2-DIMENSIONAL INTEGRETED SEISMIC INTERPRETATION OF REFLECTION DATA, ATTRIBUTE ANALYSIS, PETROPHYSICAL AND ROCK PHYSICS BASED FACIES ANALYSIS OF DHANDI AREA

By

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بسم الله الرحمن الرحيم

To start with the greatest name of Almighty Allah. Most gracious and merciful, with Him is the knowledge of the Hour, He sends down the rain, and knows that which is in the wombs. No person knows what he will earn tomorrow, and no person knows in what land he will die. The knower of the unseen is Allah these are the keys of the unseen, whose knowledge Allah alone has kept for himself and no one else knows them unless Allah tells him about them.

CERTIFICATE

This dissertation submitted by **SYED IBAD HUSSAIN SHAH** S/O **SYED ASHIQ HUSSAIN SHAH** is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the partial requirement for the award of BS degree in Geophysics.

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DEDICATION

I dedicate this work to my late father, my beloved mother,

my brother and my sisters

who always believed in my

Capabilities.

ACKNOWLEDGEMENT

In the name of Allah, the most Beneficent, the most Merciful. All praises to Almighty Allah, the creator of universe. I bear witness that there is no God but Allah and Holy Prophet Hazrat Muhammad (P.B.U.H) is the last messenger of Allah, whose life is a perfect model for the whole mankind till the Day of Judgment. Allah blessed me with knowledge related to Earth. Without the blessing of Allah, I could not be able to complete my work as well as to be at such a place.

I am indebted to my honorable supervisor **Assistant Prof. Dr. Ma'am Shazia** for giving me an initiative to this study. I express my sincerest appreciation to my senior **Hammad** for his guidance in the preparation of this thesis. He helped me in all aspects of work and technical support which was very valuable for my work.

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(November 2020)

ABSTRACT

The main purpose of the study is to evaluate hydrocarbon potential of Dhandi area that lies in Punjab near Rahim Yar Khan, Central Indus basin for delineation of potential leads for future prospects. This is done by the analysis of 2-D seismic and wire line log data, which have been provided by Landmark, Pakistan with the permission of Directorate General of Petroleum Concessions, Islamabad, Pakistan. This data set comprises of 6 seismic lines and a complete suite of wire line logs of 1 well SABZAL-01.

The seismic data is utilized for the identification of structural traps, marking of the different lithological horizons and naming them using the well tops data in the area. There are no faults demarcated on seismic lines as the area of study is very stable and doesn’t contain faults. On the seismic section, three prominent reflectors are marked namely Ghazij Formation, Sui Main Limestone and Upper Ranikot Formation.

Two-way time contour maps of the marked lithologies have been prepared to determine the spatial variation of time. Root mean square velocity models are generated to observe the variation of velocities with time in the subsurface. Depth contour maps are also generated for these marked lithologies.

Analysis of wire line logs includes the calculation of different reservoir characteristics like Shale Volume (Vsh), Porosity (Phi), True Resistivity of Formation (Rt), Density (RHOB), Water Saturation (Sw), Hydrocarbon Saturation (Shc) etc., using different available Logs such as Gamma Ray, LLD, LLS, Litho Density Log, and Spontaneous Potential Log. These measured Parameters, then, used further for reservoir potential evaluation. Sui Main Limestone Formation is the primary reservoir in this area. A zone of 11 meters is marked in this region. The well log data is also used for Rock Physics analysis to compute elastic logs that are cross plotted for facies modeling.

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Chapter 1

Introduction

1.1 Introduction to Hydrocarbon Exploration

Global hydrocarbon industry plays vital and irreplaceable role in development and economy of a country especially in developing countries like Pakistan, and act as a major pillar in the economy and well-being of a country. As the energy demand increases exploration industry determine to discover and develop new hydrocarbon reserves and increase production from existing reserves through the application of the best available technologies. The energy used usually comes from three major sources of hydrocarbons: Coal, Oil and gas.

Geophysicists have been trying for hydrocarbon exploration since a long time ago and developed many techniques in this regard. Seismic method is direct result evaluating and accurate geophysical method used for litho-structural analysis especially; Seismic Reflection Method has greater precision than refraction method for deep hydrocarbon exploration in petroleum geology. Petroleum geology refers to the specific set of geological disciplines that are applied to the search for hydrocarbons.

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

Pakistan has a high potential of hydrocarbons and consists of three major sedimentary basins (covering more than $2/3^{rd}$ of its area) namely, Indus Basin in the east, Baluchistan Basin in the west and Pishin basin in the northwest. Indus and Baluchistan basin are separated by Ornach Bela transform fault zone and the Pishin basin lies between Indus and Chamman transform fault. A variety of sub-basins, fold belts and monoclines with variable structural styles resulting from diverse geodynamic conditions have been identified in Baluchistan Basin and Indus Basin (Kadri, 1995). Indus is the only producing basin of Pakistan where 83 oil and gas fields have been discovered. The Indus Basin covers an area of about 533,500 Km^2 and contains more than 15,000m thick sediments ranging in age from the Precambrian to recent. This giant basin has been divided into three compartments based on structural highs namely, The Jacobabad Khairpur

High, Mari Khandkot High (Sukkur Rift) and the Sargodha High (Kazmi & Jan, 1997). Indus basin is divided into Upper Indus Basin, Middle Indus or Central Indus Basin and Lower Indus or Southern Indus Basin.

1.1.1 Seismic Acquisition

Seismic acquisition is the process of collecting seismic data. This usually involves injecting energy into the ground in the form of elastic waves, using vibrator trucks (pictured) or buried dynamite charges on land, or air gun arrays at sea. The waves propagate into the Earth and reflect, refract or diffract from subsurface heterogeneities. Energy that returns to the surface is recorded at sensors either on the land or seabed surface or in shallow 'streamers' full of pressure sensors towed behind ships in the oceanic water column. It is this data that contains information about the subsurface (Robinson and Coruh, 1988). Data can be acquired in different dimensions depending upon the objective of the survey and economy of the drilling company such as 2D and 3D.

1.1.2 Processing

After the raw data has been collected from field, the data has been passed through the whole processing sequence that includes different data processing techniques which are used to suppress the noise and enhance the quality of the data for better interpretation. The raw seismic data is processed to enhance the signal to noise ratio and get the final seismic sections. The generalized processing sequence flow chart (Khan, 2009) is given in Fig 1.1.

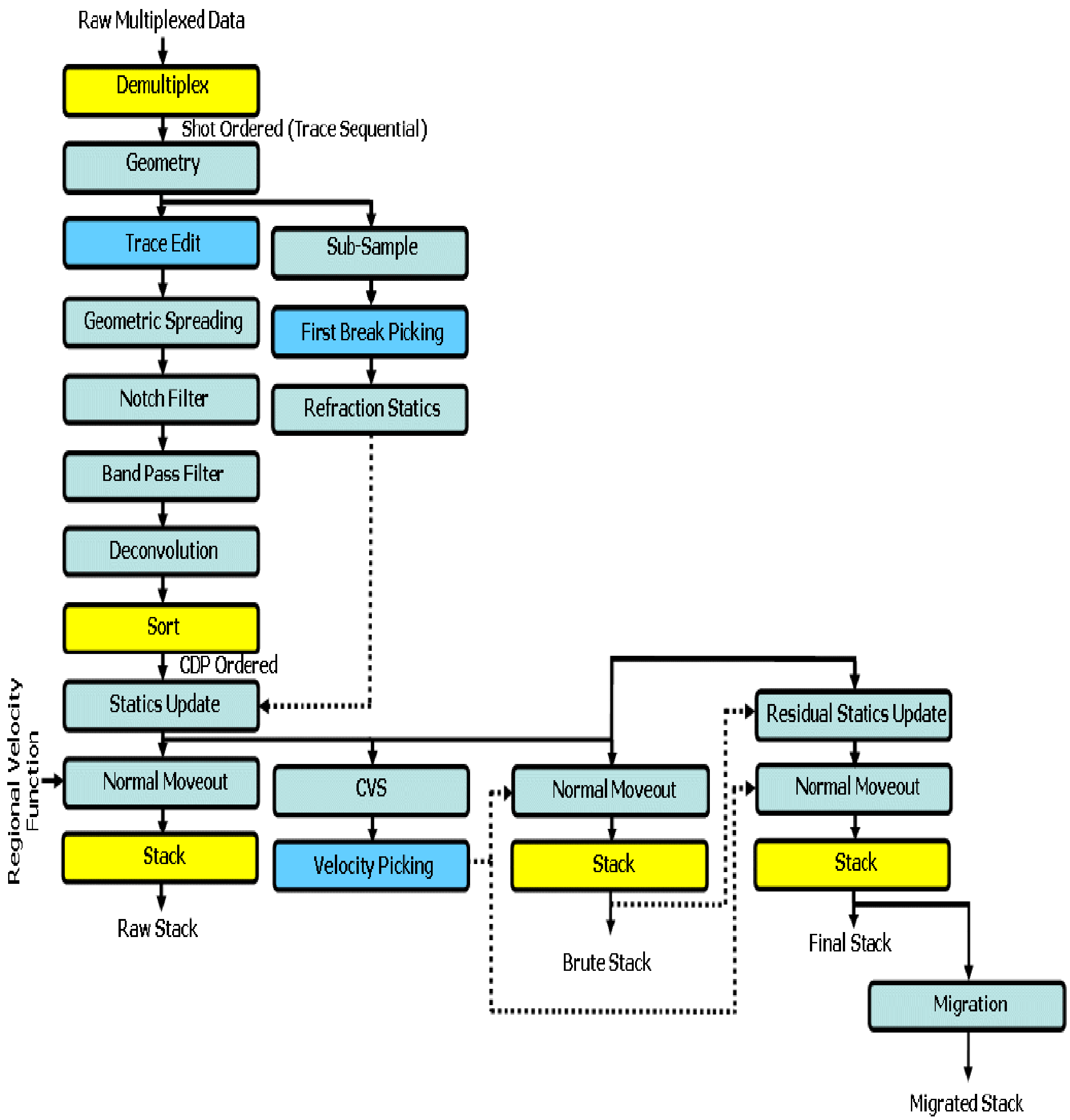


Fig 1.1: Generalized seismic processing sequence (Khan, 2009)

1.2 Objectives

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

- 2-D Structural interpretation to find out the structural traps and horizons of the formation.
- Construction of time contour map and depth contour map.
- Attribute analysis to improve understanding and mapping reservoir and to resolve structural and stratigraphic complexities.
- The hydrocarbon potential in the well; Sabzal-01.
- Petrophysical analysis for the identification of the hydrocarbon bearing zones.
- Rock Physics analysis for computation of elastic properties and facies modeling.

1.3 Introduction to Study Area

Dhandi is located in the Punjab region at the border between Punjab and Sindh. Geologically, this block is present in Central Indus Basin. Central Indus basin extended approximately between 27.5° and 32.5° latitude and 67°E longitude to the eastern boundary of Pakistan. Its tectonics, stratigraphy and hydrocarbon potential are described based on data obtained from the study of outcrops and well drilled in the area; of about 35 exploratory wells drilled. The geographic coordinate of the area are:

- **Latitude of the area: 28˚ to 30˚N.**
- **Longitude of the area: 70˚ to 72˚E.**

The latitudes and longitudes of the Sabzal-01 well are 28° 4' 12.37" N & 69° 23' 32.49" E respectively.

1.4 Data used

The data used for current research consists of 6 seismic lines and 1 well. There are 2 strike lines and 4 dip lines. The orientation of seismic lines with the locations of wells is shown in the base map Fig 1.2. The detail of these seismic lines is given in Table 1.1. Bold lines are assigned to me for the completion of this research work.

Table1.1: Orientation, nature and names of seismic lines along with wells used.

Sr. No.	Line name	Nature of line	Orientation	Wells
01.	**G846-DAN-201**	**Dip**	**SW-NE**	
02.	G846-DAN-205	Strike	NW-SE	
03.	**G846-DAN-211**	**Dip**	**SW-NE**	**SABZAL-01**
04.	**G846-DAN-245**	**Strike**	**NW-SE**	
05.	G846-DAN-246	Dip	SW-NE	
06.	G846-DAN-248	Dip	SW-NE	

1.5 Information of SABZAL-01 Well:

The well is oil and gas and has been drilled up to the Sembar formation. Information of the well data has been provided to us for dissertation. Information of the well is listed in table 1.2.

Table 1.2: Information of SABZAL-01 Well

Well Name	**SABZAL-01**
Longitude	069.960875
Latitude	028.091844
K.B. Elevation	78.8200ft.
Total Depth	3631.0
Type	Abandoned
Company	O.G.D.C.L
Field	Dhandi

Table1.3: Formation Tops of SABZAL-01 Well

FORMATION TOPS	DEPTH(m)
SIWALIK	0
DRAZINDA	693
PIRKOH	737
SIRKI	827
HABIB RAHI	894
GHAZIJ	1003
SUI MAIN LIMESTONE	1327
UPPER RANIKOT	1613
LOWER RANIKOT	1680
PAB	1723
PARH	2045
UPPER GORU	2548
LOWER GORU	2955
SEMBAR	3385

1.6 Data Formats

A format is a pre-established layout for data. A computer program accepts data as input in a certain format, processes it, and provides it as output in the same or another format. All data is stored in some format with the expectation that it will be processed by a program that knows how to handle that format. The data set used extensively in preparing this dissertation contained data regarding.

- SEG-Y
- LAS
- Navigation
- Velocity Data Function

The data is then loaded in the software for further processing.

1.7 Base Map of the Study Area

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.

Following 2-D reflection seismic lines are used to construct the Base map of 2-D seismic survey for given study area as shown in Figure 1.3.

