# COMBINING MACHINE LEARNING AND SEISMIC INVERSIONTECHNIQUE FOR RESERVOIR CHARACTERIZATION OF DHODAK FIELD, CENTRAL INDUS BASIN, PAKISTAN


**HAFIZ MUHAMMAD TAQI**

**01-262212-013**

**Department of Earth and Environmental Sciences**

**Bahria University, Islamabad**


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A thesis submitted in Fulfilment of the Requirements for the award

of the degree of Master's in Science (Geophysics)

**Department of Earth and Environmental Sciences**

**Bahria University, Islamabad**

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# Bahria University

## Department of Earth & Environmental Sciences
## Islamabad Campus, Islamabad

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# Certificate

A thesis submitted by **Hafiz Muhammad Taqi** to the Department of Earth & Environmental Sciences, Bahria University, Islamabad in partial fulfillment of the requirements for the degree of **Masters in Geophysics** (Session **2021-2023**).

| Committee Member | Name | Signature |
|---|---|---|
| Supervisor | Dr. M. Fahad Mehmood | |
| Internal Examiner | ~~Dr.~~ Dr. Muhsan Ehsan | [signature] |
| External Examiner | Dr. Zulfiqar Ahmad | Zulfiqar Ahmad |
| Post Graduate Coordinator | Dr. Muhammad Iqbal Hajana | |
| Head of Department (E&ES) | Dr. Said Akbar Khan | |

# APPROVAL FOR EXAMINATION

**Scholar's Name:** Hafiz Muhammad Taqi

**Registration No.** 52477

**Programme of Study:** MS GEOPHYSICS

**Thesis Title:** Combining machine learning and Seismic Inversion technique for the reservoir characterization of Dhodak field, Central Indus Basin, Pakistan

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# DEDICATION

I dedicate this research work to My Parents and Siblings who always loved and supported me through whole my educational carrier. I appreciate their assistance and encouragement. I also want to express my gratitude to my teachers, who assisted, collaborated, and mentored me during my throughout research.

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# ABSTRACT

The main aim to study this area is to evaluate the hydrocarbon potential of Dhodak area, Central Indus Basin, Pakistan. Major structures present in this block are anticlinical pop-up structures and thrusted fault blocks produced due to the decollement by basement. Generally, target Formations were Pab Sandstone, Lower Ranikot Formation and Dungan Limestone. Lower Ranikot Formation was our main target formation specifically for analysis to predict its reservoir properties. Synthetic seismogram was developed with the help of Density log(RhoB) and Sonic log(DT) for the confirmation of geological section made by Seismic interpretation. For the conformation of these structures Time, Velocity and Depth contour maps of these Formations are also generated which delineates through seismic data. Hydrocarbon potential of Lower Ranikot Formation in Dhodak-01 & 05 well was evaluated by Petro-physical analysis by using borehole logs. It consists for the calculation of Petro-physical properties like shale's Volume, sand's volume, Porosity calculations, Density calculations, Saturation of Water Calculations, Gas effect calculations and Hydrocarbon Saturation(Shc) was predicted. Different sort of logs which are present were used like Gamma Ray, Compensated Neutron LLD, LLS, MSFL (Resistivity logs), Spontaneous Potential log (SP Log). Rock physics modeling have used for the prediction of P and S waves variations and how Poisson's ratio occurs. Rock physics depicted the missing log prediction like S-wave specifically and fluid substitution also occurred with different conditions to confirm reservoir availability. Model Based Inversion (MBI) have been used to predict and confirm more better results came from seismic interpretation. Wavelet was extracted from the control line and the correlation occurred. LFM (Low Frequency Models) have been generated as well. Afterwards Quality control of data was occurred by inverted techniques. Lastly to confirm results with seismic inversion technique, Machine learning (PNN) based on Bayesian classifier method which gives reliable prediction of petro physical properties so it is used predict Volume of clay prediction, Porosity prediction and Saturation of water was predicted by Actual and Predicted values.

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# CHAPTER 1

# INTRODUCTION

## 1.1 General Statement

Dhodak field is located at 80 km from the Dera Ghazi khan City and us at the North most culmination of the Koh-e-Sufaid anticlinorium situated on the eastern margin of Suleiman Range. It is positioned between 30°48'46"N (latitude) 70°30'24" E (longitude). Since the early 1970s, the area has been actively explored by the “OGDCL” which is discovered this field since May 1976 and began normal production in December, 1994 the Pab Sandstone, which is cretaceous in age, was discovered to be a gas-condensate reservoir in the Suleiman Range. So far, eight wells have been drilled, with seven of them producing gas or condensate producers In this study, an attempt was made to connect the seismic data results in order to obtain a structural model (Raza et al., 1989).

## 1.2 Literature review

Petroleum system in Dhodak field is well established. It is one of the important and gas prone with largest gas field, (Sui ~ 12 Tcf) trillion cubic feet per day in Pakistan from Eocene carbonates. Moreover, Mughal kot formation , Sembar Formation as well as Goru Formation shales are common in Dhodak Field and these shales are rich in biological matter. Shale of these three formations acts as a source rock in Dhodak field (Khan and Scarselli, 2020).

In Central Indus Basin shale of Sembar Formation acts as a common source rock and contain type III kerogen, generates gas or condensate. But in some parts type II Kerogen is also present. Pab Sandstone (Cretaceous) age acts as a reservoir in this study area. Ghazij shale giving capping mechanism in the Dhodak field (Raza et al., 1989).

Seismic interpretation is the modern technique which gets the geologic information at some depth from the processed seismic record, it gives information related to tectonics. It depicts to extract and highlight the horizons and faults in seismic image (Ahmad et al., 2021).

Seismic inversion is procedure in which the originally reflectivity data which is recorded routinely converted from an interface property to a rock property known as Impedance, in reality that’s product of Sonic Density and Bulk density. Seismic inversion can be pre stacked or post stacked, deterministic, random or geostatistical. It also depicts the reservoir measurements such as well logs and cores (Chen et al., 2017).

S-wave velocity analysis gives important information about seismic reservoir characterization. Moreover, it is not usually acquired in all wells due to high cost and technical difficulties. So that different methods are developed for S-wave velocity prediction from other conventional petro physical logs, generally using rock physics methods or artificial intelligence algorithms. Both methods have their own ways to predict S-wave velocity for complex reservoirs, which affects their prediction accuracy and efficiency accordingly (Morteza Azadpour et al., 2020).

Inversion of seismic data is used to predict the earth’s acoustic impedance. Seismic inversion technique is applied to provide the detail information about the seismic data, predict acoustic impedance directly and based on what we can detect lithology. This includes basic seismic processing, wavelet extraction, log editing and interpretation as well as different models of performing inversion. Seismic inversion has been used by Hampson Russel Software (HRS).

Seismic inversion recovers the earth properties or extracts the additional information from seismic data. Moreover, Seismic inversion increases the resolution of conventional seismic data and in many cases it enhances the reservoir parameter at higher level (Veeken PCH and Silva MD, 2004).

The major application of rock physics is to estimate the elastic parameters of rocks with known mineral composition, porosity and pore geometry etc (Biot, 1941). Machine learning depicts the algorithms which learns and make predictions of data. Its necessary to train each model multiple times with different hyper parameters to reach maximum accuracy and stability predictions, like Support Vector Regression(SVR), Random forest(RF) (Druker et al.,1996).

Machine learning algorithms will have outstanding results to depicts the reservoir characterization by doing firstly Exploratory Data Analysis (EDA) and then comes towards machine learning.

The main Problem starts from Data acquisition problems then Seismic processing like noise removal etc. So during such setups important data is missed in which we do seismic interpretation and petro physical analysis. So to enhance the results we will apply machine learning approach towards it.

## 1.3 Study area

Dhodak field is located at 80 km from the Dera Ghazi khan City and at the North most culmination of the Sufaidkoh anticlinorium, situated on the eastern margin of Sulaiman range. It is positioned between 30°48'46"N (latitude) 70°30'24" E (longitude).Since the early 1970s, the area has been actively explored. Oil and Gas Development Company Limited (OGDCL) discovered this field in May 1976 and began normal production in December, 1994. The Pab sandstone, which is of cretaceous age, was discovered to be a gas condensate reservoir in the Sulamain range.So far, eight wells have been drilled, having seven of them producing gas condensate. So our target formation for analysis is Lower Ranikot Formation.

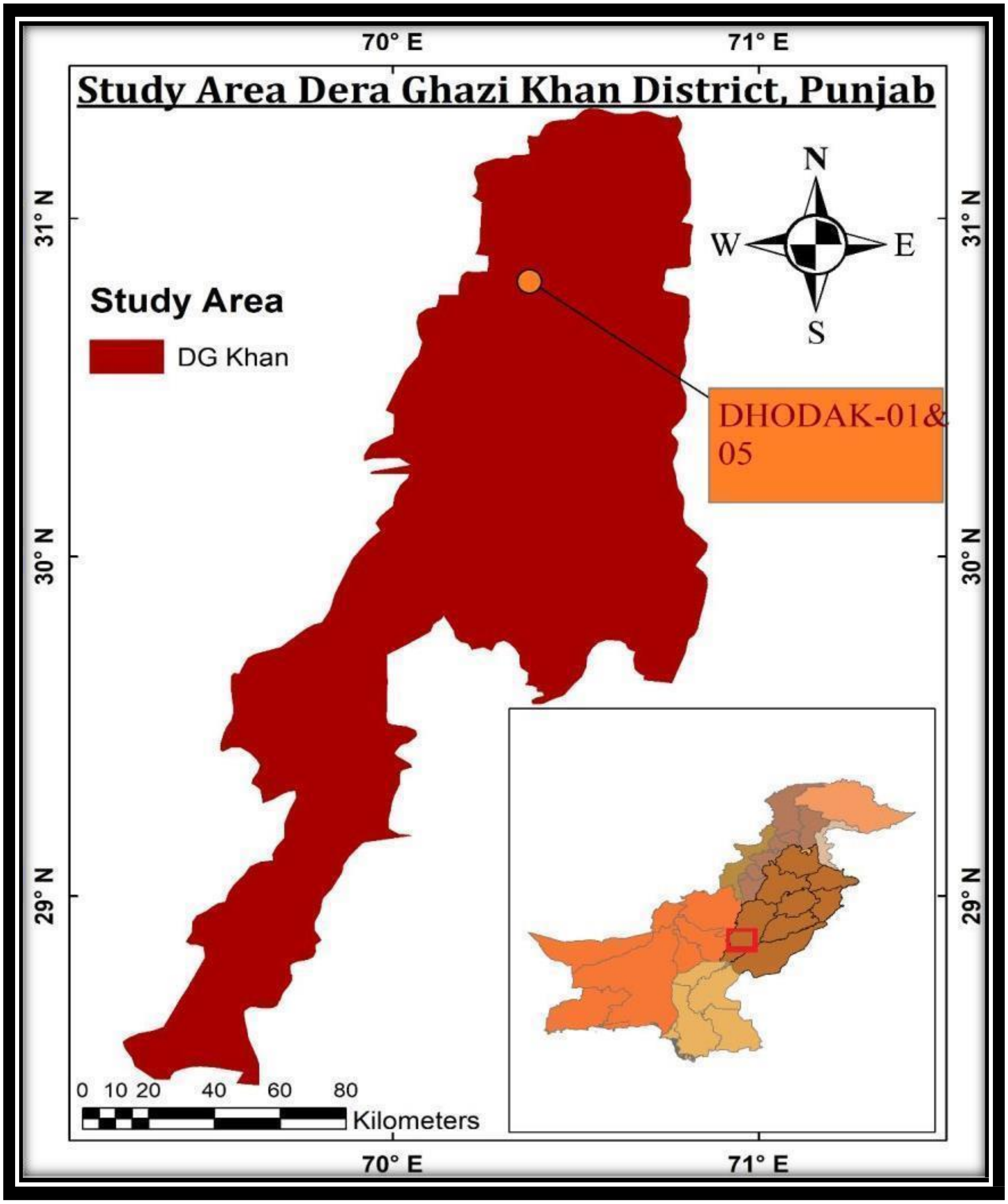


**Figure 1.1** Study area map generated by using Arc Gis software.

### 1.4 Purpose of the study

Delineate the subsurface structure using seismic data analysis:

1. 2D Seismic data interpretation to delineate the subsurface structural trend.
2. Petro physical analysis to evaluate the hydrocarbon potential of the reservoir for well.
3. Rock Physics analysis to predict hydrocarbon occurrence by fluid replacement method.
4. Seismic inversion analysis to characterize reservoir in detail as compared to seismic interpretation conventional approach.
5. Optimized Machine learning approach to characterize reservoir in a robust precise way.

### 1.5 Data source

The seismic reflection data was taken from Directorate General of Petroleum Concession (DGPC) Pakistan. The provided data is as follows:

#### 1.5.1 Seismic data

Seismic cross-sections (07 seismic lines)

| **Line Name** |
|---|
| **785-SK-04** |
| **795-SK-11** |
| **855-SK-31** |
| **855-SK-28** |
| **845-SK-27** |
| **845-SK-29** |

### 1.5 .2 Well data

We required Log data of (Dhodak-01 and Dhodak-05) wells and complete log suite i.e SP, SGR, GR, Neutron, Density, Sonic, Resistivity, Bit Size and Caliper logs.

## 1.6 Base map

Base map gives idea about Seismic lines and well points by just putting a glance and see the whole alignment of the area. The direction of the Seismic lines and probable well points has also been described on Base map. That's why we can easily interpret our seismic lines.

## 1.7 Methodology

The methodology involves the following steps:

1. Generation of Base map.
2. Create the time versus depth chart
3. Identification of the reflectors.
4. Picking the time and velocities of marked reflectors.
5. Preparation of time, velocity and depth contour maps.
6. Petro physical analysis to observe hydrocarbon potential of Dhodak-01 and Dhodak-05 Wells.
7. Rock Physics analysis to predict hydrocarbons by fluid replacement method.
8. Seismic Inversion analysis to confirm results gotten from Seismic interpretation.
9. Machine learning approach to confirm the results of petro-physical analysis and Inversion technique by its correlation.

# CHAPTER 2

# TECTONIC HISTORY AND REGIONAL GEOLOGY

## 2.1 Introduction

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

1) Punjab Platform
2) Sulaiman Depression
3) Sulaiman fold-belt

Central Indus basin is majorly segregated into 3 major parts, As moving east to west in the top Eastern side Punjab Platform comes, In the middle Sulaiman Depression comes also known as Sulaiman Foredeep. In the top western side Sulaiman Fold and Thrust belt comes. Sargodha high lies above Sulaiman Fold and Thrust belt while, Indian Shield covers the Eastern boundry. West Sukkur rift demarcates the southern side. The oldest rocks make a hole through drilling are of Precambrian Salt Range Formation (Kadri, 1995).

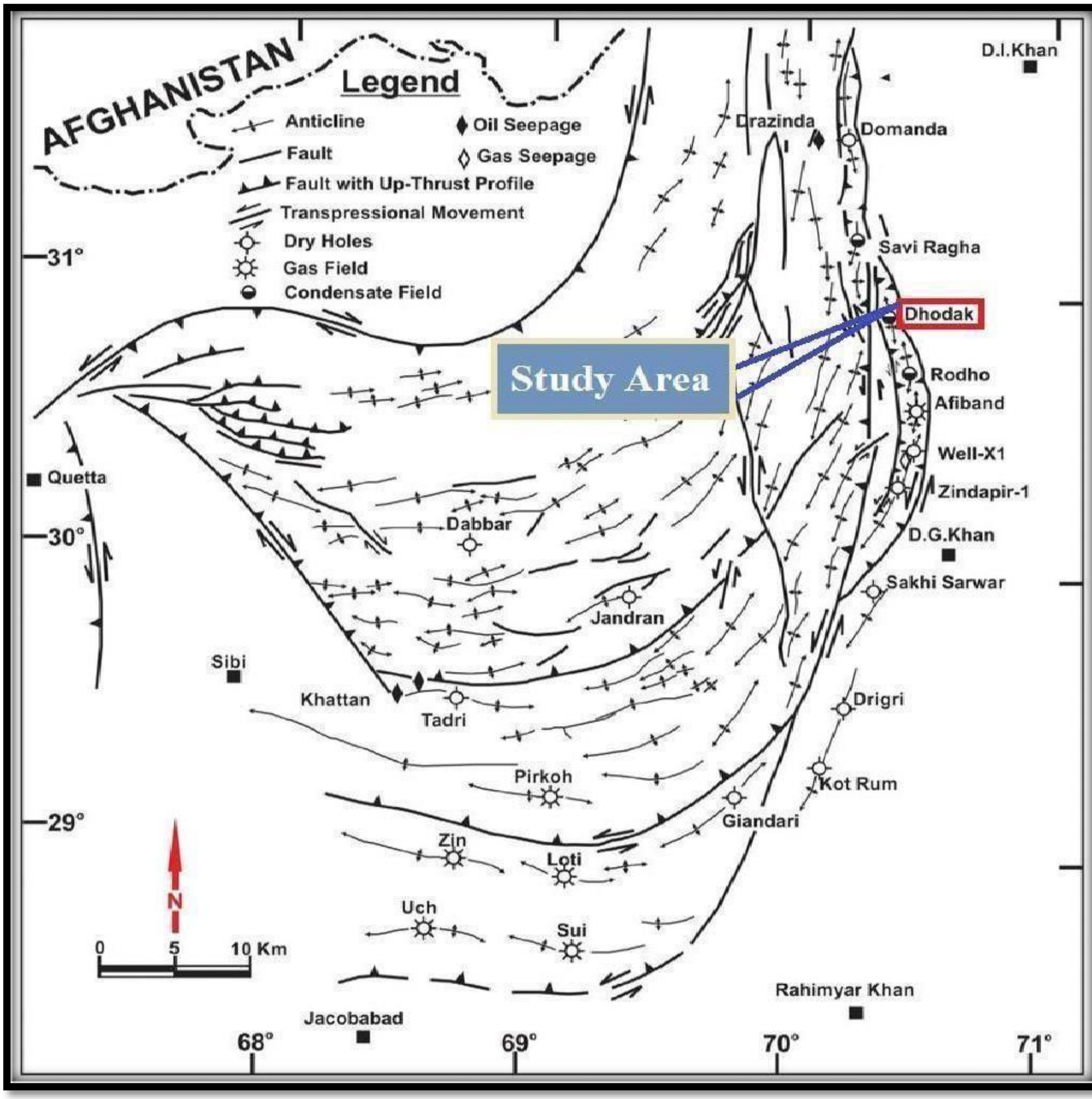


**Figure 2.1** Shows tectonic map of the studyarea (Ahmed et. al, 2012).

## 2.2 Punjab platform

Kadri (1995) reported that Punjab Platform lies the east side of Sulaiman Depression. In that surficial sedimentary outcrop are absent in that. Tectonically, that's a huge monocline plunge regarding Sulaiman depression. Punjab Platform is tectonically the smallest impacted area. On the basis of these wells the stratigraphic sequence is established. The most remarkable stratigraphic compress outs in Pakistan.

## 2.3 Sulaiman Fore-deep

It is also called Suleiman Depression. This depression is long-term fix area of reduction. Along with its southern rim it becomes bent and takes up a diagonal alignment. This depression was discovered as a consequence of two plates colliding, just as many other features. The movement of Eocene Shales is responsible for the discovery of several buried anticlines, as demonstrated by seismic data (Kadri, 1995).

## 2.4 Sulaiman Fold Belt

The main tectonic feature in the vicinity of the collision zone is the Suleiman fold belt, which has several disrupted anticlinal features (Kadri, 1995). There are also sizable anticlines that are obviously detachments at the eastern edges of the Kirthar and Sulaiman belts. Basement was splitted into three distinct blocks as a result of the Indo-Pakistan plate colliding with the Eurasian plate. These basement blocks are separated from the center region of the Indo-Pakistan Plate as well as from one another by three basement faults. The Khuzdar block and the Suleiman are splitted apart by the Kirthar basement fault (Bender and Raza, 1995).

## 2.5 Geological framework

The Central Indus Platform Basin (CIPB) is located near the continental margin of the Indo-Pakistan Plate. The Sulaiman range is located inside the western boundary of the CIPB, while the Jaisalmer-Mari-Kandhkot High depicts the southern boundary. Deep alluvial cover conceals the significant structural structure of the Indus platform basin from the floor, and seismic and drilling research identifies subsurface structural elements linked to Mesozoic and Precambrian extension phases. The Sargodha Ridge constitutes the north-eastern boundary. To the west, the Punjab Platform descends into the Suleiman fore-deep.

## 2.6 Structural settings

The Pezu uplift basin and the Sargodha High make it different from the Upper Indus Basin in the north. Its borders are the Sukkur Rift in the south, the Indian Shield in the east, and the Indian Plate's marginal zone in the west. In this basin the oldest rocks are exposed due to Precambrian Salt Range Formation on Punjab Platform. In the trough areas the depth of the basement is about 1500 meters. Precambrian Shield rocks are clearly discernible along the Indian Plate's edge, Precambrian rocks are mostly absent from the basin. There are Cambrian-aged marine rocks in the Karampur well. Most of the Central, south and eastern parts of Pakistan covered by structural province.

The Indus basin, typically referred to as the northern earth, is a region of the Gondwanian domain which is segregated from the northern regions and Baluchistan of the Laurasian and Tethyian domains by an axial belt. The studied region, the Indus Basin, is located in central and eastern Pakistan and is part of the North-Western Subcontinent. It is further subdivided into three distinct basins: the upper (Kohat and Potwar), middle (Suleiman), and lower (Kirthar). The Suleiman Basin is rectangular in shape and is the largest basin of the Indus basinand it is more than 170 thousand km2. It is more than 40% of the area of Indus Basin. The triangular shape Kirthar Basin is 120 thousand kilometers and Kohat and Potwar Basin is about 100 thousand km.

The Sulaiman Basin is bounded by Khairpur Jacobabad High line in the south and in north by Sargodha High line to Pezu, in the East by Indian Shield rocks and axial belt is situated in the West. The three main tectonic zones of the Sulaiman Basin are the Southern Punjab Monocline in the east, the Suleiman Fold-belt-forming area in the west, and the Suleiman Foredeep zone, which is shaped right in front of the Suleiman Fold belt. The major Indus Basin has been divided into three basins mostly due to the distinct character of the litho-stratigraphy.

For instance, the Eocene strata of the Kirthar Basin's Laki and Kirthar formations differ from those of the Sulaiman Basin's Chamalang/Ghazij Group and Kahan Group. Thus, the Khairpur and Jacobabad High surrounded two distinct basins where the Cretaceous Pab Formation originated. The Kohat and Potwar Basin consists of Precambrian to recent sedimentary rocks while the Sulaiman and Kirthar consist of the Jurassic to recent strata. Axial belt and its vicinity consist of mostly mélange of igneous, metamorphic and sedimentary rocks. The study area is in the central part of Pakistan. Previously the Sulaiman Basin has received little attention, but this paper will add insights on updated stratigraphy and new mineral discoveries.

# CHAPTER 3

# STRATIGRAPHY OF THE AREA AND PETROLEUM PLAY

## 3.1 General stratigraphy

The Central Indus Basin was in a passive marginal setting, and sediments were most likely laid down in inner rifts in intermittent interaction with Tethys under partly restricted shallow marine conditions. The Permian sequence overlies the Cambrian deposits. Up until the Late Triassic period, the Central Indus Basin was characterized by shallow marine to paretic conditions. The passive margin thermal subsidence that occurred during the early Jurassic period deposited thick layers of fine-grained clastic deposits. The carbonate platform of the Middle Jurassic was replaced by shallow marine to deltaic shale and sandstone, respectively (Iqbal et al., 1980).

The carbonates platform is replaced by a more clastic-dominated regime through out the Late Cretaceous epoch. The collision of two main tectonic plates, the Indian and Eurasian Plates, during the Middle Miocene epoch resulted in extensive molasses deposits.The Indus Basin, which runs through the northwestern section of the Indo-Pakistan peninsula, is divided into three parts: Upper (Kohat and Potwar), Middle (Sulaiman), and Lower (Kirthar).

## 3.2 Sembar Formation

The Sembar Formation is 133 meters thick on average. The name "Sembar" refers to thetype locality of this formation, which is Sembar Pass. The Sembar Formation's lithology contains black-colored shale with inter bedded Siltstone. These Glauconitic- siltstone and Shale are common.

This formation forms a gradational contact with the Cretaceous Goru Formation above it, whereas the lower contact is unconformable with Jurassic age formations. Sembar Formation has a geologic date of Early Cretaceous (Iqbal et al., 1980).

## 3.3 Goru Formation

Goru Formation is 536 meters thick on average. The Goru Formation's main lithology is shale, with inter-bedded Siltstone as well as containing Limestones. Shale is prevalent in the bottom part of the formation with thin beds of limestone which is tarnished light grey, while thin bedded limestone makes up the majority of the top half of the formation. The Fossils found in this deposit are Foraminifera and Belemnite (Iqbal et al., 1980). The Goru Formation is divided into two members, which are listed below.

### 3.3.1 Lower Goru Member

The change in lithology from Marl to Claystone characterizes the top portion of the Lower Goru component. Lower Goru Shale is dark grey in colour, somewhat hard, sub platy, sub fissile, mildly Calcareous, Silty, and grades to Siltstone locally. Siltstone,on the other hand, is light grey in color, friable, calcareous (calcium carbonate) and Glauconitic in places, and grades to fine sandstone locally (Iqbal et al., 1980).

### 3.3.2 Upper Goru Member

Upper Goru is a part of the Upper Cretaceous age. The lithology of the top portion of the Upper Goru varies from Sandstone, Clay-stone, Marl, and Limestone, respectively. In the higher section, Marl grades to Argillaceous Limestone and is light to medium grey in colour, compacted, sub blocky, with Silt and Sand. Limestone is medium to dark grey in colour, slightly hard, sub blocky, Argillaceous (higher clay content), and grading to Marlin some locations. Upper Goru shale is dark grey in color, somewhat hard, sub Fissile, and changes to calcareous Clay stone with time (Iqbal et al., 1980).

### 3.4 Pir-Koh Limestone

Thick bedded Limestone dominates the lithology of this formation, with intercalations of greenish grey Marl and Shale. The geologic age of this formation is Middle Eocene,and it was formed in a shallow marine environment (Iqbal et al., 1980).

### 3.5 Mughal Kot Formation

The nature of this formation is extremely heterogeneous. The primary hue of this formation is dark grey, and its lithology includes Calcareous Mudstone with Quartzite sandstone and argillaceous Limestone intercalations (Clay dominant). The summit of this formation is marked by a dark-colored Limestone that is widely dispersed and known as the Fort Munro Limestone component. Dolomite (Calcium Magnesium Carbonate) dominates the upper section of this formation, and it is commonly associated with unconformities in that area (Kadri, 1995). This geologic formation is Upper Cretaceous inage.

