Seismic Interpretation along with Attributes, Petrophysical based Facies Modeling,

&

Rockphysics Analysis of Kadanwari Area, Lower Indus Basin Pakistan.

QUAID-I-AZAM UNIVERSITY

ISLAMABAD

Kashif Muhammad Shah

BS Geophysics

2016.2020

Department of Earth Sciences

Quaid.i.Azam University

Islamabad, Pakistan.

CERTIFICATE

It is certified that **Mr. Kashif Muhammad Shah (Registration No. 04111613086)** carried out the work contained in this dissertation under my supervision and accepted in its present form by Department of Earth Sciences as satisfying the requirements for the award of **BS Degree in Geophysics.**

RECOMMENDED BY

Dr. Mona Lisa
Professor/Supervisor

External Examiner

Dr. Aamir Ali
Chairman

DEPARTMENT OF EARTH SCIENCES
QUAID-I-AZAM UNIVERSITY
ISLAMABAD

ACKNOWLEDGEMENT

In the name of Allah, the most Beneficent, the most Merciful. All praises to Almighty Allah, the creator of universe. I bear witness that Holy Prophet Muhammad (PBUH) is the last messenger, whose life is a perfect model for the whole mankind till the day of Judgment. Allah blessed me with knowledge related to the earth. I am enabled by Allah to complete my work. Without the blessings of Allah, I would not be able to complete my work and to be at such a place.

I am especially indebted to my honorable supervisor **Professor Dr. Mona Lisa** for giving me an initiative to this study. I specially acknowledge the prayers, endless love, efforts and support of my whole family (specially my mother and my father), my sisters my lovely fellows **Danish Zia, Usama Younas, Qazi Abudl Basit, Adnan Khan, Mirza Rehan and Salar Ali Khan** without which I was unable to reach at this stage.

I pay my thanks to the whole faculty of my department especially the respected teachers whose valuable knowledge, assistance, cooperation and guidance enabled me to take initiative, develop and furnish my academic carrier.

Contents

Chapter 1

Introduction to Study Area

1.1 Introduction

Lower Indus Basin comprises of the southern part of the largest Oil & Gas producing Indus Basin and covers the south eastern part of Pakistan. The study area is located in Khairpur District Sindh and it is the part of Kadanwari Gas Field. Latitude of the study area ranges from 27º 04′ 83″ N to 27º 07′ 12″ N and Longitude varies from 69º 12′ 98″ E to 69º 17′ 57″ E. Eni (formerly known as LASMO Oil plc. of U.K.) discovered a large amount of gas reserve in 1989 in Sandstone of Lower Goru (Cretaceous age) at Kadanwari.

This discovery involved the concentration of many E & P companies for the exploration of hydrocarbon from Lower Goru Sandstone. Since that time many discoveries have been made that are listed below;

Sawan and Miano Gas Field by OMV

Mari Deep Oil & Gas Field by Mari Petroleum Gas Company Ltd (MPGCL)

Rehmat Oil & Gas Field by Petronas (Memon, 2010).

The study Area location in Lower Indus Basin is shown in Figure 1.1.

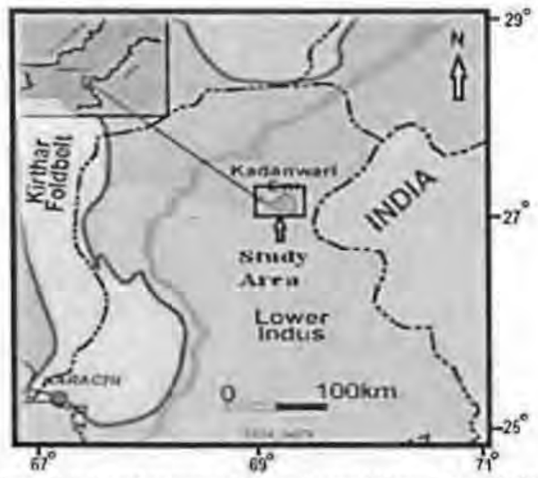

Figure 1-1: Location map of the study area (Ahmed et al., 2007)

Geologically, Kadanwari area lies in the western endurance of the Indian Plate. The structural styles and depositional features of Kadanwari area reveals that it has been gone through deformation in the middle Paleozoic age due to the rifting and drifting of the Indian plate from Gondwanaland. From early Jurassic to late Cretaceous period, Indian plate in the Tethyan ocean drifted as an isolated piece of land and finally collided with Laurasia in the northern half. Maximum marine sediments deposited from Jurassic to Cretaceous period including clastic and carbonate sedimentary rocks. Among all the marine sediments, Goru Formation is important as it serves as good reservoir for hydrocarbon accumulation and also has been proved in several Oil and Gas fields (Wandrey et al., 2004), Kadanwari Oil and Gas field of Lower Indus Basin is one of them.

1.2 Project Description

The Gas field of Kadanwari was discovered in 1989 and brought into the production state in 1995 (Ahmed et al., 2007). The main focus of this project is to delineate the petroleum system in the study area by applying different geophysical techniques on the acquired data to make further developments for future prospects. Seismic data is a technique that is broadly used for the exploration of hydrocarbon in exploration geophysics (Kearey et al., 2002). For the current project, the available data consists of 2D seismic and well log data. Many geophysical techniques included seismic attributes, petrophysical analysis and facies modeling are performed in integration with seismic and well data for complete analysis and future developments in study area. Seismic attributes and . are performed on 2D seismic to confirm subsurface structure and reservoir extents in the area while petrophysics and facies modeling are done on well log data for reservoir estimation and lithology confirmation. Petrophysics is used to find porosity & water saturation and facies models using the log curves are generated to find the different lithologies in the study area (Ahmad et al., 2013). By integrating all these techniques, the potential zones can be confirmed and new zones can be evaluated in the study area.

1.3 Data Acquisition

We have 2D seismic data of Kadanwari (Lower Indus Basin) area in the SEG.Y format shown in Table 1.1.

Table 1.1: Total number of 2D Seismic survey

LINE NATURE	LINE NAME
DIP	TJ.89.512
DIP	TJ.89.516
DIP	TJ.89.518
DIP	TJ.89.520
STRIKE	TJ.89.503

Data of the following three exploratory wells, in which one well Kadanwari.18 (ST) is side track well of Kadanwari.18 & lies almost at the same location on the base map, with proper headers and other information like log curves in digital format have been used in this research work. Basic data about the well location is listed in Table 1.2.

The Seismic and well data is provided by Directorate General of Petroleum Concessions, Pakistan and Landmark Resources (LMKR), Islamabad, Pakistan. The available 2D seismic data and wells are loaded to Kingdom software (SMT) and the base map is drawn which shows the seismic lines and well locations. The base map is shown in Figure 1.2.

Well Name	Latitude	Longitude	Start depth	End depth	status
Kadnwari 01	27 8 53.00	69 13 36.00	8.00	4000	Gas

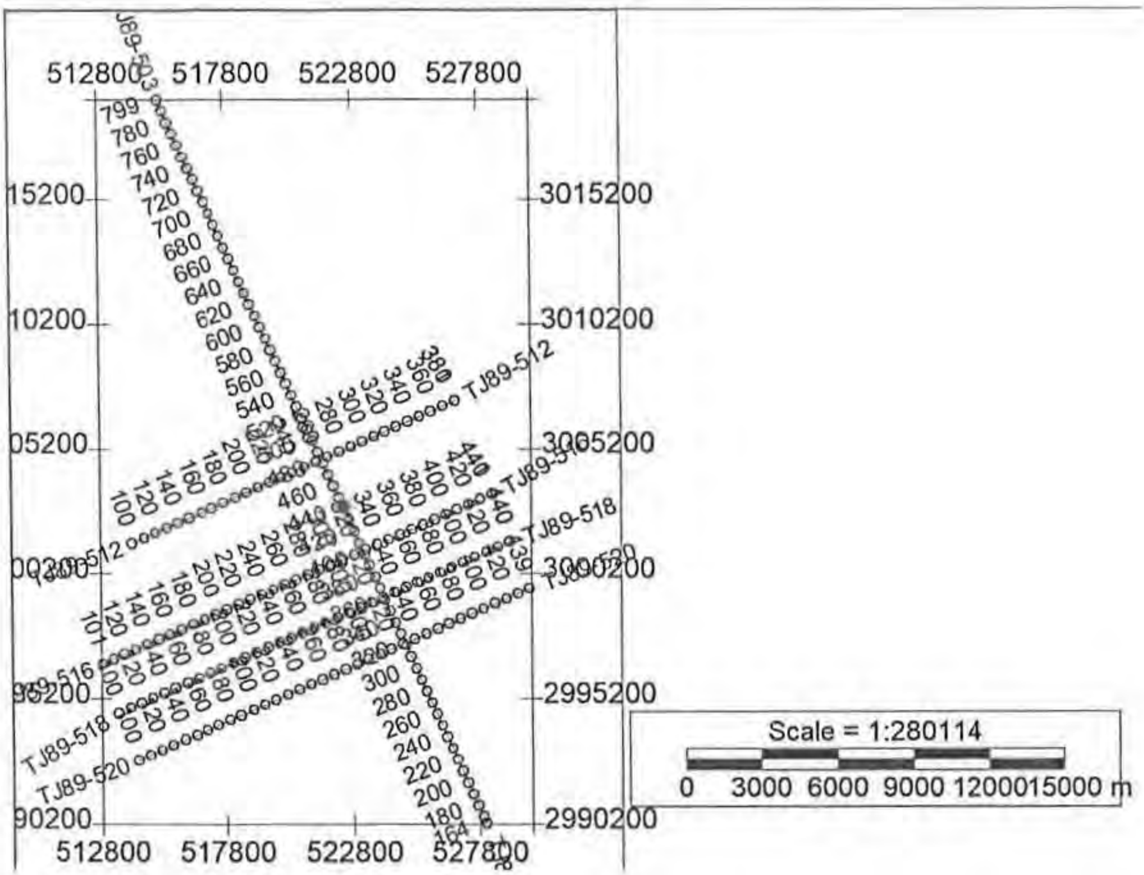

Figure 1.2: Base Map of the study area

1.4 Aims and Objective

For structural and stratigraphic interpretation, all the available geological and geophysical data (Seismic and Well data) is utilized.

