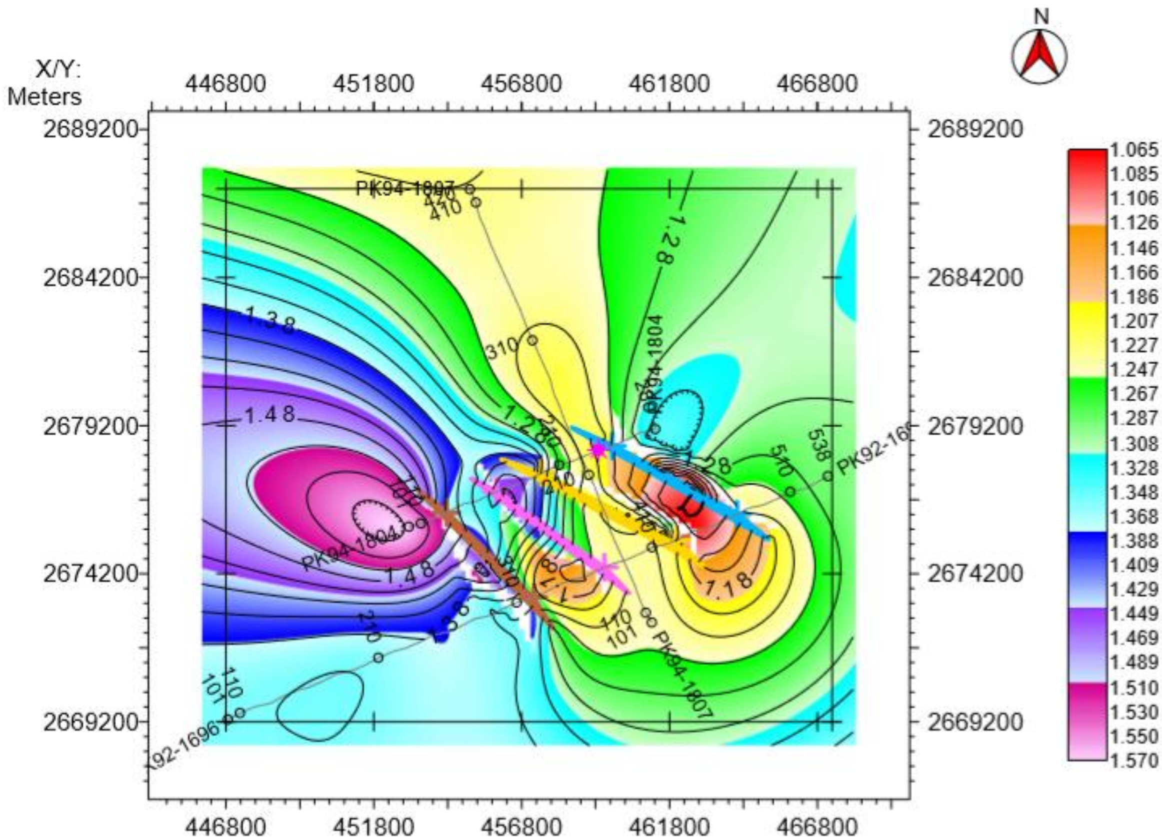


Figure 4-7 Time contour map of Lower Goru.

4.8.2 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 4-5.