### 3.6 Pab Sandstone

Vredenburg initially used the term Pab Sandstone in 1907 in the Sulaiman Fold and Thrust belt, Kirthar mountains, and Axial Belt. Moro Formation conformably overlies this Formation (Hunting Survey Cooperation, 1961). The hue of this formation ranges from light grey to light tan to brown, and the lithology includes quartzite, fine to coarse grained, hard to soft Sandstone. It's usually cross-bedded and rarely conglomeratic. Shallow maritime environment is represented by thin intercalations of dark grey Shales, which locally contain Argillaceous Micritic Limestone interbeds. This formation dates from the Upper Cretaceous period (Iqbal and Shah, 1980).

### 3.7 Ranikot Formation

This formation is similar to the Upper Paleocene Dungan Formation and the Paleocene Rakhsani Formation in southern and western Pakistan.

It's also linked to the Kohat-Potwar province's Hangu Formation (Late Paleocene) and Patala Formation (Early Paleocene) sequences.The geologic age of this strata is Lower Paleocene (Iqbal et al., 1980).

### 3.8 Dungan Formation

In the Dungan hills in Sulaiman province, the Dungan Formation is a thick limestone sequence that lies between Parh Limestone (Middle Cretaceous) and Ghazij Formation (Eocene). Massive nodular Limestone with minor Shale, Marl, and Sandstone, as well as limestone conglomerate, make up this deposit. Limestone appears to be the dominating lithology in this formation throughout the Marri-Bugti and Quetta regions. The colour of the structure ranges from dark grey to brown. This formation is known for its diverse Fossil assemblage, which includes Foraminifers and Gastropods. The geologic age of this deposit is Upper Paleocene (Hunting Survey Cooperation, 1961).

### 3.9 Habib Rahi Formation

Greenish grey,extremely hard, compact, crystalline, Fossiliferous limestone is the dominant lithology, with light grey, medium hard Marl and soft calcareous shale streaks. The geologicage of this formation is Middle Eocene, and the deposition environment was shallow marine.This formation has conformable contact with the underlying Buska Shale and Ghazij Formation's alabaster member, respectively (Iqbal et al., 1980).

### 3.10 Ghazij Formation

This formation conformably overlies the Dungan Formation (Upper Paleocene), the Laki Formation (Early Eocene), and the Ranikot group (Lower Paleocene). Along the axial belt, it creates an unconformable contact with earlier strata such as the Parh Formation (Late Cretaceous) and Shirinab Formation (Early Jurassic). The Ghazij Formation has a diverse fossil assemblage, including Foraminifers, Gastropods, Bivalves, and Algae (Iqbal et al., 1980).

### 3.11 Kirthar Formation

The Kirthar Formation (Noetling, 1903) is composed of limestone and shales inter-bedded with some Marl. This formation's Limestone is light grey cream in hue. This formation transitions over the Ghazij Formation of the lower Eocene in most locations. In different sections of the distribution, the formation is very Fossiliferous and represents distinct geologic ages .The geologic age of this deposit is Upper Eocene. (Iqbal et al., 1980).

### 3.12 Nari Formation

Sandstone and Shales with some Conglomerate constitute the Nari Formation. Quartz arenite can be found in the lowest section of this formation. Because Sandstone has a high porosity and permeability, the Nari Formation could be used as a reservoir rock (Iqbal et al., 1980). Nari Formation is approximately 1400 meters thick. Kirthar Range is the type locality (Gaj River section).The geological age of this deposit is upper Eocene.

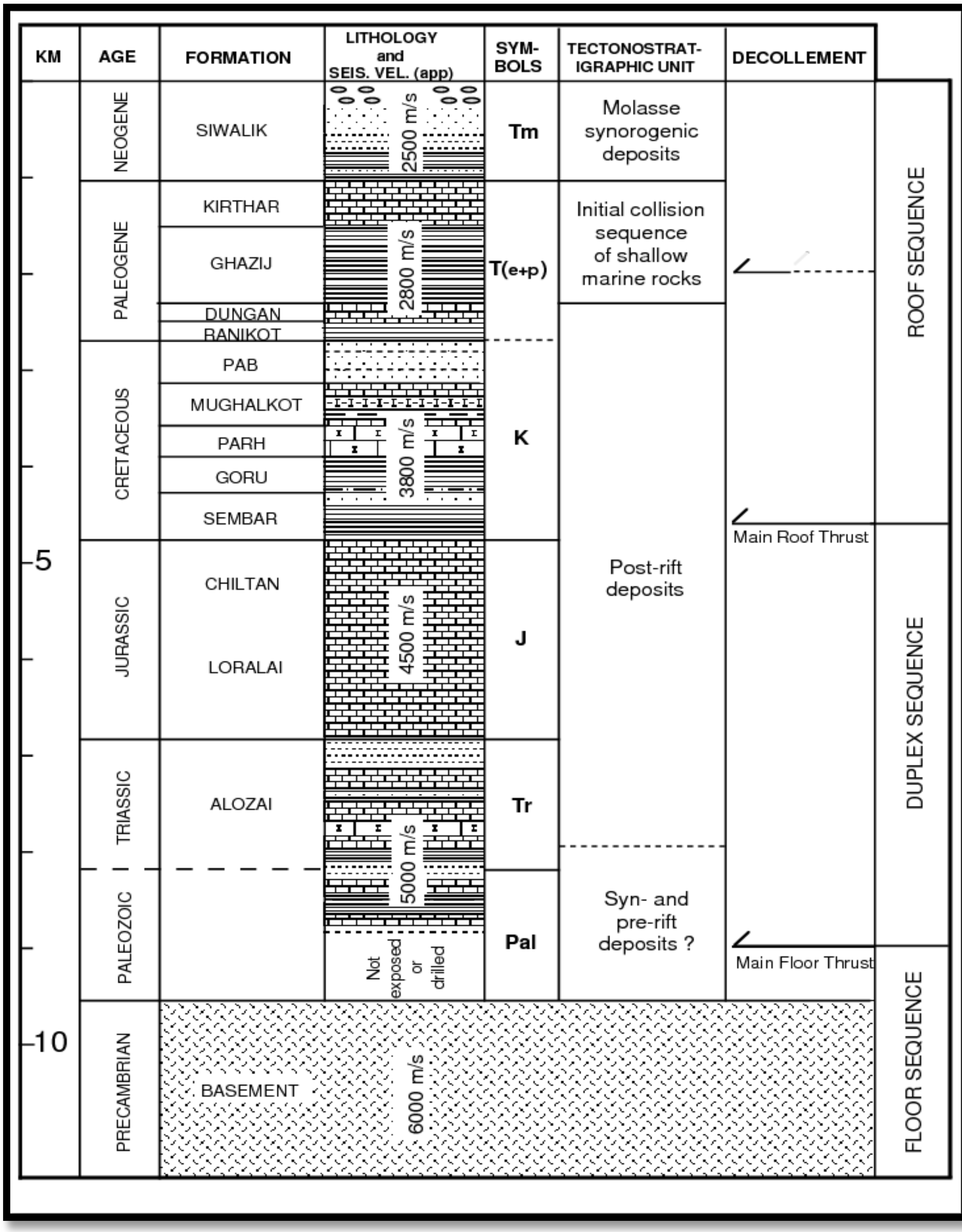


**Figure 3.1** shows generalized Stratigraphy of Study area (Jadoon et al., 1992).

| FORMATION | FORMATION TOP AGE | FORMATION TOP(m) | THICKNESS (m) |
|---|---|---|---|
| DRAZINDA SHALE | LATE EOCENE | 0.0 | 480.0 |
| HABIB RAHI LIMESTONE | LATE EOCENE | 480.0 | 30.0 |
| ALABASTER SHALE | EOCENE | 510.0 | 138.0 |
| RUBBLY LIMESTONE | EOCENE | 648.0 | 296.0 |
| GHAZIJ SHALE | EARLY EOCENE | 944.0 | 864.0 |
| DUNGAN | LATE PALEOCENE | 1808.0 | 26.0 |
| UPPER RANIKOT | EARLY PALEOCENE | 1834.0 | 95.0 |
| LOWER RANIKOT | EARLY PALEOCENE | 1929.0 | 150.0 |
| PAB SANDSTONE | LATE CRETACEOUS | 2079.0 | 39.0 |

**Figure 3.2** Borehole stratigraphy of Dhodak-01 well

| FORMATION | FORMATION TOP AGE | FORMATION TOP(m) | THICKNESS (m) |
|---|---|---|---|
| DRAZINDA SHALE | LATE EOCENE | 0.0 | 210.0 |
| PIRKOH LIMESTONE | LATE EOCENE | 210.0 | 10.0 |
| SIRKI-DOMANDA | LATE EOCENE | 220.0 | 265.0 |
| HABIB RAHI LIMESTONE | LATE EOCENE | 485.0 | 35.0 |
| ALABASTER SHALE | EOCENE | 520.0 | 175.0 |
| RUBBLY LIMESTONE | EOCENE | 695.0 | 319.0 |
| GHAZIJ SHALE | EARLY EOCENE | 1014.0 | 829.0 |
| DUNGAN | LATE PALEOCENE | 1843.0 | 14.0 |
| UPPER RANIKOT | EARLY PALEOCENE | 1857.0 | 109.0 |
| LOWER RANIKOT | EARLY PALEOCENE | 1966.0 | 159.0 |
| PAB SANDSTONE | LATE CRETACEOUS | 2125.0 | 39.0 |

**Figure 3.3** Borehole stratigraphy of Dhodak-05 well

# PETROLEUM PLAY

## 3.13 Petroleum system

The Central Indus Basin is a gas province in Pakistan that has over 70% of the country's known gas reserves. The Upper Cretaceous and Tertiary reservoirs comprises the majority of the known reserves. The potential of the Central Indus Basin's lower cretaceous sandstone play has been further indicated by the considers of Kadanwari, Miano, Mari deep, and Sawan. The existence of viable petroleum systems in the region is demonstrated by the producing sites in the southwest (Dhodak, Nandpur, and Panjpir).

### 3.13.1 Source rocks

The fundamental producing rock that is producing the hydrocarbon is known as the source rock. Shale, which has a total organic content of reaches till 31% which is recognized as a great source rock. The Jurassic-era Datta and Shinwari formations have very suitable to good potential. The Datta Formation in the Nandpur-1 well is in the start of the oil window.Based on the pyrolysis outcomes, Paleocene-aged Ranikot Shale has a TOC of 3.48%. Shale from the Paleocene (Ranikot Patala) contains a Type III kerogen TOC of up to 3.47%. In Dhandi-1 and Sabzal-1, the Sur Formation shale exhibits excellent source potential. Sembar Formation and Interclations of shales are acting source rock for Dhodak field, which plays really pivotal role in the formations of Hydrocarbons in that region. Sembar Formation and Interbedded shales of Goru Formation are acting as Source rock in that vicinity.

### 3.13.2 Reservoir rocks

In Khaur Dhulian, Dina, Dhadumbar, Balkassar, Joya Mir, and other tiny fields in the Potwar Sub basin, the fractured carbonates of Sakesar and Chorgali formations of

Eocene epoch are the principal producing reservoirs (Kadri, 1995). Moreover, Pab Sandstone, Lower Ranikot and Dungan Limestone acts as reservoir rocks in Dhodak Field. Our main target to study is Lower Ranikot Formation.while Dungan and Pab Sandstone are also acting as reservoir in that area.

### 3.13.3 Seal rocks

Cretaceous period begins with a global rise in sea level. The start of the Cretaceous represents a global rise in sea level, allowing organic life to flourish. Cretaceous Shales from the Sembar Formation are wide which contains huge amount of organic elements. The source rock in the Dhodak locality has been formed at anoxic condition. The principle source rock is characterized as the Sembar for the most part of the Indus Basin locality which consists of Type-III kerogen, that has the capability of production of gas (Shah, 2004). In our vicinity Ghazij Formation is giving capping mechanism to our area.

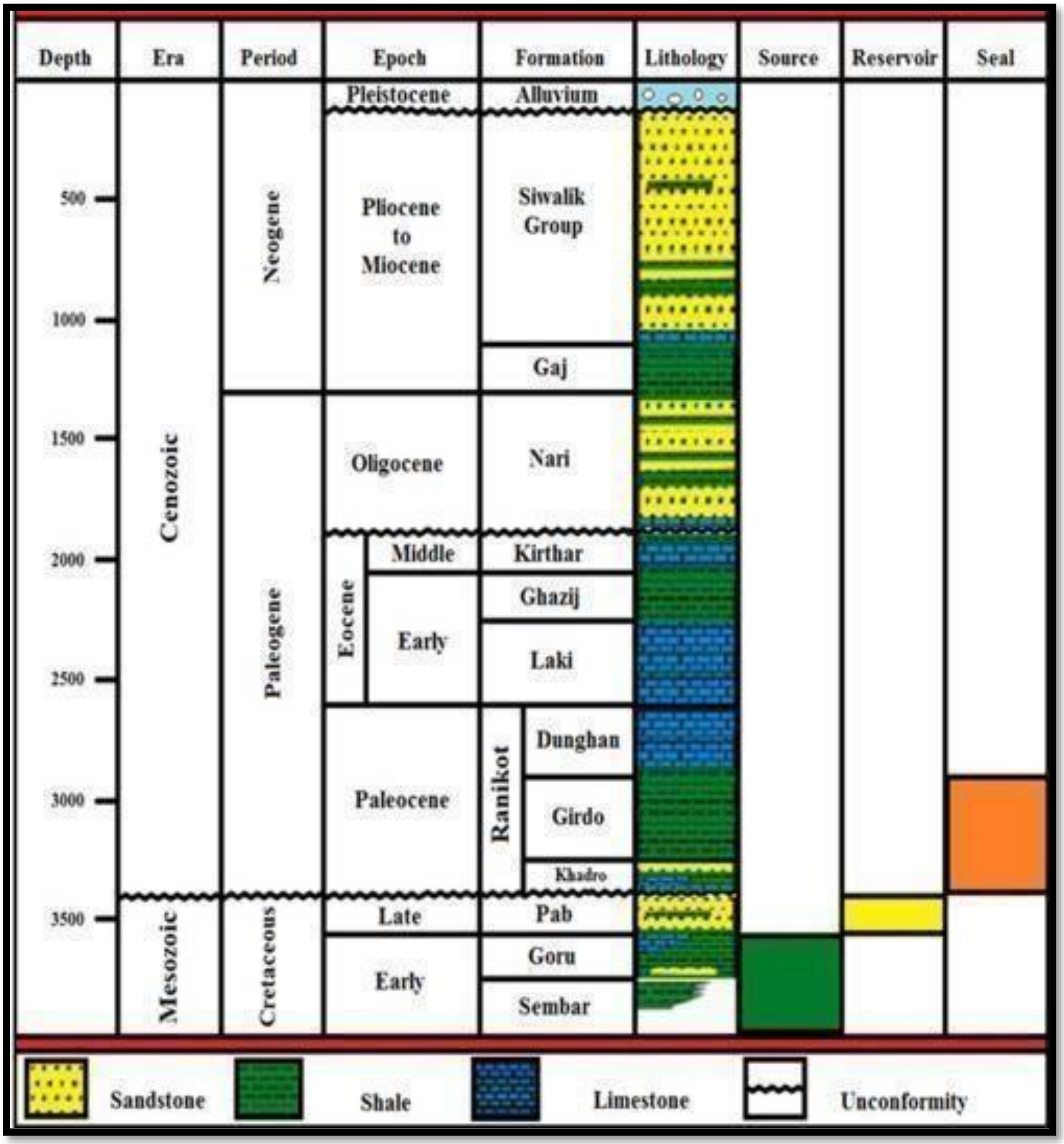


**Figure 3.4** Shows Petroleum geology of Suleiman Fold belt (Abbasi et al., 2016)

# CHAPTER 4

# SEISMIC INTERPRETATION

## 4.1 Introduction

After the completion of Seismic data acquisition and processing, one of most important steps is Seismic Interpretation. The main objective of seismic interpretation is to detect the hydrocarbon prospect to analyze the subsurface geological structures. Seismic reflection method illustrates only on the geological structures.

The goal of interpretation is to get the exact and maximum information of hydrocarbon accumulation and measure the appropriate velocities with the assistance of reliable equations (Dobrin and Savit, 1988). Initially, Seismic interpretation of the Control line 785-SK-04 started. Reflectors were identified by matching the well tops which are in time domain and wells were converted into time with the help of available velocity surveys. Three major horizons have been marked for that analysis on Four Seismic lines. While Two wells Dhodak-01 and Dhodak- 05 are seen in Basemap. But unfortunately data was not sufficient to further persue Dhodak-01.So we persue only Dhodak-05 for further interpretational processes.

Pab Sandstone is proven reservoir in central Indus Basin. So we are more concerned about Lower Ranikot which is marked as our concerned reservoir and Dungan Formation (Dungan Limestone).

Three faults have been marked. The horizons and fault depicts that area lies in compressional regime. So Reverse faulting, thrusting is occurring here. Popup structure has been made in that area. Which is also indicator of probable petroleum system. Specifically of the thrusting areas, Identification of reflectors were done by Jump correlation method.The structure is clearly identified as an anticline as its high angle from the middle while lower angle at flanks.

Initially, 785-SK-04 was interpreted which is strike line, Dip lines which were GO-795-SK- 11 and 855-SK-31 wasn’t marked because it was causing mistie and affecting Grids. SK-28 was later on interpreted and tied on SP number 195. Similarly afterwards interpretation of other line were done SK-27 tied at SP number 181 and SK-29 was tieing at SP 196.5. Such process assists us to correlate the ties and to avoid any sort of misties.

Seismic modeling depicts the generation of travel times and amplitudes of seismic waves traveling through a described subsurface reflectivity design .Seismic Interpretation hasstarted from Line nearest to the Dhodak-01 & Dhodak-05 is considered to be as Control line 785-Sk-05. The alignment of this line is towards North to Southern Side.

During Seismic interpretation process, Base map is generated in Kingdom suite 8.6. Several lines are passing through it. One control line (Strike Line) while others Dip lines are passingthrough it. While Two Wells lies in that area. Dhodak-01 and Dhodak-05.

## 4.2 Analysis of Interpretation

For Seismic interpretation, there are two main statements that are utilized.

1. Structural evaluation
2. Stratigraphical evaluation

### 4.2.1 Structural evaluation

It illustrates how the time reflection was determined to be its primary parameter. By observing the geometries of the structure we predict and relate the petroleum play considering the most important part is Time. Anticlines, Synclines, Flanks, Pop up structure as Structural terms. Moreover, Structural interpretation is used for the two-way reflection times which is prefers the depth as well as time structural maps which are constructed to illustrate the geometric display of the selected reflection events.

Some seismic images are easy to for interpretation purpose. The discontinuous pattern between reflections illustrates the faults that undulates the refection shows that folded beds of rocks are there (Sheriff and Geldart,1995).

### 4.2.2 Stratigraphical Evaluation

It depicts to analyze stratigraphic approach which comes apart to seismic reflection classification. Sedimentary classifications are closely linked with seismic structures. As, environmental conditions fluctuates throughout the history. So depositional environment plays vital role in stratigraphic analysis.

## 4.3 Seismic interpretation flow chart

Following setups are required for the seismic interpretation process which tells the structural and stratigraphic analysis.

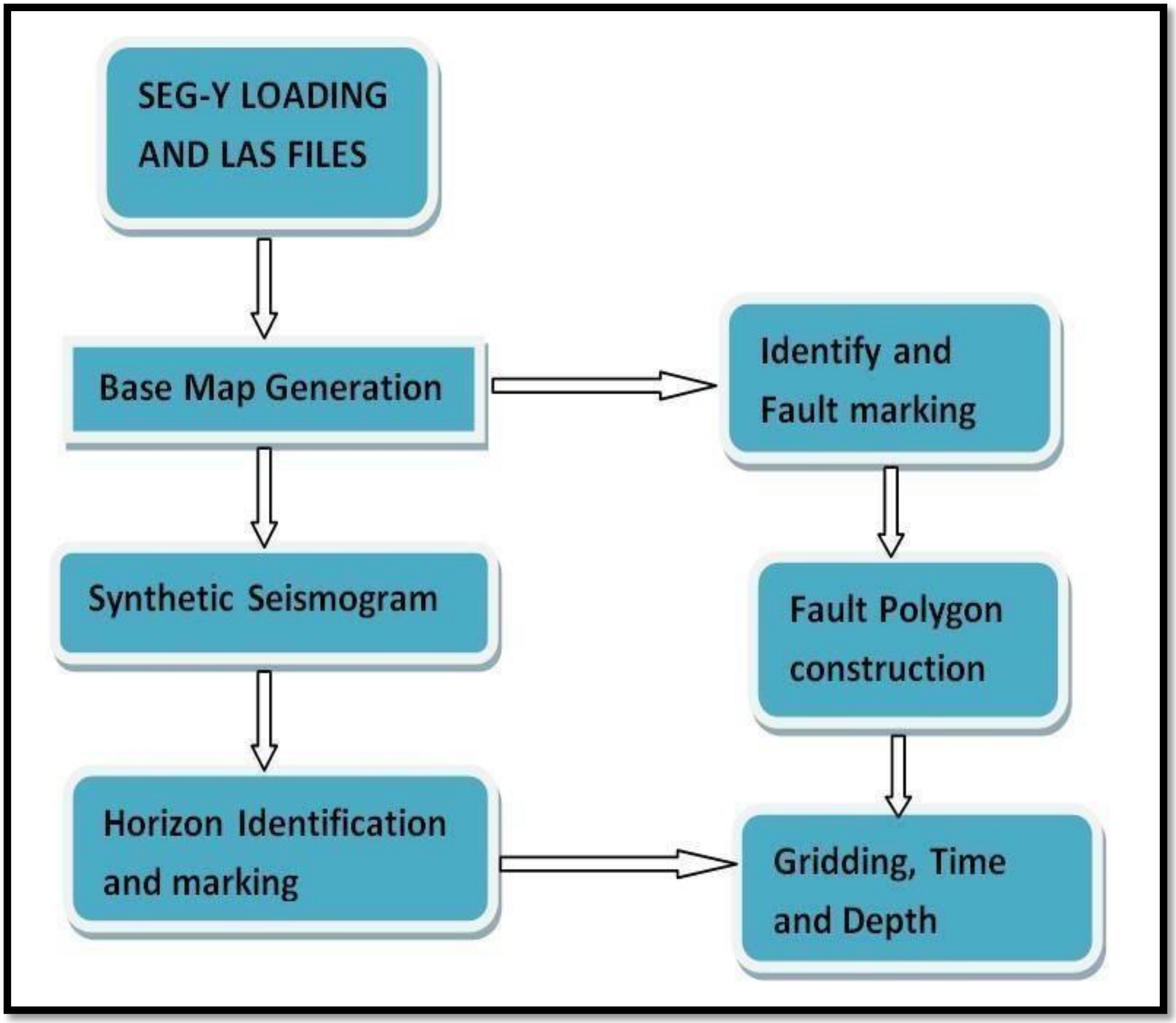


**Figure 4.1** Workflow of Seismic interpretation.

### 4.4 Base map Generation

Base map is most important component of the seismic interpretation, which gives assistance to seismic lines, and location of wells etc. One strike line and four dip lines are used to create the base map from 2D seismic reflection of the area, as shown in (Figure 4.2).

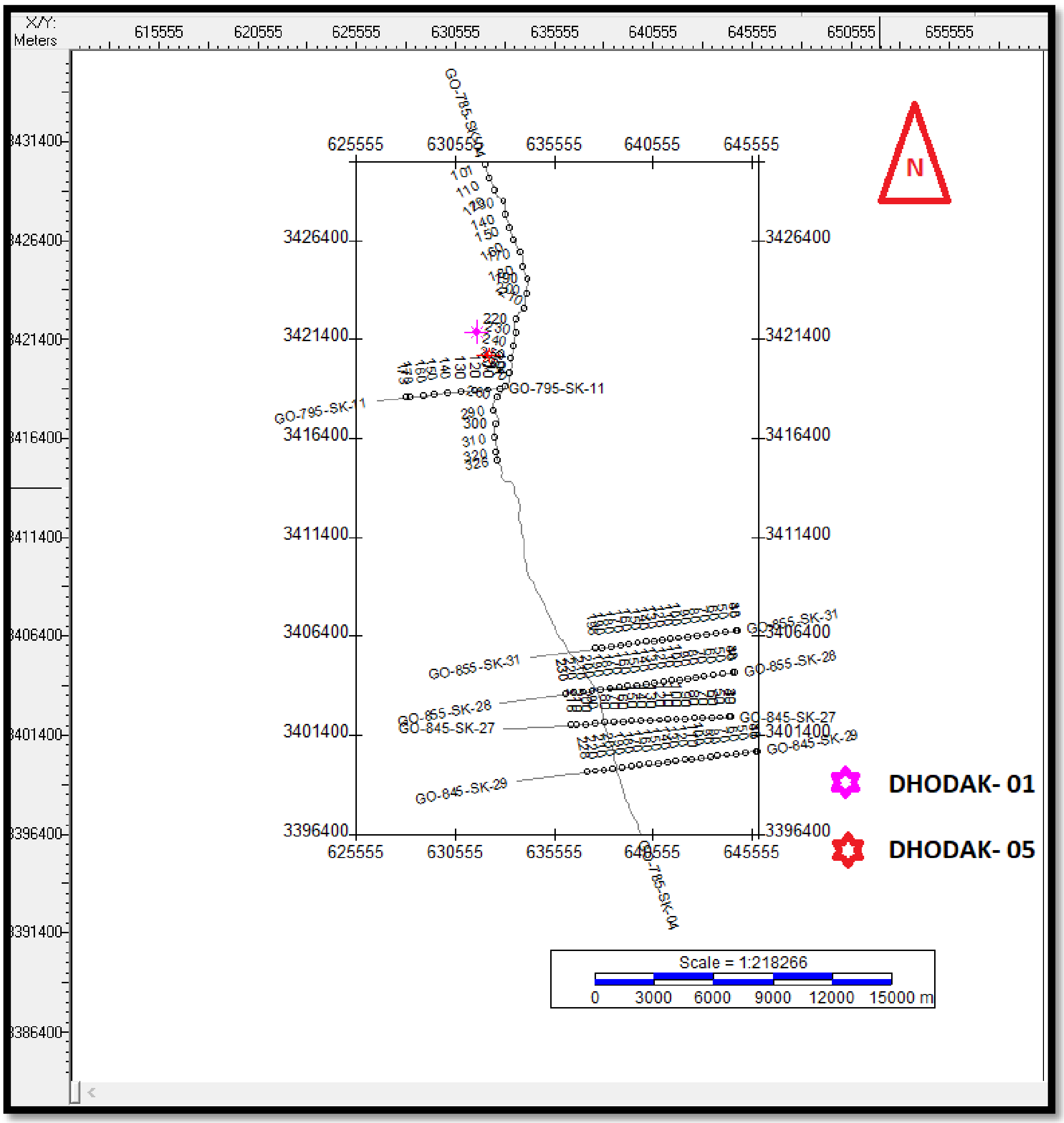


**Figure 4.2** Generated Basemap with the help of Kingdom software.

## 4.5 Control line

The well Dhodak-01 and Dhodak-05 lies very close to strike line while Dip lines lies at southern side by which control line is passing through 795-SK-11, 855-SK-31-855-SK-28, 845-SK-27, 845-SK-29.