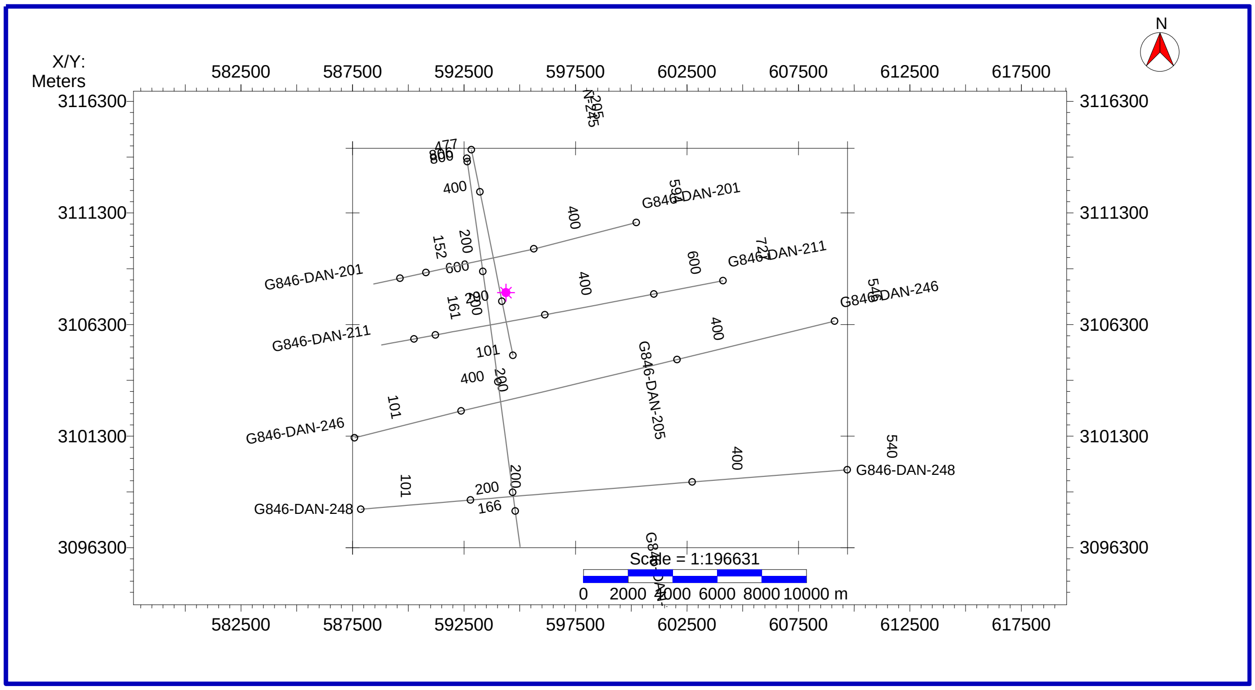


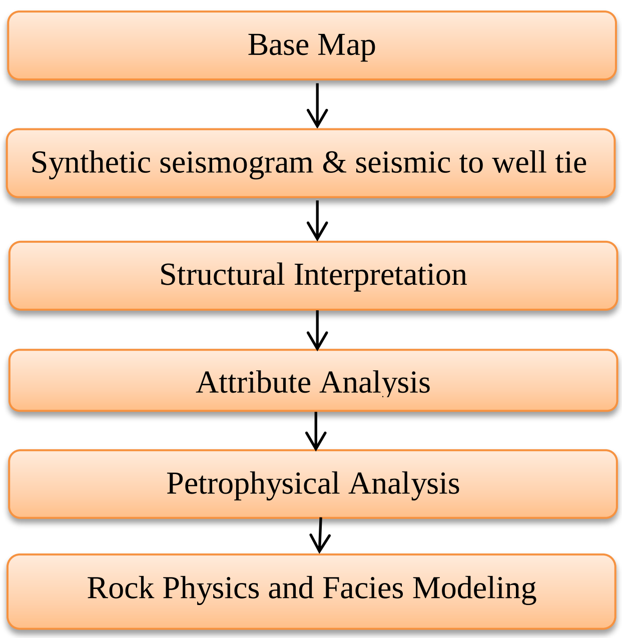
Figure 1.3: Base map of the study area.

1.8 Exploration History of Sabzal

The petroleum exploration was started in Central Indus Basin in 1983. Later, 420 lines of 2D seismic survey were carried out in 1990, 1992 and 1998 by Oil and Gas development Company Limited (OGDCL). Limestone of Eocene age is the main gas producing reservoir in Sabzal area. Twenty-four wells have been drilled in the surrounding of that area until today for the extensive development of the field. Most of the gas wells have been drilled in Sui Main limestone, as it is the main producer (Ali et al, 2005).

1.9 Methodology

Seismic reflection data of the Central Indus Basin of Dhandi area is given in order to interpret the subsurface structures and other properties. In this practice, software **Kingdom 8.8** has been used for structural interpretation. For this purpose seismic lines data was uploaded on kingdom, synthetic seismogram was generated, from well. After horizons were marked on seismic section, and time and depth contours were made. Attribute analysis was performed to confirm interpretation. Petrophysical analysis has been done by using software **Geographix Discovery** for the identification of hydrocarbon bearing zones. Rock physics and Facies modeling were performed using **Wavelet** software. The brief methodology flow work is shown below.



Workflow of Methodology adopted

1.10 Software Tools and Applications

The following software tools have been used for interpretation, analysis and workflows carried out in this thesis.

1.10.1 SMT Kingdom 8.8

- Synthetic Seismogram
- Structural Interpretation
- Stratigraphic Interpretation
- Well Correlation

1.10.2 Geographix Discovery

- Petrophysical Analysis

1.10.3 Wavelets

- Facies Analysis
- Rock Physics

Chapter 2

Geology and Stratigraphy of the Area

2.1 Geology and Tectonics of Pakistan

Pakistan is located at one of the most fascinating part of the globe. A collision mountain belt comprising the Himalaya, Karakoram and Hindukush Ranges forms its northern part. Geographically it is located in structurally complex area. Pakistan covers an area of about 803,940, out of which the land area is about 796,096 square kilometers.

Pakistan lies on a recognized high seismic belt bordering various active plates, characterized by its seismic instability. It has been the source of a number of destructive earthquakes. The collision of Indian plate with Eurasian plate which started 30-40 million years ago has produced a remarkable verity of active folds and thrust wedges with in Pakistan. These zones extend from the Kashmir fold and thrust belt in NE Pakistan, southwest through the Salt range- Potwar plateau fold belt, the Suleiman fold belt and the Makran Accretionary wedge.

2.2 Tectonic Plates of Pakistan

Pakistan overlaps with Indian and Eurasian tectonic plates. Sindh and Punjab lie on Indian Plate, Balochistan and KPK lie on Eurasian Plate. There is a three point junction of Indian, Eurasian and Arabian plate near Balochistan. (Fig 2.1).

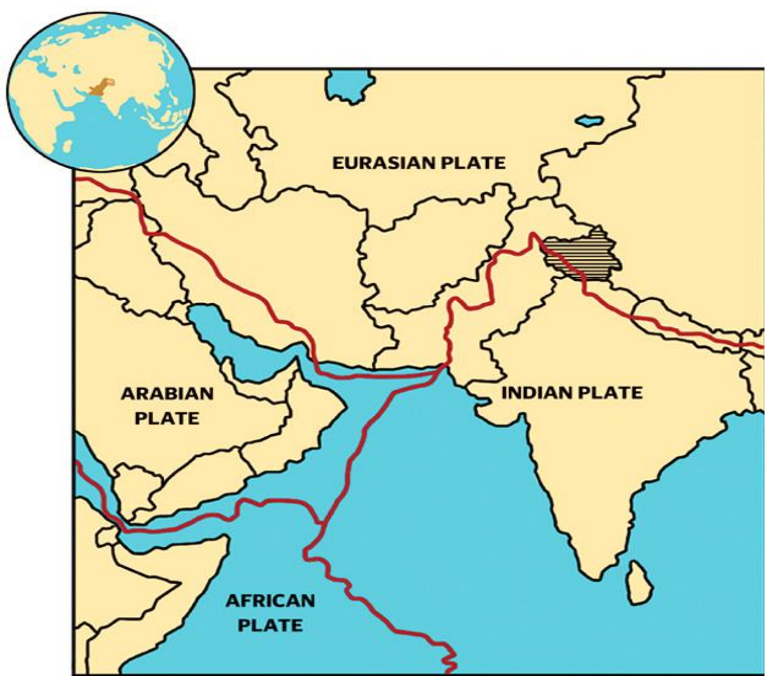


Fig 2.1 Regional Plates distribution of Pakistan

2.3 Basins of Pakistan

Indus basin is divided into number of regime i.e. compression regime at foreland margins, basement uplift in the Central Indus Basin and extensional regime in the Lower Indus Basin (Kadri, 1995).

Indus Basin is classified into following basins:

- Upper Indus Basin: Kohat sub-Basin and Potwar sub-basin
- Lower Indus Basin: Central Indus Basin and Southern Indus Basin

These Basins were welded together during Cretaceous/Paleocene along Ornach Nal/Chaman Strike slip faults. There is yet another newly identified smaller basin, termed as Kakar-Khorasan Basin (Ahmed, 1991), which carries its own geological history for most of its development. This basin came into existence due to the interaction of Indian and Eurasian Plates and is classified as Median Basin. (Kadri, 1995)

2.3.1 Balochistan Basin

The Balochistan Basin comprises the Makran Accretionary wedge and the Makran offshore trench. This is the least explored region of Pakistan. Very limited seismic survey has been done and only six wells have been drilled in this vast Basin. Despite several gas reserves shows along the Makran Coast but no commercial hydrocarbons have been found in the basin so far. (Kazmi and Jan, 1997). This basin contains Dalbandin and Kharan trough.

2.3.2 Indus Basin

This is the largest and more thoroughly studied basin of Pakistan. The Indus Basin covers an area of about 533,500 km square and contains more than 15,000 m thick sediments ranging in age from the Precambrian to Recent.

2.4 Subdivision of Indus Basin

Indus Basin is classified into following basins:

- Upper Indus Basin: Kohat sub-Basin and Potwar sub-basin
- Lower Indus Basin: Central Indus Basin and Southern Indus Basin

2.4.1 Upper Indus Basin

This basin is located in the northern Pakistan and is separated from the Lower Indus basin by Sargodha High. The northern and eastern boundaries coincide with the Main Boundary Thrust (MBT) the eastern most of the major Himalayan thrusts. The MBT runs through the Margalla Hills, Kala Chitta and Kohat Ranges western boundary of the basin is marked by an uplift of Pre-Eocene sediments and eastward directed thrusting to the west of Bannu. The basin is further subdivided into Potwar, to the east and Kohat to the west, by river Indus. (Kadri, 1995)

2.4.2 Lower Indus Basin

The southernmost part of the Indus basin is known as Lower Indus basin, Badin Block or adjacent areas are also part of this basin. The approximate limits are 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; western part 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.

2.4.3 Central Indus Basin

Central Indus Platform Basin (CIPB) rests on the continental margin of Indo-Pakistani Plate. CIPB is bounded in south by Jaisalmer-Mari-Kandhkot High, while Sulaiman Range defines the western boundary. The Sargodha Ridge (Kirana Hills) marks the north-eastern boundary. The Punjab Platform dips westward into the Sulaiman Foredeep. The structural style of the Central Indus Platform Basin is obscured at surface by thick alluvial cover. Seismic and drilling studies reveal subsurface structural features related mainly to phases of Precambrian to Cambrian and Mesozoic extension but also to the effect of the peripheral collisional orogenies and consequent foreland basin deposition. The main hydrocarbon fairways are Paleozoic-Mesozoic tilted fault blocks, tertiary reefal banks, and drape compressional anticlines (S. M. Shuaib 1993). Central Indus Basin is bounded by Sukkur Rift in the south, Sargodha High in the north and subsidiary zone of Indian plate in the west. Sargodha High in the north and subsidiary zone of Indian plate in the west. Sargodha Highs and Pizo uplift separate this basin from Upper Indus Basin in the north (AH Kazmi & Qasim Jan 1997). In Sindh province the shales of Ranikot, Sembar, Mughalkot, Ghazij and Sirki formations act as a source rock. In this area Sui main limestone and Sui upper limestone are acting as a good reservoir. Habib Rahi Formation is considered as secondary producer (Akhtar, 2005).

Geological and geophysical studies in the area provide the extensive information about the reservoir formations. For this study, Sabzal-01 is selected to get real insight to the hydrocarbon potential of Central Indus Basin. (Kazmi & Jan 1997).

2.5 Importance of Geology of an Area

Information about the geology of an area is very important in seismic survey. As the same velocity effect can be produced from the formations of different lithology and vice versa. The position and penetration of local fault and the presence of the unconformities between the rocks is very necessary for interpretation point of view. So as if we don't know geological information in area we don't recognize the different reflections appearing in the seismic section. A geological history can be compiled by considering basin forming tectonics and depositional sequence (Kingston et al., 1983).

2.6 General Geology of the Area

The area generally has flat and uniform topography and covered by alluvial plains of Central Indus Basin. The area is covered with vegetation. The area can be accessed by M-5 highway that connects the Ghotki district which then leads to the Rahim Yar Khan then to Sabzal field area. The formation of the Himalayas in the Eocene tells us about the regional tectonic setting of Pakistan. The Himalayas extend from Burma all the way to the northern part of Nepal and India into Pakistan. After separating from Gondwanaland, Indian plate started moving towards north and subsequently collided with Eurasia. In between Indian plate (South) and Eurasian plate (north) there was Tethys Ocean that gradually consumed due to continental drift.

The Sabzal area occupies some part of Sulaiman Range which resulted as the collision between Indian plate and Afghan block. It is the widest (>300km) Foreland fold-thrust belt of the Himalayan mountain system and forms connection between the Himalayan plate boundary and the Makran Accretionary prism (Raza, 1992). The Ophiolite and flysch belt bounds the Sulaiman Range from the west (Kemal et al, 1991).

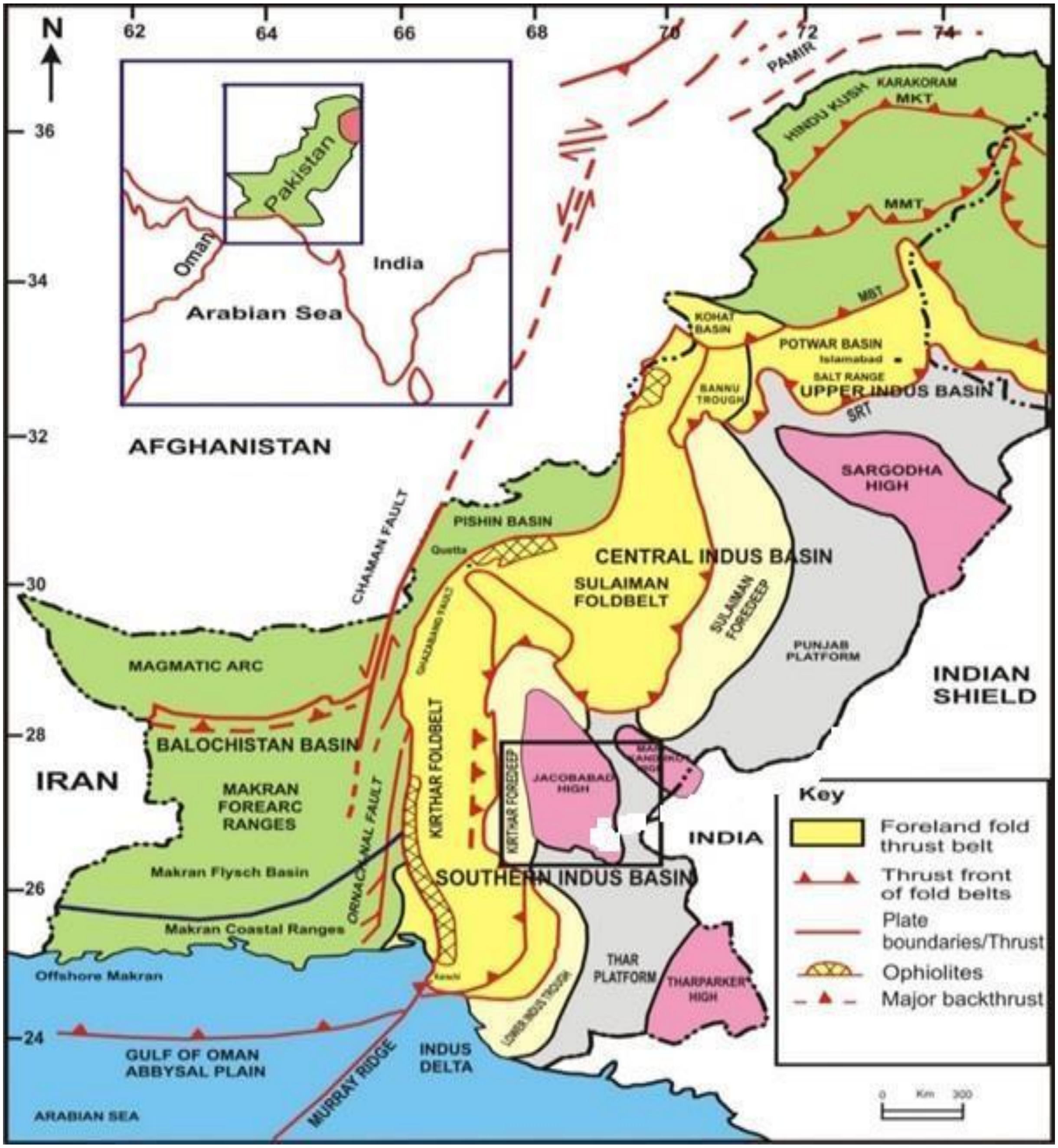


Fig 2.2 Tectonic and sedimentary basin map of Pakistan modified from Aziz and Khan 2003

2.6.1 Sabzal Field:

Sabzal field lies in the field around 70km away from Rahim Yar Khan which separates the Sulaiman sub- basin and Kirthar sub-basin from north and the South respectively. It is located on the western edge on Indian plate, west dipping zone flanking the Indian Shield. There are three different reservoirs in the area which are Sui Upper Limestone (SUL), Sui Main Limestone (SML) and Habib Rahi limestone of Lower to Middle Eocene. Ghazij Shale overlies the Sui Upper Limestone and underlies the Habib Rahi formation and strata of quartz bearing limestone entrapped by the overlying Sirki shale (Qadri, 1995).