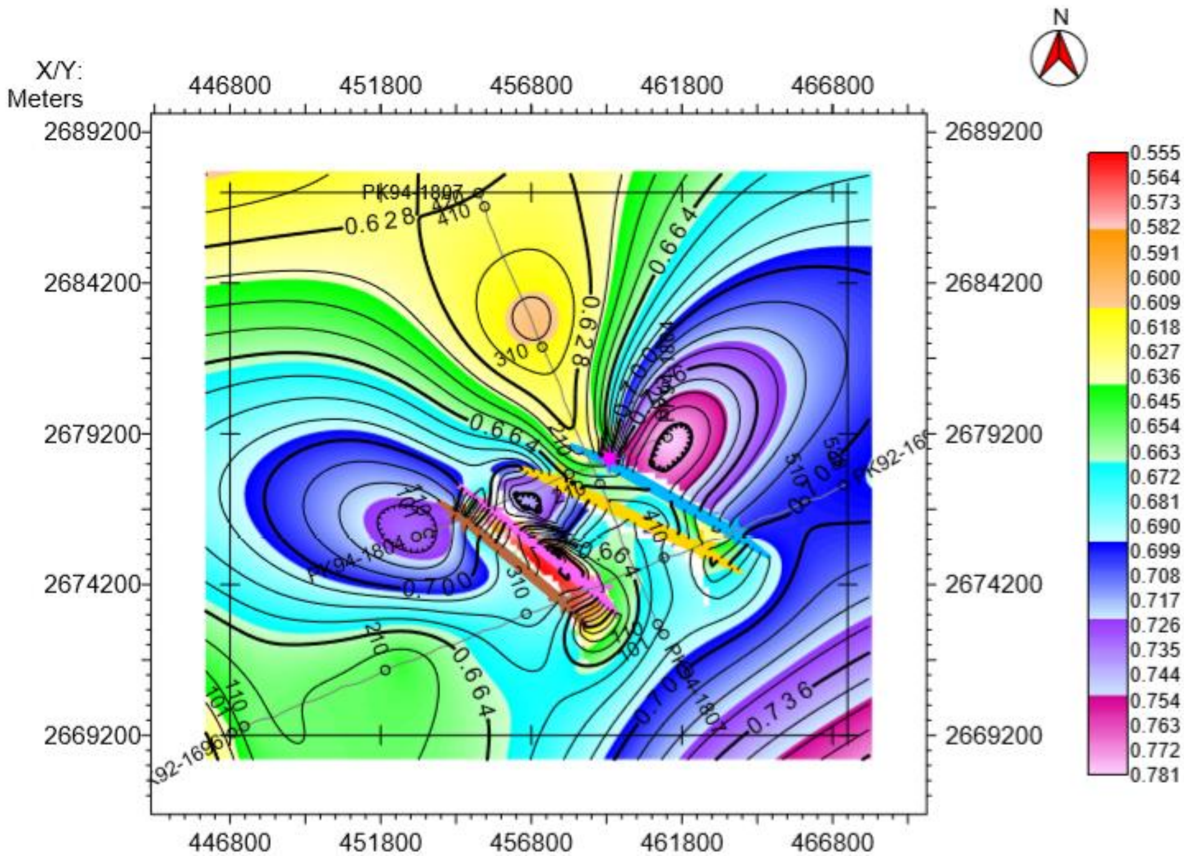


Figure 4-8 Time contour map of Upper Goru.

4.8.3 Depth Contour Map of Lower Goru

The depth contour maps have been generated using the kingdom software. Time contour map of lower Goru, as shown in the figure 4-6 the brown color shows the highest area and blue color shows deeper area.