Seismic attributes computed to find the possible reservoir characteristic and estimate the extents of reservoir in the area.

Petrophysical analysis for different reservoir level are performed using log curves of the available wells to find the capability of storing and transmitting hydrocarbons.

Facies are modeled using log data to identify various geological units at the reservoir level encountered in the study area.

1.5 Methodology:

Review the existing literature to completely understand the geology, stratigraphic and tectonic set up of the study area.

2D Seismic interpretation is performed using commercial softwares, mainly named as SMT (seismic micro technique) Kingdom.

Use the interactive tools of SMT (seismic micro technique) Kingdom for applying seismic attributes and ..

To compute petrophysical properties of reservoir, geophysical and geological well logs in digital format are used.

Results and discussion of this research work should be concluded from the structural & stratigraphic interpretation and computations.

Possible recommendations for future prospects on the basis of final results. 1.6. Significance This research work will be helpful for identification of subsurface structures of Kadanwari area that are favorable for hydrocarbon accumulation and trapping. Seismic attributes application on 2D seismic data proved helpful for confirmation of structural interpretation and potential at the reservoir levels. Facies modeling confirmed the identification of lithologies/rock types, so generation of facies in the study area gives understanding of reservoir i.e. sand at certain depths. Petrophysical analysis for hydrocarbon estimations using well log data at reservoir level helped to find potential quantitatively at the reservoir level. Using well (Kadanwari.01), hydrocarbon estimation are made to find the producing zones for the wells. By integrating all these geophysical techniques possible hydrocarbons zones can be identified and new potential zones can be marked.

Chapter 2

Geology and Tectonic Setting of Kadanwari Area

2.1. Introduction

For the precise interpretation of seismic data, information about the geology of area plays an important role. Seismic data consist of reflections coming from different lithologies and to interpret horizons on the seismic section, we should have geologic information of the lithologies from which these reflections occurred. To understand geology completely, we have to analyze the Basin development. Three parameters are studied to find the Basin development history namely: Basin forming tectonics, depositional sequences and basin modifying tectonics.

Pakistan comprises of two main sedimentary basins on the basis of genesis and different geological histories i.e. Indus Basins & Baluchistan Basin and one newly identified small basin that is KakarKhorasan Basin or Pishin Basin (Kadri, 1995). Indus Basin and Baluchistan Basin developed through different geological episodes and at last joined together during Cretaceous/ Paleocene period along Ornach Nal/Chaman strike slip faults. Pishin Basin came into existence by the interaction of Eurasian and Indian plates with its own geologic history and it is called as Median Basin. Indus Basin is further divide into three sub.basins i.e.

Upper Indus Basin comprise of Kohat and Potwar provinces

Central Indus Basin comprise of central gas province and Sulaiman province

Southern Indus Basin comprise of Kadanwari.Miano, Karachi Embayment, Badin region and Kandhkot (Kadri, 1995) Central Indus Basin and Southern Indus Basins are collectively called the Lower Indus Basin. The study area (Kadanwari) also exists in Lower Indus Basin. Regional setting of the Indus Basin and its structural styles are discussed to get better understanding of the study area.

2.2 Regional Tectonic Setting and Structural Styles of Indus Basin

Indus Basin extends over western part of India and NW margin of Pakistan, covering an area of about 873,000 square kilometers (Wandery et al., 2004). Indus basin is bounded by Indus offshore at south side, Indian shield at east side and MMT at the north side, while the western margin of it is separated from Baluchistan Basin by Bela.Muslimbagh.Waziristan Ophiolitic. Some basement highs also present over platform areas that serves as dividers (Ahmed, 1998). Regional setting and structural elements of Indus Basins is shown in figure 2.1.

Structures of Lower Indus Basin are explained at the sub basin level to differentiate between different structural styles present in the largest basin and to understand favorable structures for the hydrocarbon exploration. A brief discussion is given below.

2.3 Upper Indus Basin:

It is characterized by complex structural styles i.e. intense folding and complex imbrication as product of ongoing collision between Eurasian and Indo.Pak Plates and the stratigraphic sequences ranging from Precambrian to recent. It is separated by Sargodha high from Lower Indus Basin. Its northern and eastern boundaries coincide with MBT, which is the southern most part of Himalayan thrust. Salt Range (part of Himalayan foreland fold and thrust belt), the surface expression of the decollement thrust in which crystalline basement is not involved, exposed the sediments from Precambrian to Quaternary age (Kadri, 1995)

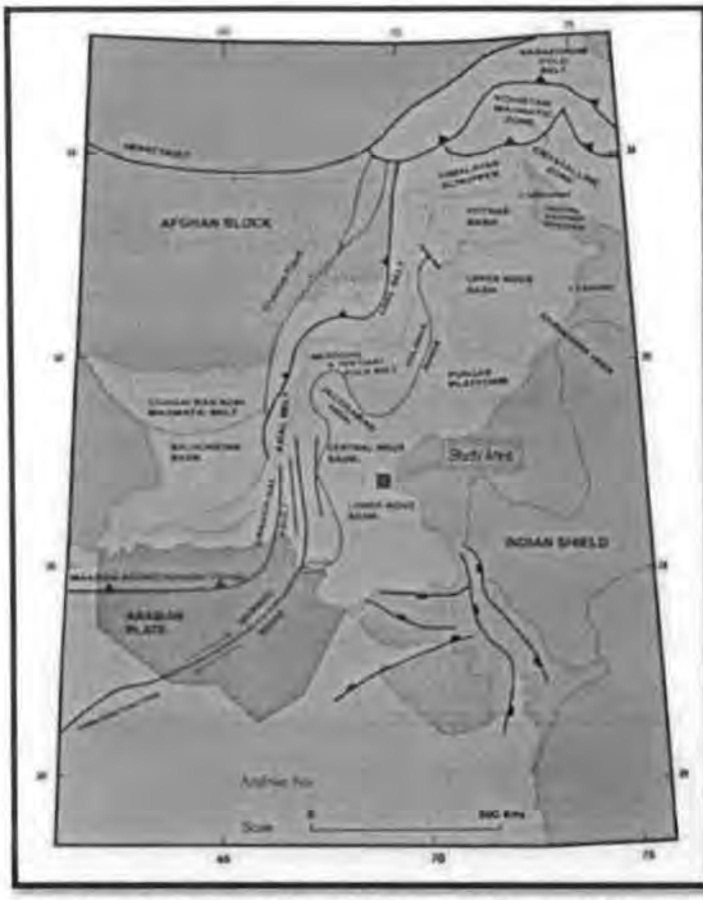

Figure 2-1: Regional Tectonic Setting Map of Pakistan with Structural Elements (modified after Kazmi & Rana, 1982)

2.4 Lower Indus Basin:

It is further divided into two basins that are explained below. Central Indus Basin: It is composed of duplex structures, these are characterized by large anticlines and domes in the passive roof sequence of Sulaiman fold belt followed eastward by gently dipping strata of Punjab monocline. Central Indus basin is attached to Jacobabad high in south, Sulaiman fore deep in west, Sargodha high in north and Indian Shield in east (Kazmi and Jan, 1997). Southern Indus Basin: At platform areas, it depicts buried structures that are formed due to the extension of plates resulting from the latest counter.clockwise motion of Indian plate. Large numbers of closely chain like anticlinal structures form, some of which produce gas fields like Sari, Hundi and Kothar, at Karachi Trough margin (Kadri, 1995). Due to the extensional tectonics in the Cretaceous age had created the tilted fault blocks over a wide area of the Eastern Lower Indus sub.basin. Seismic reflectors that represent Cretaceous period layers or older layers are broken by a system of faults with normal dip separation (Kemal, 1991). The overall trend of the structures of Lower Indus Basin depicts extensional tectonics which resulted in normal faulting exhibiting horst and graben structures (also known as Book Shelf Geometry).

Graben structure is of vital importance in hydrocarbons exploration. The study area lies in the Lower Indus Basin (i.e. Sukkur Rift south side) and it is bounded by Shahgarh depression from east, Kirthar Fold belt from west, Sukkur Rift form north and Thar Platform from south. The study area bounded by structures is shown in figure 2.2.

Figure 2-2: Detailed Structural map bounding the Study area (modified after Maqsood, 2003)

Major Formations of the study area that are interpreted for the hydrocarbon assessment are Lower Goru (contain E.sand and G.sand), Sembar Formation and Chiltan Formation. The age of Lower Goru and Sembar Formation is Cretaceous and Chlitan Limestone belongs to Jurassic period. The stratigraphy of these formations is explained as they are considered important for the hydrocarbon exploration.

2.5 Chiltan Formation:

The age of Chiltan Formation is Middle Jurassic. It is widespread platform area that underwent drowning partly by the renewed rifting between the Indian and African plates and partly by eustatic sea level rising in the Callovian.Oxfordian time. As a result the carbonate system was overcome by siliciclastics (Sembar and Lower Goru) (Afzal et al., 2009) so the depositional environment is shallow marine. The lithology consists of dark colored limestone which is thick bedded to massive. The variation in color is observed from one place to another. In Dara Manda, the thickness of Chiltan Formation is 757 m and is poorly fossiliferous. Chiltan act as good reservoir at many locations, shales at top provides the seal and source at deeper level attain good maturity (Shazia et al., 2014). It has lower contact with Shirinab Formation which is gradational and upper confirmable contact with Mazar Dirk Formation.