## 4.6 Seismic to Well tie

Formation Depth = Formation Top – Kelly Bushing (KB) + Seismic Reference Datum(SRD) Seismic Reference Datum = 700 m , Kelly Bushing = 516.4m

For the calculation of the formation depth, it is really necessary to get the Kelly Bushing (KB) and seismic reference datum(SRD) on the equal elevation, otherwise variation of the elevation will result into incorrect depth values. Formation depth comes by subtracting the KB value by Formation Top.

**DATUM EQUIVALENT FORMULA OF (DHODAK-01)**

- Formation Depth = Formation Top + Seismic Reference Datum– Kelly Bushing

| FORMATION | FORMATION DEPTH = FORMATION TOP – KELLY BUSHING + SEISMIC REFERENCE DATUM | FORMATION DEPTH (m) | TWO WAY TIME (sec) |
|---|---|---|---|
| DUNGAN | 1808-513.7+700 | 1994.3 | 0.86 |
| LOWER RANIKOT | 1929-513.7+700 | 2115.3 | 0.96 |
| PAB SANDSTONE | 2079-513.7+700 | 2265.3 | 0.99 |

**Figure 4.3** Two Way Time calculation of Dhodak-01.

**DATUM EQUIVALENT FORMULA OF (DHODAK-05)**

•Formation Depth = Formation Top + Seismic Reference Datum– Kelly Bushing

| FORMATION NAME | FORMATION DEPTH = FORMATION TOP – KELLY BUSHING + SEISMIC REFERENCE DATUM | FORMATION DEPTH (m) | TWO WAY TIME (sec) |
|---|---|---|---|
| DUNGAN | 1843-516.4+700 | 2026.6 | 0.92 |
| LOWER RANIKOT | 1966-516.4+700 | 2149.6 | 0.96 |
| PAB SANDSTONE | 2125-516.4+700 | 2308.6 | 1.03 |

**Figure 4.4** Two Way Time calculation of Dhodak-05

## 4.7 Synthetic seismogram

Obtaining the correlation of the seismic data with the well data is Synthetic seismogram generation method. In initial tracks we have Sonic and Density curves relationship. So resultant gives Acoustic Impedance contrast and Reflection Coefficient (RC). Ricker wavelet has been taken while, GR log is reference log. Control line traces have been matched with borehole traces, Lower Ranikot is our reservoir. So we are more concerned about that. 52 % is correlation, while Ricker wavelet is used for that purpose.

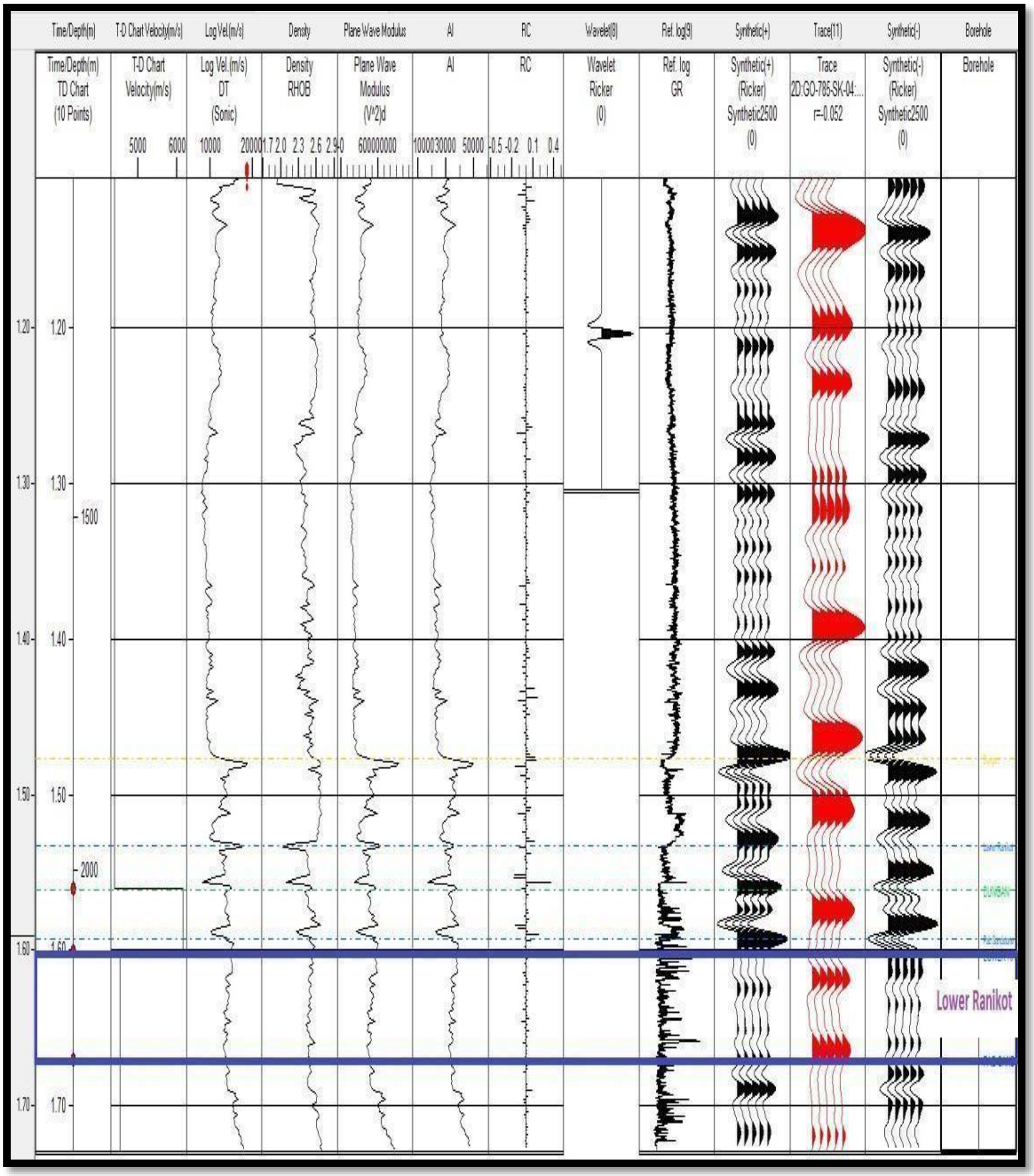


**Figure 4.5** Depicts that Synthetic Seismogram of Dhodak-05 well correlation

## 4.8 Identification of reflectors

Seismic section comprises of combination of traces. Firstly during seismic data interpretation dominant reflection is marked on it. Such reflections illustrates good features and continuous pattern tracked through area (Badley et al., 1985).

Prominent reflectors are picked on seismic section by seismic to well tie with the help of velocity analysis along shot point of Dhodhak-05 well. For marking of reflector time of every formation computed for formations of interior, Seismic sections are in time domain. As the given depth value of Formations tops considered with reference to Kelly Bushing (KB). Conversion into Seismic Reference Datum (SRD) is really necessary in order by use of formula for marking them on seismic section. This phenomenon is called Seismic, Well tie method (Badley et al., 1985).

## 4.9 Horizon marking

When a hanging wall exists, the horizon must be significantly raised as compared to corresponding foot wall, whenever a foot wall is present, the horizon should be substantially lowered in relation in accordance with horizon when the compressional regime is in effect.

Following are the horizons chosen of these formations:

1. Dungan
2. Lower Ranikot
3. Pab Sandstone

### 4.9.1 Fault marking horizons

Fault is gap or break in the continuous pattern of reflector. Structural analysis illustrates that they creates variety of traps of hydrocarbon accumulation. Horizons depicts the prominent factor of reflection Fault is gap or break in the continuous pattern of reflector. Structural analysis illustrates that they creates variety of traps of hydrocarbon accumulation from where Horizons depicts the prominent factor of reflection coefficient that illustrates the prospect area of tectonic and stratigraphic variations (Yilmaz, 2001)

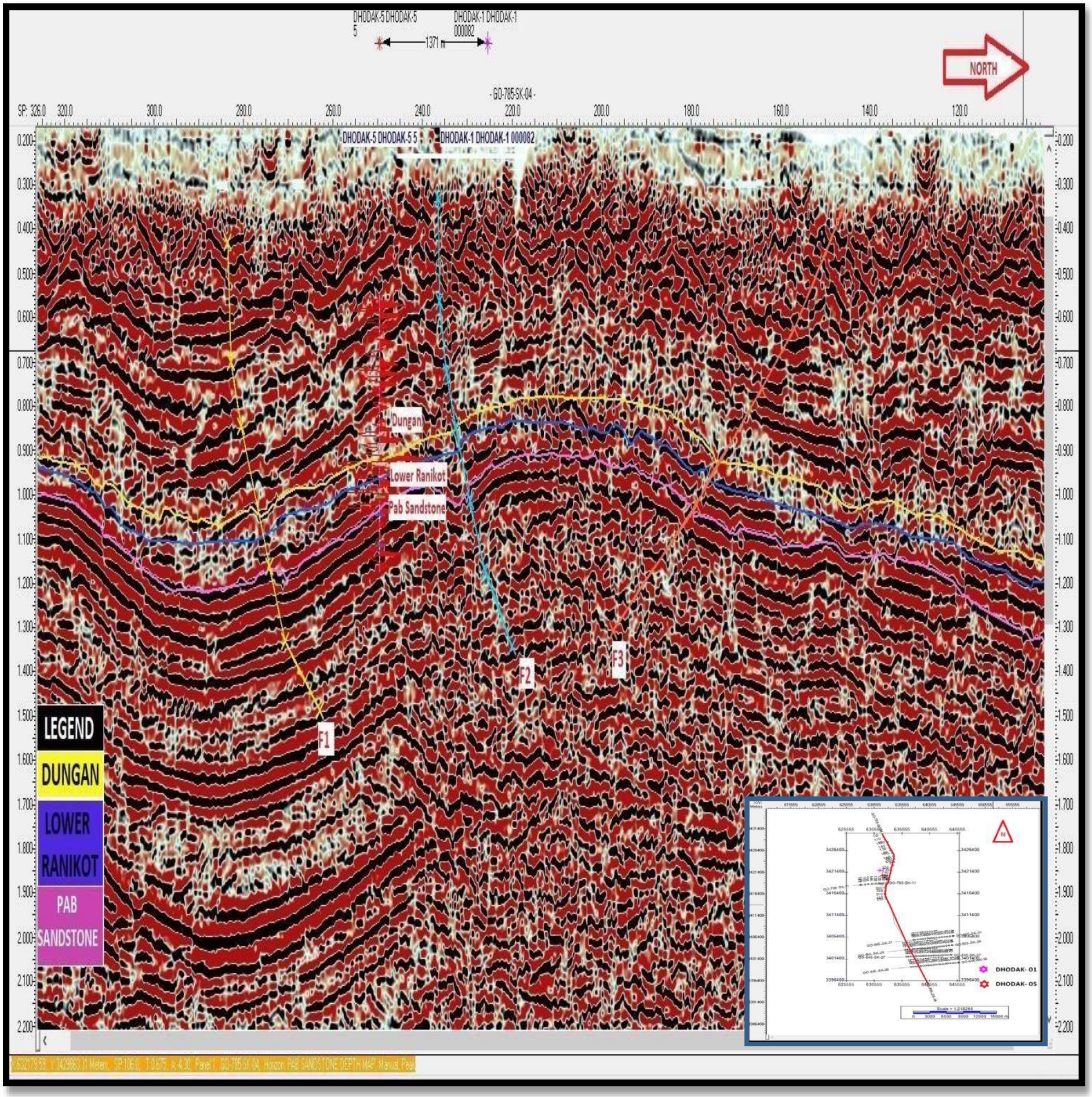


**Figure 4.6** Interpreted Seismic line 785-Sk-04

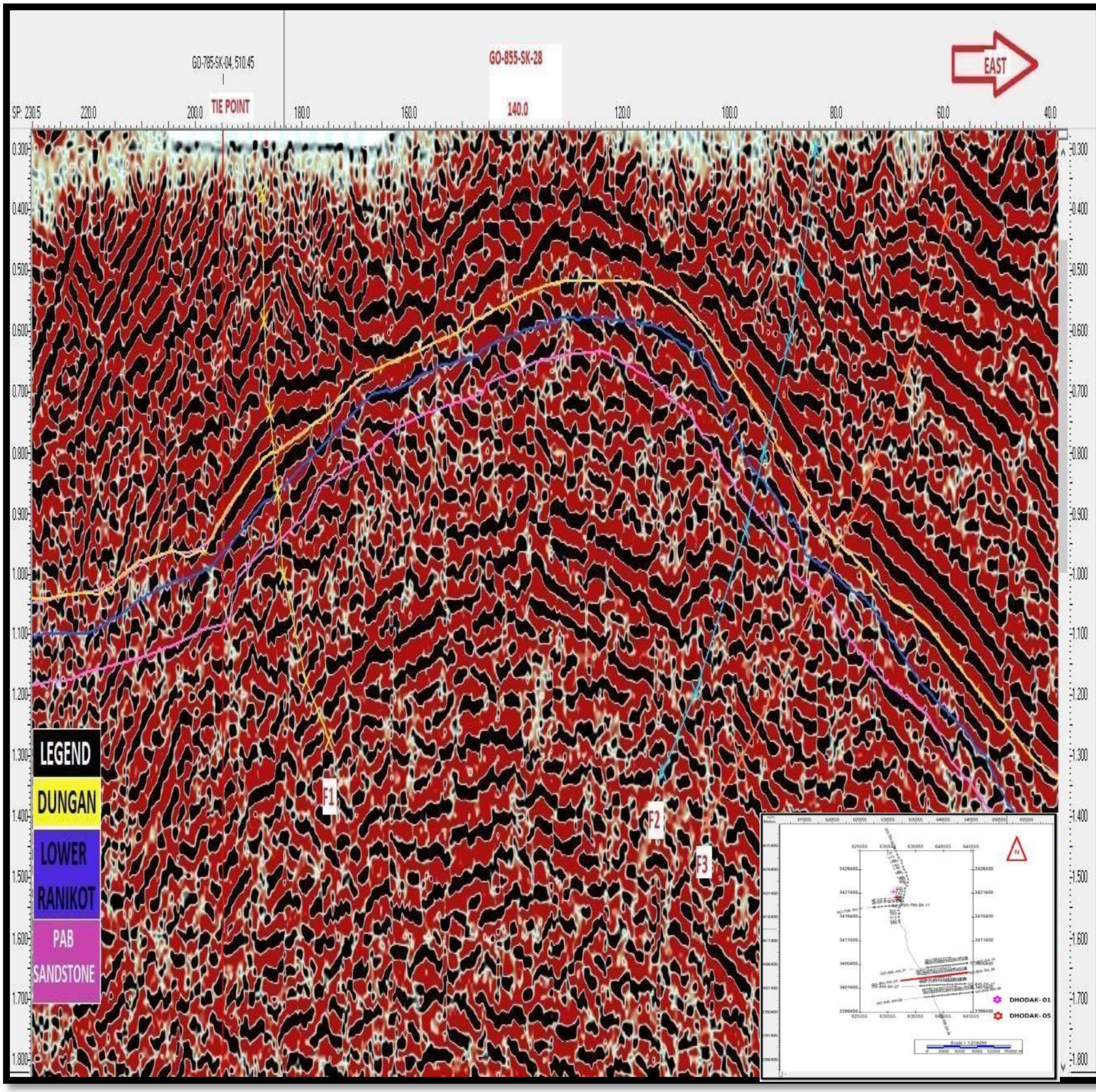


**Figure 4.7** Interpreted Seismic line 855-Sk-28.

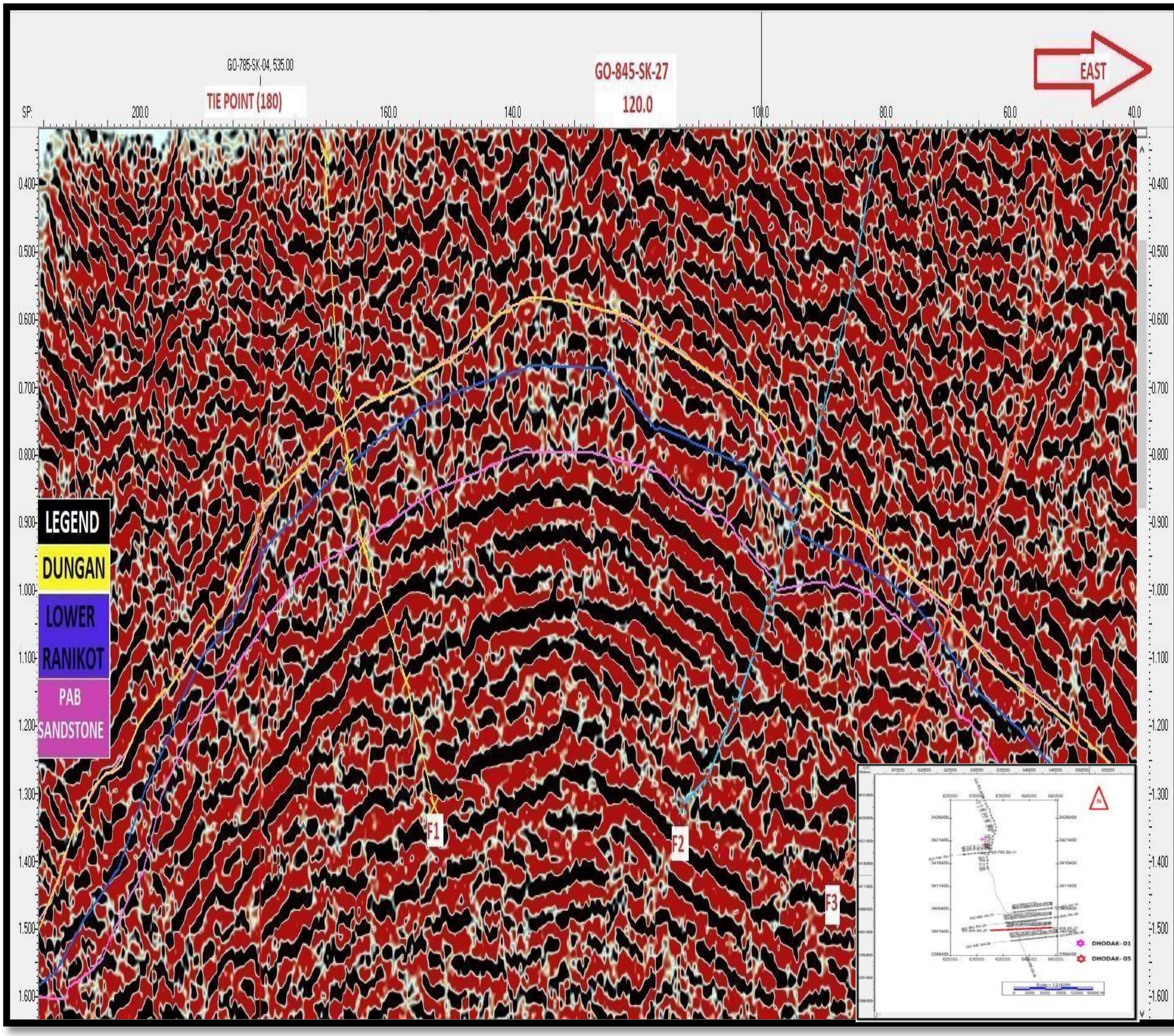


**Figure 4.8** Interpreted Seismic line 845-Sk-27.

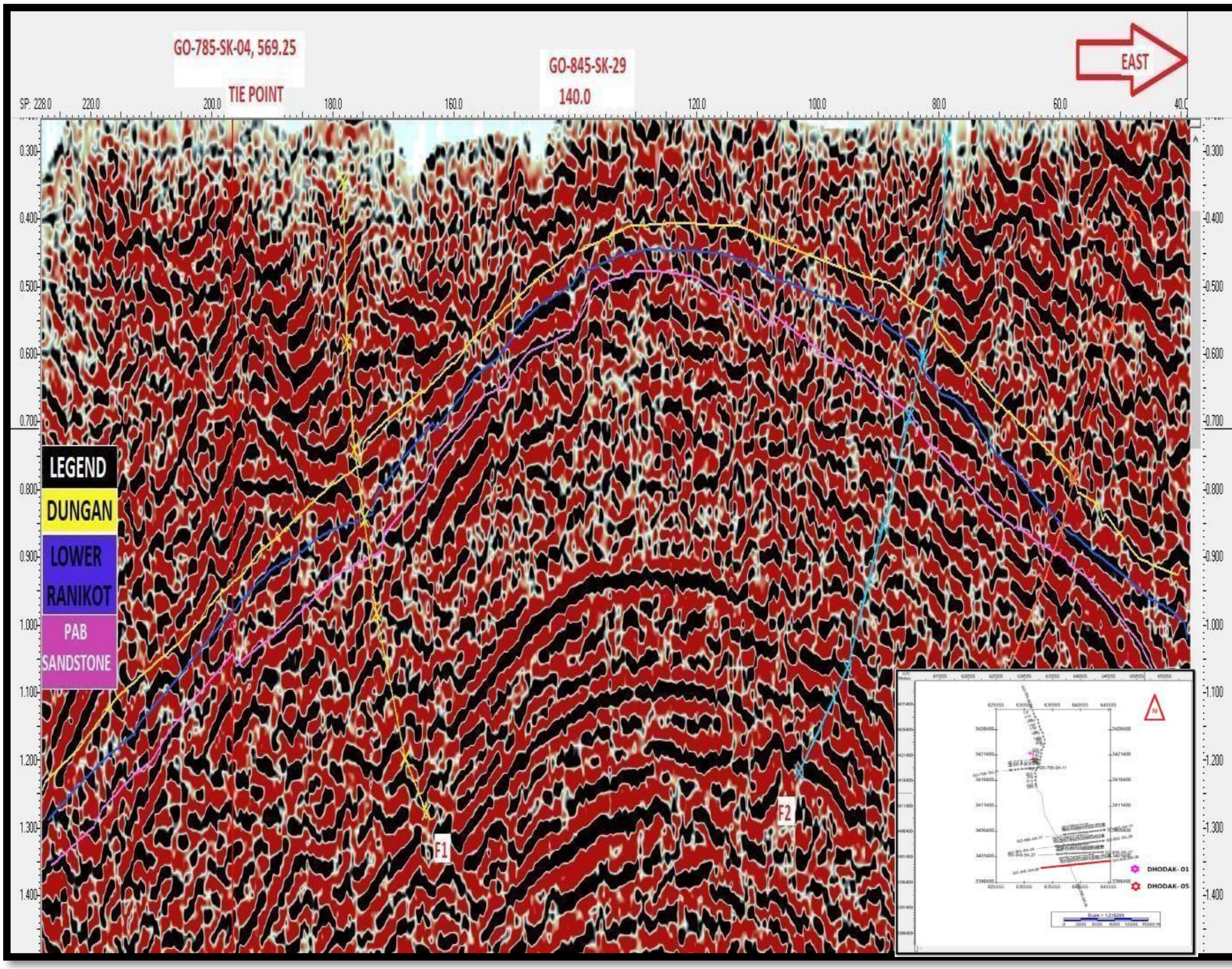


**Figure 4.9** Interpreted Seismic line 845-Sk-29.

### 4.9.2 Selection of horizon

Selection of horizon is fundamental process, 3 different formations was picked which were Dungan, Lower ranikot and Pab Sandstone formation.

## 4.10 Reflector delineation

We applied "s=v*t/2" for each point to find the depths. Whereas "v" is average velocity,"t" is time and we only require one way travel time so that, it is divided by "2"

### 4.11 Seismic lines interpretation

Seismic line is the combination of all the seismic traces of a line. Whereas each line has its specific own header which have fundamental information regarding the seismic acquisition and seismic processing. The most important aspect of interpretation of seismic lines is to identify the correct horizons , selection of fault as well, if there is any.

### 4.12 Structural interpretation of Dhodak area

Anticlines and faults are the common structural features and most favorable for oil and gases. The study area was located in compressional regime. So that thrust faulting occurs due to compressive stresses. The structure formed due to these thrust faults is “Popup structure”. Whereas, almost all the production of hydrocarbon took place by this pop up structure. The gap in seismic section illustrates the faults, sinuous reflections illustrates folds in seismic section.

### 4.13 Contour maps

Generation of these contour maps is done by kingdom 8.6 software. The line connects points of equal values is contour line. The usage of contour map is to analyze the slope steepnesses and elevation of the sedimentary rock's subsurface. The Two Way Travel(TWT) of horizon illustrated the seismic interpretation.

### 4.14 Time contour map

The use of all seismic lines in the creation of Time contour maps is a crucial aspect. On the base map, each horizon and fault's two-way time (TWT) is indicated which is contoured to create time contour map. First of all faults were marked and then fault polygon or fault boundary was created. The marking fault point is “fault cut”. Then the TWT is contoured.

### 4.14.1 Time contour map of Dungan Formation

The contour interval of time contour map of Dungan Formation is 0.02 seconds. It illustrates that the area lies in the compressional regime which was also marked in seismic sections. The central portion in between the faults shows shallow area that illustrates the occurrence of Pop-up structure.