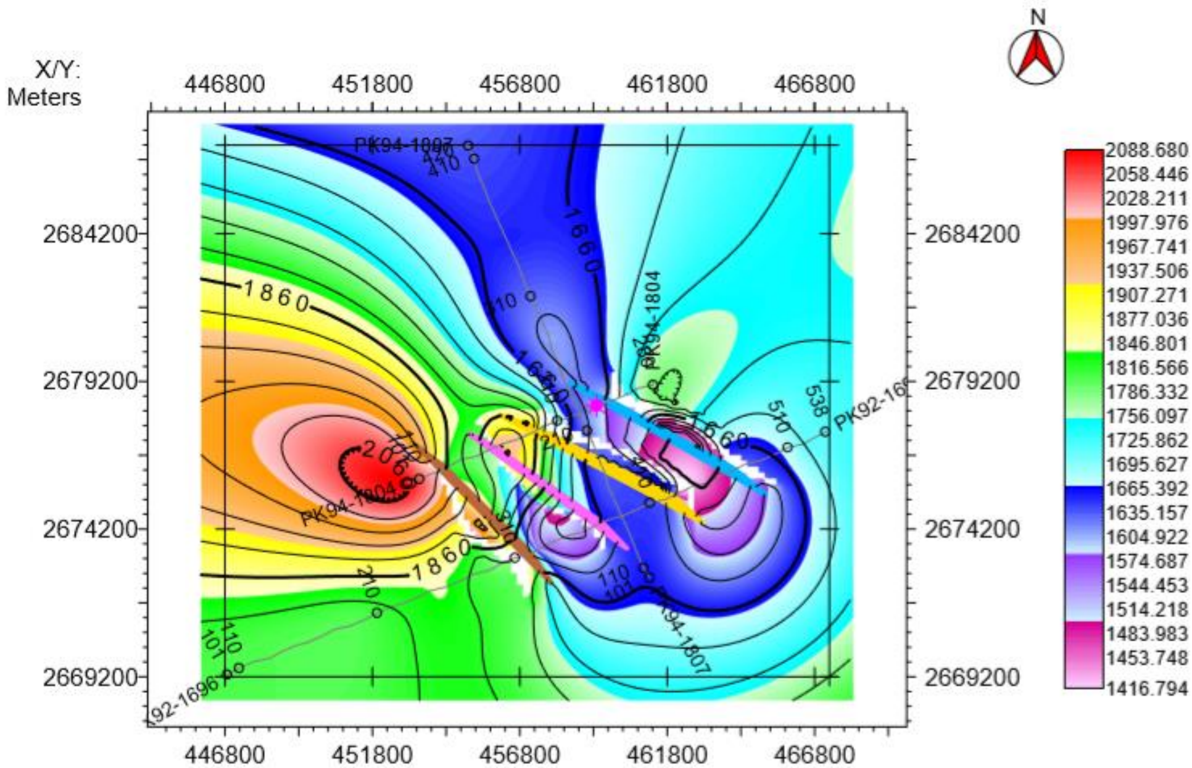


Figure 4-9 Depth contour map of Lower Goru

4.8.4 Depth Contour Map of Parh Limestone

The depth contour maps have been generated using the kingdom software. Time contour map of Upper Goru, as shown in the figure 4-9.