2.6.2 Tectonic Setting:

Sabzal structure is situated on Mari-Khandkot high developed in southern part of the Central Indus basin of Pakistan which is located on western edge of Indian plate, west dipping zone flanking the Indian Shield. During the rifting phases, the deposition of siliciclastic sediments results from uplifted Indian shield took place over Jurassic Chiltan Limestone, while carbonates of Parh and fort Munro were deposited during the transgression. Normal block faulting and regional transform faults were generated during the phases of rifting. The sedimentation was terminated as a result of the contienental collision between Indian and Eurasian plates. Significant erosion resulted in an unconformity and deposition of thick molasses (Siwalik group) the tertiary sediments form a dome shape structure over the faulted block of Cretaceous sediments in Sabzal area (Kemal, 1992; Zaigham and Mallick, 2002)

2.7 Petroleum Play of the Study Area

The Petroleum System consists of a mature source rock, migration pathway, reservoir rock, trap and seal appropriate relative timing of formation of these elements and the processes of generation. Lower Indus basin is main hydrocarbons producing basin of the Pakistan 37% hydrocarbons of the Pakistan are extract from the lower Indus basin (Kadri 1995).

2.7.1 Source Rock

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

Source Rock in the study area is Upper Ranikot Formation.

2.7.2 Reservoir Rock

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

Sui Main Limestone acts as a reservoir in this area.

2.7.3 Seal Rock

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

Ghazij Shale is acting as a cap rock for Sui Main Limestone.

2.8 Stratigraphy of the Central Indus Basin

Stratigraphy of Central Indus Basin includes formations from Triassic to recent. The lithological Units encountered in the well are given in table 2.1. The oldest stratigraphic unit drilled in Sabzal-01 is Sember Formation. Regional unconformities are present at the base of Tertiary Levels. Generalized stratigraphic column of the Central Indus Basin is shown in figure 2.3.

Table 2.1: Stratigraphy of Dhandi

Age	**Rock unit (Formation)**
Pliocene-Pleistocene	• Siwalik Formation
Eocene	• Drazinda Formation • Pirkoh Formation • Sirki Formation • Habib Rahi Formation • Ghazij Formation (Main Seal)
Paleocene	• Sui Main Limestone (Main Reservoir) • Upper Ranikot Formation (Main Source) • Lower Ranikot Formation
Cretaceous	• Pab Formation • Parh Limestone • Upper Goru Formation • Lower Goru Formation • Sembar Formation

2.8.1 Siwalik Group:

The lower contact with Drazinda Member is unconformable. Environment of deposition is fresh water and the age is Early Pleistocene.Having different Sandstone beds and is Source rock for Uranium deposits and is equivalent to Kohat-Potowar Basin's Siwalik Group.

2.8.2 Drazinda Member:

Lower contact with Pirkoh Limestone is unconformable. Environment of deposition is shallow marine shelf deposit and age is middle Eocene.

2.8.3 Pirkoh Limestone Member:

The lower contact with Sirki is conformable. Environment of deposition is shallow marine inner to outer shelf and the age is Middle Eocene.

2.8.4 Sirki Formation:

The lower contact with Habib Rahi Member is conformable. Environment of deposition is shallow marine inner to outer shelf and its age is Middle Eocene.

2.8.5 Habib Rahi Limestone Member:

The lower contact with Ghazij Formation is conformable. Environment of deposition is shallow marine inner to outer shelf and age is Middle Eocene.

2.8.6 Ghazij Formation

Vertebrate's fossils are found in Ghazij formation. Dinosaurs and Whale Fossil in Barkhan in Eastern Baluchistan. Age of deposition is early Eocene. Poorly sorted pebbles Conglomerates with some Sandstone, Limestone and Marl. Gastropods and Foraminifera's are fossils in this formation.

2.8.7 Sui Main Limestone

Environment of deposition is shallow marine inner shelf in term of lithology Sui Main Limestone comprises of limestone with subordinate beds of shale. Its age is Paleocene.

2.8.8 Ranikot Group

Blandford (1876) was the first to use the name "Ranikot Group", named after Ranikot Fortress, in the northern part of the Laki Range, Sindh. He used the name to designate strata lying between his "volcanic" and "Kirthar or lower Nummulitic Group". Blandford also called Ranikot Group as "Infra-Nummulitic". In the present report, however, Blandford's original description of the group is considered to represent strata that were identified by him in 1879 as "Cardita beaumonti beds", "trap group" and "Ranikot group". Ranikot group was subdivided as "Lower Ranikot (Sandstone)" and "Upper Ranikot (limestone)" by (Shah, 2009) It comprises the following formations:

Ranikot Group

- Khadro Formation (Cardita beaumonti beds)
- Lakhra Formation (upper Ranikot limestone)
- Bara Formation (Lower Ranikot sandstone)

2.8.9 Pab Formation

The Pab is light grey to light tan to brown, quartzose, fine to coarse grained, hard to soft sandstone. It is occasionally conglomeratic and generally cross bedded. Thin intercalations of dark grey shales are common and in the south it locally contains inter-beds of argillaceous micritic limestone.The formation bears good reservoir characteristics and has been established to contain gas in Dhodhak gas field.

2.8.10 Parh Limestone

The Parh is the most uniform Post-Jurassic formation in the Indus Basin. It represents a light grey, white, thin bedded argillaceous limestone which typically exhibits lithographic to porcellaneous character and can be easily recognized in the field. The fauna is dominated by Globotruncana, Globogerina and Guembelina. No macrofossils are known. The Parh consists mainly of limestone. Minor variations in color and argillaceous content exist but do not appear to be of regional significance. It has conformable and gradational contact with Goru formation.

2.8.11 Goru Formation

The sequence is followed by late cretaceous Goru formation; lower Goru and Upper Goru at the depth of 2955m and 2548m respectively. The Goru formation is dominantly shale or mudstone, frequently calcareous. On the basis of its lithological content it has been divided into Lower Goru. The name Lower Goru has been applied to the lower sandy member, whereas within the same area, the upper shale unit is termed as Upper Goru. The petroleum potential of Lowe Goru Sand is very good as it contains the entire hydrocarbon in Sindh Monocline.

2.8.12 Sember Formation

The oldest stratigraphic unit drilled in Sabzal-01 is Sembar formation at depth of 3385m. Sembar Formation is the most likely source of oil and gas for most of the producing fields in the Indus Basin. While the Sembar has been identified as the primary source rock for much of the Greater Indus Basin, there are other known and potential source rocks.

Of all the possible source rocks in the Indus Basin, however, the Sembar is the most likely source for the largest portion of the produced oil and gas in the Indus foreland.

The Sembar is composed mainly of clastic rocks, primarily shales followed by sandstones and siltstone with minor limestones. Characteristically the formation in outcrops consists of blacky silty shale with nodular black siltstone and limestone beds. The formation within this basin approaches more than 1,000m in thickness. Sember formation is believed to be the source of hydrocarbon in the Badin Platform fields and huge gas accumulation in Sulaiman Province.

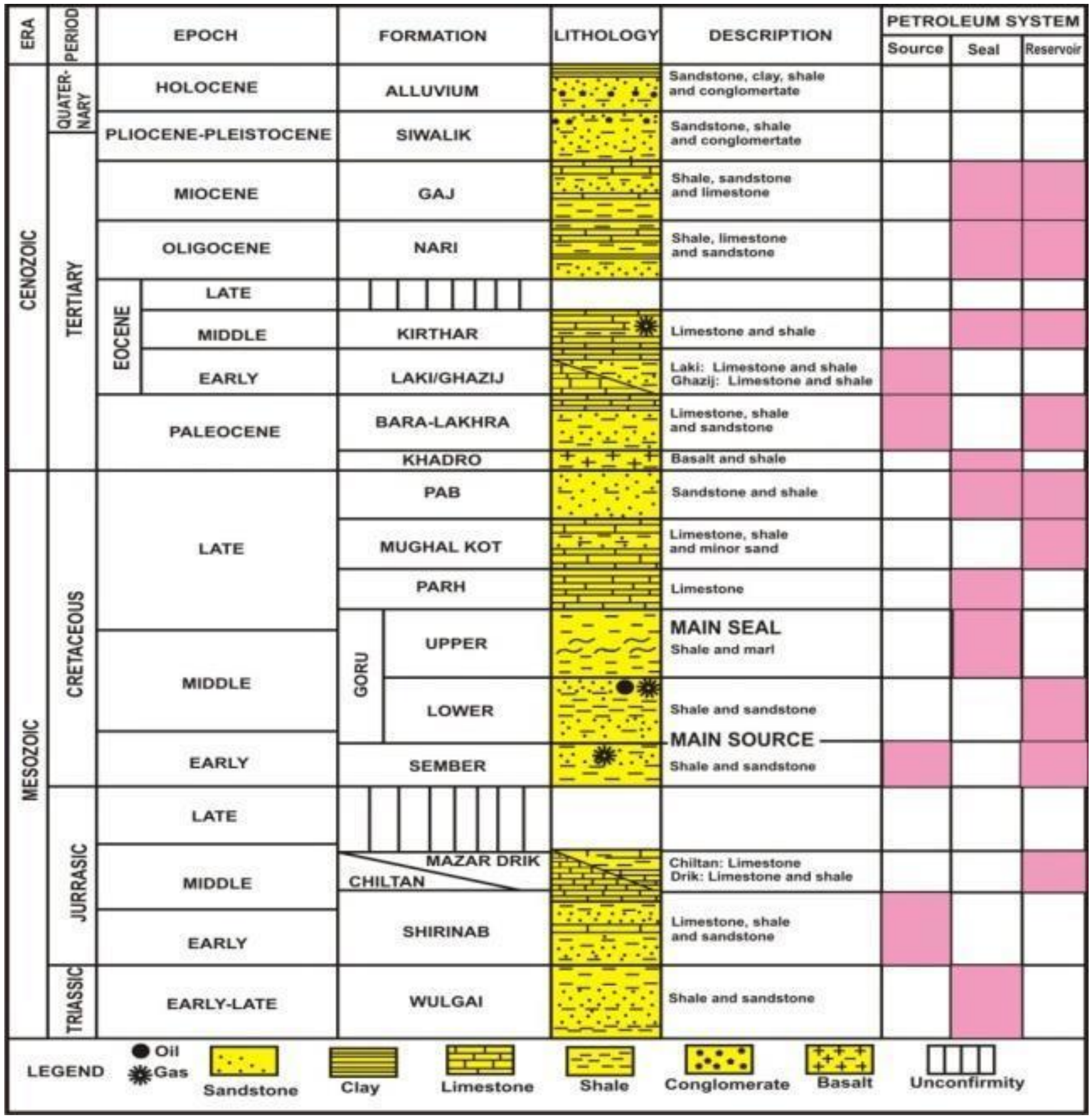


Figure 2.3: Generalized Stratigraphic Column of the Central Indus Basin.

Chapter 3

Seismic Interpretation

3.1 Seismic Interpretation

Interpretation is a technique or tool by which an attempt is made to transform the whole seismic information into structural or stratigraphic model of the earth. Since the seismic section is the representative of the geological model of the earth, by interpretation, one tries to locate the zone of final anomaly (Sheriff, 1999).

Interpretation is the transformation of the seismic reflection data in to a structural picture by the application of correction, migration and time depth conversion (Dobrin and Savit, 1988). The computer based working (Processing & Interpretation) is more accurate, precise, efficient and satisfactory which provides more time for further analysis of data. This whole work is carried out using a combination of computer software products, which include all office Software suit and SMT Kingdom suit.

3.2 Types of Seismic Interpretation

There are two types of seismic interpretation

- Stratigraphical Interpretation
- Structural Interpretation

3.2.1 Stratigraphical Interpretation

Stratigraphy analysis involves the delineating of 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. Hydrocarbon accumulation is indicated by the amplitude, velocity, frequency or the change in wave shape. Variation of the amplitude with the offset is also an important hydrocarbon indicator. Unconformities are marked by drainage pattern that help to develop the depositional environment. Reef, lenses, unconformity are example of stratigraphy traps. (Sheriff, 1999).

3.2.2 Structural Interpretation

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, 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. For large scale interpretation, we have to use the grids of seismic lines.

3.3 Interpretation Workflow

The Interpretation was carried out 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 Figure 3.1, which provides the complete picture depicting how the dissertation has been carried out by loading navigation data of seismic lines and SEG-Y in HIS kingdom Software, base map was generated. Faults and Horizons of interest were then marked manually. Identification of marked horizons was done with help of synthetic seismogram, generated with help of welzl data and faults were marked by keen observation on seismic section and knowing geologic history of study area.

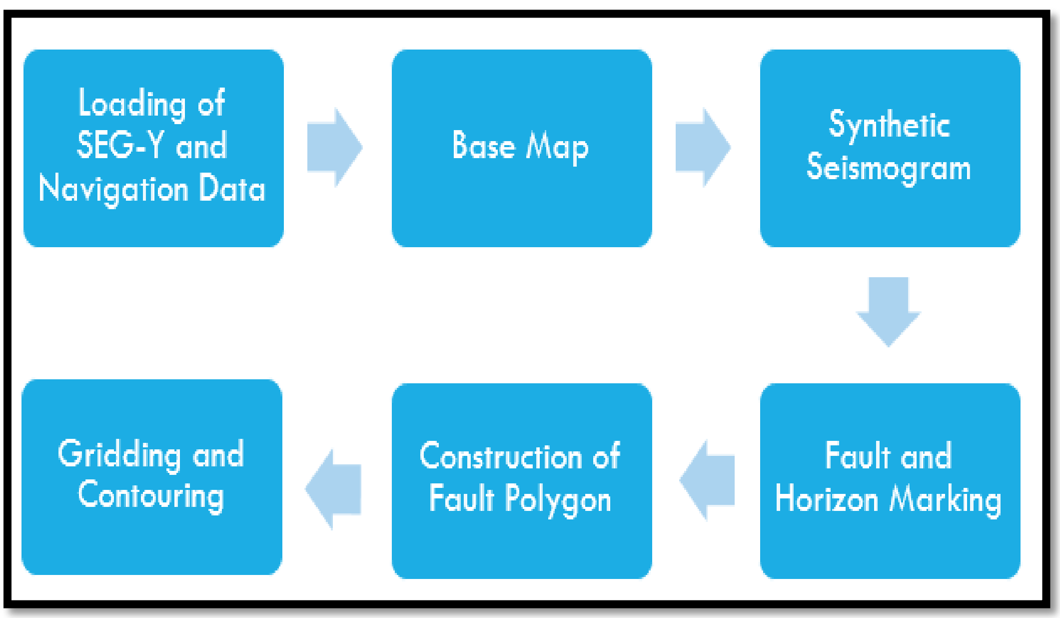


Figure 3.1: Workflow for seismic data interpretation.