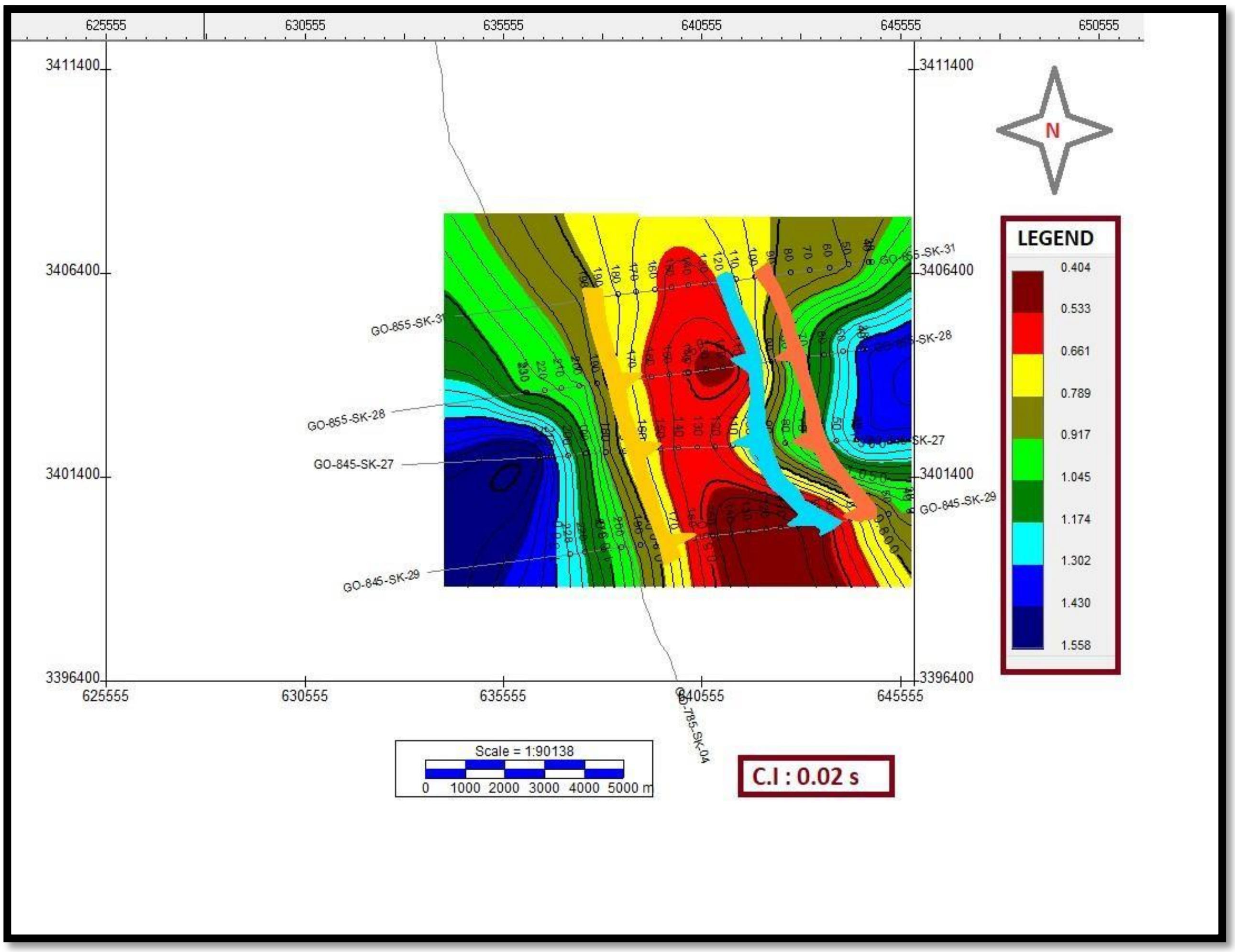


**Figure 4.10** Time contour map of Dungan Formation.

### 4.14.2 Time Contour map of Lower Ranikot Formation

The contour interval of Lower ranikot contour map is 0.02 seconds. One decollement fault and two back- thrust is considered in mapping of Lower Ranikot Formation and Pab Sandstone Formation. Map shows the fluctuations in time of subsurface Lower Ranikot Formation. Brown to red colour shows minimum time, while dark blue colour shows maximum time. Moving west to east between Fault polygon 1 and fault polygon 2 time decreases and then towards eastern side time again increases. So where time decreases, depth also decreases that illustrates more time is required for signal to travel from deeper side.

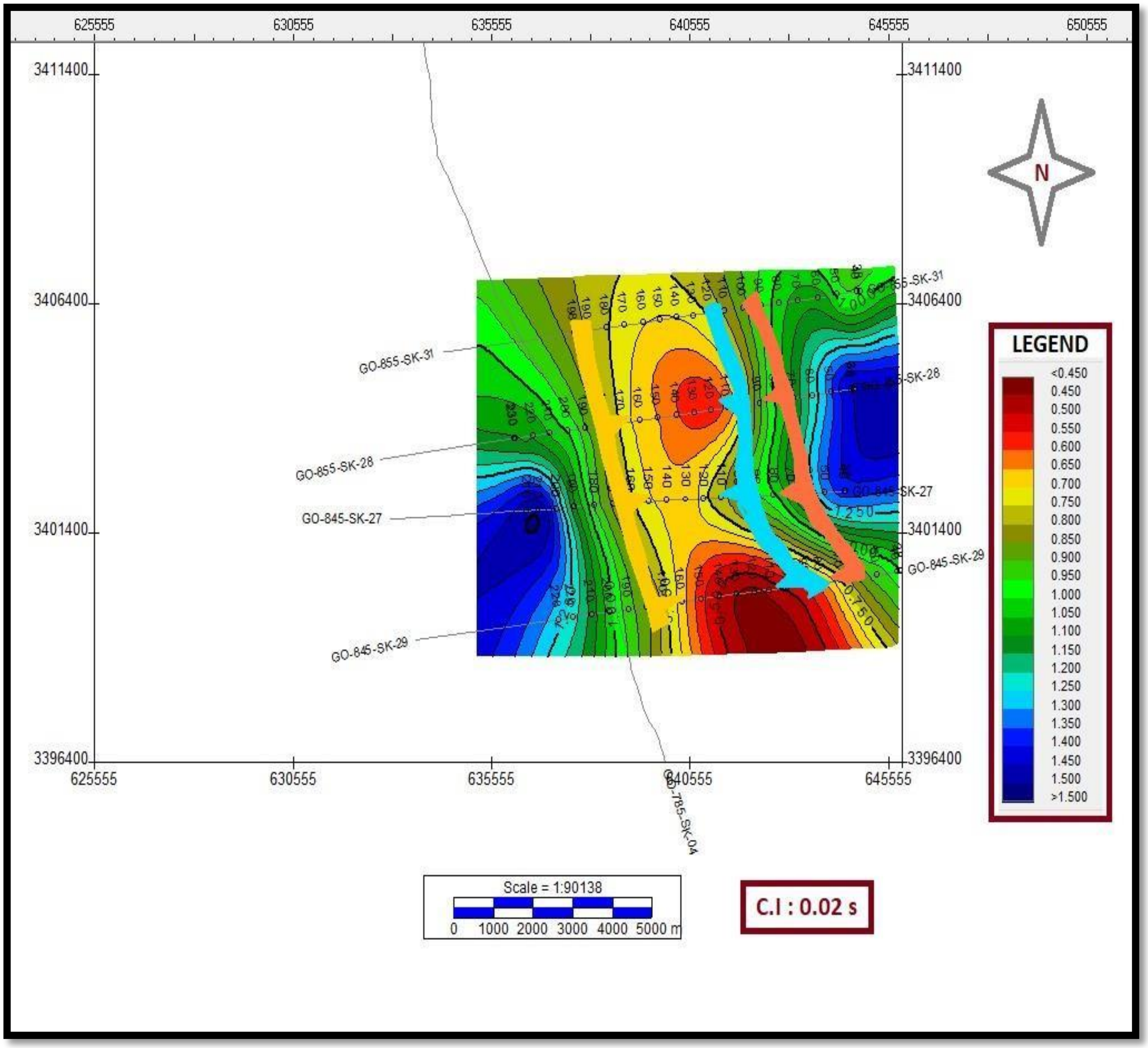


**Figure 4.11** Time contour map of Lower Ranikot Formation.

### 4.14.3 Time Contour map of Pab Sandstone Formation

Two way travel time of contour map of Pab Sandstone Formation is marked with contour interval of 0.02 seconds. This map is showing changes of time in subsurface of Pab Sandstone. Brown to red colour is showing minimum time, While dark blue colour shows maximum time. While moving west to east between fault polygon 1 and fault polygon 2 time decreases and then towards eastern side time again increases. So where time decreases, depth also decreases that illustrates more time is required for signal to travel from deeper side.

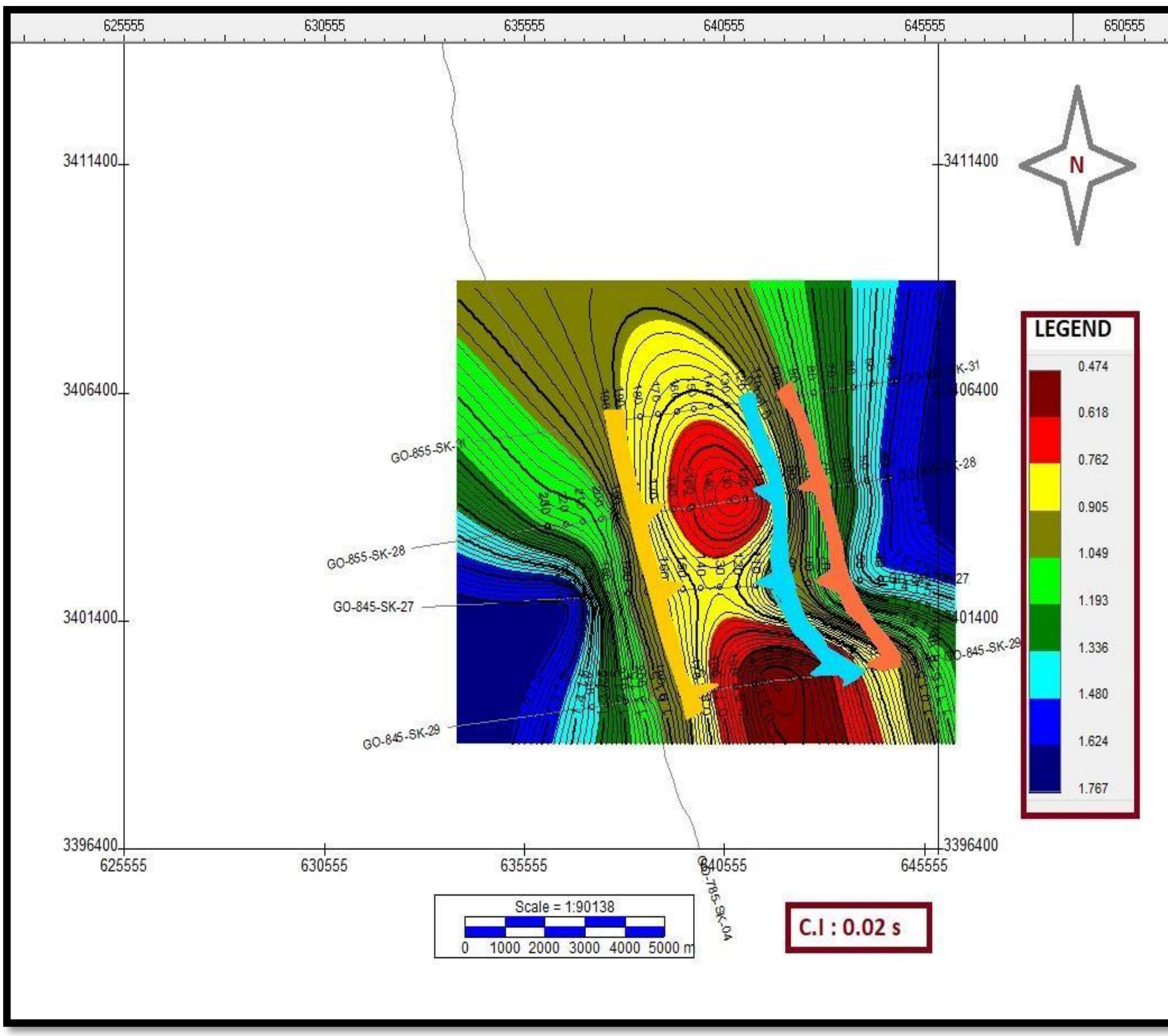


**Figure 4.12** Time contour map of Pab Sandstone.

## 4.15 Velocity analysis

For the velocity analysis, velocity panels were used which are present on the top of seismic sections. Vrms velocities are find with the help of velocity panels. Velocities are inserted using the closest velocity panel for every SP(shot point) on seismic lines. Conversion of time into depth was done by velocities as well. Velocity analysis was performed in Kingdom suite software for the making of Depth contour maps

$S = V * t / 2000$

Where $V$ = Velocity

$t$ = Time of horizon

### 4.15.1 Depth Contour maps

Time horizons converts into depth horizons corresponds to get interval velocity as Parameter. It gives idea to shallowest to deep horizons. Fault polygons also illustrates the SP number of given fault passing area. We have marked three depth contour maps of Dungan Formation, Lower Ranikot Formation and Pab Sandstone respectively. The reddish part is of shallower depth depicts reverse faulting and making Pop up structure.While moving away from that yellow to brown and green part lies as depth region as shown in scale.

### 4.15.2 Depth contour map of Dungan Formation

Depth contour map of Dungan Formation has been prepared by contour interval of 0.05m. The closeness of contours depicts the abrupt change in elevation. Depth contour maps concludes that the area lies in compressional regime as faults marked on seismic sections. Pop-up structure has made by faults and such faults enclose the possibility of the occurrence of hydrocarbons.

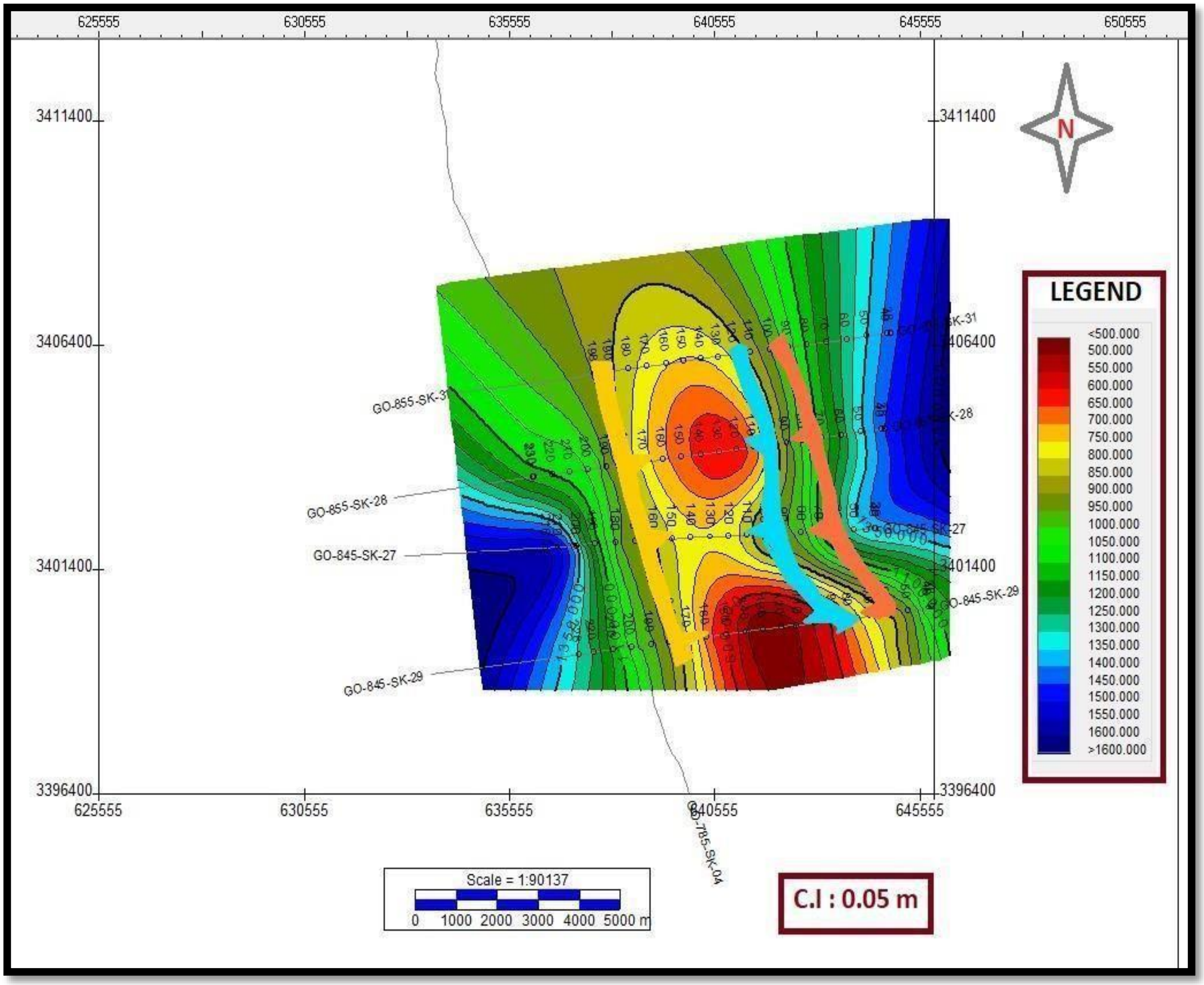


**Figure 4.13** Depth contour map of Dungan Formation.

### 4.15.3 Depth contour map Lower ranikot Formation

Depth contour map of Lower Ranikot Formation has been prepared by contour interval of 0.05m. The closeness of contours depicts the abrupt change in elevation. Depth contour maps concludes that the area lies in compressional regime as faults. One decollement fault and two back thrust has considered in mapping of Lower Ranikot Formation. The closeness of contours illustrates sudden elevation shift. Such contour maps illustrates presence of the same faults that were identified on seismic sections and the advent of a compressional regime.

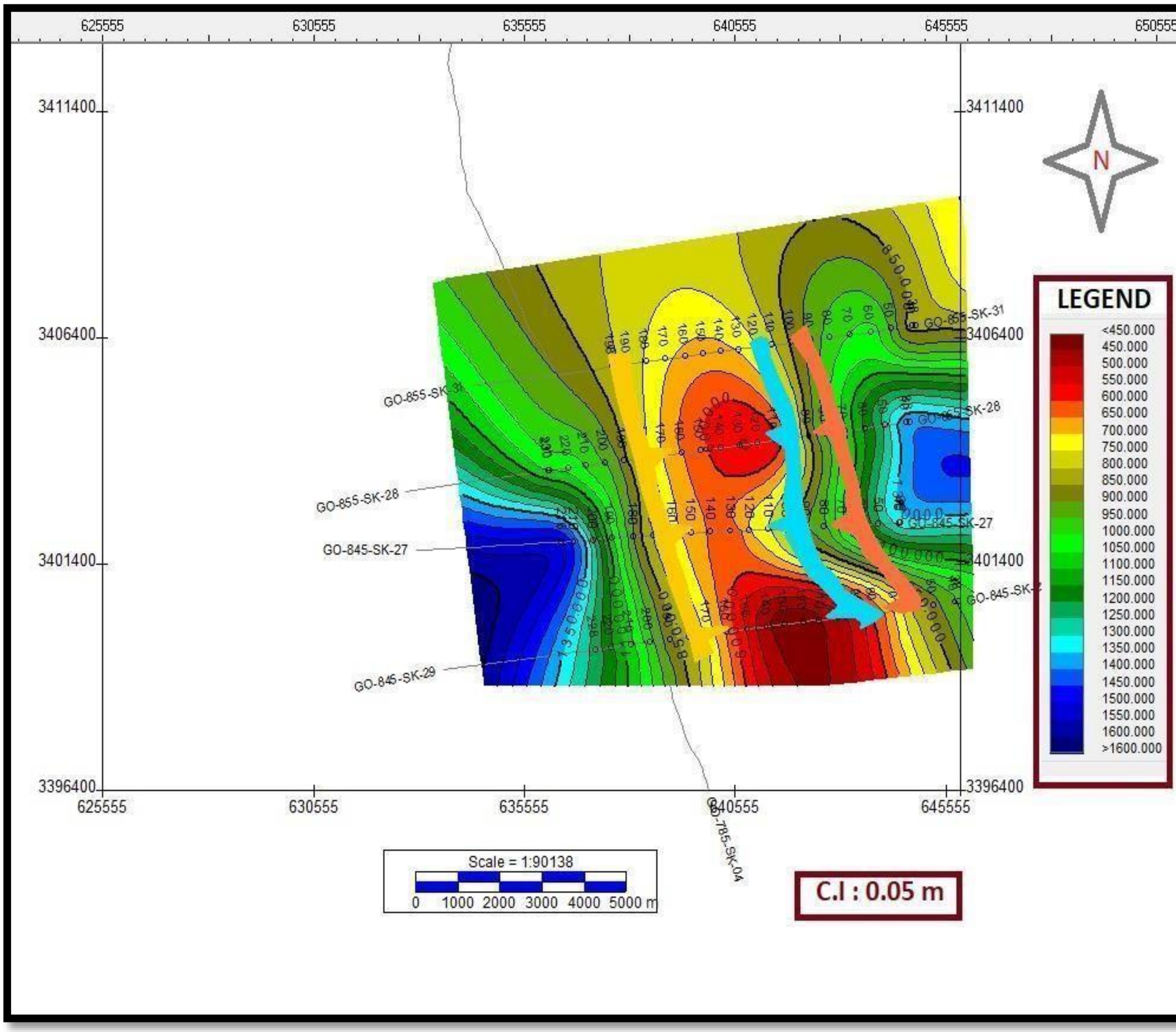


**Figure 4.14** Depth contour map of Lower Ranikot Formation.

### 4.15.4 Depth contour map of Pab Sandstone Formation

Depth contour map of Pab Sandstone Formation has prepared by contour interval of 0.05m. The closeness of contours depicts the abrupt change in elevation. Depth contour maps concludes that the area lies in compressional regime as faults. One decollement fault and two back thrust has considered in mapping of Pab Sandstone Formation. The sharp shift in elevation depicts the closeness of the contours and less depth values while moving away from that shows greater values and greater depth.

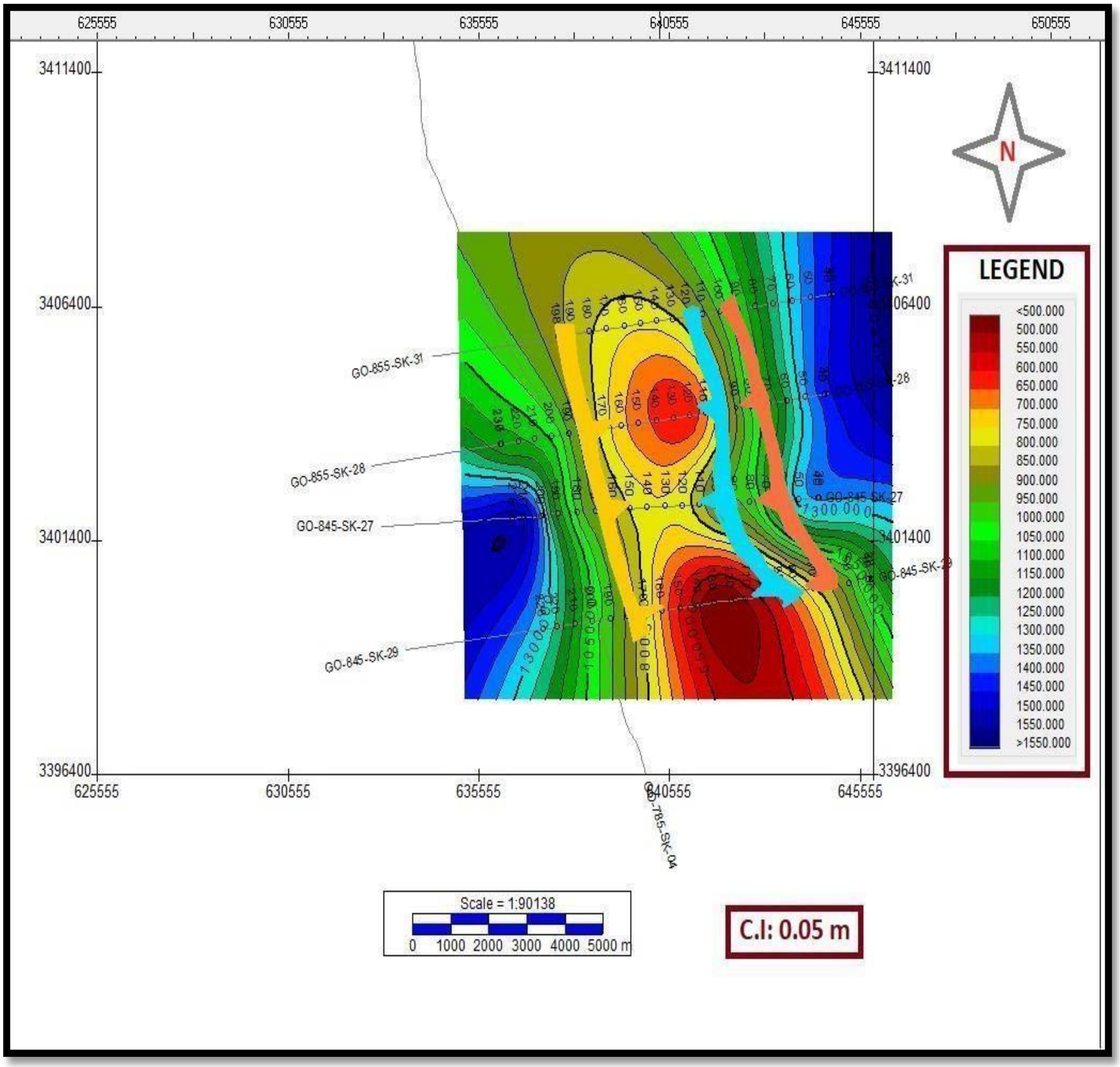


**Figure 4.15** Depth contour map of Pab Sandstone.

# CHAPTER 5

# PETROPHYSICAL ANALYSIS AND INTERPRETATION OF WELL LOGS

## 5.1 Introduction

Petro-physical analysis illustrates the identification of zone of interests (ZOI) in borehole. Well logs are continuous recordings from well which are depth versus different petro-physical characteristics of rock properties which includes Thickness, Lithology, Porosity, Fluid saturation, Fluid identification and its characteristics**.**

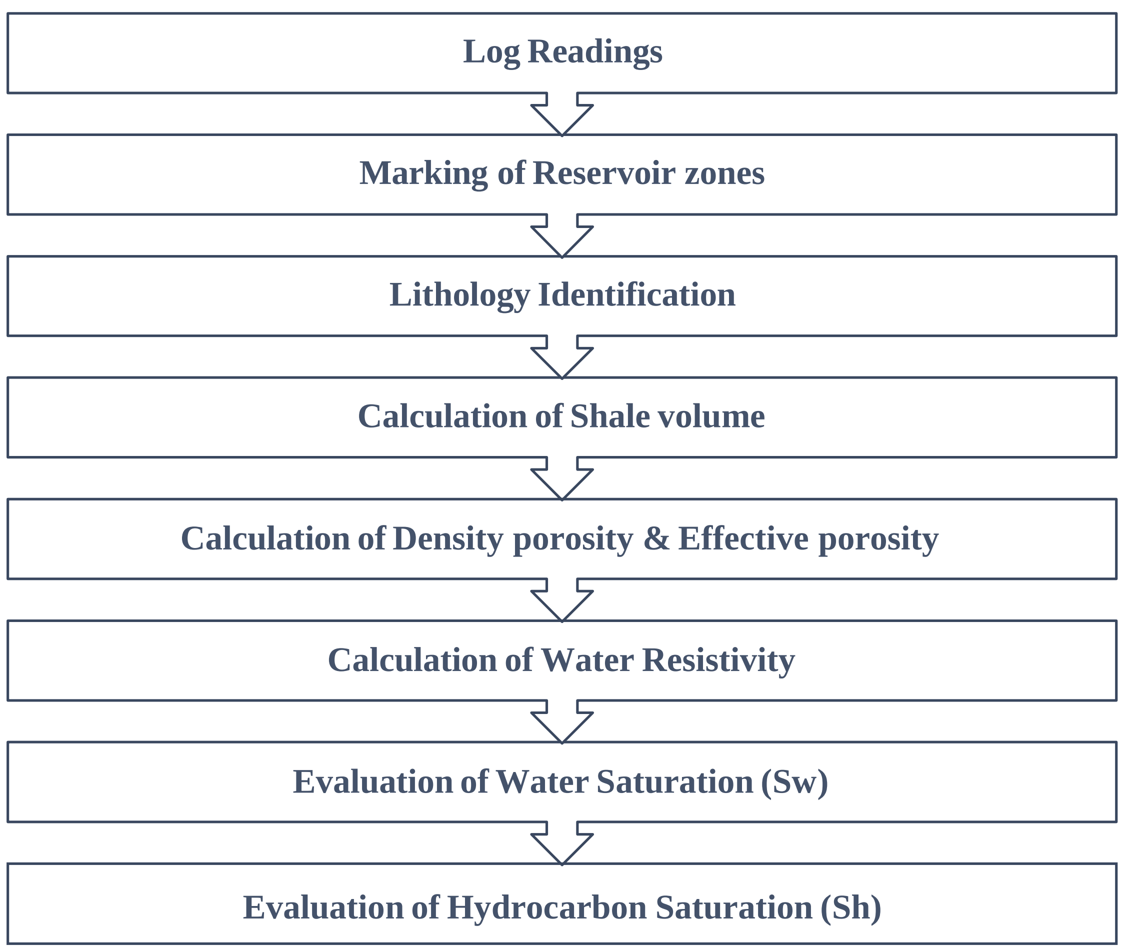


**Figure 5.1** Work flow of Log interpretation.

## 5.2 Seismic and well data

Basemap of Dhodak area has shown in figure That is used in study. Acquistion and processing of data is used by OGDCL in 1979 and 1985. Composite suit logs consists of Gamma ray Log, Porosities logs(Density log, Sonic log, Neutron log) and Resistivity logs. These were run in the Dhodak-5 for the analysis of log prediction of reservoir characteristics.