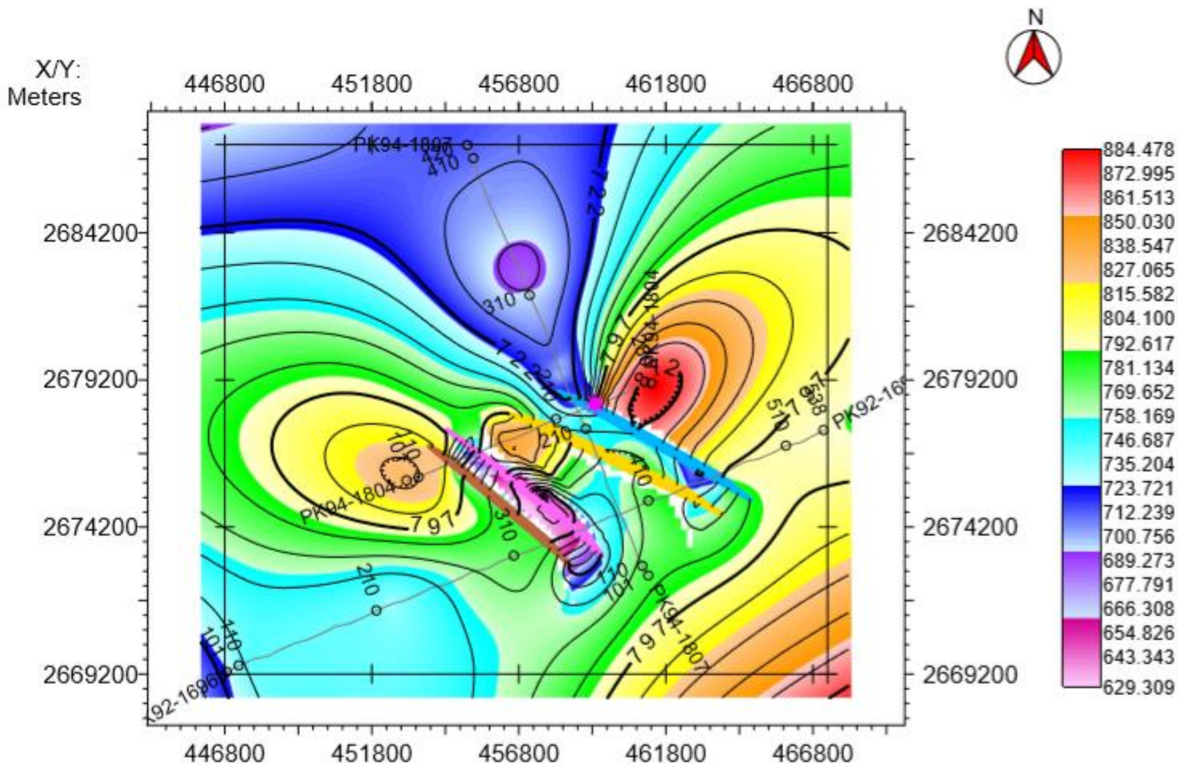


Figure 4-10 Depth contour map of Upper Goru

4.9 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 Lower Ranikot
- Reflector 2 is named as Khadro.
- Reflector 3 named as Parh.
- Reflector 4 named as Upper Goru.
- Reflector 5 named as Lower Goru

- The seismic section shows a system of conjugate normal faults, making Horst and Graben structures.
- Time to depth conversion of seismic section gave a true picture of sub-surface structure

5 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 (Khan, 2010). 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 (Taner et al., 1979).

5.1 Applications of Seismic Attributes

Uses of Seismic attributes include

- To check seismic data quality identifying artifacts
- Performing seismic facies mapping to predict depositional environments
- Hydrocarbon play evaluation
- Reservoir characterization

5.2 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 of these cases. Attributes can be classified into many types but there are two broad classifications of the attributes (Taner et al, 1994).

5.2.1 Geometrical Attributes

Geometrical attributes are used to enhance the visibility of the geometrical characteristics of seismic data; they include dip, azimuth, and continuity.

5.2.2 Physical Attributes

Physical attributes have to do with the physical parameters of the subsurface and so relate to lithology. These include amplitude, phase, and frequency.

5.3 Envelope of Trace

The envelope is the envelope of the seismic signal. It has a low frequency appearance and only positive amplitudes. It often highlights main seismic features. The envelope represents the instantaneous energy of the signal and is proportional in its magnitude to the reflection coefficient. The envelope is useful in highlighting discontinuities, changes in lithology, faults and changes in deposition, tuning effect, and sequence boundaries. It also is proportional to reflectivity and therefore useful for analyzing AVO anomalies. This attribute is good for looking at packages of amplitudes. This attribute represent mainly the acoustic impedance contrast, hence reflectivity. It always remains positive whether the reflection coefficient is positive or negative and it highlights the petroleum play as a bright spot. This attribute is mainly useful in identifying:

- Bright spot
- Gas accumulation
- Sequence boundaries, major changes or depositional environments
- Unconformities
- Major changes of lithology
- Local changes indicating faulting