2.6 Sembar Formation:

Sembar Formation Sembar Formation has Early Cretaceous age that contains black shale with interbeded siltstone, argillaceous limestone mixed with glauconitic and phosphatic nodules & sandy shale is present in the basal part. Subsurface depth varies from 1000m in the platform to 5000 m in foredeep areas. TOC of the formation ranges between 0.55 wt.% to 9.48 wt.% and it contain 0.14 .18.69 mg HC/g rock potential. The immature samples contain 1.0 wt.% generating 2.88 mg HC/g rock with HI of 240 mg HC/g TOC (Ahmad et al., 2012). The thickness of Sembar Formation at type locality is 133 m while its environment of deposition is deep marine. The fauna includes Belemnites, Ammonites and Forams. The upper contact is conformable with the Goru Formation while its lower contact is disconfirmable with the Mazar Drik Formation.

2.7 Goru Formation:

Goru Formation Goru Formation of Early Cretaceous period consists of interbeds of limestone, siltstone and shale. The limestone is thin bedded and fine grained in nature. Goru Formation has been dived into two members i.e. Lower Goru member and Upper Goru member. In the Lower Goru Formation sand beds intercalated with shale have been recognized. The limestone is dominated in upper and lower parts. The depositional environment is shelf to shallow marine for both members and its thickness is 536 m in type locality.

The 12 fauna include Belemnites and Forams. Both the upper and lower contacts are conformable i.e Parh Formation present at upper contact and Sembar Formation at lower contact. Both Lower and Upper Goru members have been encountered in Kadanwari.18 well and Kadanwari.19 well. Sands of Lower Goru Formation, that are interbedded with shales act as important reservoirs. Two sands have been marked i.e. G.sand and E.sand.

G.sand: G.sand is part of Lower Goru Formation. It is clastic deltaic system originated in fluvial.toshallow water setting during the Early Cretaceous age. Lower Goru sands especially G.sand and E.sand are sourced by the Lower Goru and Sembar formations and transgressive marine shales form the seal. Lower Goru sands form narrow bars aligned along the SW.NE palaeo.coastline. The trapping mechanisms are mixed both structural and stratigraphic. They are characterized by structural dips/closures to the E.SE and facies changes to NE (Del monte et al., 2009).

E.sand: E.sand is part of Lower Goru formation. It is important reservoir. E.sands are delta.front sediments deposited when the seafloor was flat and shallow allowing a fast progradation of the delta front and dissipation of flood energy in mouth.bar attached delta front lobes.

The resulting reservoir is thin (15.25m) with a gradual facies transition and reservoir quality deterioration from mouth bars to the distal delta front lobes. The presence of lobate deltas rich in good quality sand (corresponding to producing fields) separated by interlobes areas is explained in terms of discharge efficiency of the various channels of a river system. Those with higher discharge were able to build elongated mouth bars with good quality reservoir sands, while those with minor discharge built smaller mouth bars with a shale/silt dominated delta front. The latter are the mud prone interlobes that act as stratigraphic lateral seals (Del monte et al., 2009).

2.8 Petroleum System of Lower Indus Basin

Petroleum system comprise of mature source rock, migration pathways, reservoir rock, trap and seal. Beside these, appropriate relative timing for the maturation of source rock is required. To explain thepetroleum system of the Lower Indus Basin, we will briefly explain these components.

Source Rocks: Sembar Formation and Lower Goru Formation shales are considered as main source rocks for hydrocarbons. By the Geochemical analysis of potential source rock and produced hydrocarbon revealed that Sembar Formation is favorable source of oil and gas for most productive fields in Indus Basin (Wandrey et al., 2004). Sembar consists mainly of shales with small amount of siltstone and sandstone. Gross thickness of sembar is approximately from 50 m to 1000 m. Subsurface depth varies between 1000m to 5000m in platform to foredeep areas (Ahmad et al., 2012). It has an average of 1.4 percent TOC content and it is Type Ⅲ Kerogen. The oil window (0.6.1.3 percent vitrinite reflectance) suggest that it ranges from thermally immature to overmature, at west of Indus Basin it is more thermally mature due to deeply buried as compared to the eastern side of the Basin (Wandrey et al., 2004).

2.8.1 Reservoir Rocks:

In Lower Indus Basin, there are many reservoir i.e. Chilton of Jurassic age, Sembar Formation, Goru Formation, Mughal Kot, Parh Limestone and Pab Sandstone of cretaceous age and Sui main Limestone of Eocene age but the main reservoir are the deltaic and shallow marine sandstones. Sandstone porosities are high upto 30 percent and permeability ranging from 1 to >2000 millidarcy. Reservoir quality decreases in west of the basin but thickness increase due to progressive erosion toward east and truncation of cretaceous rocks (Wandrey et al., 2004). Migration pathways for hydrocarbons to get into Lower Goru reservoir from Sembar shales is provided by the major faults and these faults also act as seal to create the trap.

2.8.2 Traps

Till now maximum production is from the structural traps including anticlines & thrusted anticlines that occur in the foreland portion of the basin, also there exists horst and graben structures due to extension and rifting of Indian.Eurasian plate (Wandrey et al., 2004).

2.8.3 Seals

The main seals of the Lower Indus Basin are shales interbedded with and overlying the sand reservoirs of Lower Goru Formation (Wandrey et al., 2004). Transgressive shales of Upper Goru andLower Goru Formation can provide effective sealing mechanism for the hydrocarbons in the Lower Goru sand reservoirs (Viqar.un.Nisa and Quadri 1986). Other effective seals may be impermeable seals above truncation traps, faults and updip facies changes.

Chapter 3

Seismic Interpretation

3.1. Interpretation of 2D Seismic Data Seismic:

Interpretation begins with mapping the large scale structure of the area. This structural interpretation mainly consists of creating horizons and fault planes. Horizons are surfaces that are created by the interpreter by selecting a reflector and following it over the volume. There are several possible reasons why a reflector is selected to be interpreted as a horizon. The simplest reason is that the reflector is outstandingly clear and strong, making it easy to track. Sequence boundaries are important horizons to distinguish between the different geologic periods. Another example of an important horizon is the top of a reservoir. A fracture in the subsurface rock caused by tectonic forces is called fault. Faults cause discontinuities in the layered structure that make the creation of horizons more difficult. To be able to continue a horizon over a fault, it is necessary to know the amount of vertical displacement between both sides of the fault. It may be possible that one reflector seamlessly continues over a fault into a different reflector. To avoid that these two reflectors are incorrectly interpreted as belonging to one horizon, the entire fault surface should be known (Bakker, 2002).

By interpreting seismic data we become able to interpret the subsurface geologic structural analysis like faults, folds, horizons and stratigraphic analysis (seismic stratigraphy). All these efforts are made to investigate the subsurface for some specific reasons like for fresh ground water deposits, minerals and hydrocarbons analysis on the basis of seismic data interpretation following analysis can be made: Structural analysis: Structural analysis is used for the search of structural traps that contain hydrocarbons. Various structural styles are present in the subsurface like horst and graben, flower structures, pop.up structures, imbricate & duplexes and growth faults. Reflectors are marked as horizon where significant change in lithology takes place. Time and depth structure maps are constructed to display the geometry of selected reflection events by means of contour of equal refection time and depth respectively. First time structure maps are generated and then it is converted into depth structural maps by means of T.D charts that are acquired in the well logging procedure.

3.2 Stratigraphical analysis:

It involves the subdivision of seismic section into sequences of reflections that are interpreted as the seismic expression of genetically related sedimentary sequence. There are two main aims of stratigraphical analysis. Firstly, reflections are used to define the chronostratigraphical units, since reflections are produced from stratal surfaces and unconformities but the boundaries of diachronous lithological units tend to be transitional and not to produce reflections. Secondly, genetically related sedimentary sequences comprise a set of concordant strata that shows discordant with underlying and overlying sequences, so typically bounded by angular unconformities variously representing onlap, downlap, toplap or erosion (Kearey et al., 2002).

3.3 Structural Analysis

Marking of faults and horizon on given seismic data is structural analysis. Its main purpose is to search for the potential zones in the subsurface from which hydrocarbon can be extracted. These zones are marked as structural traps which provide suitable conditions for the accumulation and preservation of the hydrocarbon. Mostly two way travel time is used for structural interpretation of seismic data and later the time structures are converted to depths. The depth maps shows the depth of the geometric features but the accuracy of depth depends on the accuracy of certain data like velocities of the area that is obtained from the check shot or vertical seismic profile surveys. These surveys give us Time vs Depth relation from which velocity can be calculated. Firstly the faults are interpreted on time sections. Faults are correlated with each other by making polygons that show certain structure and then on these time faults, horizons are marked which indicate the beddings i.e. from where there is certain change in lithology. From these fault and horizon interpretation on time sections we get TWT time maps. These maps are very helpful in the indication of structural traps, the orientation of faults and their geometries

3.4 Basic Work flow of Seismic Interpretation:

Following are the major interpretation steps that are taken to interpret the 2D seismic date:

1. Area base map preparation
2. Marking of faults on seismic section
3. Horizon Interpretation
4. Construction of fault polygons
5. Contour maps preparation

3.4 Area Base Map Preparation

Base map of the area is prepared when the latitude & longitude of the study area is loaded into the interpretational software and then seismic lines are loaded. The seismic data may be 2D or 2D. The 2D lines comprise of dip and strike lines according to the structure. The wells in the study area are loaded and displayed on the base map. We have 2D seismic with cubic base map and two wells while one of the well has side track well

3.5 Marking of Faults on Seismic Section

Faults are interpreted on seismic section where there is certain discontinuity or breakage in the beddings. Certain steps are necessary to identify the faults in the study area.