3.4 Generation of Synthetic Seismogram

Synthetic seismograms provide a crucial link between lithological variations within a drill hole and reflectors on seismic profiles crossing the site. In essence, they provide a ground truth for the interpretation of seismic data. Synthetic seismograms are useful tools for linking drill hole geology to seismic sections, because they can provide a direct link between observed lithology's and seismic reflection patterns (Handwerger et al., 2004).

SABZAL-01 is the only well in our available data that having the DT and ROHB log to generate the synthetic seismogram. With the help of SABZAL-01 well, I construct the synthetic seismogram (Figure 3.2) in order to mark the horizons.

Hence on the basis of synthetic seismogram, all the formation tops of the SABZAL-01 are. The display of the synthetic synthetic seismogram is shown in figure 3.2.

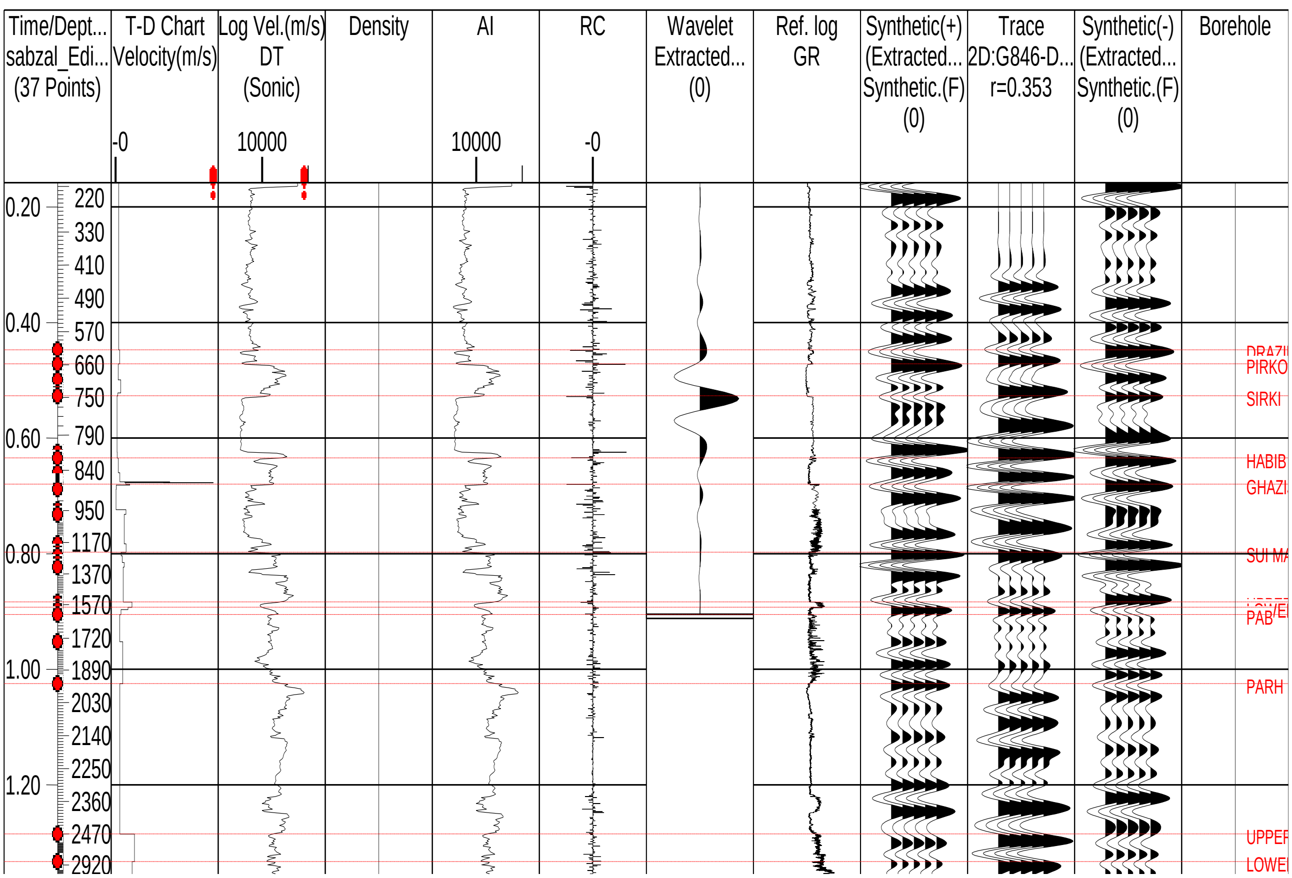


Figure3.1: Synthetic Seismogram of well SABZAL-01.

3.5 Fault Marking

Conventional seismic interpretations are the arts that require skills and thorough experience in Geology and Geophysics to be precise (Mc. Quillin et al., 1984). Fault marking on real time domain seismic section is quite a hard work to do without knowing tectonic history of Area (Sroor, 2010). Faults are marked on the basis of breaks in the continuity of reflection. This Discontinuity of the reflector shows that the data is disturbed here due to the passing of the faults. The SABZAL-01 is lying in Central Indus Basin where the area is very stable and only basin uplift has occurred during the collision of Indian and Eurasian plate hence we don't find any major faults in this area.

3.6 Picking of Horizons

Interpreting seismic sections, marking horizons, producing time and depth maps is a task which depends on interpreter's ability to pick and follow reflecting horizons (reflectors) across the area of study (Mc. Quillin et al., 1984). Reflectors usually correspond to horizon marking the boundary between rocks of markedly different lithology but it does not always occur exactly at geological boundary of horizon which is sometimes important problem in seismic interpretations (Kemal et al., 1992). However basic aim in seismic section interpretation is picking a horizon, and mostly, reflections on the section represent a certain geological formation where change in acoustic impedance occurred and this is the seismic way to interpret subsurface stratigraphic features.

3.7 Interpreted Seismic Sections

Using well data of well **SABZAL-01**, horizons are marked on dip lines G846-DAN-201, G846-DAN-211 and strike line G846-DAN-245.The marked horizons are Ghazij (Light Green), Sui Main Limestone (Sky blue) and Upper Ranikot (Yellow) on the basis of the change in the acoustic impedance also confirmed by the synthetic seismogram .The interpreted seismic section G846-DAN-201 is shown in figure 3.3.

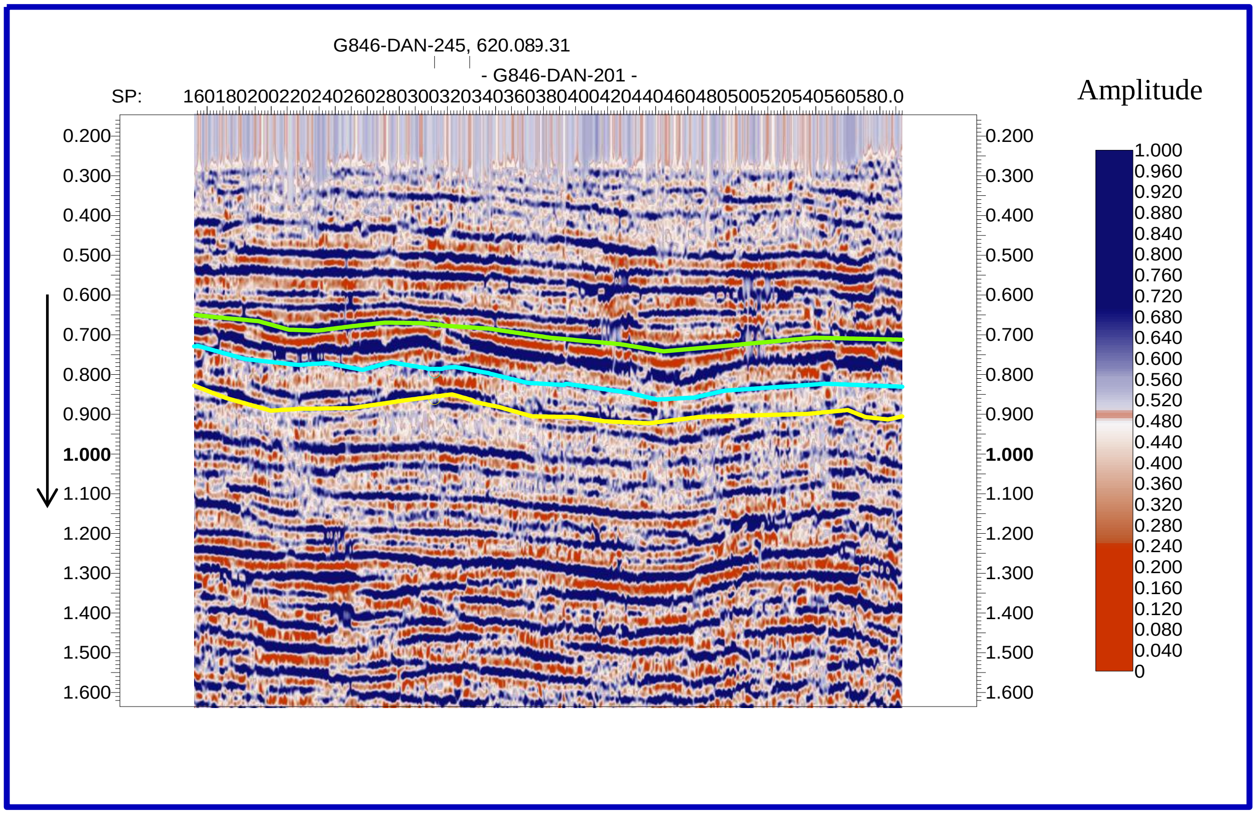


Figure3.2: Interpreted Time section of line G846-DAN-201

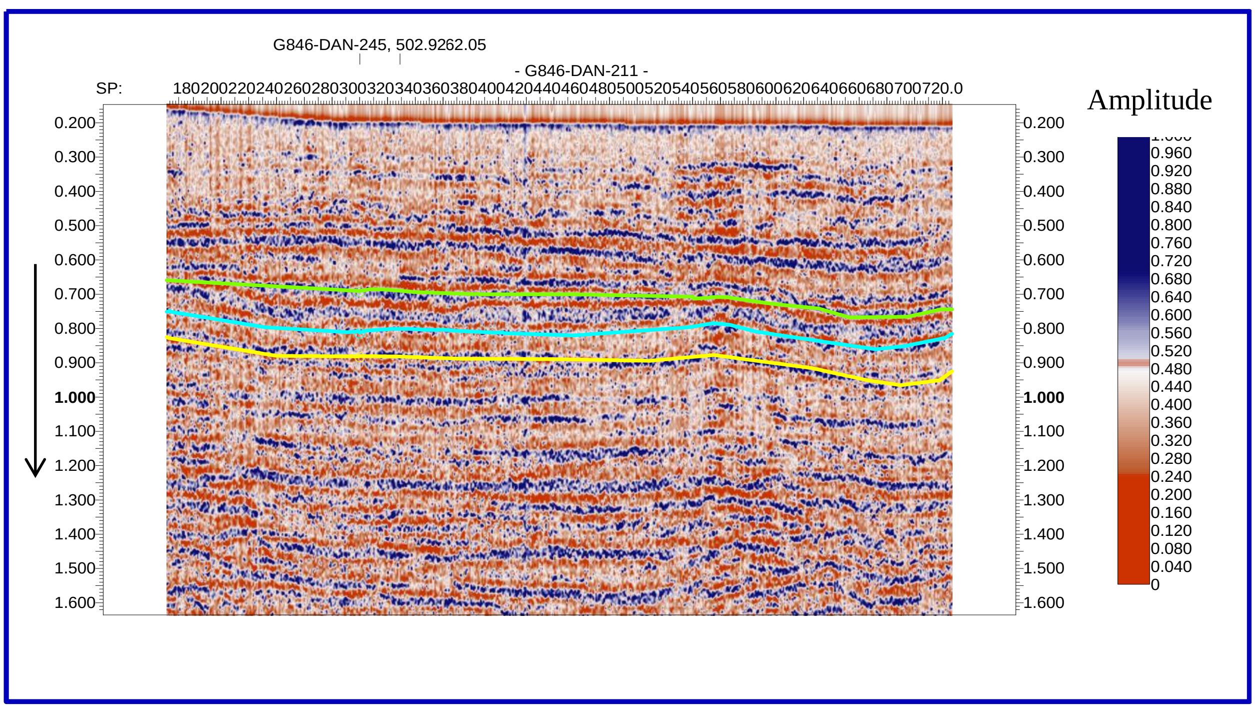


Figure 3.4: Interpreted Time section of line G846-DAN-211

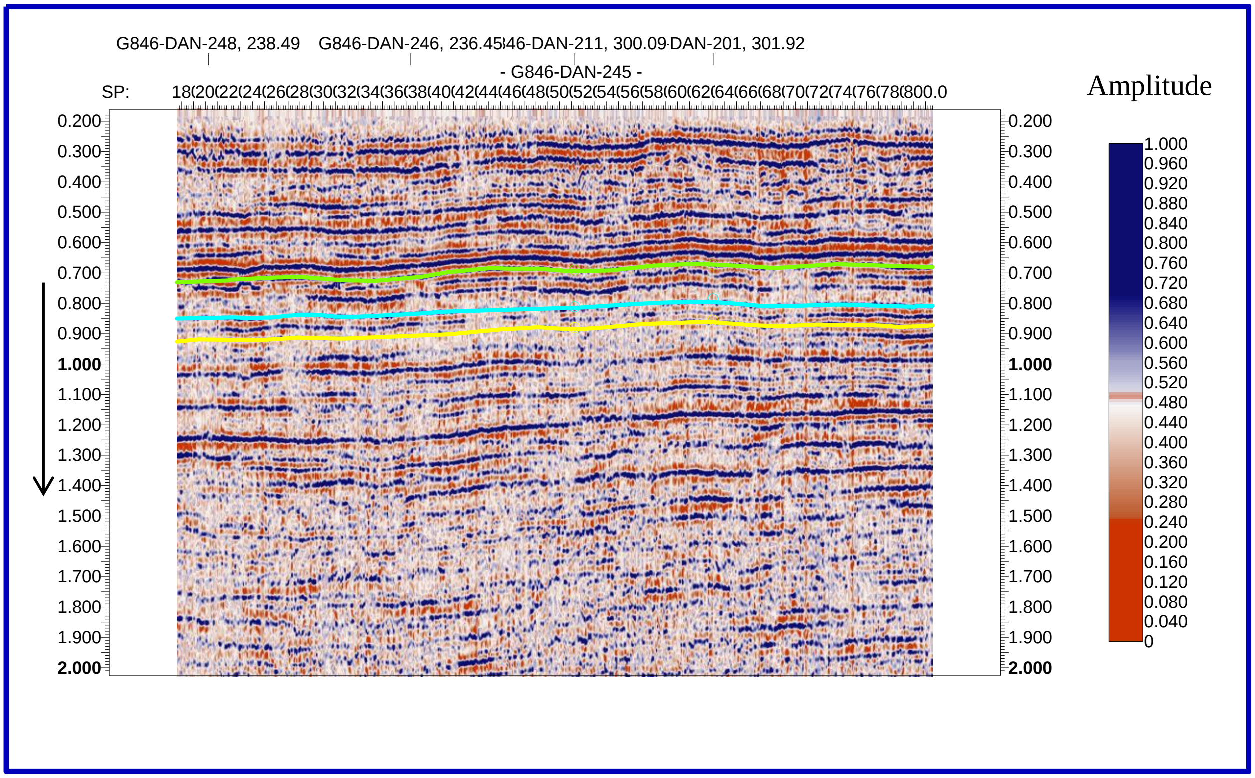


Figure 3.5: Interpreted Time section of line G846-DAN-245

Using kingdom we digitize the seismic line G846-DAN-211 with the strike line G846-DAN-245 Then we removed the Mistie however, in the given seismic section doesn't show any faults. The reason behind is that the given line is a strike line and the orientation of the line is against the basin configuration.