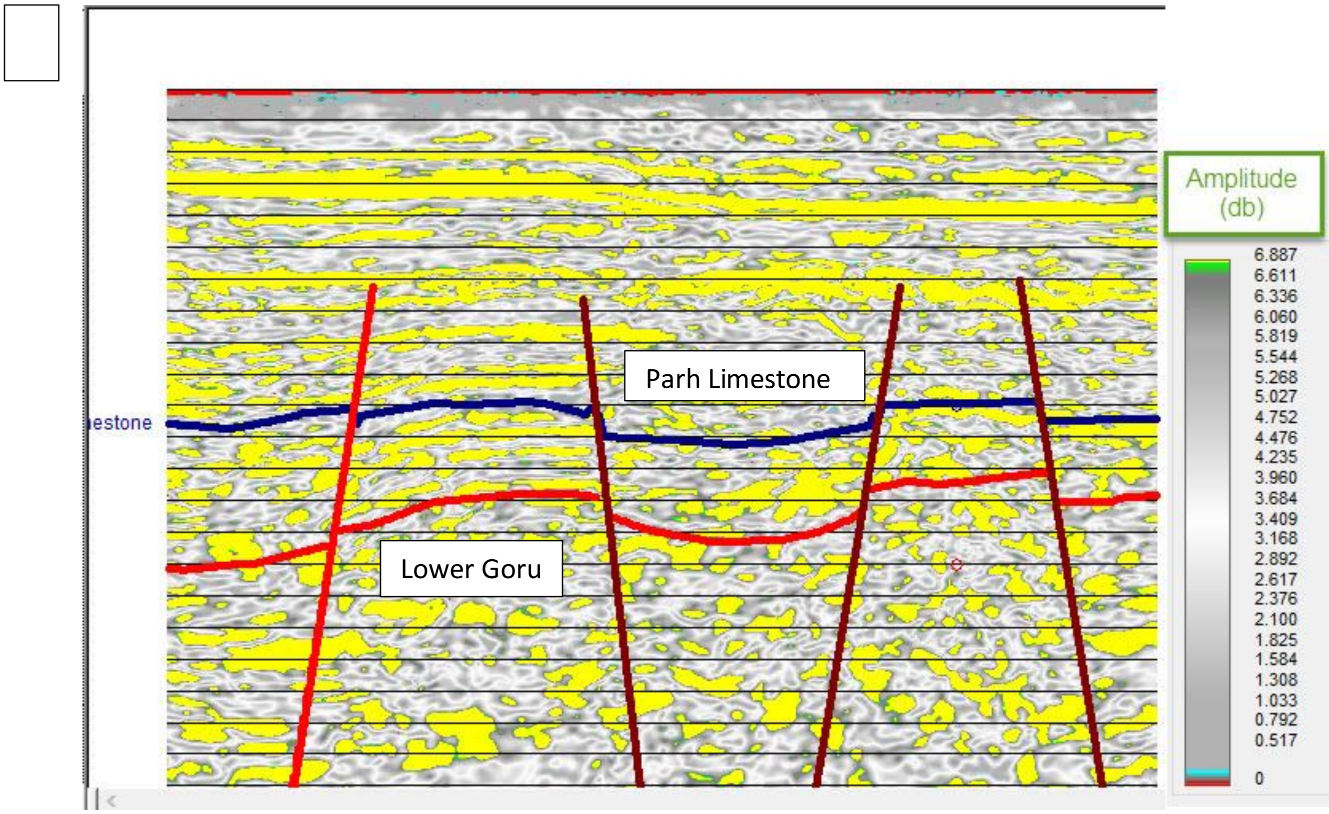


Figure 5-1 Trace Envelop Attribute Map of Seismic Line PK92-1696

5.4 Phase Attribute

The argument of the complex function is defined as the phase. The phase component is independent of seismic amplitude therefore can be used as a good indicator of reflector continuity. The figure below shows the instantaneous phase computed for two versions of a seismic trace one with a normalized maximum amplitude of 1 and other with 0.2 thus by decreasing the amplitude by 20% it can be seen that with the decrease of amplitude the 2nd trace show very weak events while the instantaneous phase show no change for both the traces this indicates that the phase is independent of seismic amplitude thus it is useful for confirming the continuity of reflectors. As the variations in the amplitude occurs no change in the real and imaginary part of the seismic trace is observed however the change in the instantaneous phase is observed .