The steps are:

Geology of area

Faults correlation

3.6 Geology of Area

The study about the stress regime like compressional or tensional helps us to identify the pattern of the faults. Mostly in compressional regime reverse faults are dominant with minor normal faults but in extensional regime we observe normal faulting. Also previous knowledge of study area helps about the age of the faults so primary and secondary features are easy to understand. Kadanwari area is extensional regime where we observe flower structures with negative faulting. Major fault extend into the basement while splays along the major fault terminate to it. Geology of the area is important to propose us the possible structure of the area.

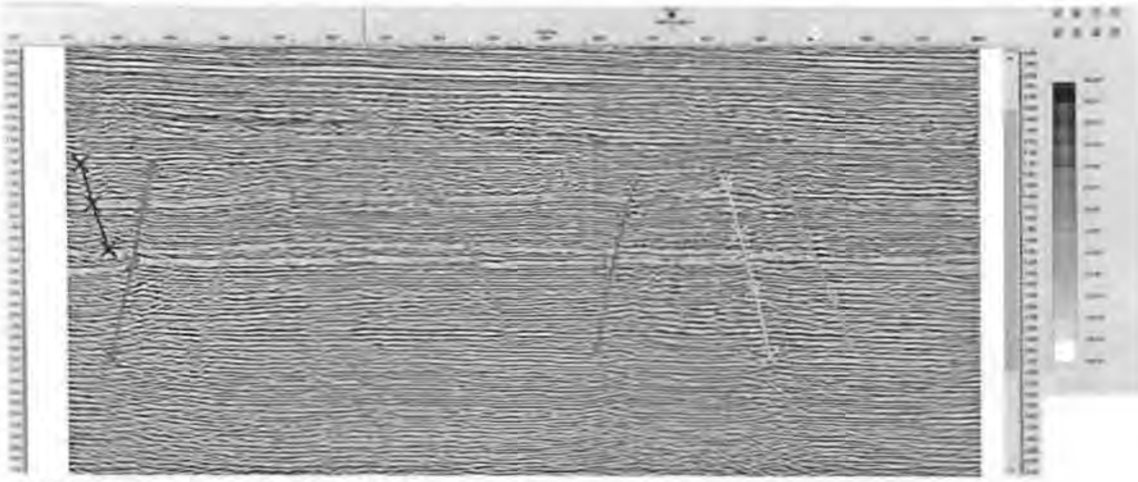

Fig 3.2 Interpreted Seismic Dip Line KAD - 516

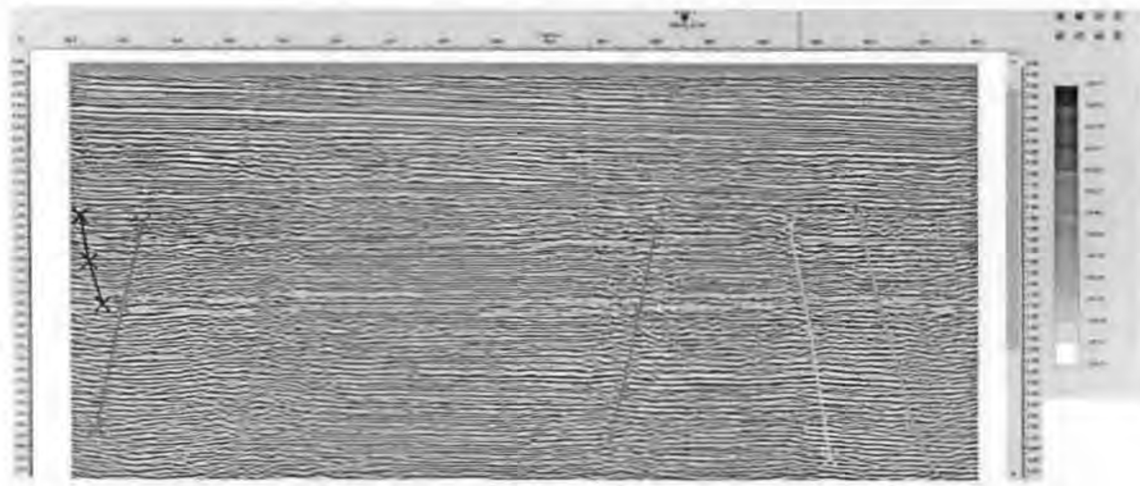

Fig 3.4 Interpreted Seismic Dip Line KAD - 520

3.12 Conclusion of Interpreted Section:

Three horizons are interpreted on the seismic sections i.e. TLG (Top of Lower Goru), G-sand, E-sand, Sembar Formation (Prominent reflector after Sembar formation). Horizons are deeper on the western side while become shallow at the eastern side. Total seventeen faults are interpreted from faults. Some faults continued upto the last section. their lateral extent cover the whole survey while some faults closed in the middle of the survey after interpreting on some lines, so fault creation and termination continues to the last section. All the faults on the interpreted sections are normal, some faults are major faults and while small faults i.e of splays terminating against the major faults. Major faults cut the horizons deep below the Chiltan formation while small faults limited to the sands of Lower Goru. Faults type indicate extensional regime making horst and graben structures that can be related to the rifting of Australia and Antarctica from Indo-Pak Plate in Cretaceous Period.

3.13 Time and Contour Maps Preparation

Final step of seismic interpretation is time contour maps. Time contour maps are first prepared because the data is readily available in time. Detail of maps are given with sequence of interpretation on seismic section. Time contours for the following horizons are prepared and discussed.

1. Top of Lower Goru (TLG) (Time & maps)

2. G.sand (Time Contour maps)

3. E.sand (Time Contour maps)

3.14 Top of Lower Goru (TLG) Time Contour Maps

First Top of Lower Goru is marked on the seismic section. It is of cretaceous age. Lithology of Lower Goru is composed of shale with inter-bedded sands. ENI subdivided the sands into eight sub groups from A.sand to H.sand. Out of these E-sand and G-sand are the major reservoirs (Del monte et al, 2009). It is much faulted then other interpreted horizons on the seismic section. Kadanwari.1 well is gas producing in the Lower Goru Formation. Fig 3.5 shows time contour map of TLG.

3.15 G-sand Time Contour Maps:

G-sand is part of Lower Goru formation. It is clastic deltaic system originated in fluvial.to.shallow water setting during the Early Cretaceous age. Lower Goru sands especially G-sand and E-sand are sourced by the Lower Goru and Sembar Formations and transgressive marine shales form the seal. The trapping mechanisms are mixed both structural and stratigraphic. They are characterized by structural dips/closures to the E.SE and facies changes to NE (Del monte et al, 2009). Fig 3.6 shows time contour map of G.sand

3.16 Interpretation of G-sand maps:

The time contour map of G-sand horizon have faults as that of Top of Lower Goru (TLG) map shown in Figures 3.5and 3.6. All the faults are normal forming the same trend of horst and graben. All the faults have same orientations described for Top of Lower Goru formation.

3.17 E-sand Time and Depth Contour Maps

E-sand is part of Lower Goru Formation. It is important reservoir and consists of delta.front sediments. The overall mechanism of the reservoir is the combination of higher discharge that build mouth bars with good quality sand reservoir and minor discharge building small mouth bars with shale/silt dominated delta fronts. The resulting reservoir is thin (15.25m) with a gradual facies transition building mud prone interlobes at later stage that act as stratigraphic lateral seals (Del monte et al, 2009).

3.18 Interpretation of E-sand maps:

Faults of Top of Lower Goru formation extend to the depth of E-sand shown in the time and depth contour maps of E-sand horizon,Between thin beds of sands, shale is present which act as source and seal for the reservoir sand and make complete petroleum system in the Lower Goru formation.

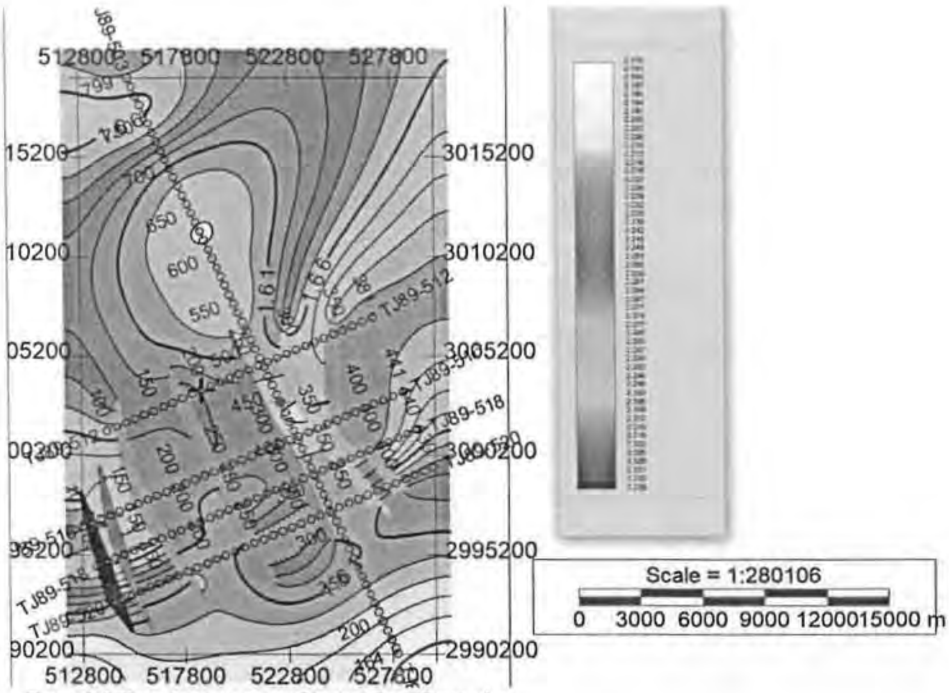

Figure 3.5 Time Contour map of Lower Goru Formation.