3.8 Contour Maps

The contours are the lines of equal elevation (time or depth). Mapping is usually final product of exploration, the one on which whole operations depends for its effectiveness (Coffeen, 1986). Contour maps show relief on horizons with contour lines that represent equal two way time (TWT) below a reference datum. These contour maps describe the slope of the formation, its dip, and any faulting or folding. In constructing a subsurface map from seismic data, a reference datum must first be selected. The datum may be sea level or any other depth above or below sea level.

3.8.1 Time Contour Maps

Time contour maps give a reliable picture of the subsurface if drawn properly. Sui Main Limestone Formation is of interest producing oil and gas, and composed of Limestone. Time contour map of this formation show 2D-variations with respect to time and the hydrocarbons probably accumulate at those places where contour values are low. Time counter map of Ghazij is shown in figure 3.6

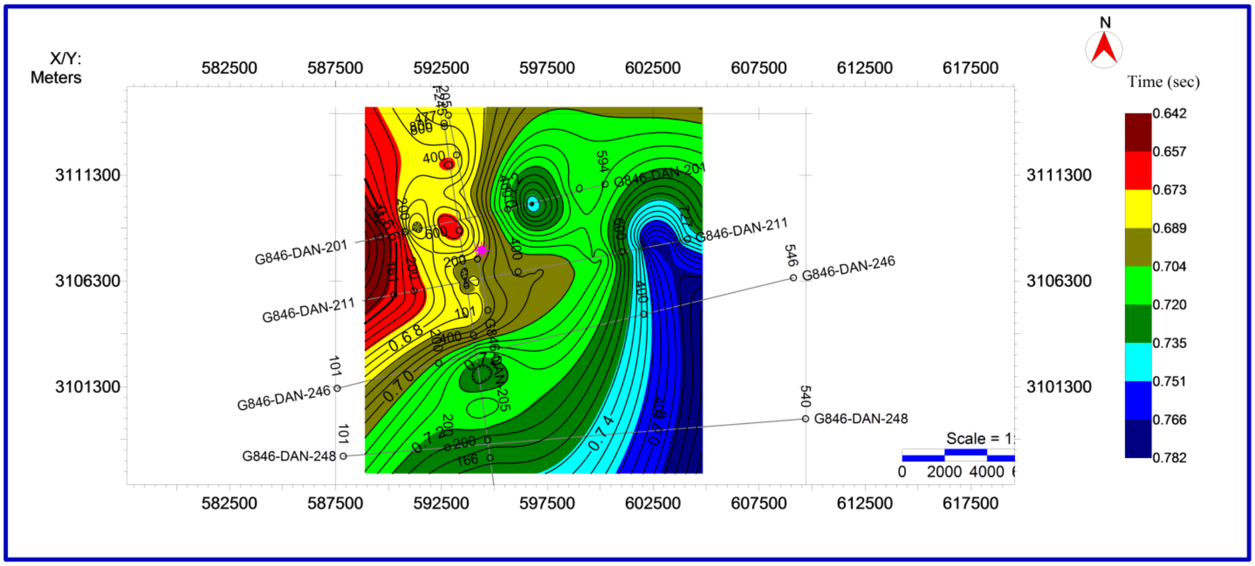


Figure 3.6: Time contour map of Ghazij Formation.

Time contour map of Sui Main Limestone is shown in figure 3.7. Sui Main Limestone is also oil producing but its yield is less than Upper Ranikot.

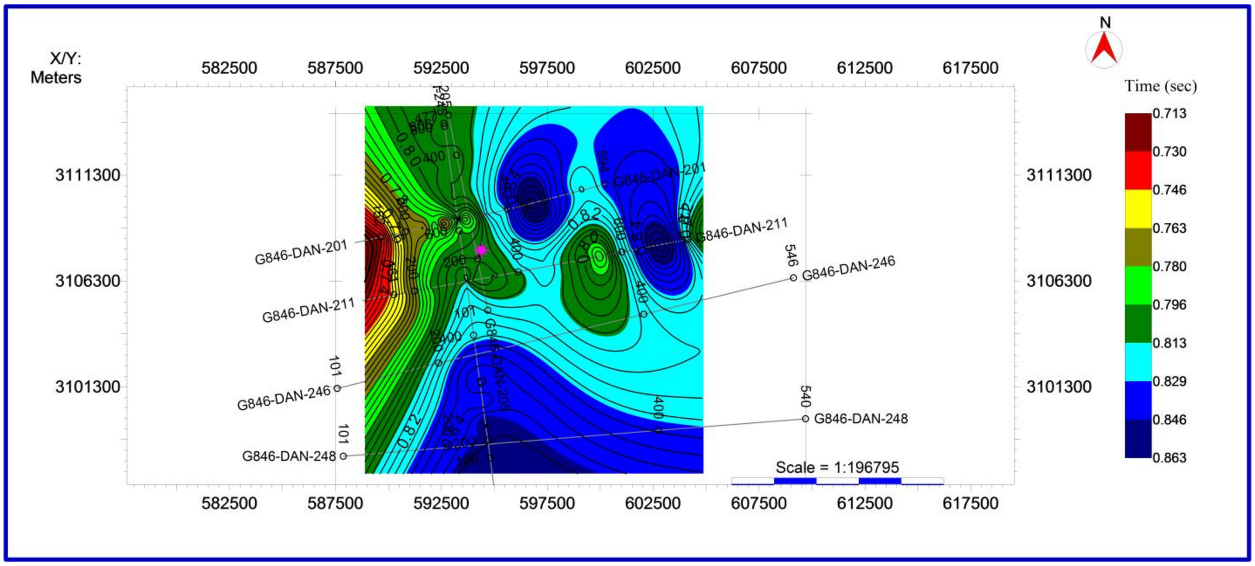


Figure 3.7: Time contour map of Sui Main Limestone Formation.

Time contour map of Upper Ranikot is shown in Fig 3.8 also shows the same pattern of variation in time as the previous ones. Maroon colored part of map showing shallowest zone of formation whereas blue colored part is indicator of deepest zone.

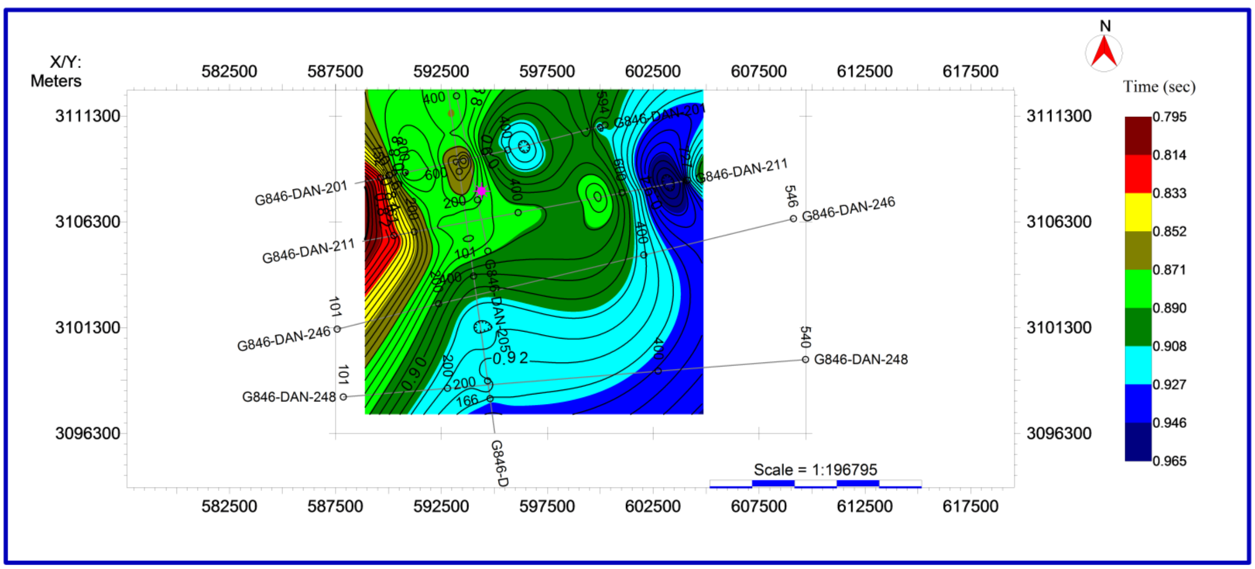


Figure 3.8: Time Contour map of Upper Ranikot Formation.

3.8.2 Depth Contour Maps

Depth contour maps are not as common as time contour maps. Mostly, the depth estimates are made with the help of time contour maps in a particular area. However, depth contour maps can give an extra edge when there's a good velocity control. Contouring can be a challenging job when done over areas of extensive faulting or mapping small features in stratigraphically complex regimes.

As Sui Main Limestone and Upper Ranikot are recognized as good reservoir rocks of the Sembar formation, depth contour of these formations is shown in figure (3.9 & 3.10). Region shown in maroon color is the shallowest with low values of depth might be the good zone for the accumulation of hydrocarbons.

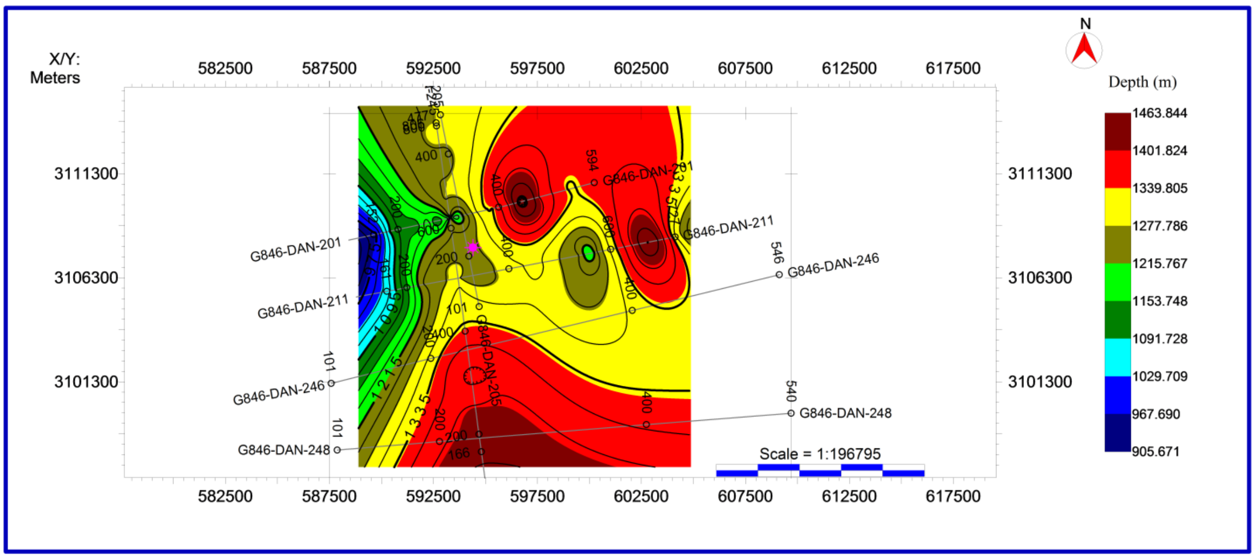


Figure 3.9: Depth contour of Sui Main Limestone formation.

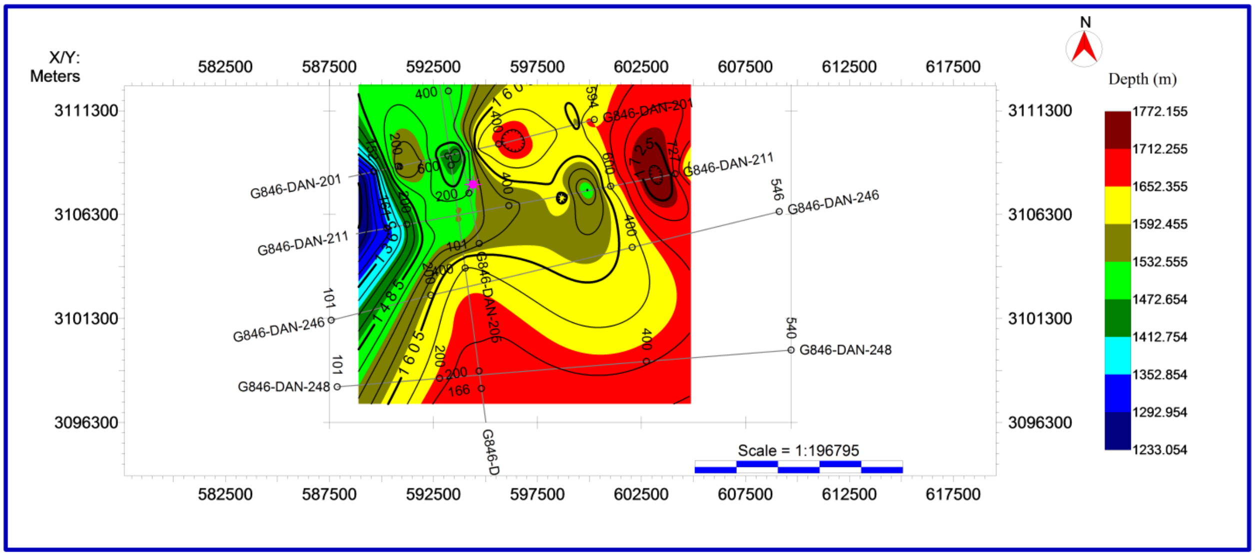


Figure 3.10: Depth contour of Upper Ranikot Formation.