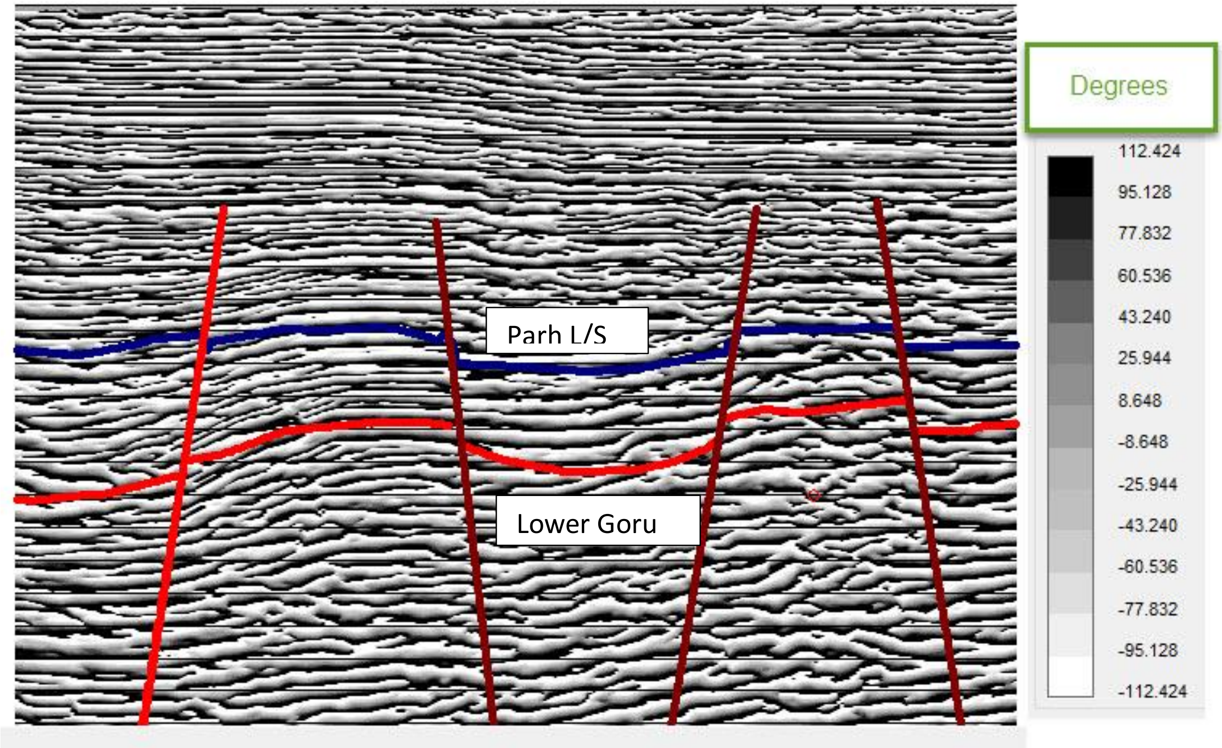


Figure 5-2 Phase Attribute of Seismic Line PK94-1804

This attribute may make it easier to pick weak events due to its independence from reflection magnitude. It can be used to assist picking of horizons in low amplitude/high noise areas. Note, however, that it does show abrupt changes at +90 and -90 degrees (due to the arc tan function used to calculate the instantaneous phase). The phase attribute is basically a physical attribute that can be effectively used as a discriminator for geometrical shape classifications:

- Best indicator of lateral continuity,
- Relates to the phase component of the wave-propagation.
- Has no amplitude information, hence all events are represented,
- Shows discontinuity, but may not be the best. It is better for showing continuity.
- Sequence boundaries.