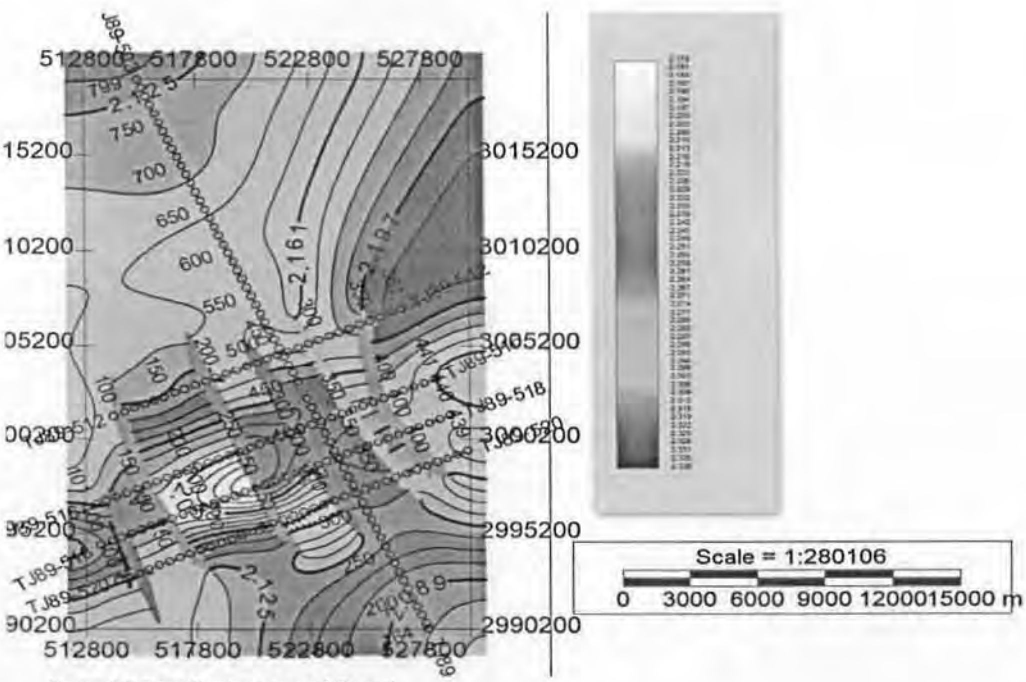

Figure 3.6 Time Contour map of G sand

Chapter 4

Seismic Attributes

4.1. Introduction to Seismic Attributes:

The measurable property of seismic data such as dip, frequency, amplitude, phase and polarity are termed as seismic attributes. Its main goal is to extract more information out of seismic data and utilize it for interpreting subsurface structural, stratigraphical and lithological features. It is measures on time window called time slice, on a single trace or multiple traces and on the interpreted surface. One of the methods can be adopted to obtain the attributes or all of the above mention can be applied to measure the attributes. Six workflows within the seismic interpretation process are necessary for attributes generation and for their result interpretation. It include: extracting seismic attributes with various methods; detecting and analyzing seismic attribute anomalies; validating hydrocarbon prospects; transforming seismic attributes to reservoir properties; and differentiating multi-survey seismic attribute anomalies (Chen et al., 1997).

4.2. Classification of Seismic Attributes

We divide the seismic attributes into two categories

A) Geometrical seismic attributes or Reflection configuration,

B) Physical seismic attributes or Reflection characteristics (Taner, 2001).

4.3 Geometrical Seismic Attributes:

It is generally utilized in seismic stratigraphic interpretation and fault or structural interpretation of 2D data volumes. It enhances the visibility of geometrical characteristics of seismic events to the interpreter. It provide the information for event terminations, curvature, concordant or chaotic conditions, continuity, unconformities, dip azimuths, faults, dips, etc. Small deviations of dips identify the parallel beddings while higher deviations shows lateral coherency computed over running time window. Smaller mean dip zone indicate horizontal parallel bedding pattern and larger mean coherencies indicate diverging or converging bedding areas. Dip changes zones indicate possible angular unconformities and small faults. The chaotic zones are identified by the larger deviation and low lateral coherencies.

4.4 Physical Seismic Attributes:

It is used for lithological and reservoir characterization. It is divided into two subclasses;

Attribute computed from seismic data planes (2D sense): These are calculated from analytical traces and most commonly used attributes. These attribute are trace envelope and its first and second derivate, instantaneous phase, band width instantaneous frequency, apparent polarity, instantaneous acceleration, instantaneous Q, and their statistic computed along reflectors over a time window. Anomalous changes of instantaneous phase give the thin bed indications. Instantaneous attributes calculated at maximum of trace envelopes are called "Principal" attributes. It is also called Response attributes.

Attributes calculated from pre-stack data: It reflect variation of different attributes with offset, such as instantaneous frequency and amplitude. Stack sections display the simple mean of the offset varying attributes, so the standard deviation, mean values and gradients computed from pre-stack data give insight to their validity and lithological composition. As most of the computations contain considerable amount of noise so signal to noise improvement of data or the attributes is necessary.

4.5 Significance of Seismic Attributes:

- Geometrical seismic attributes are significant as it indicates:
- Discontinuity of surfaces
- Sequence boundaries
- Depositional settings
- Bedding patterns

Physical seismic attributes give information related to the physical parameters of the subsurface. It indicates:

- Gas and fluid accumulation (bright spots)
- Effects of absorption and sharpness of events
- Thin bed effects (thin bed indicator)
- Fracture zones, porosity and possible permeability indicator

4.6 Attributes Applied on Study Area:

There are numerous attributes that can be applied to the seismic data but we selected those attributes which gives best result for the reservoir sands (G and E). Attributes are applied on the sand levels to identify their potential for hydrocarbons. Four attributes are selected that are listed below:

1) Envelop Trace

2) Phase

These attributes are discussed with the help of maps at levels of Lower Gower sands.

4.7 Discontinuity

The most obvious characteristic of geologic faults is lateral discontinuity of the geologic strata. The equivalent seismic representation is the discontinuity of seismic reflectors. To verify these discontinuities of the seismic data, discontinuity attribute is applied on data. It is geometrical attribute, and measures the lateral relations in the data. It is designed to emphasize the discontinuous events such faults (Subrahmanyam and Rao, 2008). Color bar of the discontinuity attribute shows the discontinuities and continuity on the basis of color. High discontinuity values on this seismic attributes corresponds to discontinuities in the data, while low discontinuity values correspond to continuous features. Discontinuity varies between zero and hundred when applied on the given seismic data, where zero is continuous and hundred is discontinuous. Most of the discontinuous events lie in range having values from 40 to 55

4.8 Interpretation of Attributes

Lower Goru Level

Top of lower Goru (above G-sand): Top of Lower Goru (TLG) starts from 1,971ms and ends on 2,314ms. Attribute is applied on horizon of TLG keeping the same time window as that of TLG horizon i.e. 1,971ms to 2,314ms. This level is potentially significant for well of the area according to the attribute. Phase and Envelop Trace attribute for Line KAD.512 is shown in fig 4.1 and 4.2