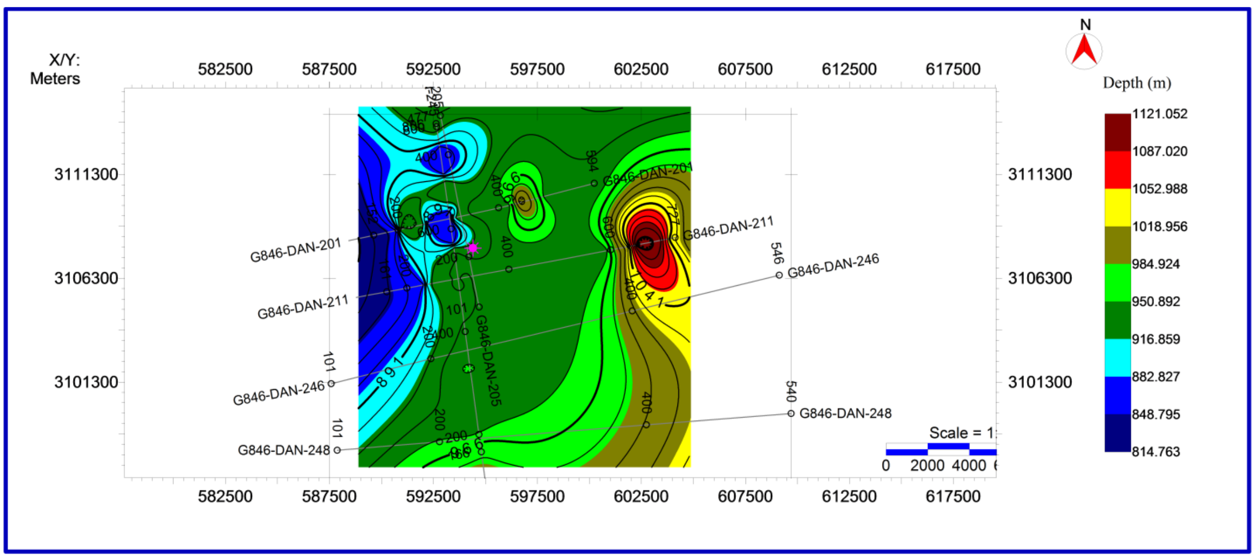


Figure 3.11: Depth contour of Ghazij Formation.

Chapter 4

Attribute Analysis

4.1 Introduction

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

4.2 Types of Seismic Attributes

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

4.2.1 Pre-Stack Attributes

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

4.2.2 Post-Stack Attributes

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

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

4.2.3 Physical Attribute

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

4.2.4 Geometric Attribute

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

4.3 Attribute Analysis of Line G846-DAN-211

4.3.1 Envelope of Trace (Reflection Strength/ Instantaneous Amplitude)

The Trace Envelope is a physical attribute and it can be used as an effective discriminator for the following characteristics.

- Mainly represents the acoustic impedance contrast, hence reflectivity
- Bright spots, possible gas accumulation
- Sequence boundaries
- Thin-bed tuning effects
- Major changes in depositional environment
- Unconformities

- Major changes of lithology
- Spatial correlation to porosity and other lithological variations
- Indicates the group, rather than phase component of the seismic wave propagation

(Subrahmanyam 2008).

Figure 4.1 shows envelope attribute of line G846-DAN-211. Since this attribute is the square of the real and imaginary components of seismic trace, it always has positive values. Thus the vertical resolution of this attribute decreases and it is not able to highlight sand shale intervals. However it is useful in highlighting the major lithological changes such top of Ghazij.

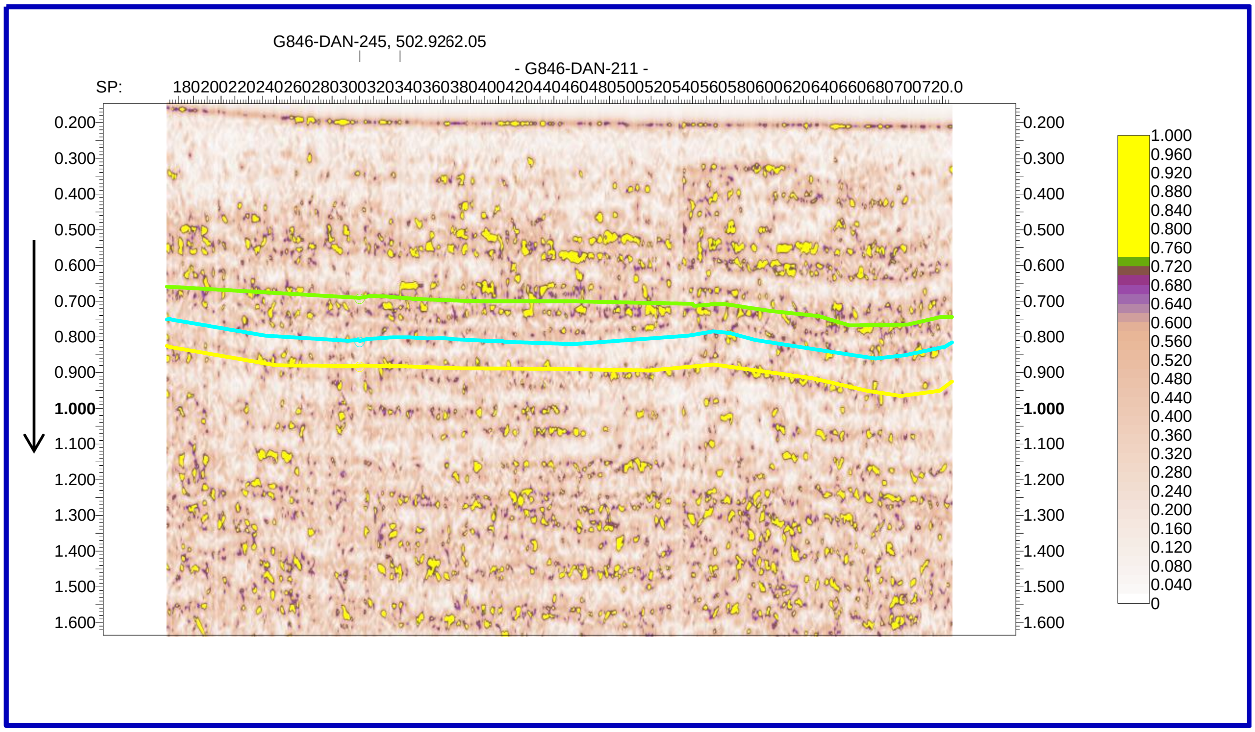


Figure 4.1 Envelope Attribute Map of Line G846-DAN-211

4.3.2 Apparent Polarity

Attributes that are sensitive to small perturbations in the data are unstable. Apparent polarity is an example. It is defined as the sign of the seismic data at envelope peaks scaled by the envelope peak and held constant in each interval around a peak. Average energy exhibits more contrast than reflection strength. Average energy has exactly the same information as RMS amplitude and almost the same as reflection strength. Its greater contrast is due to its presentation of the information. This provides a measure of reflectivity and allows one to map direct hydrocarbon indicators within a zone of interest.

The attribute has a blocky response and individually highlights the seal, reservoir and source rocks as shown in Figure 4.2.

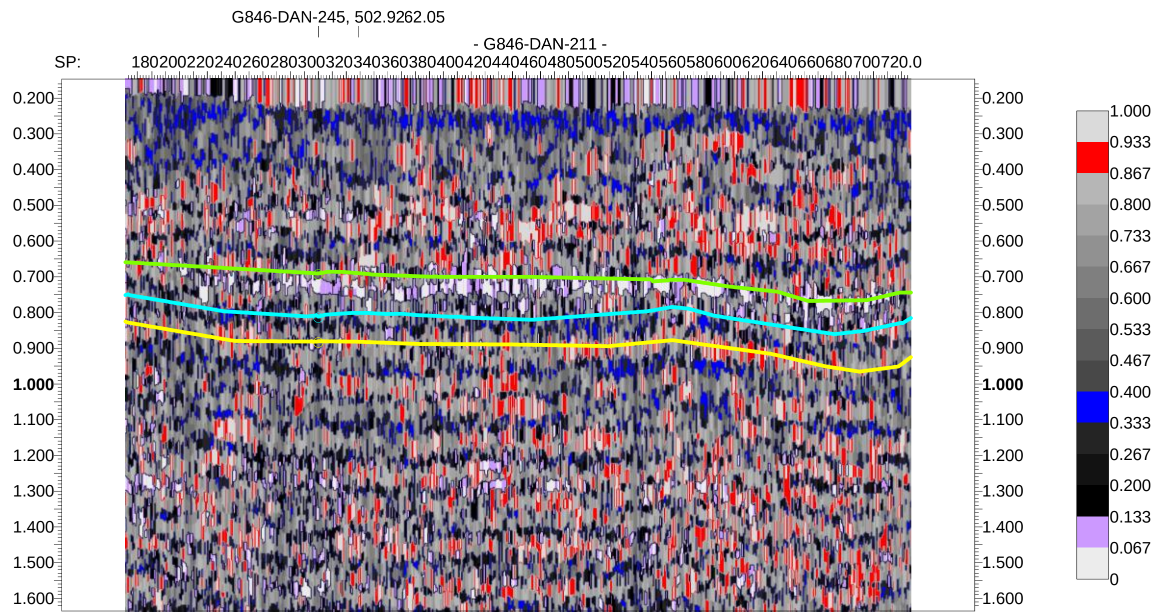


Fig 4.2: Apparent Polarity Attribute for Seismic line G846-DAN-211

4.3.3 Instantaneous Phase

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

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

Instantaneous phase highlights the continuity of reflectors. Since it is independent of amplitude, therefore it is capable of highlighting subsurface imagery in case of low amplitudes. Figure 4.3 shows phase attribute of line G846-DAN-211. It is a good attribute to confirm the continuity of marked reflectors. As shown in Figure 4.3 the marked horizons lie over the yellow color, it further confirms that the data is zero phase.

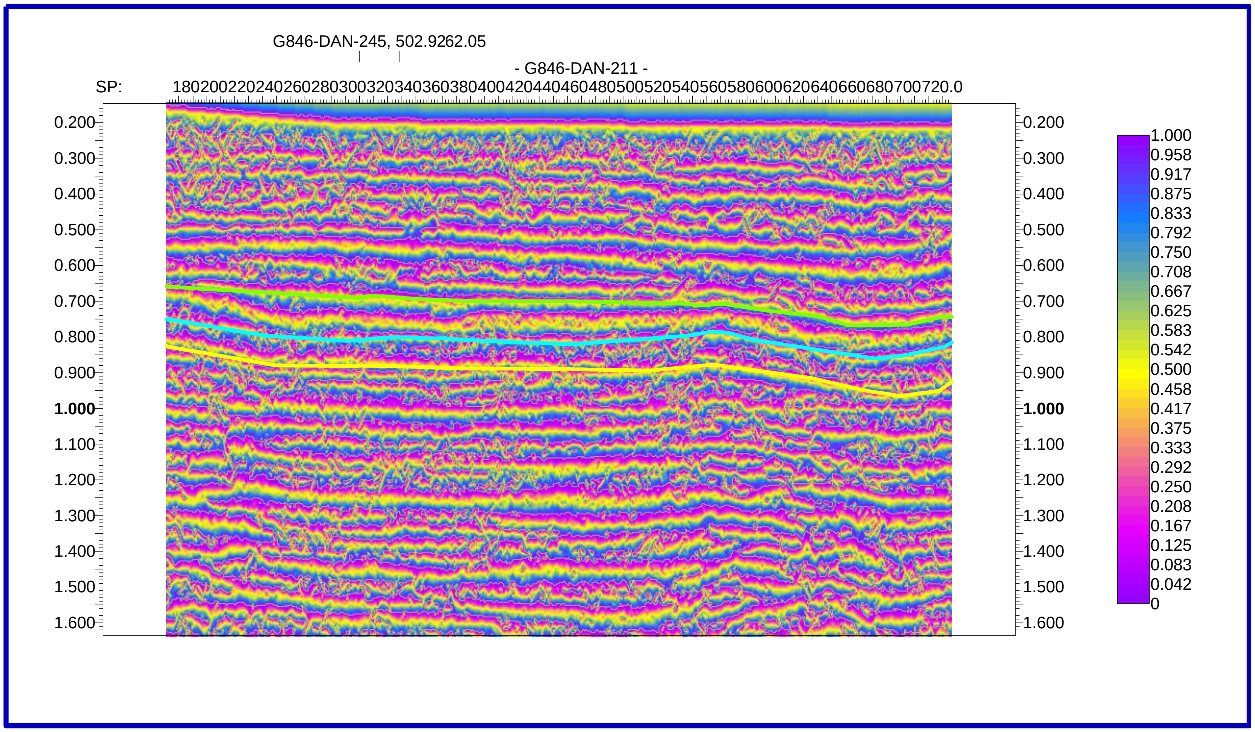


Figure 4.3 Phase Attribute Calculated For Seismic Line G846-DAN-211

4.3.4 Instantaneous Frequency

Instantaneous Frequency (Hz) is the rate of change of phase over time. The instantaneous frequency attribute responds to both wave propagation effects and depositional characteristics, hence it is a physical attribute and can be used as an effective discriminator (Subrahmanyam 2008).

Its uses include:

- Hydrocarbon indicator by low frequency anomaly. This effect is sometimes accentuated by unconsolidated sands due to the oil content of the pores

- Fracture zone indicator, since fractures may appear as lower frequency zones
- Bed thickness indicator. Higher frequencies indicate sharp interfaces such as exhibited by thinly laminated shale, lower frequencies are indicative of more massive bedding geometries, e.g. sand-prone lithology.

Frequency attribute is used as a geologic indicator in a number of scenarios. It is most commonly used to highlight the hydrocarbon reservoir with low frequency as the reservoir tends to absorb the higher frequencies. Figure 4.4 shows the frequency attribute of line G846-DAN-211.

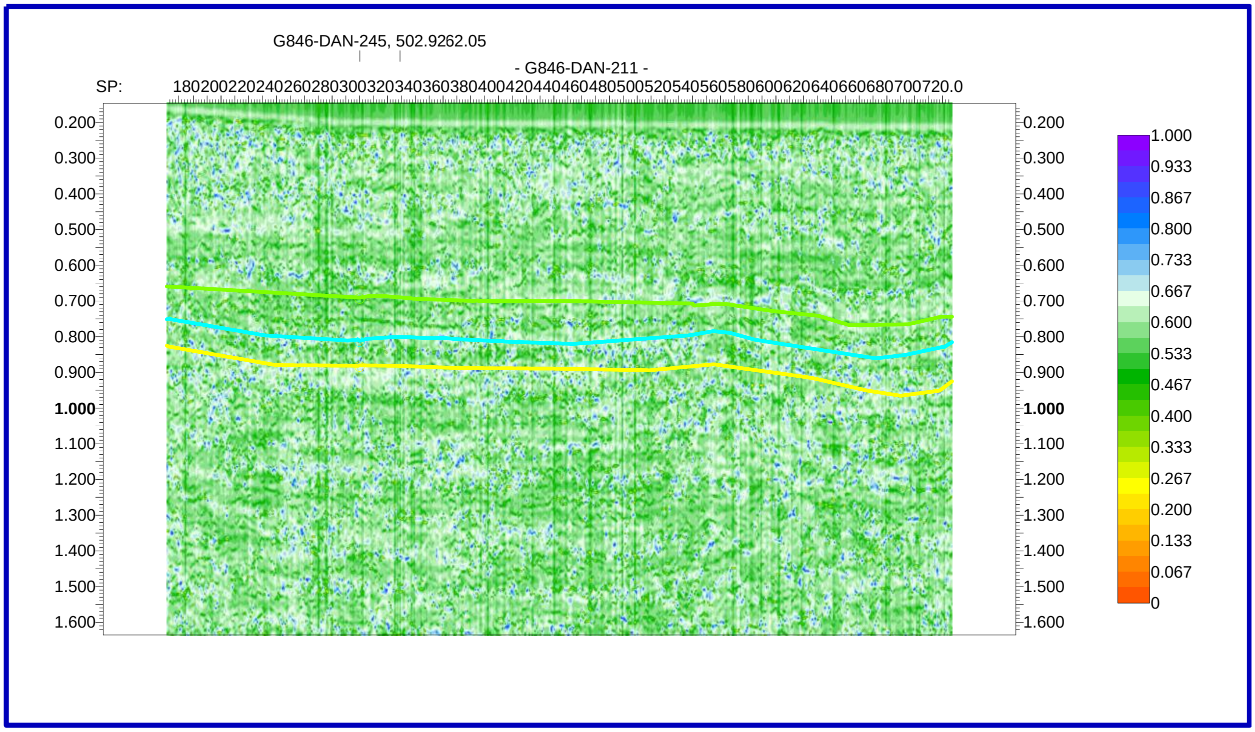


Figure 4.4 Frequency Attribute Calculated For Seismic Line G846-DAN-211.