## 5.3 Petroleum prospect

Sember Formation has acts as potential source rock. Characteristics of reservoir shown in Pab Sandstone and Lower Ranikot Formation. Top seal is provided by Ghazij Shale is for reservoir zone of Ranikot formation while the shales of lower ranikot formation acting as seal for Pab sandstone.

## 5.4 Objectives of log data interpretation

Following are main objectives of log data interpretation

- To get suitable reservoir zones (pay zones), log interpretation is done.
- Computation of reservoir rock characteristics by different wireline logs, Petro-physical parameters are hydrocarbon saturation, water saturation, porosity, volume of shale and clean.

## 5.5 Petro-physical interpretation

In petro-physical interpretation, there are different wireline logs used to analyze the log data of Dhodak-05. To calculate the volume of shale, gamma ray log is used. For calculations of the density porosity, the density log is used. To calculate liquid filled porosity values neutron log is used. Resistivity log is useful for the calculation of saturation of water.

## 5.6 Marking of Reservoir zone

The marking of probability of hydrocarbon zone, zone of interest is done by 3 major indicators.

- Caliper should be stable.
- Decreasing trend of gamma ray values
- Cross over between Neutron curve and Density curve.
- The curve separation between MSFL and LLD as displayed in figure

To evaluate the saturation of water and saturation of hydrocarbon in Lower Ranikot of Early Paleocene age which indicates the possibility of prospect zone encountered at variable depth. As, marking of reservoir zone was done on the basis of volume of clean and neutron densitycross over. Formations where zone of interest (ZOI) lies in logs shown in table.

### 5.6.1 Dhodak-01 petro-physical analysis

Petro-physical analysis of Dhodak-01 of Lower Ranikot Formation of our zone of interest is as follows:

| **Lower RanikotFormation (Dhodak-01)** | | |
|---|---|---|
| | **Zone 1** | **Zone 2** |
| Starting Depth(m) | 1990 m | 2027m |
| Ending Depth(m) | 2012 m | 2057m |
| Thickness(m) | 22 m | 30m |

**Table 5.1** Shows Zone of interests of Lower Ranikot Formation of Dhodak-01

Resisitivity logs were missed beyond in that region of Dhodak-01 well. Only Few log readings were available. On the basis of these we have marked Zone of Interest.In the lower Ranikot the interval 1990m to 2012m has Effective Porosities values by 9%.While, Zone of Interest-2 starting from 2027m-2057m has about 11% Effective porosities values. Interclations of Shales are also present in that zone-2. Cross-over between NPHIand RHOB while Resistivity logs aren’t present in both zones. Only LLD is present which is not sufficient to predict resistivity parameter itself. 0.010 is average Saturation of water value in Dhodak-01 means about 20 % saturation of water and 80% saturation of hydrocarbon is there in that zone.

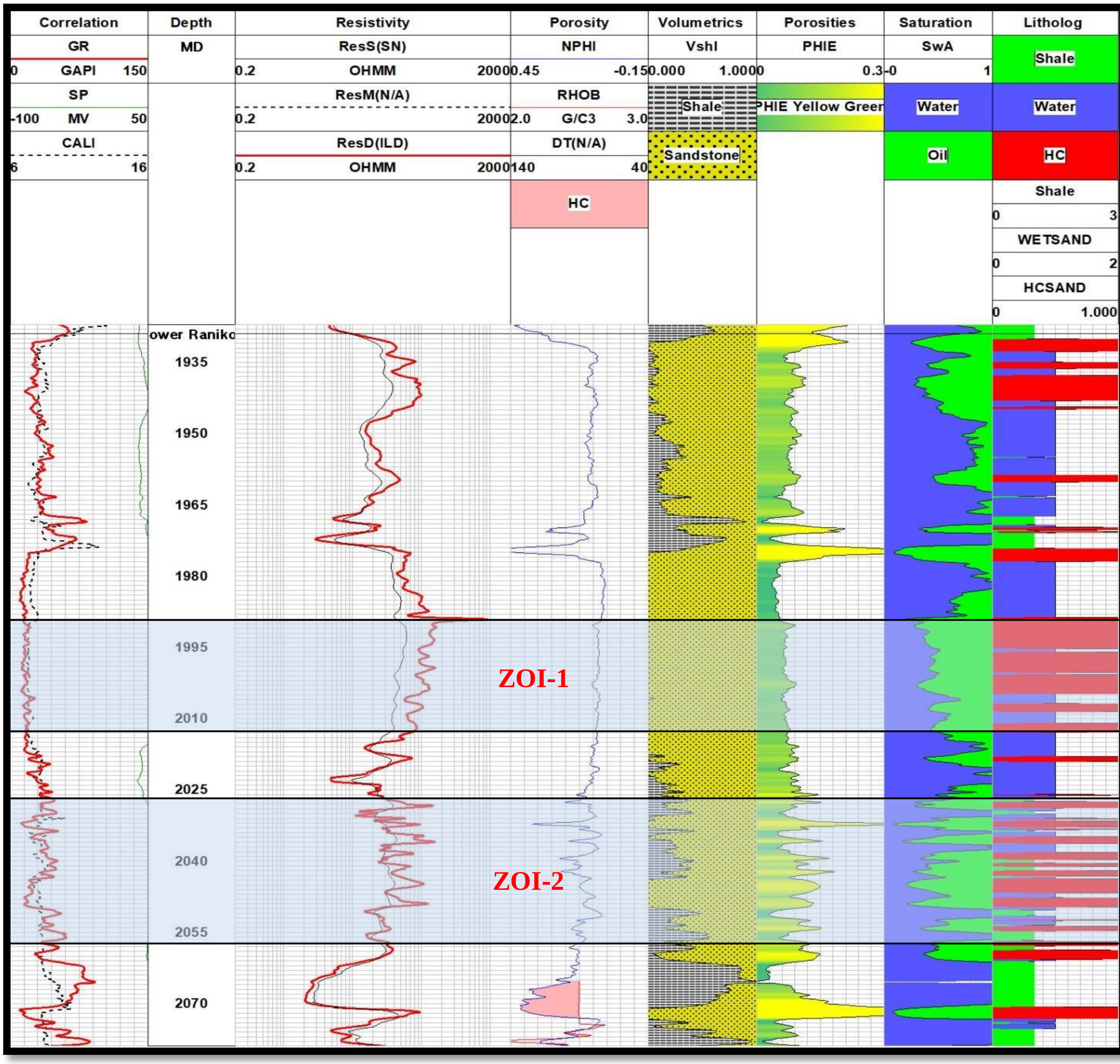


**Figure 5.2** Petro-physical analysis of Dhodak-01 curves of ZOI-1 & ZOI-2.

### 5.6.2 Volume of shale

Shale is more radioactive then other rocks like carbonates or sand, that's why gamma ray logs are used for the calculations of the volume of shale in porous reservoir rock. For the calculation of the gamma ray index, the determination of value of shale from gamma ray log is important (schlumberger, 1972).

## 5.7 Calculation of porosity

Calculation of hydrocarbon potential from well, these sort of parameters are calculated

- Density porosity
- Average porosity
- Effective porosity

### 5.7.1 Calculation of density porosity

The calculation of bulk density of formation is done by Density log. The usage of bulk density is for the calculation of total porosity of formation. Formation density log records in track 2 and track 3 of standard API log on linear scale. The measurement of bulk density is done by g/cm3 which is ranging from 1.95 to 2.95 g/cm3.

For the calculation of formula of bulk density of formation is as follows (sclumberger, 1989).

$$\mathbf{DPHI = \Phi = \rho ma - \rho b / \rho ma - \rho f}$$

Where:

**ρma**= Matrix density (for Limestone =2.71 g/cm3)

**ρb** = Bulk density of rock

**ρf** = Fluid density (For saline water = 1.1 g/cm3)

**Φ** = DPHI = density porosity of rock

### 5.7.2 Calculation of Average porosity

Porosity has its own importance in the production of oil and gas in well. Let suppose porosity is greater than 6% then formation is considered as productive Formation. So that porosity of every meter is average for the calculation of total reservoir pore volume. But in our case overgauged conditions were there so sonic porosity is considered as Average porosity.

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

### 5.7.3 Calculation of Effective porosity

Average porosity is used for the calculation of effective porosity by use of following equation (schlumberger, 1972).

**EPHI = APHI * (1-Vshale)**

### 5.7.4 Calculation of water saturation (Sw)

"Saturation of water"(Sw) refers to the percentage of water in pore spaces. On the other hand, "saturation of hydrocarbon" refers to the residual percentage of pore spaces that are saturated with gas and oil. The formula developed by Archie's (1942) formula.

It is used to calculate the saturation of water.

$$(S_w)^n = \sqrt{\left(\frac{a}{\varphi^m}\right) \times \left(\frac{R_w}{R_t}\right)}$$

Where,

$S_w$ = Saturation of Water

φ = Effective Porosity

m = 2 Cementation exponent

a = 1 (Tortuosity factor)

n = 2 (Saturation exponent)

$R_w$ = Formation water resistivity

$R_t$ = Formation true resistivity

### 5.7.5 Calculation of Hydrocarbon saturation(Sh)

Calculation of hydrocarbon saturation is done by this formula:

$$\mathbf{S_h = 1 - S_w}$$

## 5.8 Results of Dhodak-01 well

| | ZONE 1 | ZONE 2 |
|---|---|---|
| **Depth (m)** | 1990m - 2012m | 2027m - 2057m |
| **Thickness (m)** | 22 m | 30 m |
| **Average Volume of Shale** | 15 % | 21 % |
| **Average Volume of Clean** | 85 % | 79 % |
| **Effective porosity (EPHI)** | 9 % | 11 % |
| **Neutron porosity(NPHI)** | 15% | 12 % |
| **Saturation of Water(Sw)** | 32 % | 35 % |
| **Saturation of Hydrocarbon(Sh)** | 68 % | 65 % |

**Table 5.2** Depicts the results of Petrophysical analysis of Dhodak-01.

| Lower Ranikot Formation (Dhodak-05) | | |
|---|---|---|
| | **Zone 1** | **Zone 2** |
| Starting Depth(m) | 1973 | 2028 |
| Ending Depth(m) | 2000 | 2061 |
| Thickness(m) | 27 | 33 |

**Table 5.3** Shows ZOI-1 & ZOI-2 of Lower Ranikot Formation of Dhodak-05

### 5.8.1 Zone 1 of Dhodak-05

Zone-1 starts from 1973m-2000m has appropriate Porosities ranges upto 19%. Shales Interclations are also present in that Zone.Also there is cross-over between NPHI and RHOB while Resisitivity logs MSFL,LLS and LLD are showing dominant crossover that illustrates Hydrocarbon-Zone.

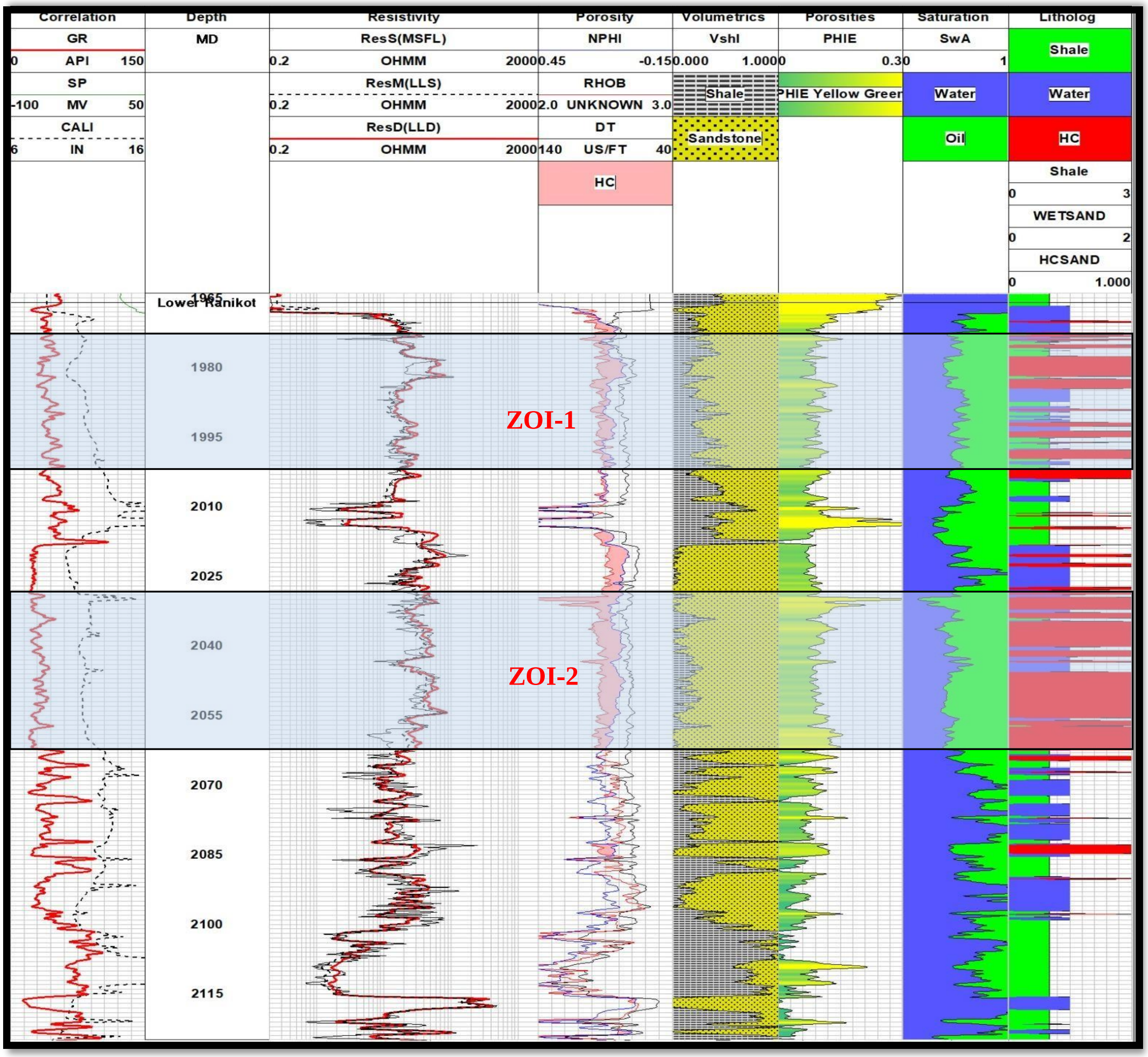


**Figure 5.3** Petro-physical analysis of Dhodak-05 curves of ZOI-1 & ZOI-2.

### 5.8.2 Zone 2 of Dhodak-05

Zone 2 starting from 2028m-2061m in the lower Ranikot interval. It has good Porosities by 18%. Interclations of shales are also present in that zone. Also there is cross-over between NPHI and RHOB while Resisitivity logs MSFL, LLS and LLD are showing dominant crossover depicts hydrocarbon zone. Zone-2 is more favorable with respect to Zone-1 as it contains 75% Hydrocarbon Saturation.

## 5.9 Dhodak 5 picket plot

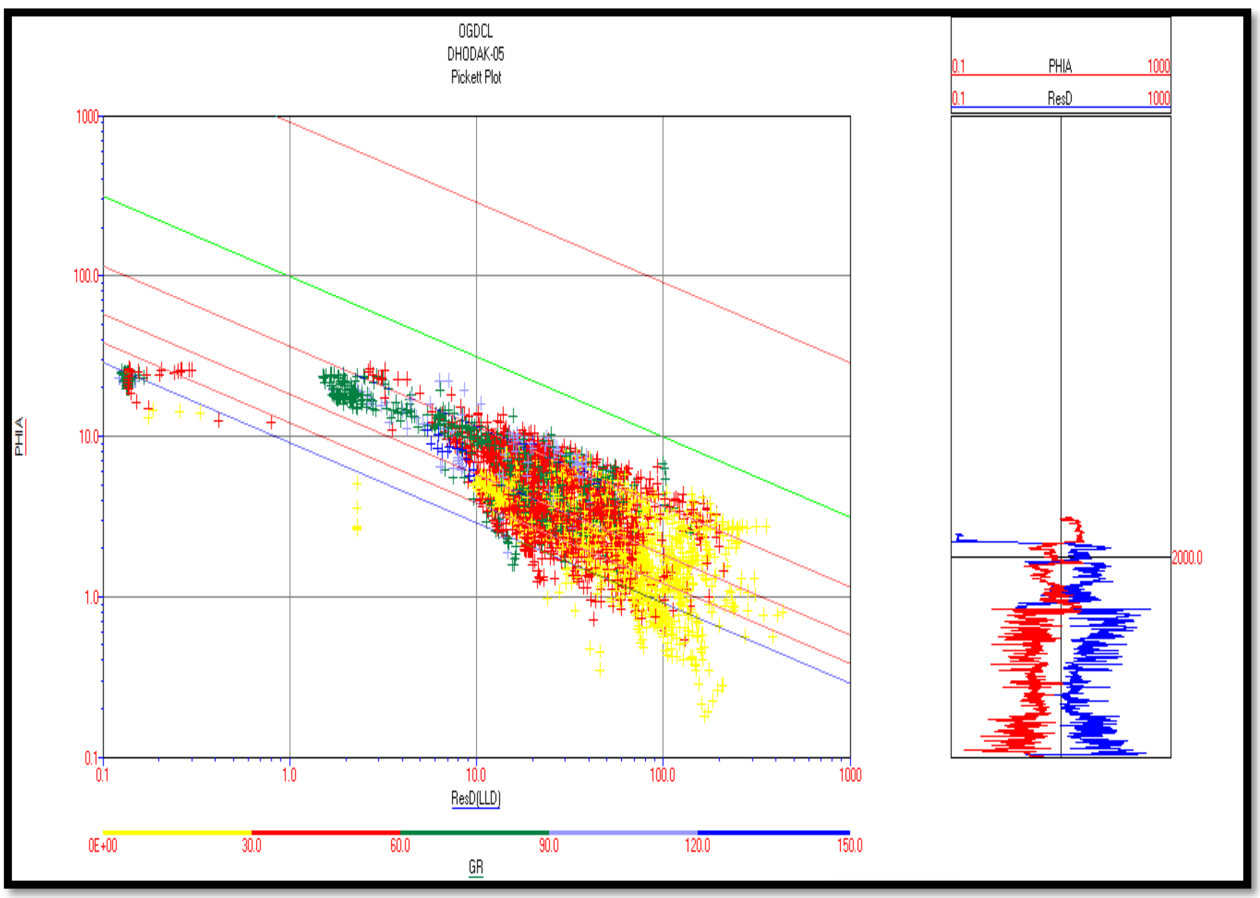


**Figure 5.4** Illustrates the Picket plot of Dhodak-05 well.

## 5.10 Results of Dhodak-05

Following are the results of petro-physical analysis of Dhodak-05 well:

| | **Zone 1** | **Zone 2** |
|---|---|---|
| **Depth(m)** | 1973 m – 2000 m | 2028 m – 2061 m |
| **Thickness (m)** | 27 m | 33 m |
| **Volume of Shale** | 28 % | 25 % |
| **Volume of Clean** | 72 % | 75 % |
| **Effective porosity (EPHI)** | 10 % | 11 % |
| **Sonic Porosity (DT)** | 22.8 % | 22.57 % |
| **Average Porosity (APHI)** | 19 % | 18% |
| **Saturation of water(Sw)** | 40 % | 25% |
| **Saturation of Hydrocarbon(Sh)** | 60 % | 75% |

**Table 5.4** Illustrates the results of Petro-physical analysis of Dhodak-05.

# CHAPTER 6

# ROCK PHYSICS AND FLUID REPLACEMENT MODELING

## 6.1 Introduction

Rock physics modeling is the prediction of P and S waves variations and how poisons ratio occurs. Rock physics depicts the missing log prediction like S-wave. We would have to either create or have to get elastic properties. It is used to predict abnormal (density logs mostly) or absent logs which are of S-wave. It also minimizes the effects of uncertainty related to seismic attribute interpretation. Rock physics modeling is important parameter to create link between Elastic properties such as impedance and velocities of reservoir (Miguel Bosch., et al 2010).

The relationship between rock properties have described with respect to Elastic moduli, that is used further for the computation of velocity (Wawrzyniak-Guz, 2019).

## 6.2 Fluid replacement modeling

Reservoir rock assessment in AVO mostly fluid replacement modeling is used (Ross, 2000; Russell et al., 2003). Fluid replacement depicts the better understanding of the seismic properties and pore fluids which relies on different these saturations like water, gas and oil (Gassmann's relation, 1951).

**Workflow of Rock physics :**

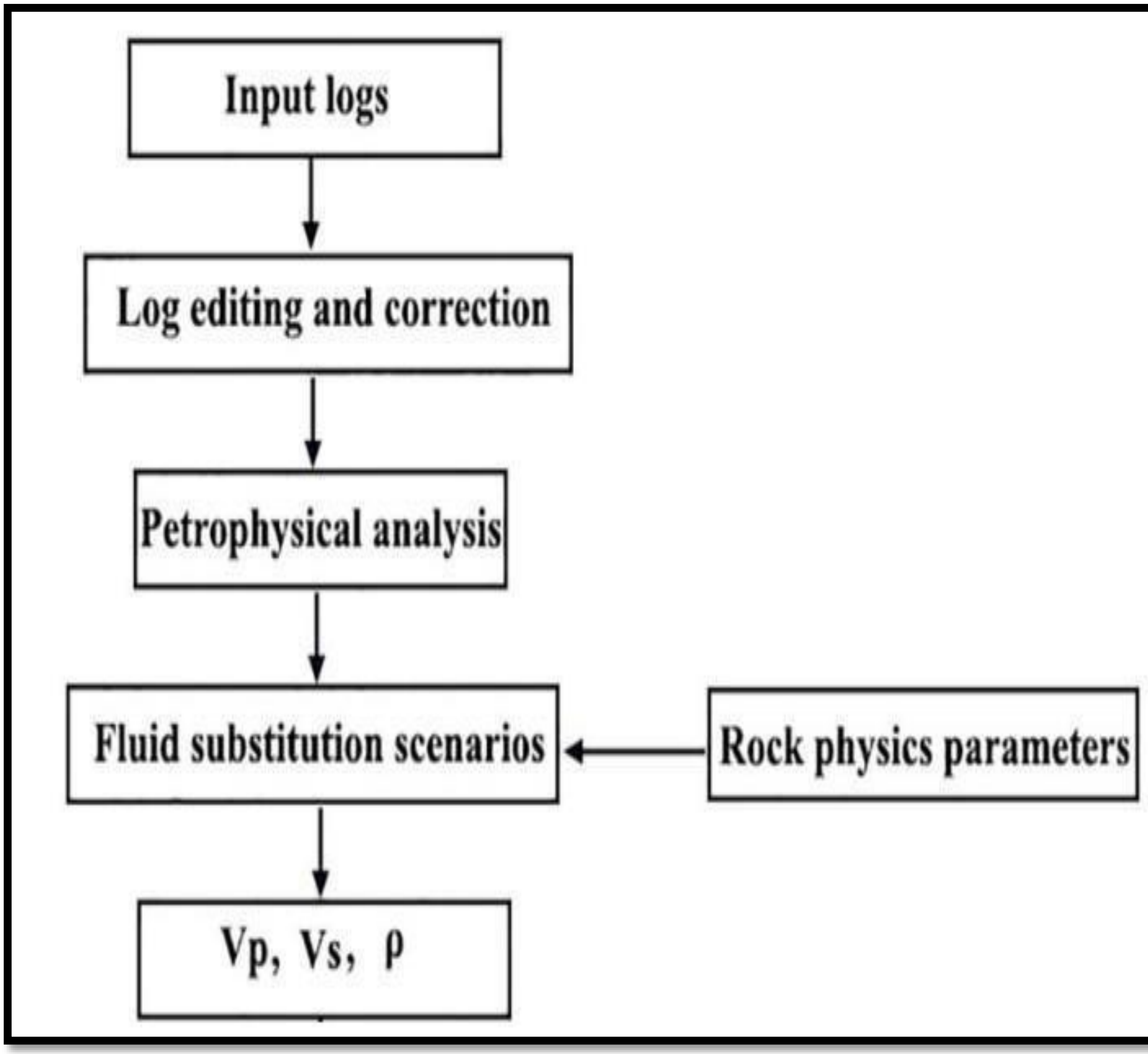


**Figure 6.1** Fluid replacement workflow

## 6.3 Scenerios in for fluid substitution

Different sort of fluids (water, gas) were introduced and substitutes into reservoirs and had different proportions. This was done to evaluate and better assessment of the quantitatively parameter of appropriate fluids presence in the reservoir by the depiction of amplitude matching. These major three scenarios are as follows:

1. **Insitu case (60% gas 40% water)**
2. **Gas 100 % and water 40 %**
3. **Gas 0% , water 100%**

### 6.3.1 Insitu case (60% gas 40% water)

Insitu case we exert 60 % gas and 40% water as substitution method to see the results of the curves how it responds and their variations of behavior.