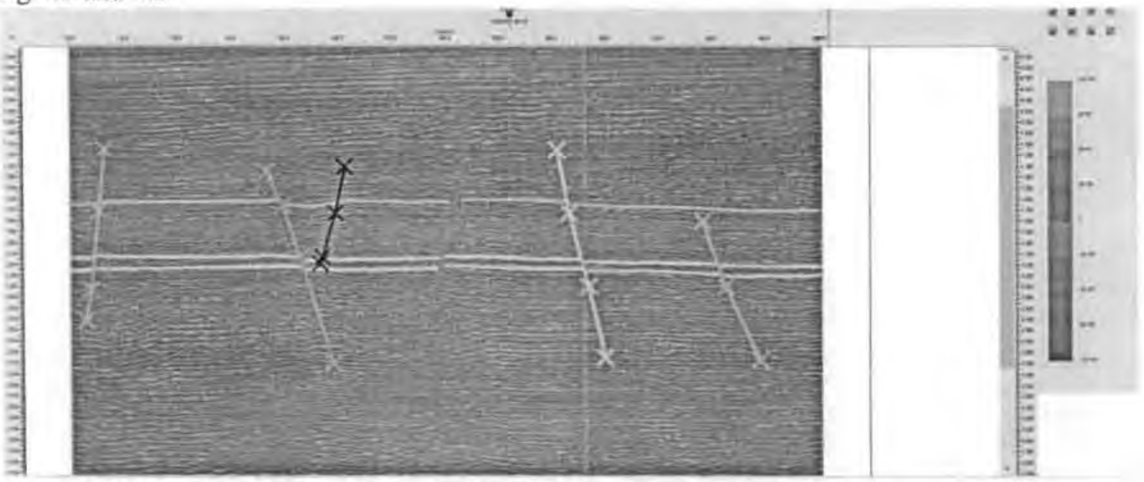

Figure 4.1 Phase Attribute for Line 512

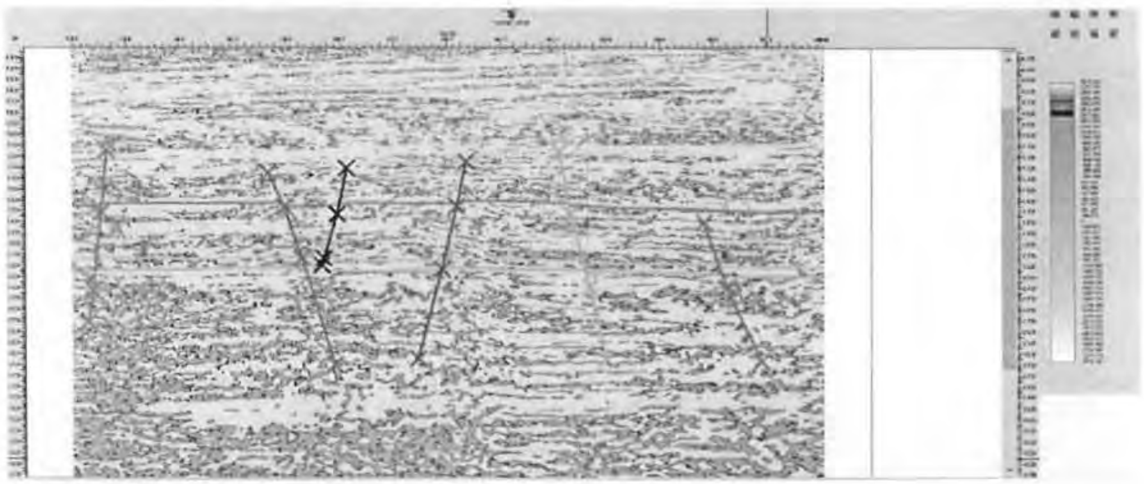

Figure 4.2 Envelop Trace Attribute for Line 512

G.sand Reservoir Level

G.sand ranges from 2,226ms to 2,639ms. Attribute for G.sand reservoir level is applied on the horizon of G.sand by keeping the time window of the horizon. G.sand Envelop Trace and Phase attribute is displayed in figures above.

Chapter 5

Petrophysics, Rockphysics and Facies Modeling

5.1 Introduction

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

Porosity, and the lithology of the reservoir rock (Schlumberger, 1998).

The petro physical analysis was carried out by using the following wire line logs of Kandanwari well 01 issued by DGPC:

- Density log
- Neutron log
- Resistivity log
- Spontaneous Potential log Gamma Ray log

5.2 Log Curves

The log data of Kandanwari was available in Logging ASCII Standard (LAS) format. The log curves along with some parameters given in the LAS file header are used to calculate all basic and advance parameters. Fig 5.1 shows petrophysical logs loaded at Wavelets (Khan et al., 2006; Khan & Akhter 2015)

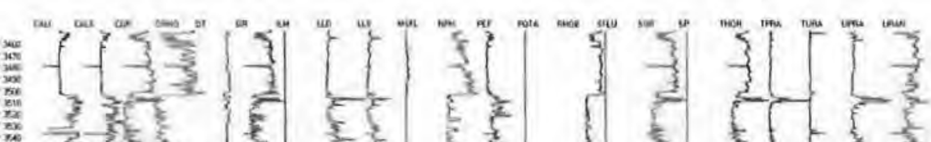

Fig 5.1 Petrophysical logs of well KAD-01 for depth range 3450-3850 meters. *(Khan et al., 2006; Khan & Akhter 2015)*

5.3 Calculation of the Volume of Shale

The source formations are commonly shally with higher radioactive content and are Therefore indicated by a higher Gamma Ray value. On the other hand, it is also assumed that the radioactive material is not present in other formations which are termed as clean Formations. This creates a contrast between shale and other formations. The mathematical Formulation used to calculate the Volume of Shale is given in fig 5.2.

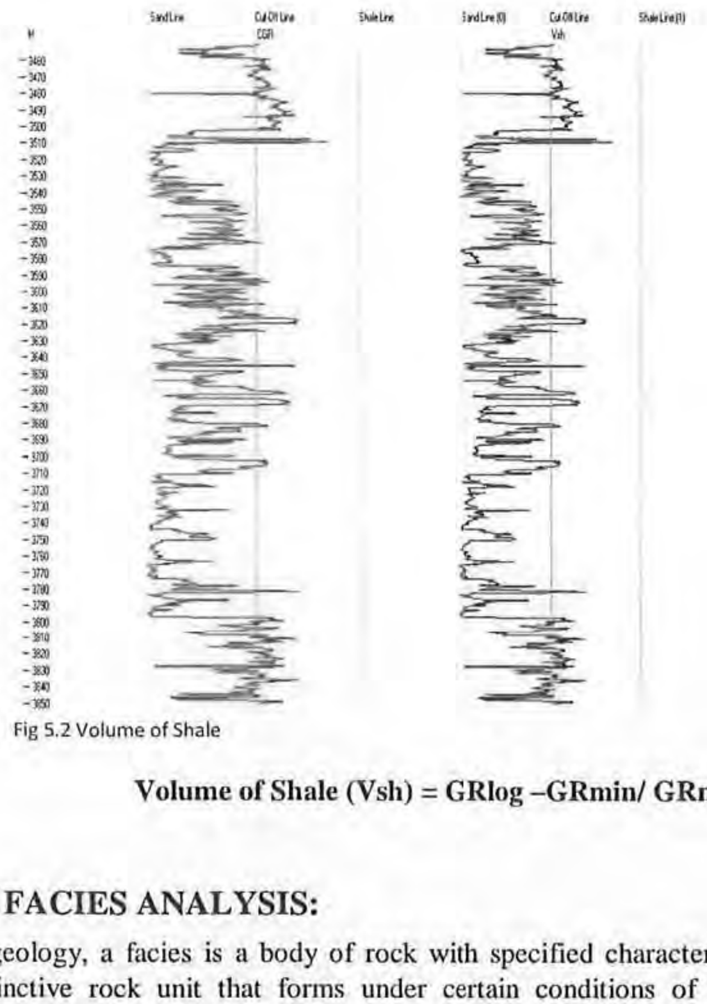

Fig 5.2 Volume of Shale

Volume of Shale (Vsh) = GRlog –GRmin/ GRmax. GRmin

5.4 FACIES ANALYSIS:

In geology, a facies is a body of rock with specified characteristics. Ideally, a facies is a distinctive rock unit that forms under certain conditions of sedimentation, reflecting a particular process or environment.

5.5 TYPES OF FACIES

Sedimentary facies Sedimentary facies are bodies of sediment recognizably different from adjacent sediment deposited in a different depositional environment, as shown in figure 6.9 given below.

5.6 METAMORPHIC FACIES

The sequences of minerals that develop during progressive metamorphism define a facies series.

5.7 WALTHER'S LAW OF FACIES

Walther's Law of Facies, or simply Walther's Law, states that the vertical succession of facies reflects lateral changes in environment. Conversely, it states that when a depositional environment "migrates" laterally, sediments of one depositional environment come to lie on top of another. A classic example of this law is the vertical stratigraphic succession that typifies marine transgressions and regressions. However, the law is not applicable where the contact between different lithologies is non-conformable (Lucia 1995).

5.8 CROSSPLOTS

Cross plot of different well logs are made to define our reservoir i.e Lower Goru on basis of facies. Shale and Sand are delineated by using polygon methodology.

5.8.1 NPHI VS RHOB

Cross plot of neutron porosity and density log is made to distinguish the Lower Goru. Shale was prominent in the analysis with the presence of sandy beds shown in fig 5.3

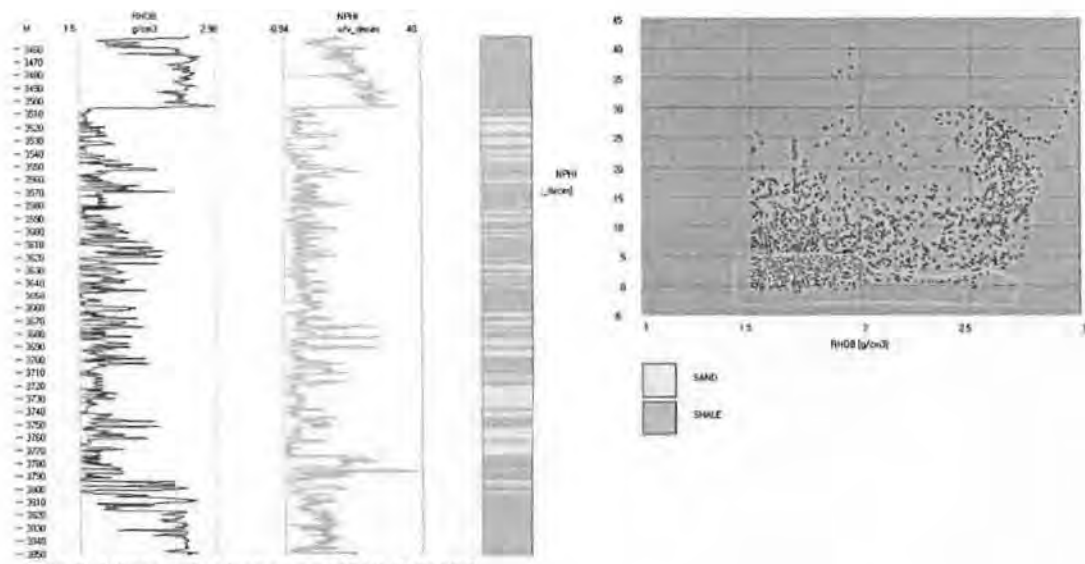

Fig 5.4 Cross plot between NPHI & RHOB.