Chapter 5

Petrophysical Analysis

5.1 Introduction

Petrophysics is the study of the physical and chemical properties that describe the occurrence and behavior of rocks, soils and fluids. Petrophysicists evaluate the reservoir rock properties by employing well log measurements, core measurements and seismic measurements, and combining them with geology and geophysics (Paal Fristad, 2012). It is mainly used in the hydrocarbon industry to study the behavior of different kinds of reservoirs. It also explains about the chemistry of pores of the subsurface and how they are connected. It helps in controlling the migration and accumulation of hydrocarbons. While explaining the chemical and physical properties, petrophysics also explains many other related terms such as lithology, water saturation, density, Irreducible water saturation, Hydrocarbon saturation, Net pay thickness, permeability and porosity and many more. The key role of petrophysics is to evaluate the rock properties by placing measurement tools in the bore hole.

Petrophysics uses different geophysical tools (GR, Caliper Log, SP, LLD and LLS etc.), core data and production data and integrates the results extracted. These geophysical tools are designed to quantify some specific reservoir properties such as porosity, shale volume, net pay, effective porosity, saturation of hydrocarbon etc. Petrophysical analysis is often less related to seismic data but more concerned to well log data for reservoir description.

5.2 Reservoir Petrophysical Properties

- Lithology
- Porosity (ϕ)
- Water Saturation (SW)
- Hydrocarbon Saturation
- Net Pay

5.3 Tracks

In petrophysical analysis we have specified tracks of logs responses. Each track contains the response of particular log run in the well. These tracks are:

5.3.1 Lithology Track

The lithology track consists of the following logs:

- Gamma Ray (GR) Log
- Spontaneous Potential (SP) Log
- Calliper Log

5.3.2 Resistivity Track

Resistivity track consist the Resistivity log which measure the resistivity of the formation. Resistivity logs are of various types these are described below

- **LLD**

  Laterolog log deep (Deep Laterolog) also measures the true formation resistivity beyond the outer boundary of invaded zone.
- **LLS**

  Shallow Laterolog measures the resistivity in the invaded zone
- **MSFL**

  Micro-spherically focused log measures the resistivity of the flushed zone.

5.3.3 Porosity Track

Porosity track consist the following logs:

- Density Log
- Sonic Log
- Porosity Log
- Neutron Log

5.4 Objective

The petrophysical analysis has been carried out in order to measure the reservoir characterization of the Sinjhoro area using the borehole data of SABZAL-01 well. We used log curves including spontaneous potential log (SP), Gamma ray (GR), Sonic log (DT), Caliper Log (CALI), Latero Log Deep (LLD), Latero Log Shallow (LLS), Neutron log(NPHI, density log(RHOB) for petrophysical analysis. The following parameters are calculated for reservoir rock:

- Volume of shale
- Porosity

- Water saturation
- Hydrocarbon Saturation

The scales used for different log track area explained in the table below.

No.	**Logs Name**	**Abbreviation**	**Scale**	**Unit**
1.	Gamma Ray Log	GR	0----------320	API
2.	Caliper Log	CALI	6----------16	INCHES
3.	Density Log	RHOB	1.95----------2.95	µsec/ft
4.	Sonic Log	DT	140----------40	Gm/cm3
5.	Neutron Log	NPHI	0.45----------(-0.15)	PU
6.	Latero-log Deep	LLD	0.2----------2000	Ωm

Table5.1: Scale used for the different logs.

5.5 Volume of Shale

We have two methods for the calculation of volume of shale

5.5.1 Linear Method

In linear method we compute the volume of shale by following formula.

$$\text{IGR} = \frac{\text{GRlog} - \text{GRmin}}{\text{GRmax} - \text{GRmin}}$$

IGR give us maximum volume of shale and we found minimum volume of shale by nonlinear method.

5.5.2 Non Linear Method

In nonlinear method three formulas are used to compute minimum volume of shale. I utilize the one which give minimum volume of shale and mostly Stabier formula gives minimum volume of shale.

- Stabier: (Most preferable)

$$\text{Vsh} = \frac{\text{IGR}}{3 - 2\text{IGR}}$$

Where, IGR= Index Gamma Ray

- Larinov: (Used for Older rocks)

$$\text{Vsh} = 0.33 \times (2^{2\text{IGR}} - 1)$$

➢ Clavier:

$$Vsh=1.7-(3.38-(IGR+0.7)^{2})^{0.5}$$

5.6 Porosity

Porosity parameters are following:

- Density Porosity
- Sonic porosity
- Effective Porosity
- Neutron porosity (Given)

5.6.1 Density Porosity

Porosity values calculated from density log is called density porosity. I calculate the density porosity by using the following equation:

$$\Phi d = \frac{\rho ma - \rho b}{\rho ma - \rho f}$$

Where,

ρm = density of matrix (gm/cm3)

ρf = density of fluid (gm/cm3)

ρb = log Response in zone of interest

5.6.2 Sonic Porosity

For Sonic porosity I used the formula of consolidated rocks because we know that these rocks are old and well consolidated. The formula is given as:

$$\Phi s = \frac{\Delta T - \Delta Tma}{\Delta Tf - \Delta Tma}$$

Where,

Φs=Sonic porosity μs/ft

ΔT =Log response

ΔTma = Transit time in matrix

ΔTf= Transit time in fluids

5.6.3 Effective Porosity

The interconnected pore volume or void space in a rock that contributes to fluid flow or permeability in a reservoir is called effective porosity. Effective porosity excludes isolated pores and pore volume occupied by water adsorbed on clay minerals or other grains. Effective porosity is less than total porosity. Effective porosity log is created by using average porosity logs and volume of shale log. The mathematical relation for effective porosity is as follows:

$$\varphi_e = (1 - V_{sh}) \times \varphi_{avg}$$

5.6.4 Neutron Porosity

The neutron log is sensitive mainly to the amount of hydrogen atoms in a formation. Its main use is in the determination of the porosity of a formation. The count rate is low in high porosity rocks and the higher in low porosity rock.

5.6.5 Average Porosity

The total porosity is the sum of all the porosities calculated from different logs divided by the number of logs used for calculating porosities

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

5.7 Water Saturation

Water saturation is the percentage of pore volume in rock that is occupied by water of formation. To calculate saturation of water in the formation, a mathematical equation was developed by Archie shown below. All the parameters of Archie equation can be calculated from resistivity and spontaneous potential logs.

$$Sw = \left(\frac{a}{\Phi m}\right) x \left(\frac{Rw}{Rt}\right)$$

Where

Sw = water saturation

Rw =water resistivity (formation)

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

Rt = log response (LLD)

Rw has been calculated with help of following formula:

$Rw = \phi^2 \times R$,

Where

ϕ = porosity in clean sand

R = Observed LLD curve in clean zone

5.8 Hydrocarbon Saturation

The fraction of pore spaces containing hydrocarbons is known as hydrocarbon saturation. The simple relation used for this purpose is given below:

$S_w + S_H = 1$

The saturation of hydrocarbons is percentage of pore volume occupied by hydrocarbon.
Where,

S_H = Hydrocarbon saturation

S_w = Water saturation

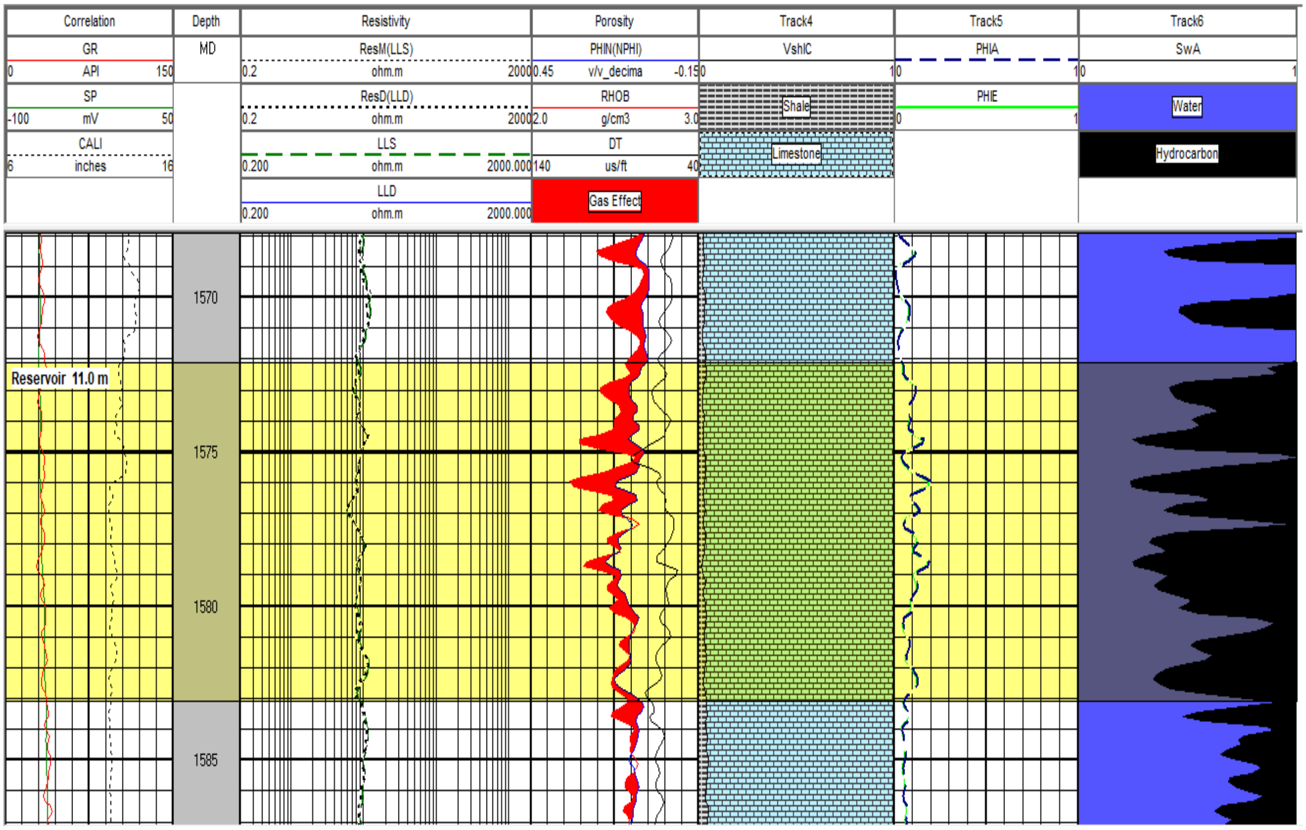


Figure 5.1: Petrophysical Analysis of SABZAL-01 Well.

The petrophysical results can be seen in the table 5.2

Table 5.2 showing results of Petrophysical Analysis

Sr. No	**Rock Properties**	**Sui Main Limestone**
1.	Average Volume of Shale	93%
2.	Average Porosity	9%
3.	Effective Porosity	8.87%
4.	Average Saturation of Water	37%
5.	Average Saturation of Hydrocarbon	63%

Chapter 06

Rock Physics and Facies Modeling

6.1 Introduction

Rock physics is an integration science linking seismic data, its derived attributes, Petrophysical data, computed as well as lab measured elastic parameters and core data. It consists of a wide range of empirical relations that have been established through best-fit least square regression. Correlations can be established between any two or more rock properties that can be used to compute one rock parameter with another.

Rock physics templates have been developed to visualize lithological and mineralogical variations in terms of Petrophysical logs; derived rock physics derived seismic attributes, and can be applied for the quantitative interpretation of well log and seismic data. (Perez et al, 2011) constructed rock physics templates using a combination of Hrtz-Mindlin contact theory and the lower modified Hashin-Shtrikman bounds to guide interpretations of estimated ultimate recovery in shales.

Figure 6.1 shows the Petrophysical logs of well SABZAL-01 for the depth 1500 to 3000 meter. To compute the elastic logs we need sonic, shear sonic and density logs.

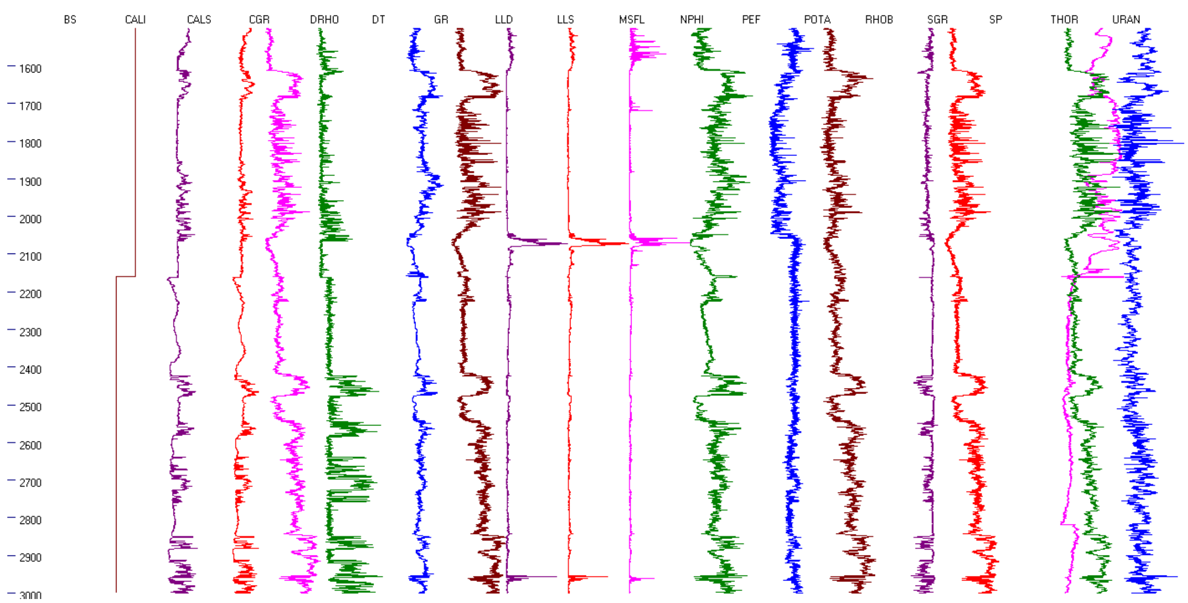


Figure 6.1: Petrophysical logs of SABZAL-01 for the depth interval 1500-3000 meter.