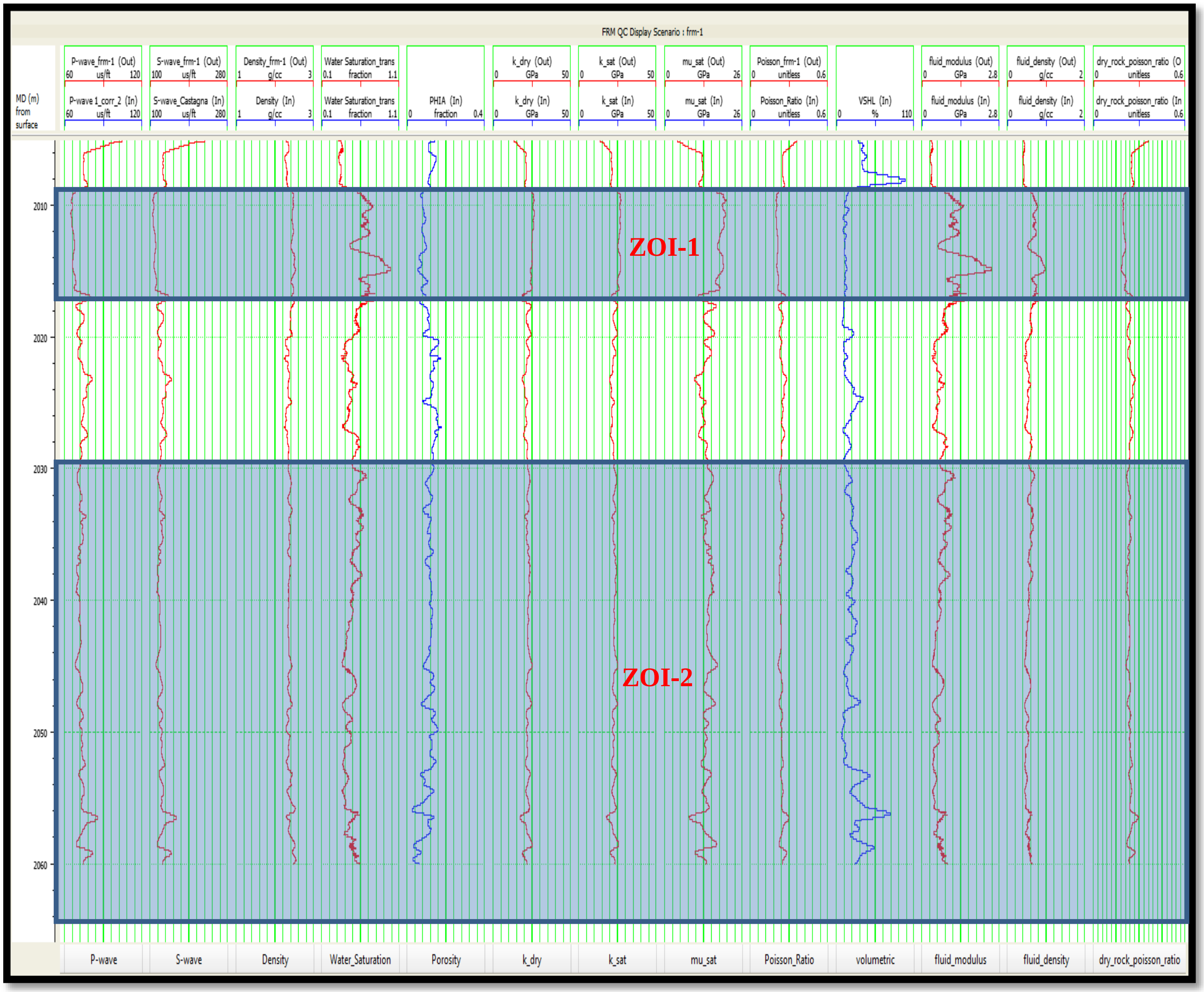


**Figure 6.2** Depicts Insitu condition holds substitution of 60% Gas and 40% water scenario.

### 6.3.2 Gas 100 % and water 0 %

In Second case we exerted 100 % gas and 0% water as substitution method to see the results of the curves how it responds and their variations of behavior.

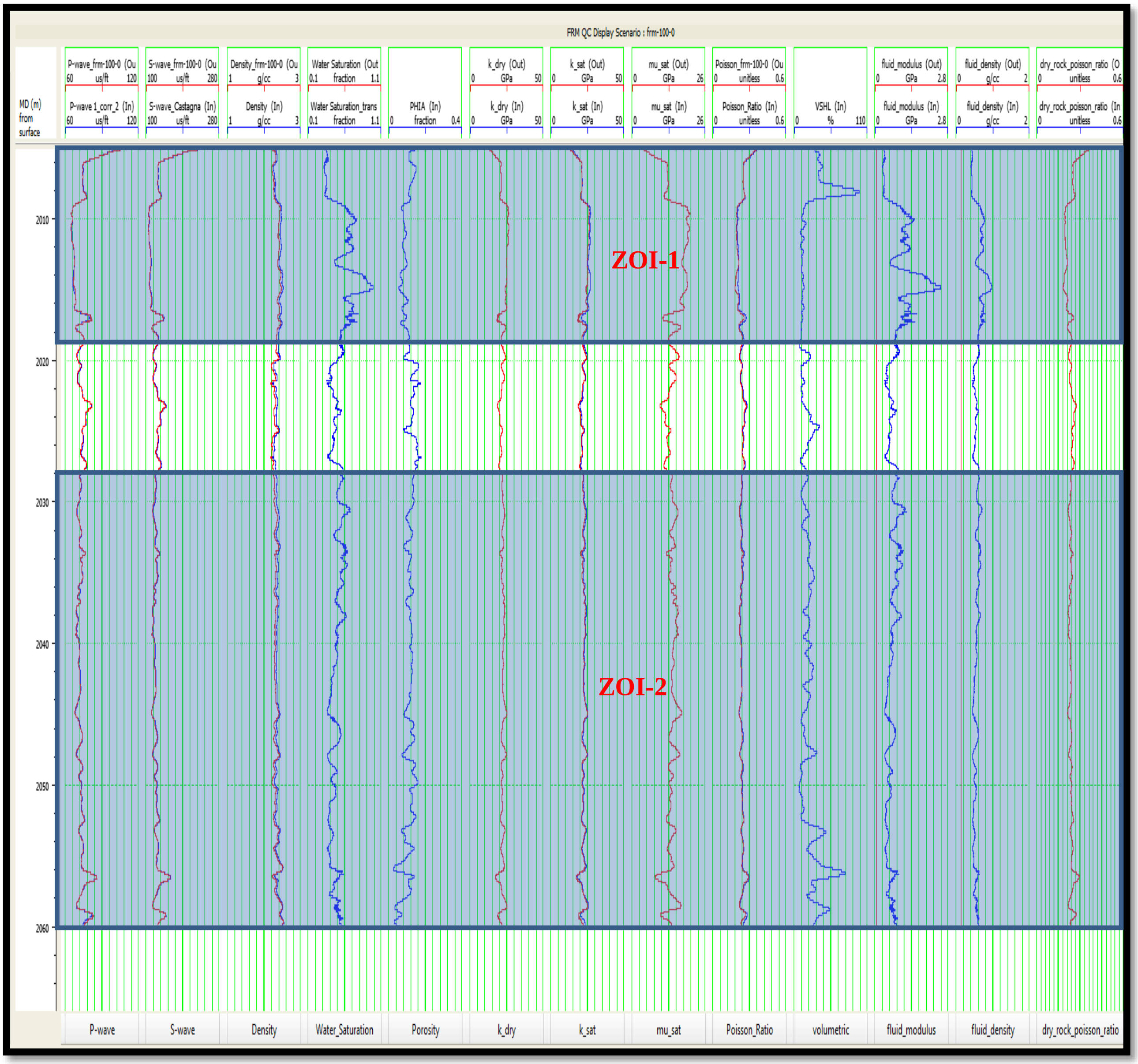


**Figure 6.3** Depicts that substitution of 100% Gas and 0% water scenario.

### 6.3.3 0% gas 100% water case

In Third case we exerted 0 % gas and 100% water as substitution method to see theresults of the curves how it responds and their variations of behavior.

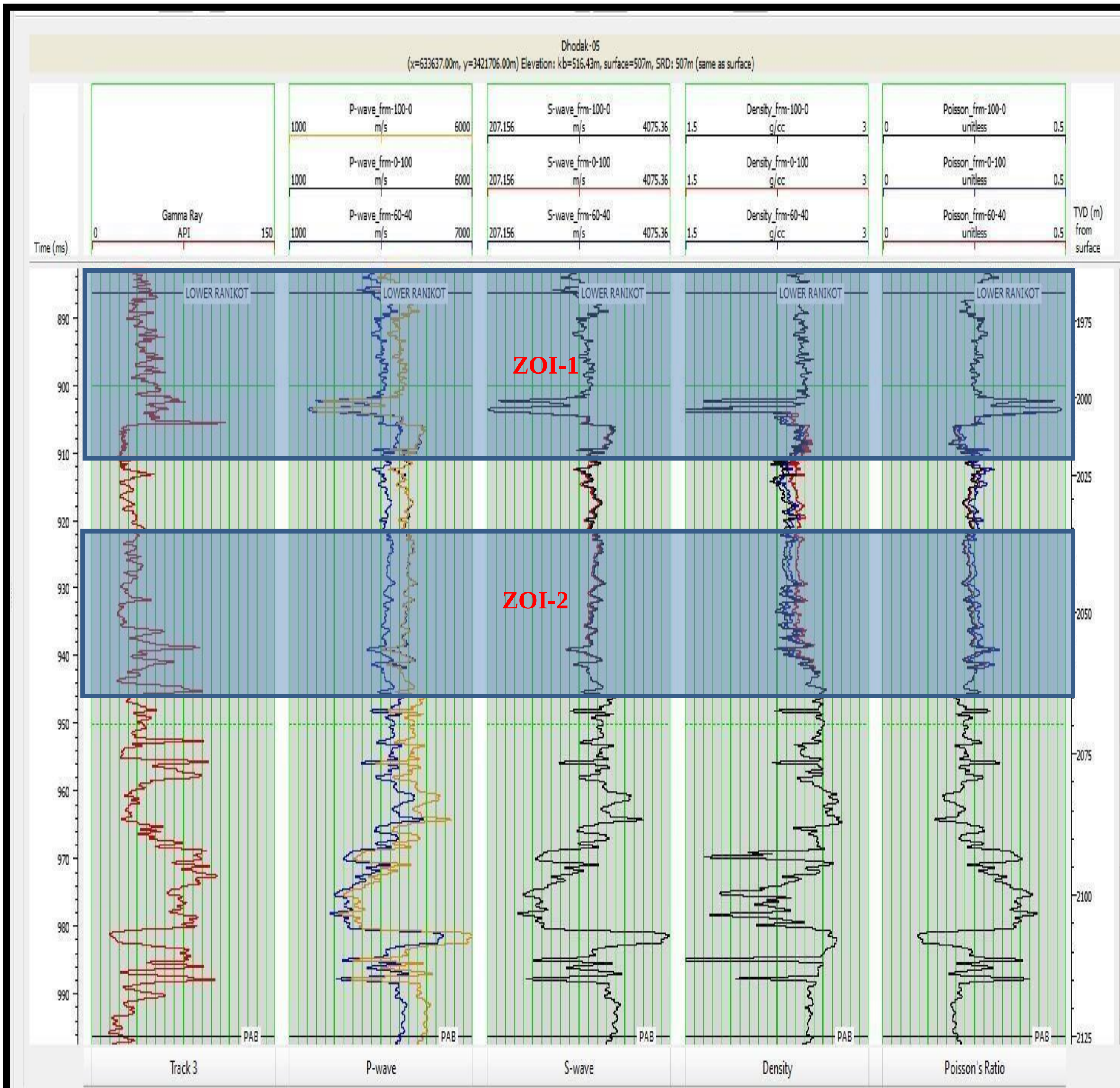


**Figure 6.4** Depicts that substitution of 0 % Gas and 100% water scenario.

## 6.4 Outcome

As shown in figure we have substituted different scenarios and exerted values and made S-Wave Prediction. Moreover, Bad borehole log which was Density log has also been optimized. Thus, we illustrated Lower Ranikot is acting reservoir and have lot of potential to act as reservoir.

# CHAPTER 7

# SEISMIC INVERSION TECHNIQUE FOR RESERVOIR CHARACTERIZATION

## 7.1 Introduction

Seismic inversion technique is playing momentous role in the previous two decades for detection of the hydrocarbon reserves. Seismic data gives information about the interface properties while seismic inversion is the illustration of layer properties of the data set to enhance the reservoir characteristics (Li and Zhao, 2014).

Seismic Inversion relys on the properties of subsurface strata. Borehole data and the resolution of elastic dataset of particular area to predict its characteristics (Pendrel, 2006).
It is non uniform procedure which happens by the combination of seismic and well log dataset inverse modeling of logs which have created from seismic data (Hampson et al., 2001).

Thus the updation of the model occurs continuously till calculated parameters best fit matching occurs with the reference data set which are elastic properties. It also assists to interpret the hidden information of the reservoir for the better prediction (Vecken and Da Silva, 2004).

The product of Density and Velocity can be seen as inverted impedance. The main aim of the seismic inversion is to predict the hidden info of the seismic data and converts that dataset into different rock properties like Acoustic impedance, Density, velocity, shear impedance etc Similarly, petro-physical properties like porosity, water saturation and shale volume also makes good relationship between impedance and Petro-physical properties (Veeken, 2004).

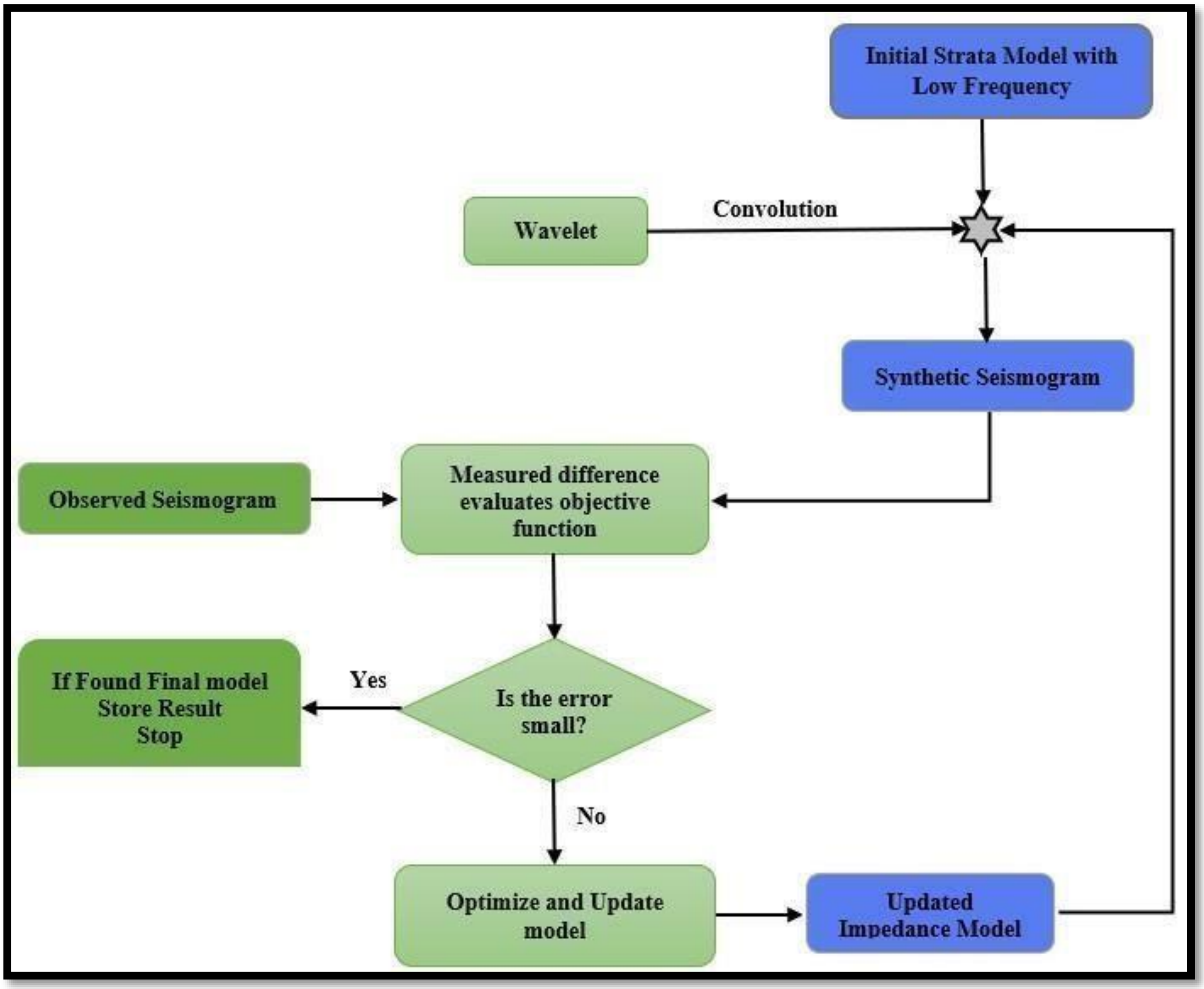


**Figure 7.1** Basic workflow of inversion (Sen, 2006).

## 7.2 Objective of Inversion

The main ambition of performing inversion is perform nearly best fit model. The Seismic data is usually not that much refined as noise factor is there so its insufficient to get reliable results by forward modeling. So multiple models sometimes fitted with the measured data with equally well. So that's necessary factor to predict the model along with its uncertainty factor (Mrinal K. Sen, 2006).

## 7.3 Model Based Inversion

In Model Based Inversion, the observed and synthetic dataset has compared with each other. Synthetic data is matching with observed data solution then the model would be accepted. If its not matching then that's not model isn't acceptable and improvising occurs in both synthetic and observed datasets. It is more appropropriate because its doesn't invert seismic data (Mallick, 1996).

Model based inversion is relatively effective in thin bed reservoirs as elastic data has band limited. It also comprises of high and low frequency features that are why elaborated information related to stratigraphic and physical properties comes.

$J = \text{weight}_a \times (S\text{-}W * R) + \text{weight}_b \times (M\text{-}H * R)$............................(1)

## 7.4 Methodology

The extraction of seismic data from underlying geology. Hampson-Russel software is widely used to predict geophysical parameters. AVO, Reservoir characterization,Mutli component Interpretation and Inversion can be covered by HRS.

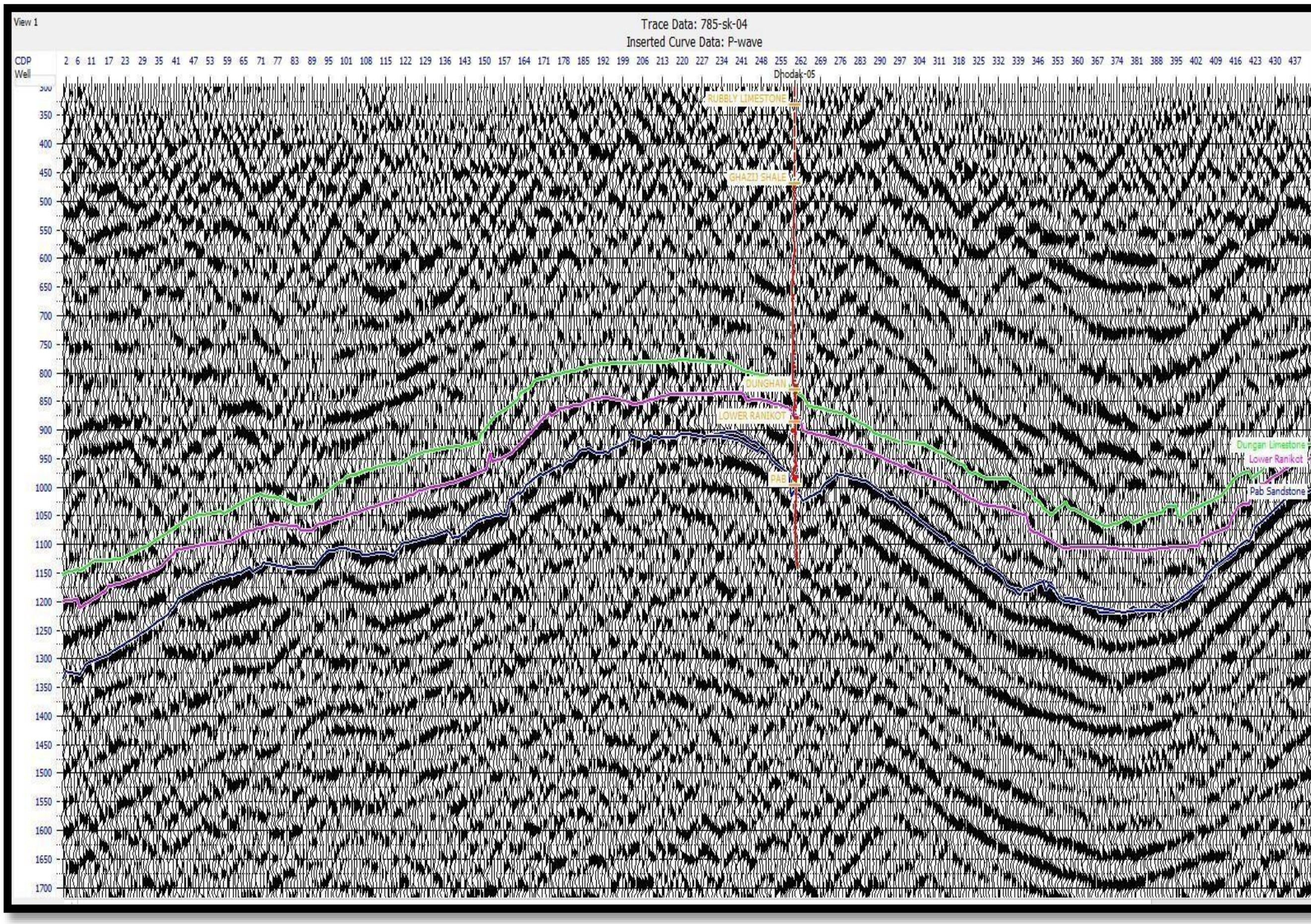


**Figure 7.2** Depicts the Seismic section of 785-sk-04 (control line).

## 7.5 Extracted wavelet

Extracted wavelet in figure illustrates behavior of seismic data along with its features Amplitude and Frequency. 10-30 Hz is range of frequency of wavelet. The length of the wavelet is 200ms. The amplitude is depicted by wavelet in Time and Frequency domains.

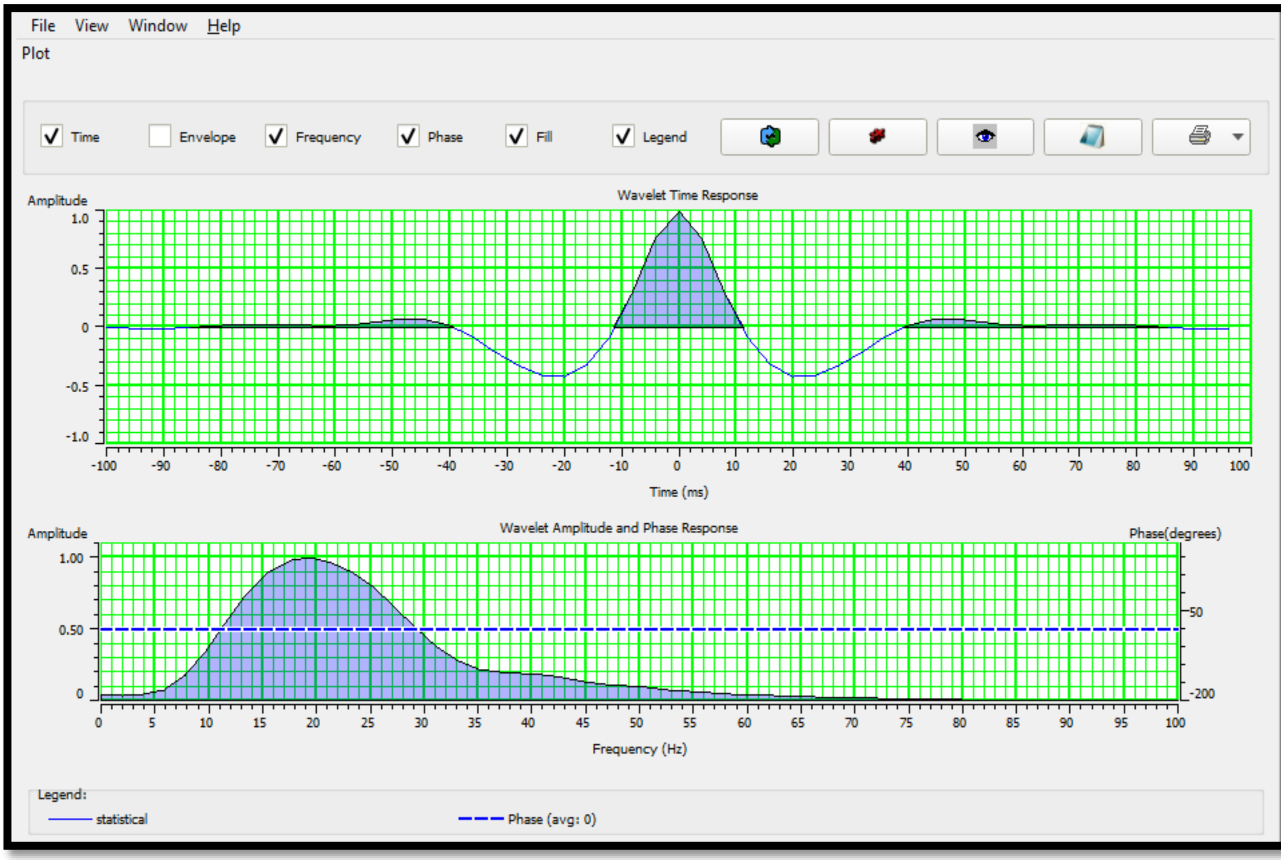


**Figure 7.3** Wavelet Extracted from seismic of Dhodak-05.

## 7.6 Dhodak-05 correlation

Seismic to Well Tie correlation was done on Dhodak-05.By using Sonic and Density log of Dhodak- 05 synthetic seismogram was generated. For Synthetic generation purpose wavelet was used. Correlation of Well in zone of interest is 40%.