5.8.2 Vp VS RHOB

Crossplot of Vp(rock physic property) and RHOB(well log) is constructed and almost equal intervals of Sand and Shale were identified.

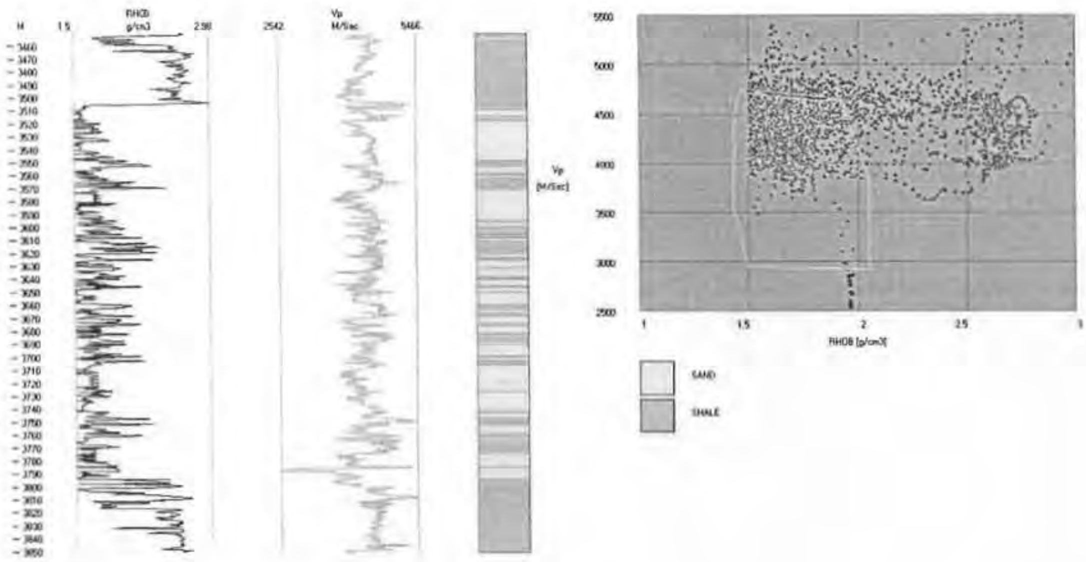

Fig 5.5 Cross plot between I & RHOB.

5.8.3 GR VS SP

Regression analysis of gamma ray and sp log was plotted

SP=31.195+0.0.54GR

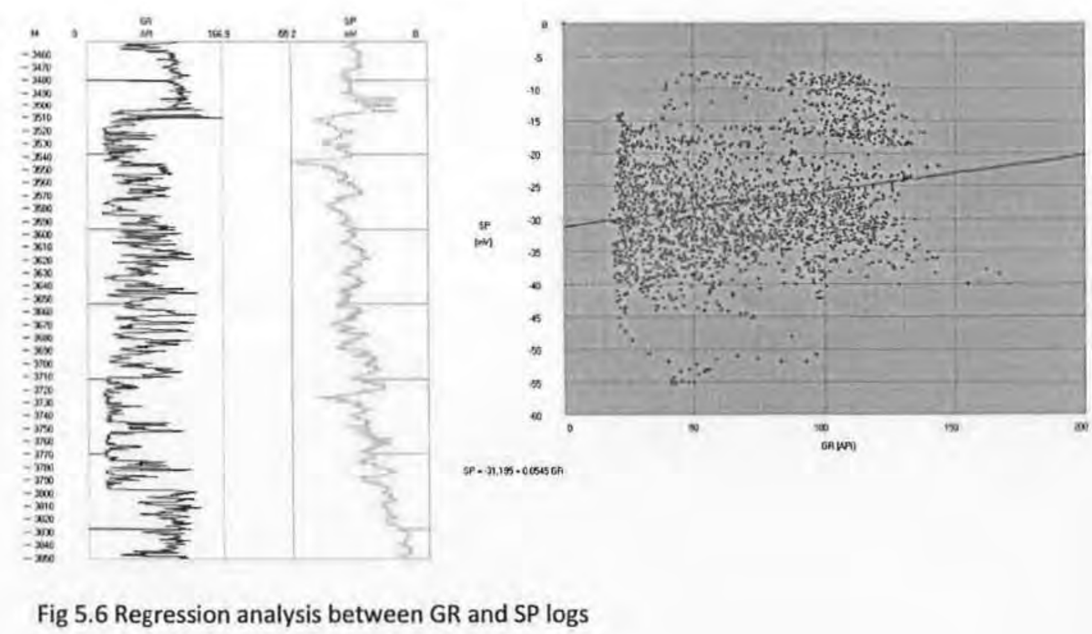

Fig 5.6 Regression analysis between GR and SP logs

5.9 ROCK PHYSICS

Rocks are identified by physical properties such as porosity, rigidity, compressibility, properties that will affect how seismic waves physically travel through the rocks. The Rock Physicist seeks to establish relations between these material properties and the observed seismic response, and to develop a predictive theory so that these properties may be detected seismically. Rockphysics properties calculated for well KAD.01 are shown in fig 5.7

Following rock parameters and engineering properties are calculated using well

- Vp/Vs
- Bulk modulus
- Shear modulus
- Young's modulus
- Poisson's ratio
- Porosity
- Lambda rho
- Meu Rho

5.9.1 Shear Modulus

The ratio of shear stress to the shear strain (angle of deformation). It is concerned with the deformation of a solid when it experiences a force parallel to one of its surfaces while its opposite face experiences an opposing force (such as friction). It describes the material's response to shearing strains relation moduli.

$$\mu = \rho * Vs_{,}$$

where

μ = Shear modulus

Density and vs. is S-wave velocity

5.9.2 Bulk Modulus

The bulk modulus (K) of a substance measures the substance's resistance to uniform compression. It is the ratio of volume stress to volume strain. It is defined as the pressure increase needed to affect a given relative decrease in volume. It describes the material's response to uniform pressure. It is calculated by using relation as under.

$$K= \rho\ (Vp\ 2 * \frac{4}{3}Vs2),$$

5.9.3 YOUNG MODULUS

Young's modulus or modulus of elasticity (E) is a measure of the stiffness of an isotropic elastic material. It is the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's Law holds. It describes the material's response to linear strain.

$$E = (9 * K * \mu)/(3 * K + \mu)$$

5.9.4 POISSION'S RATIO

Poisson's ratio (σ) is defined as the transverse strain divided by longitudinal strain. This means that it is the measure of incompressibility of the rock body. In Post stack data shear wave velocity has been estimated only as a parameter as post stack data do not have shear components. Also Poisson's Ratio is more dependent upon P. wave velocity rather than S.Wave velocity (sheriff, 1999).

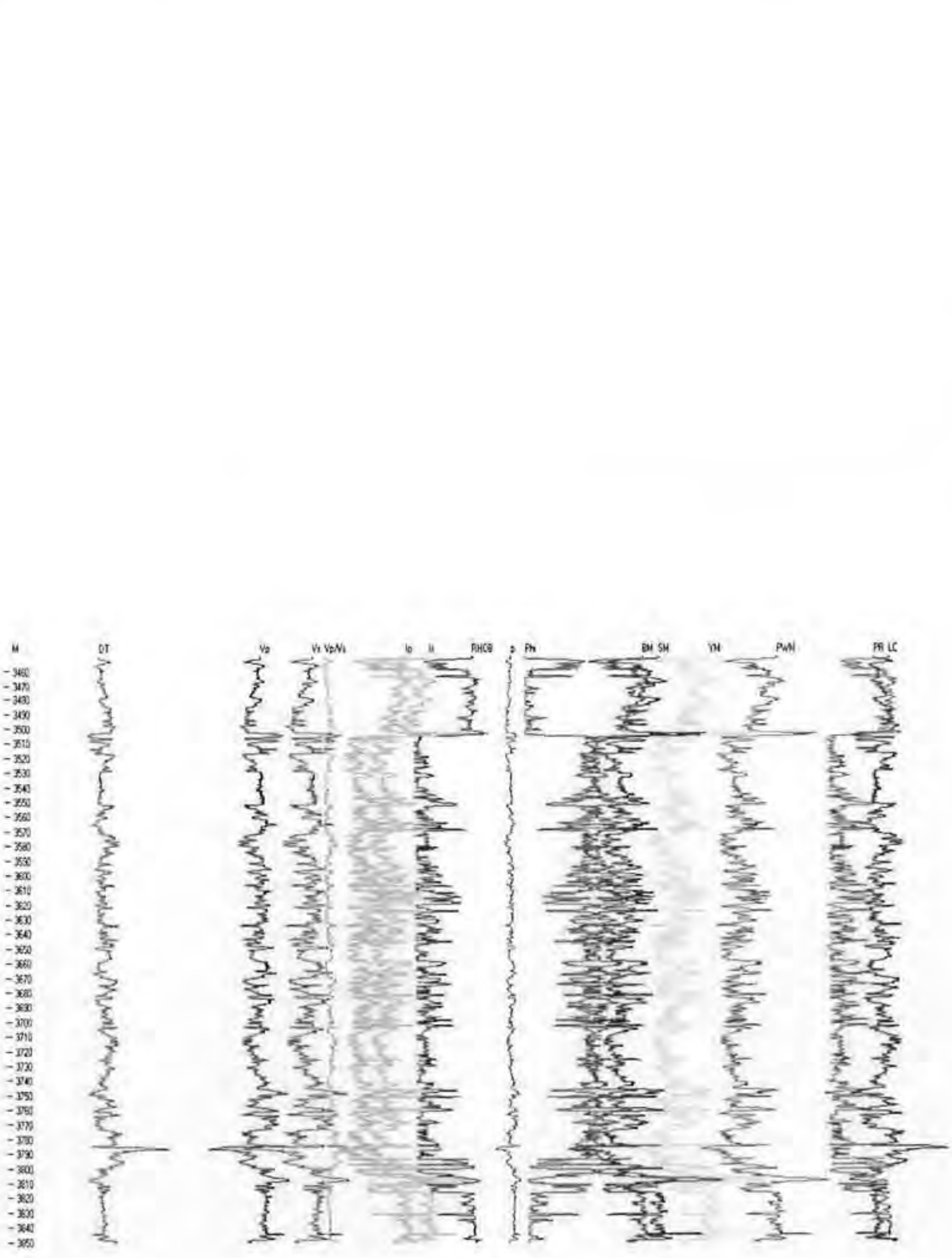

Fig 5.7 Rockphysics and engineering properties for well KAD-01

References

Afzal, J., Kuffner, T., Rehman, A.U., and Ibrahim, M. (2009). Seismic and Well.log Based Sequence Stratigraphy of The Early Cretaceous, Lower Goru "C" Sand of The Sawan Gas Field, Middle Indus Platform, Pakistan, SPE.PAPG Annual Technical Conference, Islamabad, p.p.01.