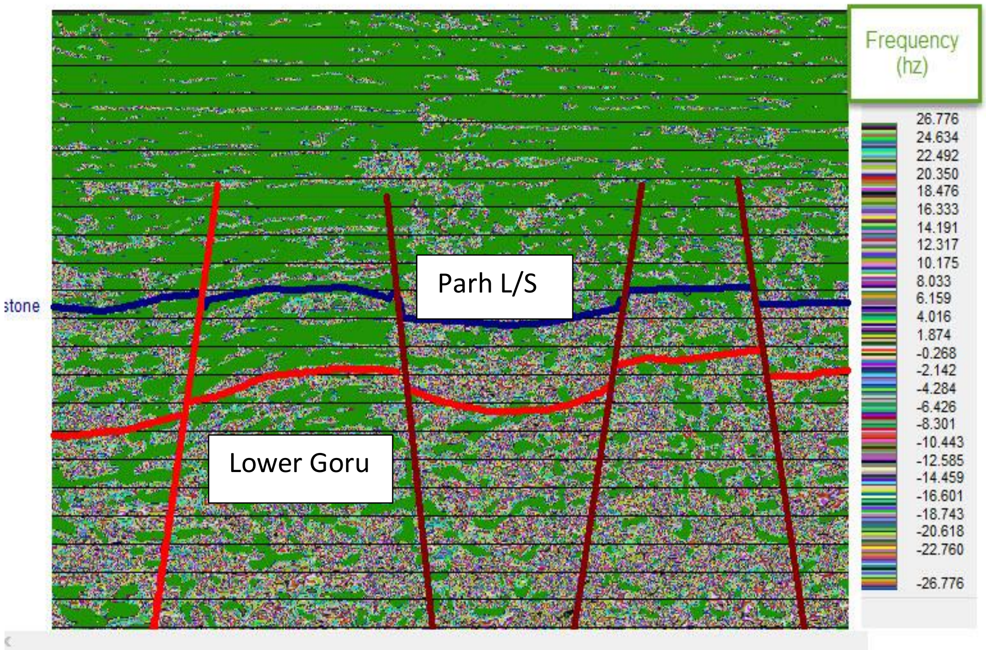


Figure 5-3 Frequency Attributes of Seismic Line PK-94 1804

5.5 Conclusion of Seismic Attributes:

Complex seismic trace attributes have become important qualitative and quantitative measures for geophysical exploration. Attributes have made it possible to define seismic data in a multidimensional form and neural network technology enables us to unravel the complex nonlinear relationships between seismic data and rock and fluid properties. Recently published case histories clearly show that multiple attributes overcome the failures associated with single attribute usage. Combined attributes translated by neural networks are becoming principal tools for lithology prediction and reservoir characterization. It is not too unreasonable to expect considerable improvement in the accuracy of predictions in the near future.

6 Petro physics

Petrophysics is the study of the physical and chemical properties that describes the occurrence and behavior of the rocks, soils and fluids. To accurately characterize an oil or gas reservoirs, measurements such as resistivity and density are made, from which effective porosity, saturations and permeability can be quantified

6.1 Types of Logs

- Gamma Ray
- Spontaneous Potential
- Caliper
- Resistivity
- Sonic
- Density
- Neutron

6.2 Spontaneous Potential log:

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

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

6.3 Caliper log:

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

6.4 Resistivity log:

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

6.5 Sonic log:

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

6.6 Density log:

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

6.7 Neutron log:

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

6.8 Volume of Shale:

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

$$I_{GR} = GR_{log} - GR_{min} / GR_{max} - GR_{min}$$

I_{GR} = Gamma ray index

GR_{log} = Gamma ray reading of formations

GR_{max} = Maximum gamma ray

GRmin= Minimum gamma ray

The following formula is used to find volume of shale

Consolidated:

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

Unconsolidated:

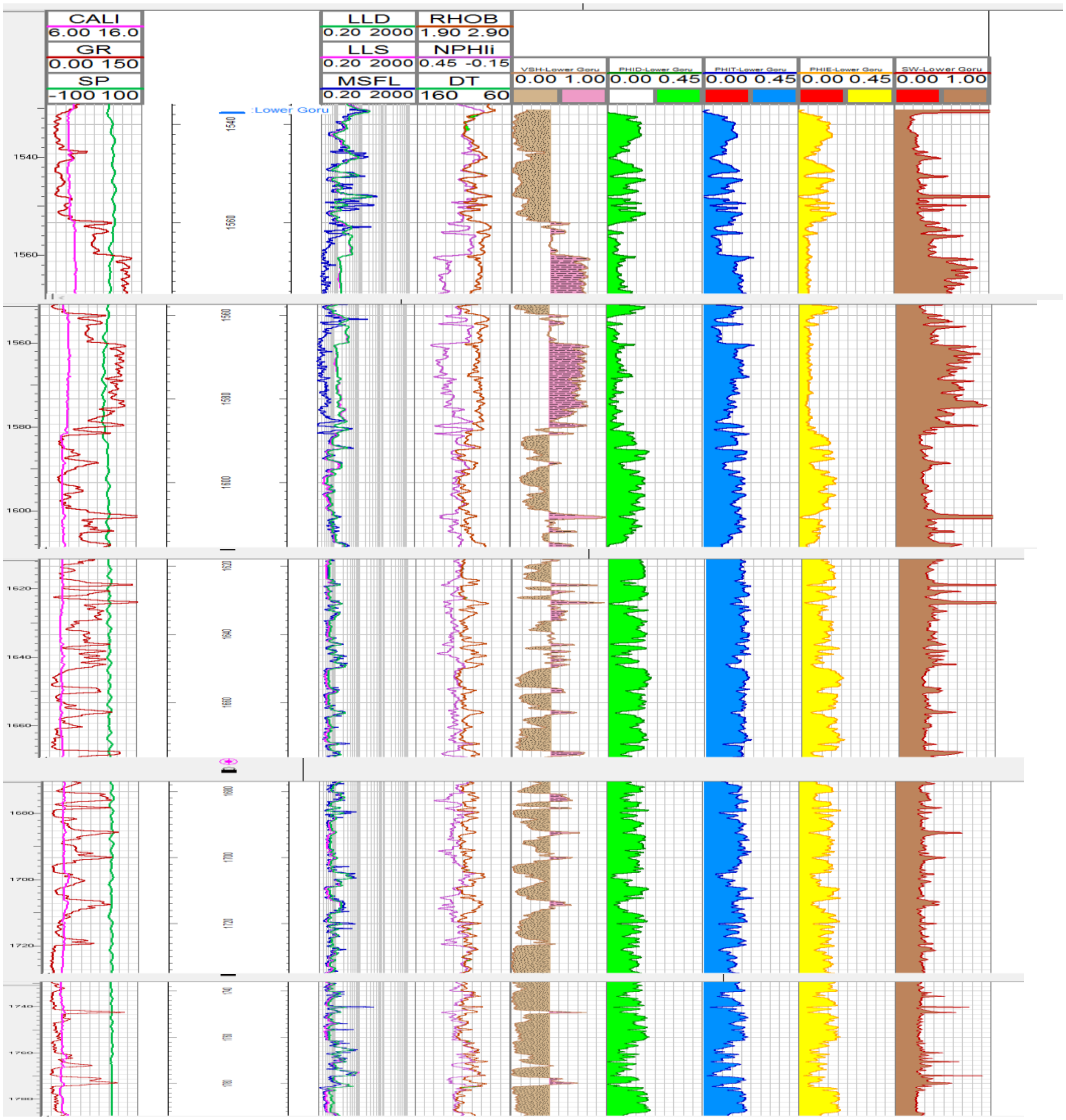
$$Vshale=0.883[2(3.7*I_{GR})-1]$$

6.9 Petrophysical Result

Table 4. Show the petrophysical properties

Petrophysical property	**Lower Goru**
Volume of shale	11%
Prosity	15%
Water saturation	74%
Hydrocarbon saturation	24%

Petrophysical analysis



CAPTER 7

Conclusions

After applying seismic and well data on the study area and using different software tools
It is conclude that;

- On the basis of seismic as well as well data reflector of geological importance were identified among which Lower Goru which 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.
- Petro physical analysis of the reservoir show a high water saturation.

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