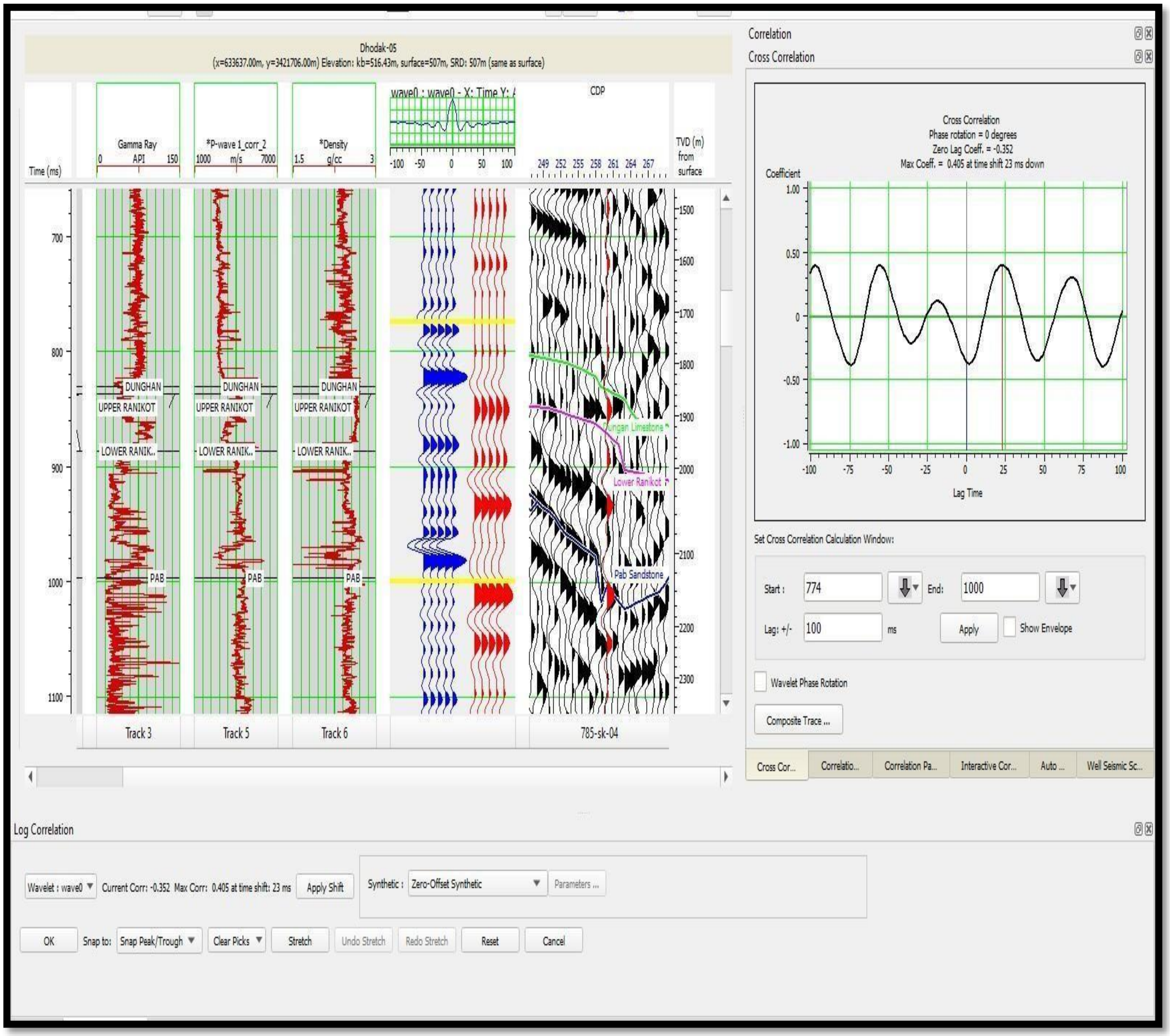


**Figure 7.4** Dhodak-05 correlation.

## 7.7 Low Frequency model

Low Frequency model enhances both quality and quantity of seismic inversion outcomes. Basicinput required to predict low frequency model comes from well data (Nishat kumar, 2012)

The Low Frequency model of Dhodak-05 well is as follows:

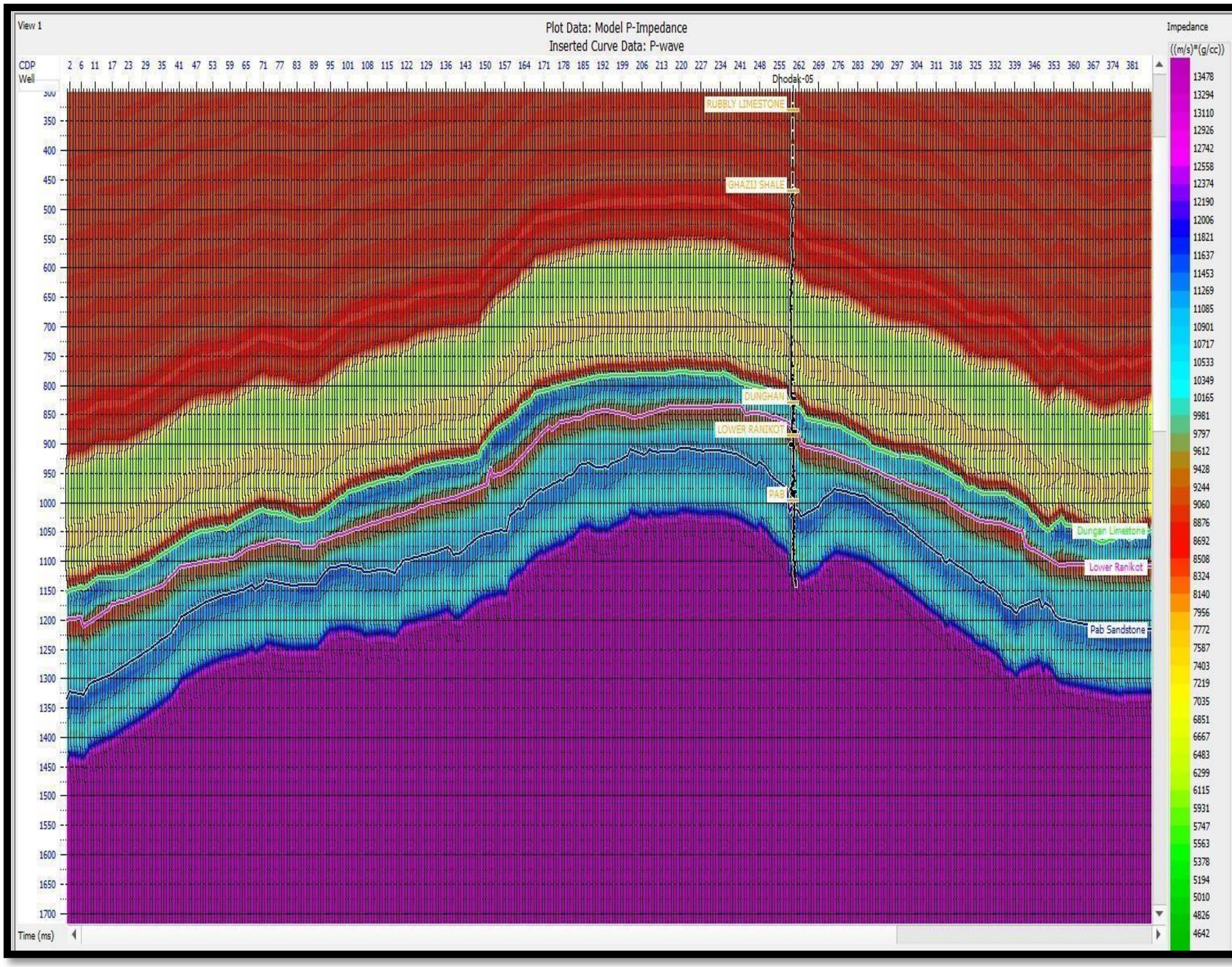


**Figure 7.5** Low Frequency Model of Well Dhodak-05.

## 7.8 Quality Control

Data QC is one of the most important step of any dataset. Quality control was done prior to execute the inversion. Red curves are depicting inverted results and blue ones represent original log details. The difference (error) between the seismic in (Black) and synthetic traces (Red) was 1266.91 with 0.99 value, which is a great outcome and giving suitable results.

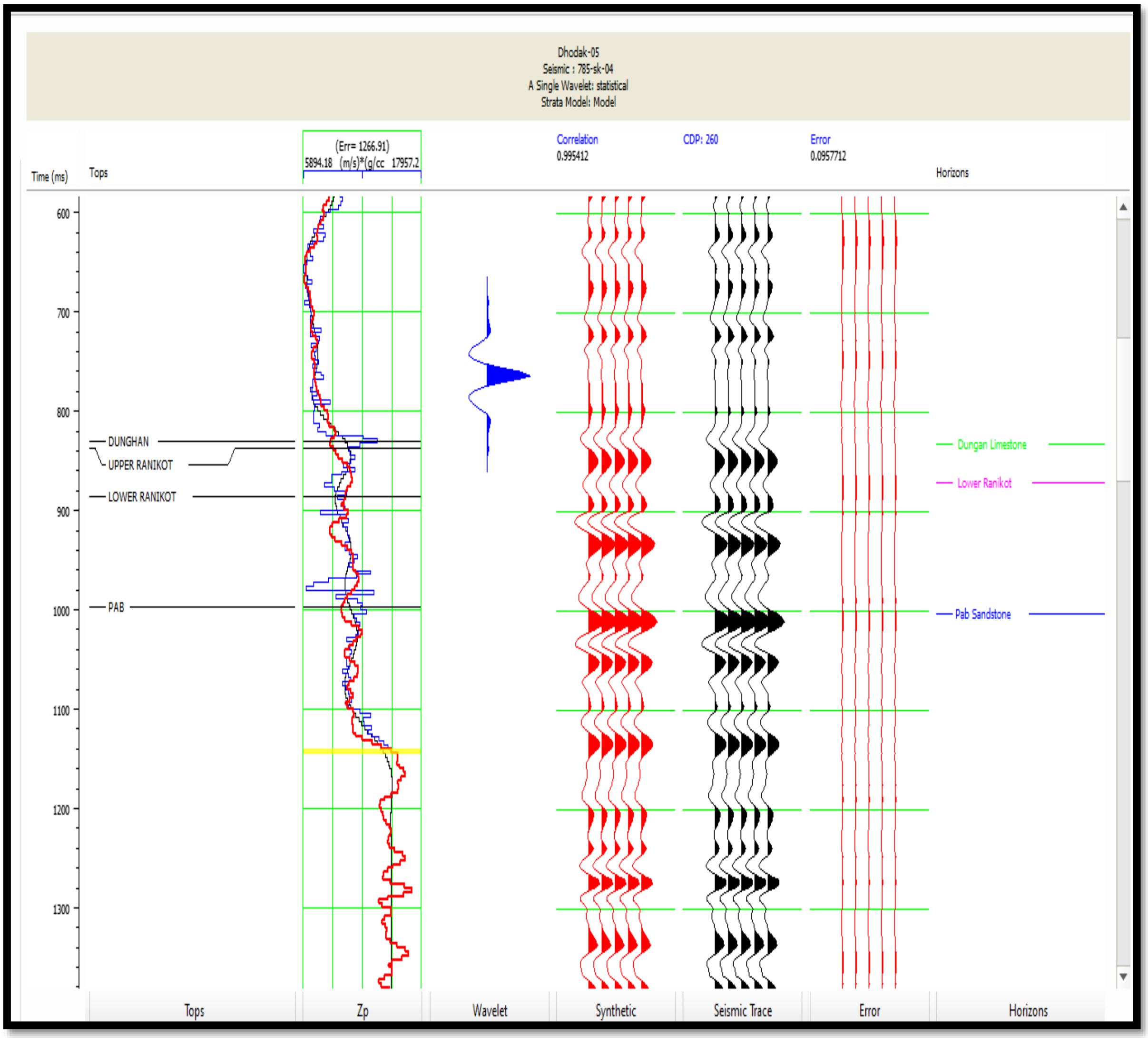


**Figure 7.6** Inversion analysis of Dhodak-05.

## 7.9 Inverse Seismic Model

Figure depicts the inverted plot gotten from elastic data and these are obtained from inverted Seismic models.

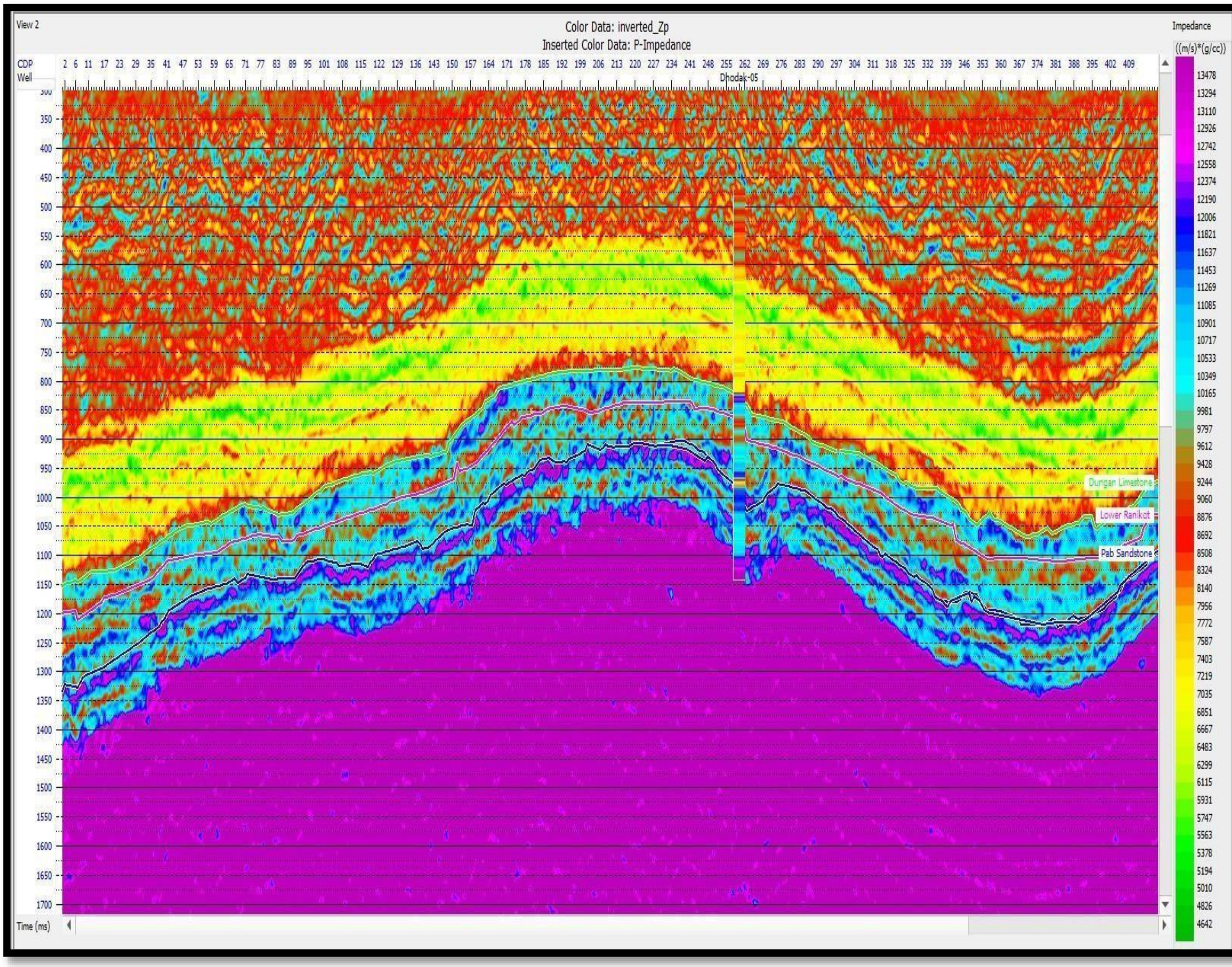


**Figure 7.7** Inverted seismic P-Impedance values at Dhodak-05.

The P-Impedance values for the reservoir sands ranging from 8500 to 11000 {(m/s)*(g/cc)}

# CHAPTER 8

# MACHINE LEARNING IMPLEMENTATION FOR RESERVOIR CHARACTERIZATION

## 8.1 Introduction

Machine learning has plays momentous role in hydrocarbon industry from last couple of years. Machine learning algorithms will have outstanding results to depicts the reservoir characterization by doing firstly Exploratory Data Analysis (EDA) and then comes towards machine learning.

The main Problem starts from Data acquisition problems then Seismic processing like noise removal etc. So during such setups important data is missed in which we do seismic interpretation and petro-physical analysis. So to enhance the results we will apply machine learning approach towards it.

## 8.2 Methodology

By using Probabilistic Neural Network (PNN) we have calculated Volume of Clay, Porosity and Saturation.

## 8.3 Probabilistic Neural Network (PNN)

PNN is widely used for several years in geophysical studies. It depicts the distance of weighted substance approach to the tiny points for the interpolation (Mahmood et al., 2017).

## 8.4 Volume of Clay prediction using PNN (Machine learning)

Clay plays vital role in hydrocarbon industry as its minerals plays momentous role in the composition in source rocks as well as reservoir rocks which ultimately is produces and store hydrocarbons. Clay mineral affects the physiology and chemistry of sandstone, limestone's andunconventional shale. We have predicted volume of clay by using PNN.

Multi-Attribute List: Multi Attribute List 1

| | Target | Final Attribute | Training Error | Validation Error |
|---|---|---|---|---|
| 1 | Volumetric | ( Model_P-wave )**2 | 0.122932 | 0.000000 |
| 2 | Volumetric | Amplitude Envelope(inverted_Zp) | 0.116105 | 0.000000 |
| 3 | Volumetric | Filter 0/10-50/60(Model_P-Impedance) | 0.112027 | 0.000000 |
| 4 | Volumetric | Dominant Frequency | 0.110960 | 0.000000 |
| 5 | Volumetric | Integrated Absolute Amplitude | 0.108706 | 0.000000 |
| 6 | Volumetric | Cosine Instantaneous Phase | 0.107588 | 0.000000 |
| 7 | Volumetric | Amplitude Weighted Phase(Model_P-Impedance) | 0.106651 | 0.000000 |
| 8 | Volumetric | Filter 5/10-15/20(Model_P-Impedance) | 0.104869 | 0.000000 |
| 9 | Volumetric | Apparent Polarity | 0.103620 | 0.000000 |
| 10 | Volumetric | Cosine Instantaneous Phase(inverted_Zp) | 0.102041 | 0.000000 |
| 11 | Volumetric | Instantaneous Phase | 0.100548 | 0.000000 |
| 12 | Volumetric | Amplitude Weighted Cosine Phase(Model_P-Impedance) | 0.099337 | 0.000000 |
| 13 | Volumetric | Filter 55/60-65/70(inverted_Zp) | 0.098246 | 0.000000 |
| 14 | Volumetric | Average Frequency | 0.097271 | 0.000000 |
| 15 | Volumetric | ( Model_Synthetic )**2 | 0.096579 | 0.000000 |
| 16 | Volumetric | Quadrature Trace | 0.096044 | 0.000000 |
| 17 | Volumetric | ( inverted_Syn )**2 | 0.095582 | 0.000000 |
| 18 | Volumetric | Amplitude Weighted Cosine Phase | 0.094937 | 0.000000 |
| 19 | Volumetric | Derivative Instantaneous Amplitude | 0.094514 | 0.000000 |
| 20 | Volumetric | Second Derivative | 0.094084 | 0.000000 |

**Table 8.1** illustrates Training error,Validation error of Volume of Clay prediction.

The correlation between Actual and predicted volumetric assessment is 96%- 97% while factor of error is 0.3 to 0.4% which is negligible so we have enormous sort of results.

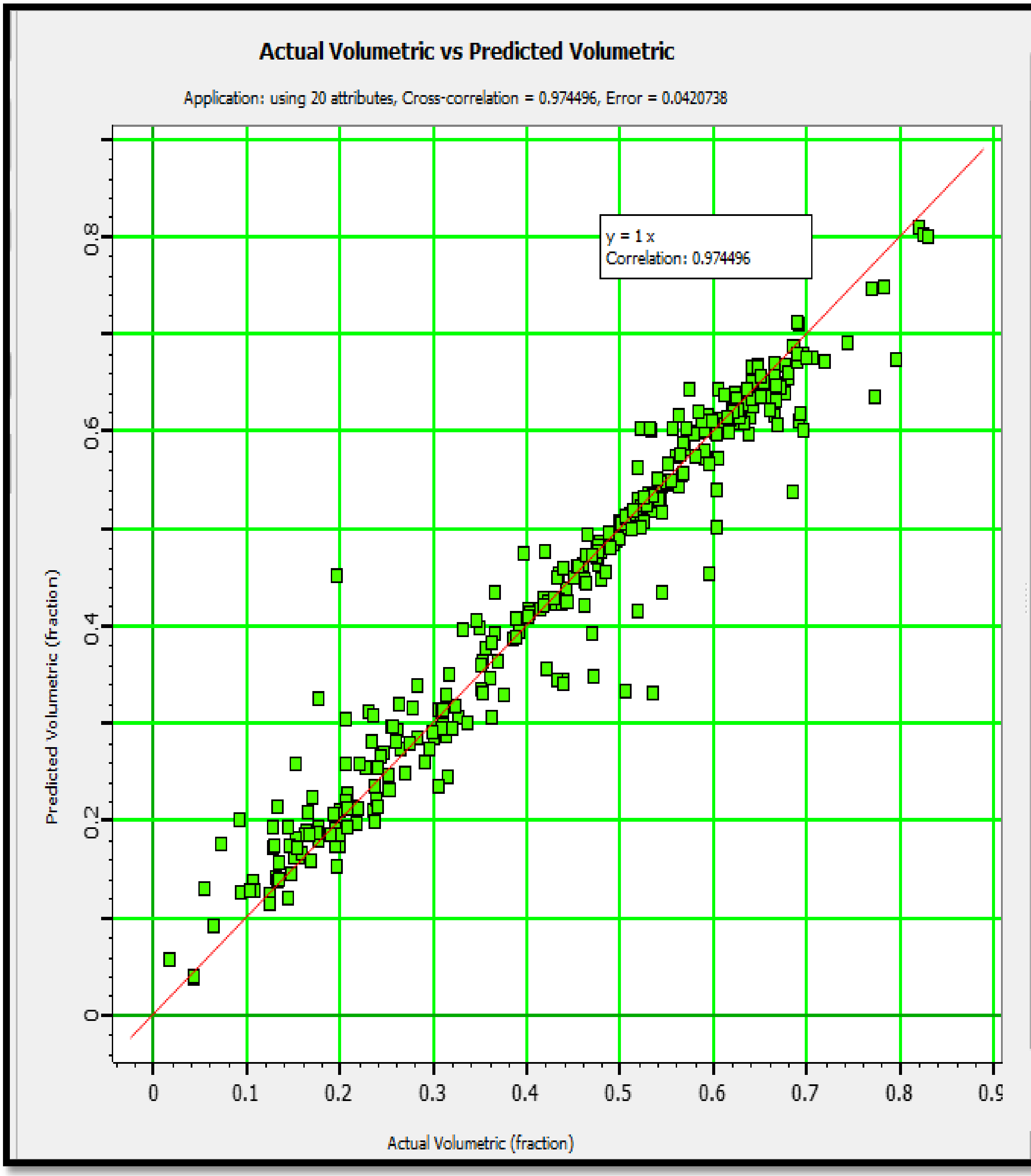


**Figure 8.1** Cross plot of Actual Volume of Clay and Predicted Volumr of Clay (modeled).

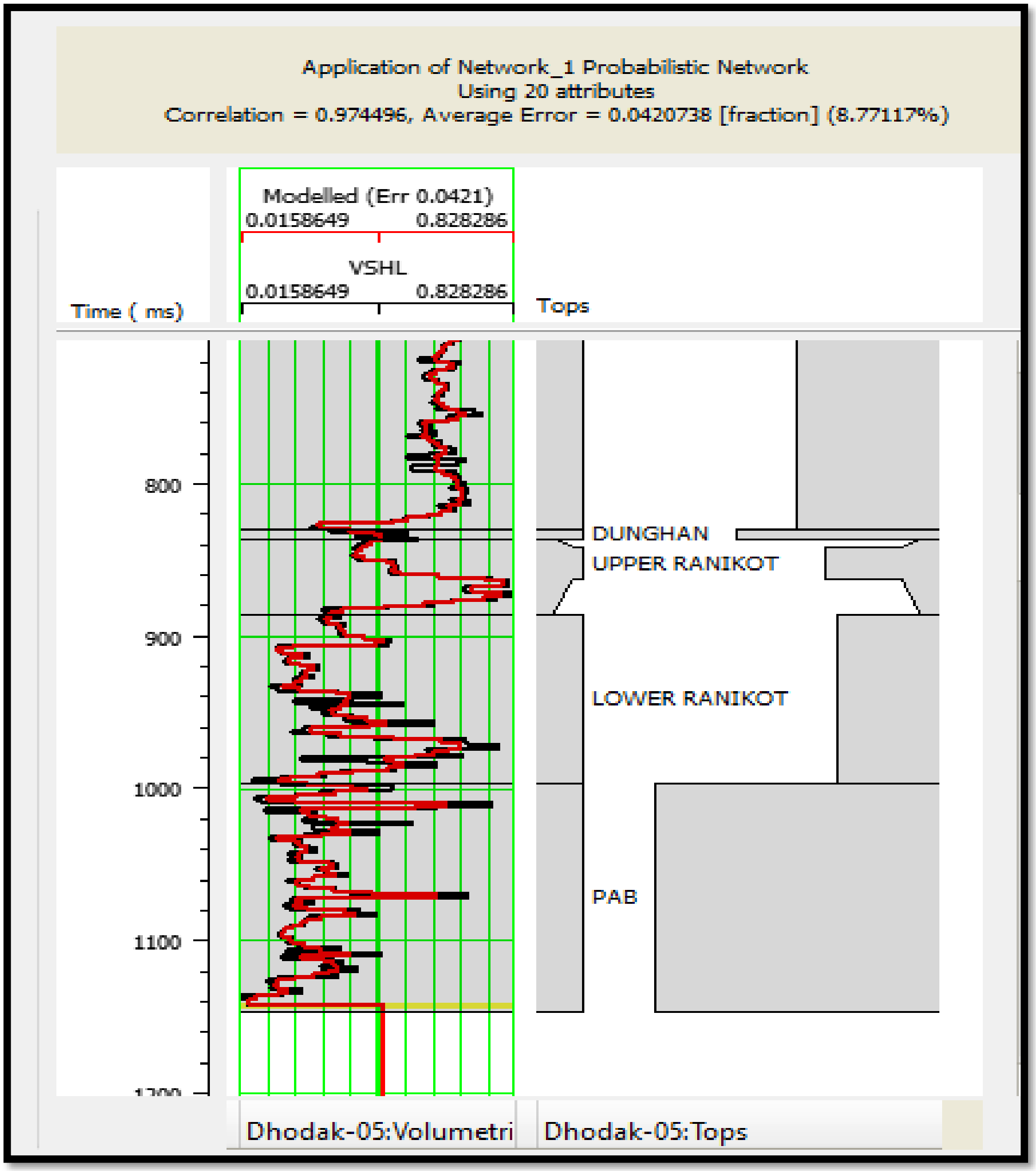


**Figure 8.2** Training result of PNN of Actual Volume of Clay and Predicted VClay

### 8.4.1 Results

The correlation between Actual (Black ,Petro-physically calculated) and Predicted (Red, PNN) volumetric assessment is 96% - 97% while factor of error is 0.3 to 0.4% which is negligible.