Ahmad, A. H. M., Khan, A. F., & Wasim, S. M. (2013). Facies analysis and depositional environment of the Jurassic, Jumara Dome sediments, Kachchh, western India. Journal of the Geological Society of India, 82(2), 181.189.

Ahmad, N., and Chaudhry, S. (2002). Kadanwari Gas Field, Pakistan: a disappointment turns into an attractive development opportunity, Petroleum Geoscience, v. 8, p. 307.316.

Ahmad, N., Mateen, J., Shehzad, K., Mehmood, N., and Arif, F. (2012). Shale Gas Potential of Lower Cretaceous Sembar Formation in Middle and Lower Indus Sub.Basin, Pakistan, SPE.PAPG Annual Technical Conference 2011, Islamabad, Pakistan, 2011, Article no 10392.

Ahmed, N., Palekar, A., Subhani, M. A., and Spandini, G. (2007). Porosity Prediction using 2D Seismic Inversion, Kadanwari Gas Field, Pakistan, Journal of Hydrocarbon Research, Vol 17.

Ahmed, R. (1998). Distribution of Infracambrian reservoir on Punjab platform in Central Indus Basin of Pakistan. SPE.PAPG Annual Technical Conference, Pakistan.

Asquith, G.B., Krygowski, D., & Gibson, C. R. (2004). Basic well log analysis. American Association of Petroleum Geologist.

Bakker, P. (2002). Image structure analysis for seismic interpretation, Netherlands Ministry of Economic affairs, within the framework of the Innovation Oriented Research Programme (IOP Beeldverwerking, project number IBV97005)

Coffeen, J.A. (1986). Seismic Exploration Fundamentals: Seismic technique for finding oil, Second Edition PennWell Publishing Company, Tulsa, Oklahoma

Del Monte, A. A., Luoni, F., Baruffini, L., and Ahmad, N. (2009). Evaluating Sand Body Thickness on Seismically Thin Reservoirs: An Integrated Approach Applied to Kadanwari Field, SPE.PAPG Annual Technical Conference, Islamabad.

Guoping Zuo., Lu, F., Fan, G., and Shao, D. (2012). Study of Hydrocarbon Detection Methods in Offshore Deepwater Sediments, Gulf of Guinea, Annual Convention and Exhibition, Long Beach, California, Article no 40999. 87

Ibrahim, S.M. (1977). Stratigraphy of Pakistan, Memoir.12, Published by Geological Survey of Pakistan, Quetta.

Jinghua, Z., Chapman, M., Liu, E., and li, X.Y., (2006). Application of . to detection of dispersion anomalies associated with gas saturation, The leading edge.

Kadri, I.B. (1995). Petroleum Geology of Pakistan Published by Pakistan Petroleum Limited, Karachi, Pakistan.

Kazmi, A.H., and Jan, M.Q., (1997). Geology and Tectonic of Pakistan, Graphic publishers, Karachi, Pakistan.

Kazmi, A.H., and Rana, R.A., 1982. Tectonic Map of Pakistan, 1:1,000,000. Geology Survey of Pakistan Quetta, Pakistan.

Kearey, P., Brooks, M., and Hill, I. (2002). An Introduction to Geophysical Exploration, Blackwell Science Limited, oxford.

Kemal, A. (1991). Geology and New Trends for Petroleum Exploration in Pakistan. PAPG Bulletin, 16. 57.

References

Afzal, J., Kuffner, T., Rehman, A.U., and Ibrahim, M. (2009). Seismic and Well.log Based Sequence Stratigraphy of The Early Cretaceous, Lower Goru "C" Sand of The Sawan Gas Field, Middle Indus Platform, Pakistan, SPE.PAPG Annual Technical Conference, Islamabad, p.p.01.

Ahmad, A. H. M., Khan, A. F., & Wasim, S. M. (2013). Facies analysis and depositional environment of the Jurassic, Jumara Dome sediments, Kachchh, western India. Journal of the Geological Society of India, 82(2), 181.189.

Ahmad, N., and Chaudhry, S. (2002). Kadanwari Gas Field, Pakistan: a disappointment turns into an attractive development opportunity, Petroleum Geoscience, v. 8, p. 307.316.

Ahmad, N., Mateen, J., Shehzad, K., Mehmood, N., and Arif, F. (2012). Shale Gas Potential of Lower Cretaceous Sembar Formation in Middle and Lower Indus Sub.Basin, Pakistan, SPE.PAPG Annual Technical Conference 2011, Islamabad, Pakistan, 2011, Article no 10392.

Ahmed, N., Palekar, A., Subhani, M. A., and Spandini, G. (2007). Porosity Prediction using 2D Seismic Inversion, Kadanwari Gas Field, Pakistan, Journal of Hydrocarbon Research, Vol 17.

Ahmed, R. (1998). Distribution of Infracambrian reservoir on Punjab platform in Central Indus Basin of Pakistan. SPE.PAPG Annual Technical Conference, Pakistan.

Asquith, G.B., Krygowski, D., & Gibson, C. R. (2004). Basic well log analysis. American Association of Petroleum Geologist.

Bakker, P. (2002). Image structure analysis for seismic interpretation, Netherlands Ministry of Economic affairs, within the framework of the Innovation Oriented Research Programme (IOP Beeldverwerking, project number IBV97005)

Coffeen, J.A. (1986). Seismic Exploration Fundamentals: Seismic technique for finding oil, Second Edition PennWell Publishing Company, Tulsa, Oklahoma

Del Monte, A. A., Luoni, F., Baruffini, L., and Ahmad, N. (2009). Evaluating Sand Body Thickness on Seismically Thin Reservoirs: An Integrated Approach Applied to Kadanwari Field, SPE.PAPG Annual Technical Conference, Islamabad.

Guoping Zuo., Lu, F., Fan, G., and Shao, D. (2012). Study of Hydrocarbon Detection Methods in Offshore Deepwater Sediments, Gulf of Guinea, Annual Convention and Exhibition, Long Beach, California, Article no 40999. 87

Ibrahim, S.M. (1977). Stratigraphy of Pakistan, Memoir.12, Published by Geological Survey of Pakistan, Quetta.

Jinghua, Z., Chapman, M., Liu, E., and li, X.Y., (2006). Application of . to detection of dispersion anomalies associated with gas saturation, The leading edge.

Kadri, I.B. (1995). Petroleum Geology of Pakistan Published by Pakistan Petroleum Limited, Karachi, Pakistan.

Kazmi, A.H., and Jan, M.Q., (1997). Geology and Tectonic of Pakistan, Graphic publishers, Karachi, Pakistan.

Kazmi, A.H., and Rana, R.A., 1982. Tectonic Map of Pakistan, 1:1,000,000. Geology Survey of Pakistan Quetta, Pakistan.

Kearey, P., Brooks, M., and Hill, I. (2002). An Introduction to Geophysical Exploration, Blackwell Science Limited, oxford.

Kemal, A. (1991). Geology and New Trends for Petroleum Exploration in Pakistan. PAPG Bulletin, 16. 57.

Khan, K. A., Akhtar, G., Ahmed, Z., Khan, M.A., and Naveed, A., 2006. Wavelets . A Computer Based Training Tool for Seismic Signal Processing, Pakistan Journal of Hydrocarbon Research, Vol.16(1), pp.37.43.

McQuillin, R., Bacon, M., and Barcaly, W. (1984). An introduction to seismic interpretation, Graham & Trotman Limited Sterling House, 66 Wilton Road London SW1V 1DE.

Memon. N., (2010). Oil & Gas Resources and Rights of Provinces: A case study of Sindh Center for Peace & Civil Society.

Rider, D.L (2002). Horizontal well system, U.S. Patent 6,422,318, issued July 23.

Shazia, A., Qureshi, S. N., Mirza, Q., Saleem, U., Ali, S., Haroon, M., and Tahir, M. (2014). Structural and Stratigraphical Interpretation of Seismic Profile along Safed Koh Trend (Eastern Part of Sulaiman Fold Belt), Pakistan, Journal of Engineering Science 2(4): p.p. 77.75.

Subrahmanyam, D., and Rao, P.H. (2008). Seismic Attributes.A Review, 7th International Conference & Exploration on Petroleum Geophysics, Hyderabad, P.398

Taner, M.T. (2001). Seismic attributes, rock solid images, CSEG Recorder, Houston, USA, pp.48.56.

Tittman, J., and Wahl, J. S. (1965). The physical foundations of formation density logging (gammagamma), Geophysics 30, no. 2: 284.294.