6.2 Computation of Elastic Logs

The P-wave velocity (sonic) log, S-wave velocity (computed shear sonic) log and density log are used to compute the elastic logs of various moduli along with acoustic impedance and shear acoustic logs as shown in Figure 6.2.

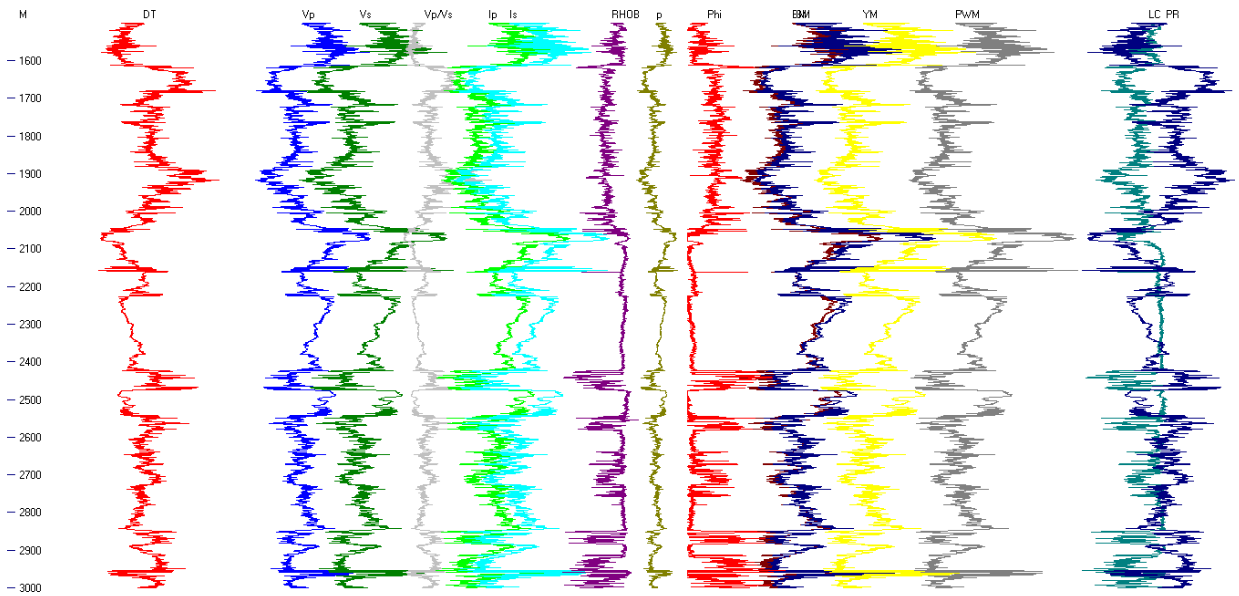


Figure 6.2: Acoustic Impedance and Elastic Logs computed from Petrophysical logs of SABZAL-01

The Petrophysical logs along with the computed Acoustic Impedance and Elastic Logs are used in various types of cross plot a brief description of each elastic parameter is given below:

6.2.1 Acoustic Impedance (AI)

Acoustic impedance is a layer property of a rock and is equal to the product of compressional velocity and density (Onajite et al., 2014). The density log and the compressional wave velocity log generated from the DT log are used to compute the acoustic impedance log by using equation:

$$AI = V_p \times \rho_b$$

Where, ρ_b is the density of the formation and V_p is the compressional wave velocity.

6.2.2 Shear Impedance (SI)

Shear impedance is a layer property of a rock and is equal to the product of shear velocity and density also known as elastic impedance (Connolly, 1998, 1999). Similarly, as acoustic impedance the density log and the shear wave velocity derived from the Castagna et al., (1993) empirical relation was bused to generate the shear impedance log using equation:

$$SI = V_s \text{ x } \rho_b$$

Where, ρ_b is the density of the formation and V_s is the shear wave velocity.

6.2.3 Young's Modulus (E)

This modulus is obtained to measure the stiffness of the material. The relation between the density, compressional wave velocity, young's modulus, and shear wave velocity is given in equation (Mavko et al., 2009).

$$E = \frac{\rho V_s^{\,2}\,(3V_p^{\,2} - 4V_s^{\,2})}{V_p^{\,2} - V_s^{\,2}}$$

Where, ρ is the density obtained from the density log (RHOB), V_s and V_p are the shear wave and compressional wave velocity respectively that is obtained from the sonic log (DT).

6.2.4 Poisson's Ratio (σ)

The Poisson's ratio is used to indicate the maturity of the shale oil/gas zone. The low value of Poisson's ratio will indicate the mature oil/gas shale zone. The relation between the Poisson's ratio, compressional wave velocity and shear wave velocity is given in equation (Mavko et al., 2009).

$$\sigma = \frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{2\left(\frac{V_p}{V_s}\right)^2 - 2}$$

6.3 Facies Modeling

Cross plot based facies analysis is an important methodology accepted worldwide to properly characterize a hydrocarbon reservoir and exploit the remaining volumes in development phase. In this study, shaly sand and clean sands are characterized using various cross plots. Common methods for cross plot based facies modeling are poly bounds and cluster analysis. In this study the polygon method is used for facies modeling. With the help of log data of SABZAL-01, different cross plots which are compared with the standard cross plots to identify the lithologies and the prospect zone to be marked.

6.3.1 Vp/Vs versus Poison Ratio

In figure 6.3 we can see that the variation in porosity for the lithology is readily distinguished from the attributes of both Vp/Vs and acoustic impedance. To calculate the Vp/Vs ratio the following equation was used.

$$\frac{V_p}{V_s} = \sqrt{\frac{0.5-\sigma}{1-\sigma}}$$

The relation between the Poisson's ratio, compressional wave velocity and shear wave velocity is given in equation (Mavko et al., 2009).

$$\sigma = \frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{2\left(\frac{V_p}{V_s}\right)^2 - 2}$$

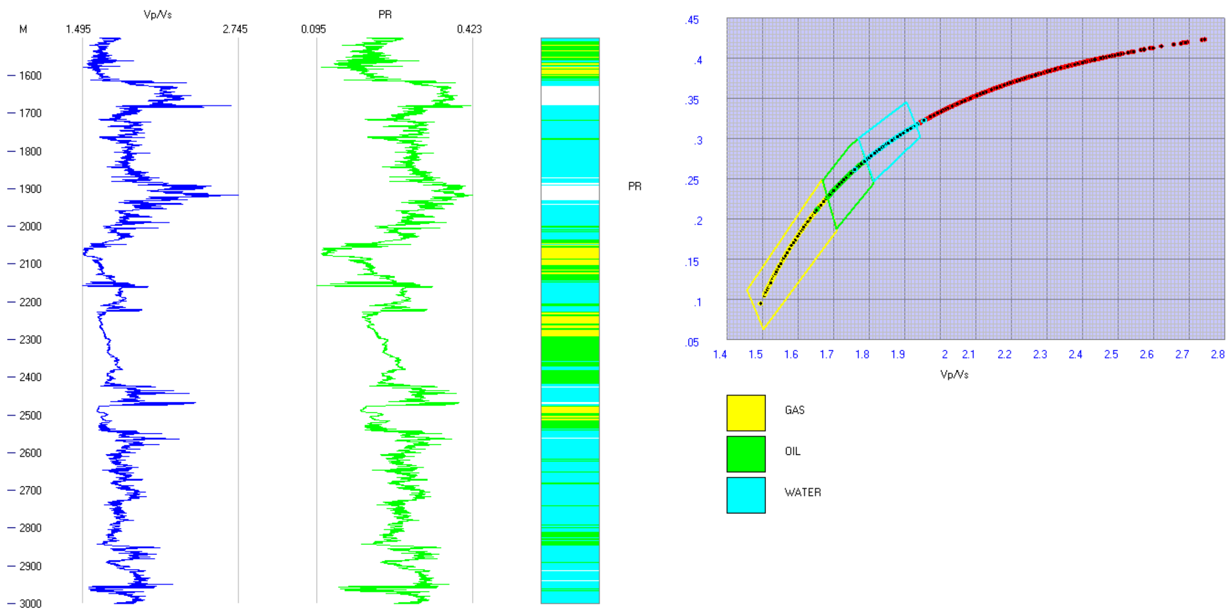


Figure 6.3: Vp/Vs and Poison Ratio Cross plot used for characterizing Gas, Oil and Water.

6.3.2 Porosity versus Density

Porosity versus density is a standard cross plot template for classification of facies as shown in Figure6.4. The GR log is used for lithology classification. It can be observed that the facies modeling results of this log are comparable with the interpretation of previous cross plots.

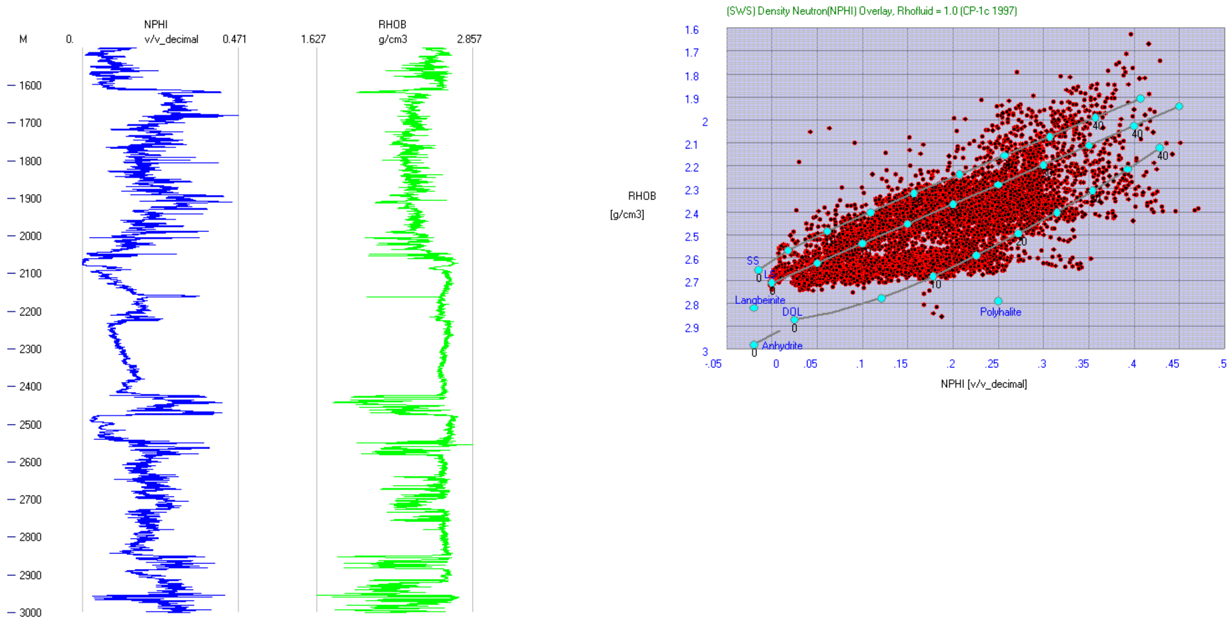


Figure 6.4: Porosity versus Poison Ratio Cross plot used for characterizing Gas, Oil and Water.

6.4 Rock Physics Empirical Relations

Another important work in Rock Physics is to establish correlations between various petrophysical, elastic and seismic parameters. A regression trend has been fitted between P-Wave velocity and porosity using 1st order least squares regression using data of well SABZAL-01 as shown in Figure 6.5. The following bempirical relation has been established with a correlation coefficeint of 0.853. it can be used to compute porosity volumes for any seismic inversion based datasets in the area.

$$NPHI = 0.637-0.0001Vp$$

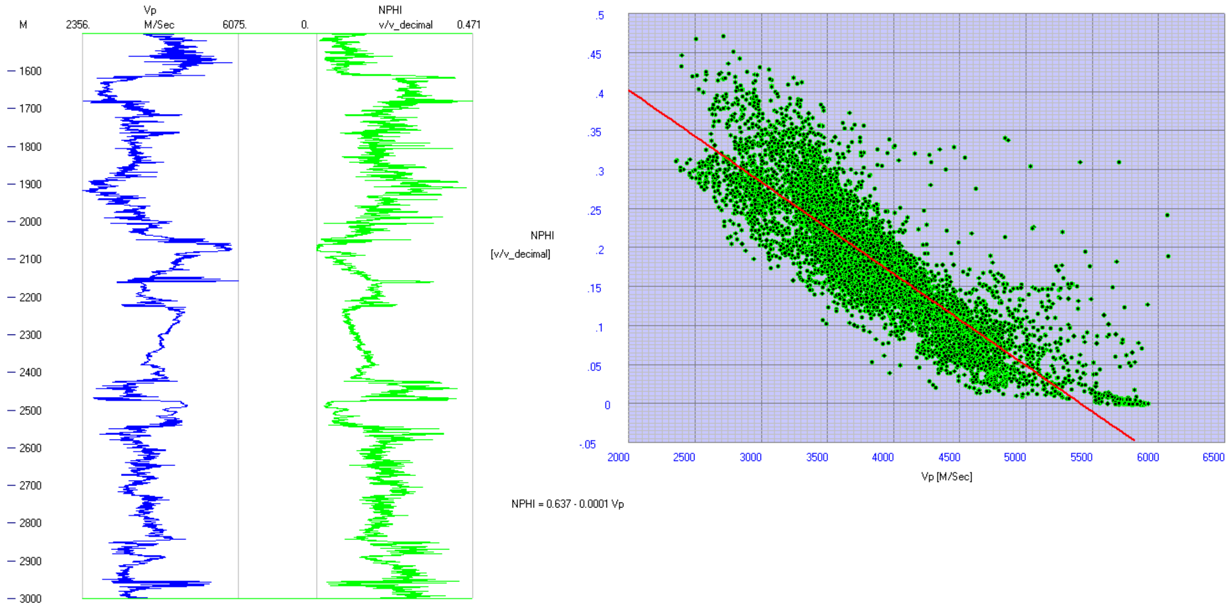


Figure 6.5: Best Fit Regression trend between P-wave velocity and porosity.

Conclusions

- On the basis of general stratigraphic column present in the area and the formation tops of the SABZAL-01 well, three reflectors are marked on seismic sections.
- The marked horizons are named as Ghazij, Sui Main Limestone and Upper Ranikot. Horizons are marked with the help of synthetic seismogram of well SABZAL-01 which is generated from well log data by using density log and sonic log.
- No fault was marked on seismic section depending on the geology and tectonics of the study area. As the area is stable and only has basin uplifting in the Central Indus Basin.
- Seismic Attributes such as Trace envelop confirm the major lithological changes such as top of Ghazij and the instantaneous phase confirm the continuity of marked horizons on seismic section.
- In petrophysical analysis the volume of shale, porosity, water saturation and hydrocarbon saturation are calculated in reservoir zones to identify the zone of accumulation of hydrocarbons within the reservoir zone. Quantitative results shows 9% porosity which is fair for the reservoir rock, 93% volume of shale, 37% water saturation and 63% hydrocarbons saturation. These results show that the reservoir zone would be effective for the accumulation of the hydrocarbons.
- Petrophysical logs have been used to compute Elastic logs and petro-elastic cross plots have been generated for facies modeling which can effectively discriminate between Clean Sand, Shaly Sand and Shale sequences in Sembar formation. The facies modeling interpretation is confirmed through two cross plots, which provide the same interpretation.

A regression trend between P-Wave velocity and Porosity has also been derived with 85% correlation.

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