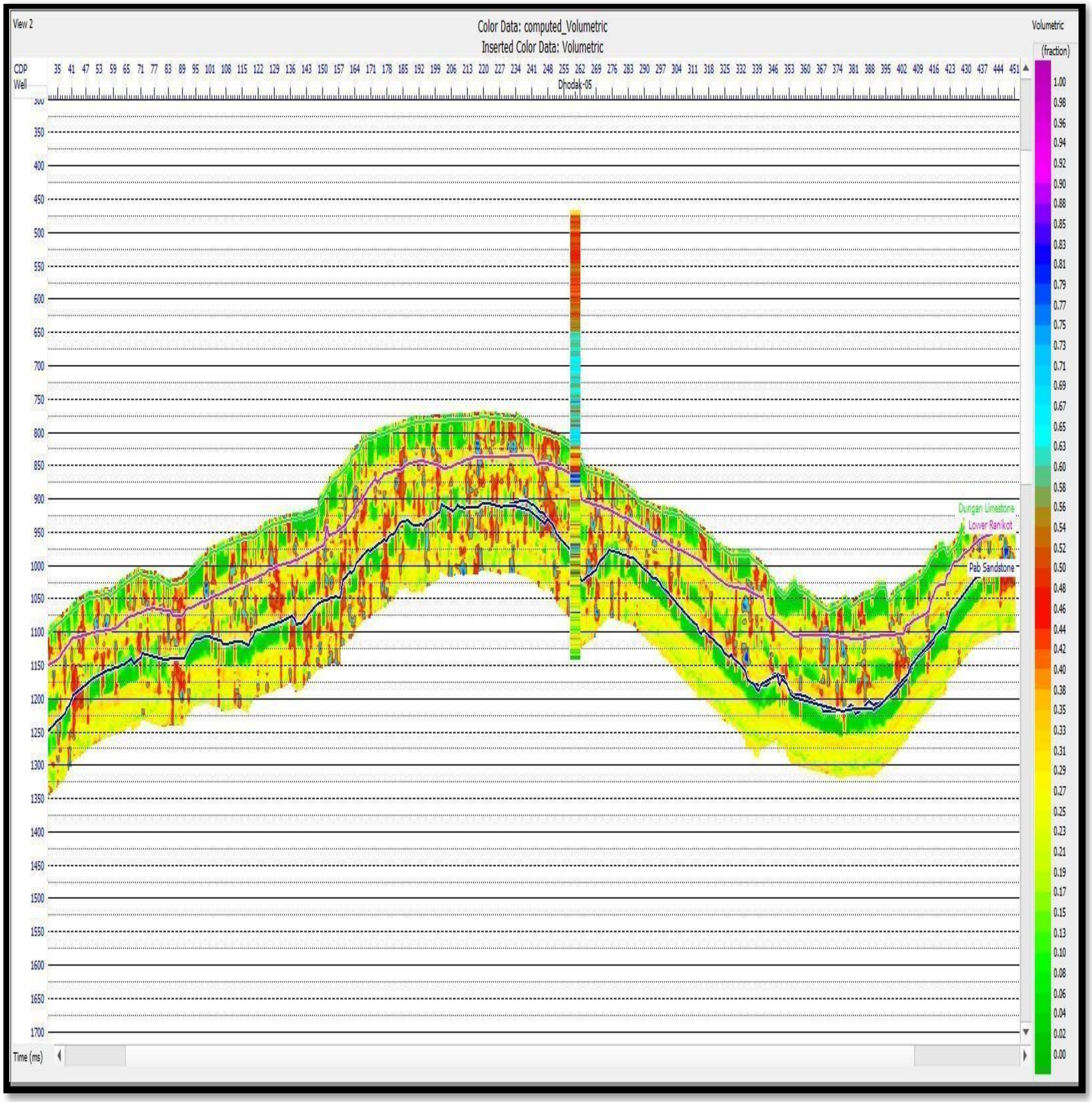


**Figure 8.3** Depicts values ranging from 0.13% to 0.81% holding good results of Dhodak-05.

## 8.5 Porosity prediction using PNN (Machine learning)

Estimation of porosity occurs from the inverted impedance and comparison occurred between actual porosity and modeled (predicted). Porosity is predicted by probabilistic Neural Network. Correlation plot results of PNN for here is as follows in Figure 5.16. Actual porosity is showing good results in Modeled porosity and correlation is about 97%.

| | Target | Final Attribute | Training Error | Validation Error |
|---|---|---|---|---|
| 1 | Porosity | 1/( Model_Density ) | 0.054383 | 0.000000 |
| 2 | Porosity | Filter 5/10-15/20 | 0.052990 | 0.000000 |
| 3 | Porosity | Filter 35/40-45/50(inverted_Zp) | 0.052480 | 0.000000 |
| 4 | Porosity | Integrated Absolute Amplitude(Model_P-Impedance) | 0.052032 | 0.000000 |
| 5 | Porosity | Dominant Frequency | 0.051601 | 0.000000 |
| 6 | Porosity | Sqrt( computed_Volumetric ) | 0.051019 | 0.000000 |
| 7 | Porosity | Average Frequency(inverted_Zp) | 0.050557 | 0.000000 |
| 8 | Porosity | Filter 55/60-65/70 | 0.050303 | 0.000000 |
| 9 | Porosity | ( inverted_Syn )**2 | 0.050106 | 0.000000 |
| 10 | Porosity | Filter 25/30-35/40 | 0.049795 | 0.000000 |
| 11 | Porosity | Filter 15/20-25/30(Model_P-Impedance) | 0.049382 | 0.000000 |
| 12 | Porosity | Instantaneous Frequency | 0.049220 | 0.000000 |
| 13 | Porosity | Amplitude Weighted Cosine Phase | 0.049085 | 0.000000 |
| 14 | Porosity | Derivative Instantaneous Amplitude | 0.048972 | 0.000000 |
| 15 | Porosity | Integrate | 0.048792 | 0.000000 |
| 16 | Porosity | Instantaneous Phase | 0.048523 | 0.000000 |
| 17 | Porosity | Filter 0/10-50/60(inverted_Zp) | 0.048290 | 0.000000 |
| 18 | Porosity | Filter 45/50-55/60 | 0.048190 | 0.000000 |
| 19 | Porosity | Filter 15/20-25/30 | 0.048076 | 0.000000 |
| 20 | Porosity | Filter 35/40-45/50 | 0.047955 | 0.000000 |
| 21 | Porosity | Instantaneous Phase(inverted_Zp) | 0.047823 | 0.000000 |
| 22 | Porosity | Filter 25/30-35/40(inverted_Zp) | 0.047705 | 0.000000 |
| 23 | Porosity | Amplitude Weighted Phase(Model_P-Impedance) | 0.047662 | 0.000000 |
| 24 | Porosity | Apparent Polarity | 0.047601 | 0.000000 |
| 25 | Porosity | Amplitude Weighted Cosine Phase(Model_P-Impedance) | 0.047555 | 0.000000 |
| 26 | Porosity | Amplitude Weighted Cosine Phase(inverted_Zp) | 0.047401 | 0.000000 |
| 27 | Porosity | Integrate(Model_P-Impedance) | 0.047336 | 0.000000 |
| 28 | Porosity | 1/( Model_Synthetic ) | 0.047282 | 0.000000 |
| 29 | Porosity | Filter 5/10-15/20(Model_P-Impedance) | 0.047227 | 0.000000 |
| 30 | Porosity | Raw Seismic | 0.047198 | 0.000000 |

**Table 8.2** illustrates that attributes of training error and validation error of porosity prediction.

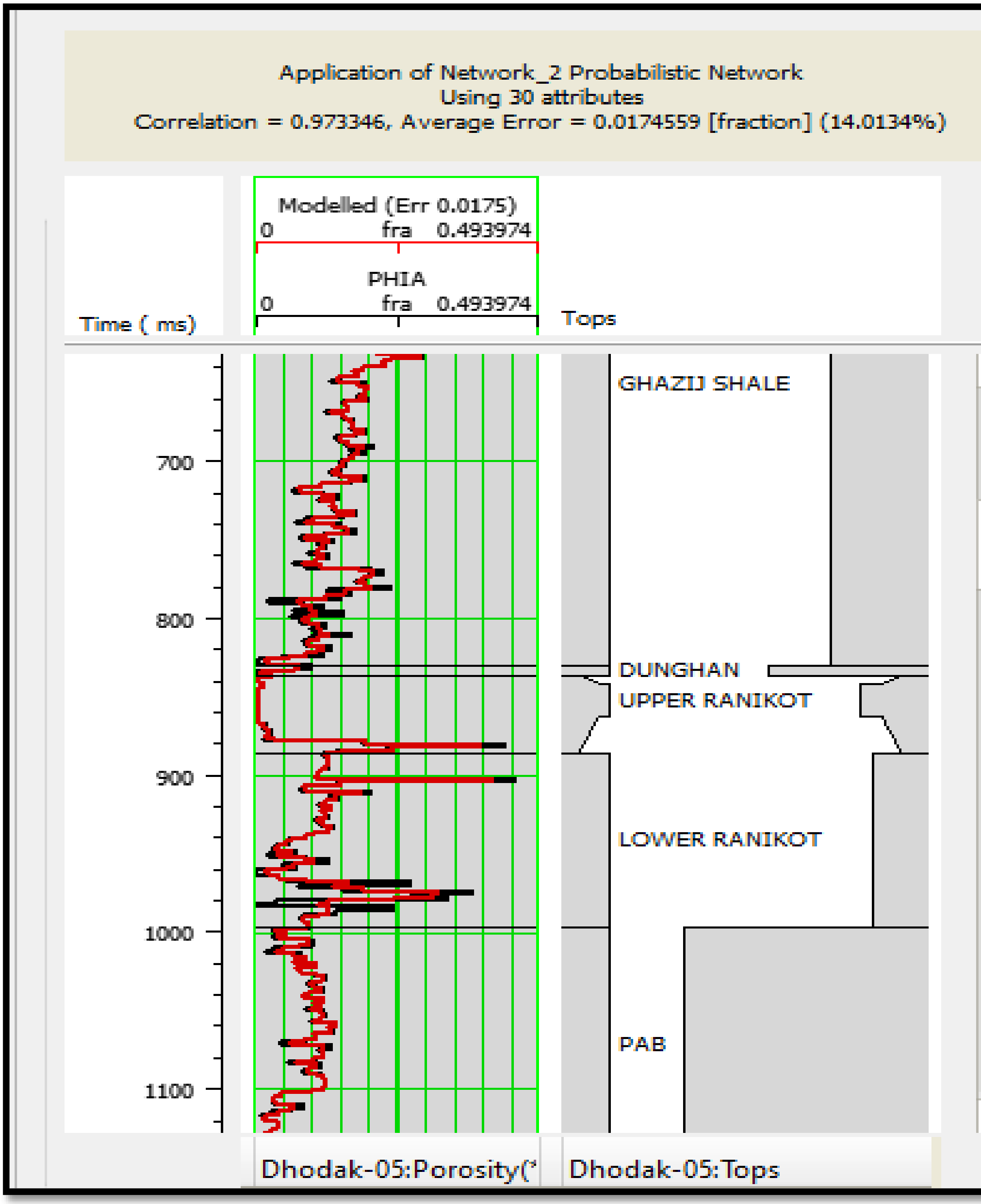


**Figure 8.4** Training result of PNN modeled porosity (red) and actual porosity (black).

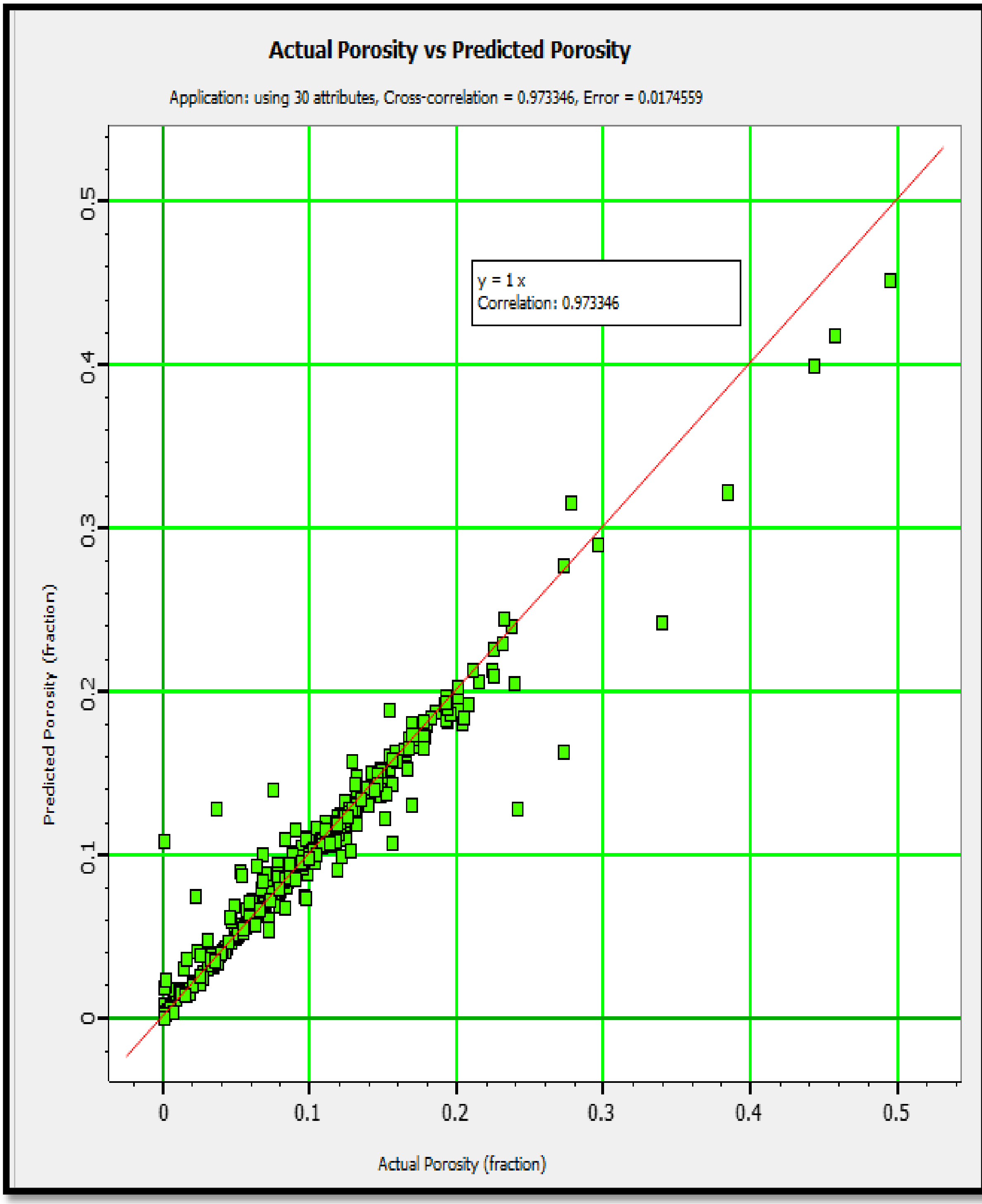


**Figure 8.5** Cross plot of actual porosity and predicted porosity (modeled).

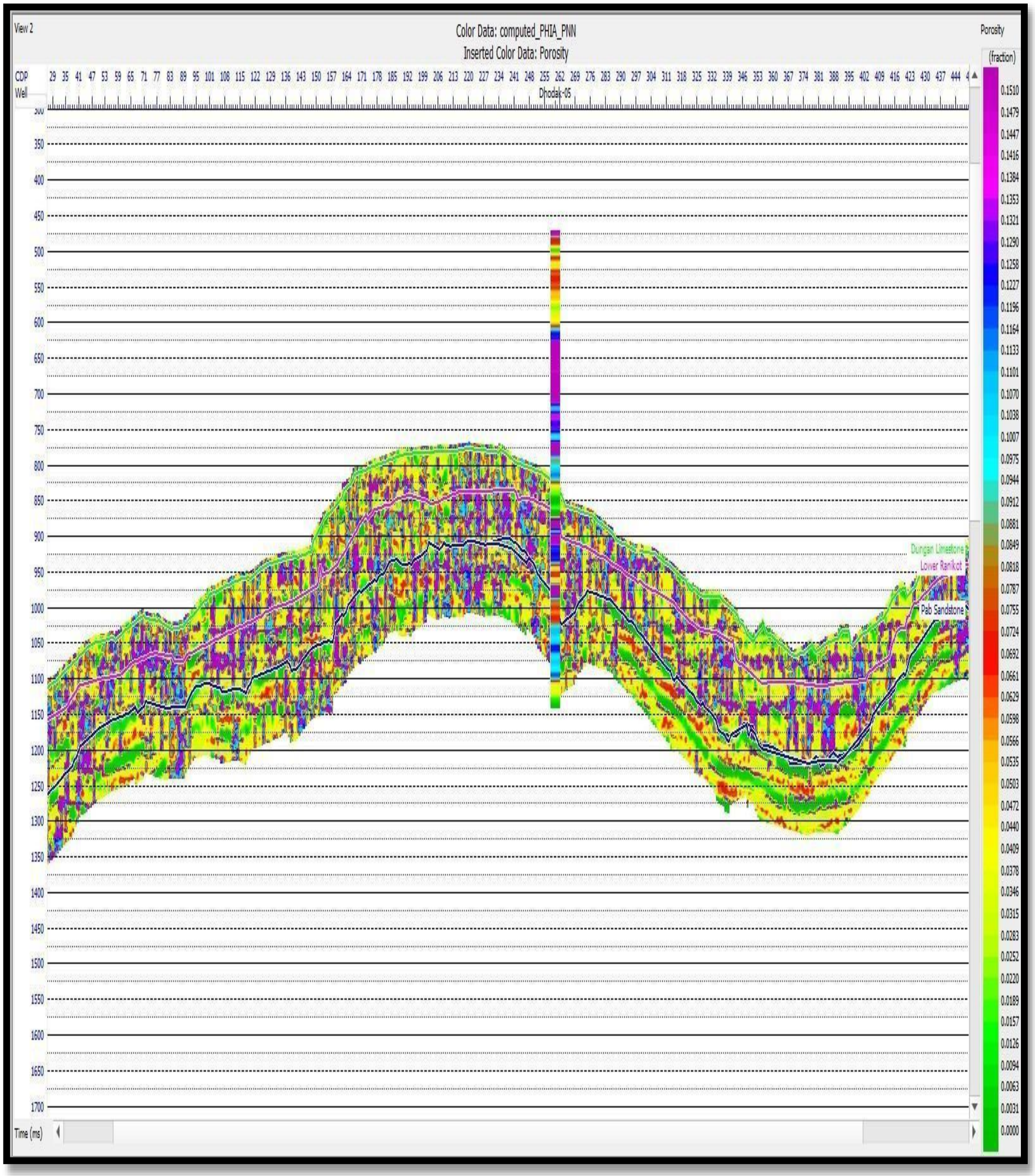


**Figure 8.6** Depicts that values ranging from 0.3% to 0.15% porosity in Dhodak-05

## 8.6 Sw prediction using PNN (Machine learning)

Saturation of water is important parameter to depict Hydrocarbon potential of reservoir. As (1-SH = SW). So training error is 12% only which is negligible.

Multi-Attribute List: Multi Attribute List 1

| | Target | Final Attribute | Training Error | Validation Error |
|---|---|---|---|---|
| 1 | Sqrt( Water Saturation ) | Average Frequency | 0.122517 | 0.000000 |
| 2 | Sqrt( Water Saturation ) | Integrate(Model_P-Impedance) | 0.110433 | 0.000000 |
| 3 | Sqrt( Water Saturation ) | Dominant Frequency | 0.101144 | 0.000000 |
| 4 | Sqrt( Water Saturation ) | Second Derivative | 0.094081 | 0.000000 |
| 5 | Sqrt( Water Saturation ) | Filter 5/10-15/20(inverted_Zp) | 0.089221 | 0.000000 |
| 6 | Sqrt( Water Saturation ) | ( computed_PHIA_PNN )**2 | 0.086739 | 0.000000 |
| 7 | Sqrt( Water Saturation ) | Integrated Absolute Amplitude(Model_P-Impedance) | 0.084129 | 0.000000 |
| 8 | Sqrt( Water Saturation ) | Apparent Polarity(inverted_Zp) | 0.081785 | 0.000000 |
| 9 | Sqrt( Water Saturation ) | Instantaneous Phase(inverted_Zp) | 0.079886 | 0.000000 |
| 10 | Sqrt( Water Saturation ) | ( Model_Synthetic )**2 | 0.077925 | 0.000000 |
| 11 | Sqrt( Water Saturation ) | Derivative Instantaneous Amplitude | 0.076735 | 0.000000 |
| 12 | Sqrt( Water Saturation ) | ( inverted_Zp )**2 | 0.075286 | 0.000000 |
| 13 | Sqrt( Water Saturation ) | Filter 35/40-45/50 | 0.074244 | 0.000000 |
| 14 | Sqrt( Water Saturation ) | Apparent Polarity | 0.073296 | 0.000000 |
| 15 | Sqrt( Water Saturation ) | Average Frequency(Model_P-Impedance) | 0.071988 | 0.000000 |
| 16 | Sqrt( Water Saturation ) | Filter 55/60-65/70 | 0.071123 | 0.000000 |
| 17 | Sqrt( Water Saturation ) | Amplitude Weighted Phase | 0.070418 | 0.000000 |
| 18 | Sqrt( Water Saturation ) | ( Model_P-Impedance )**2 | 0.069417 | 0.000000 |
| 19 | Sqrt( Water Saturation ) | Filter 45/50-55/60(Model_P-Impedance) | 0.069055 | 0.000000 |
| 20 | Sqrt( Water Saturation ) | Log( computed_Volumetric ) | 0.068626 | 0.000000 |
| 21 | Sqrt( Water Saturation ) | Sqrt( inverted_Syn ) | 0.068298 | 0.000000 |
| 22 | Sqrt( Water Saturation ) | Cosine Instantaneous Phase | 0.067911 | 0.000000 |
| 23 | Sqrt( Water Saturation ) | Filter 0/10-50/60 | 0.067597 | 0.000000 |
| 24 | Sqrt( Water Saturation ) | Amplitude Weighted Cosine Phase(Model_P-Impedance) | 0.067373 | 0.000000 |
| 25 | Sqrt( Water Saturation ) | Apparent Polarity(Model_P-Impedance) | 0.067188 | 0.000000 |
| 26 | Sqrt( Water Saturation ) | Amplitude Weighted Cosine Phase | 0.067018 | 0.000000 |
| 27 | Sqrt( Water Saturation ) | Filter 25/30-35/40 | 0.066867 | 0.000000 |
| 28 | Sqrt( Water Saturation ) | Instantaneous Phase | 0.066724 | 0.000000 |
| 29 | Sqrt( Water Saturation ) | Filter 25/30-35/40(inverted_Zp) | 0.066314 | 0.000000 |
| 30 | Sqrt( Water Saturation ) | Second Derivative Instantaneous Amplitude | 0.066114 | 0.000000 |

**Table 8.3** Illustrates that attributes of training error and validation error of Sw prediction.

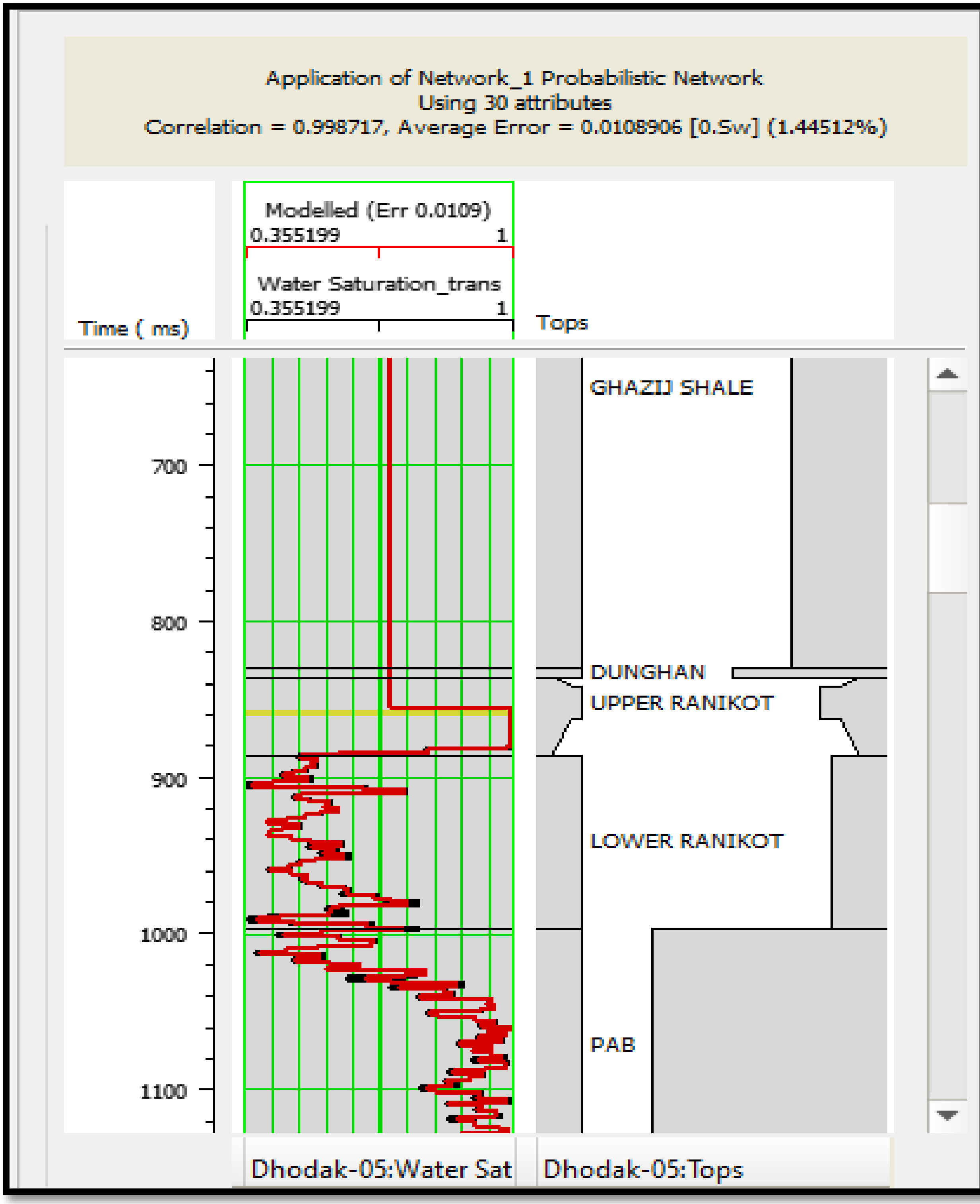


**Figure 8.7** Training result of PNN modeled Saturation of Water, actual Saturation of Water.

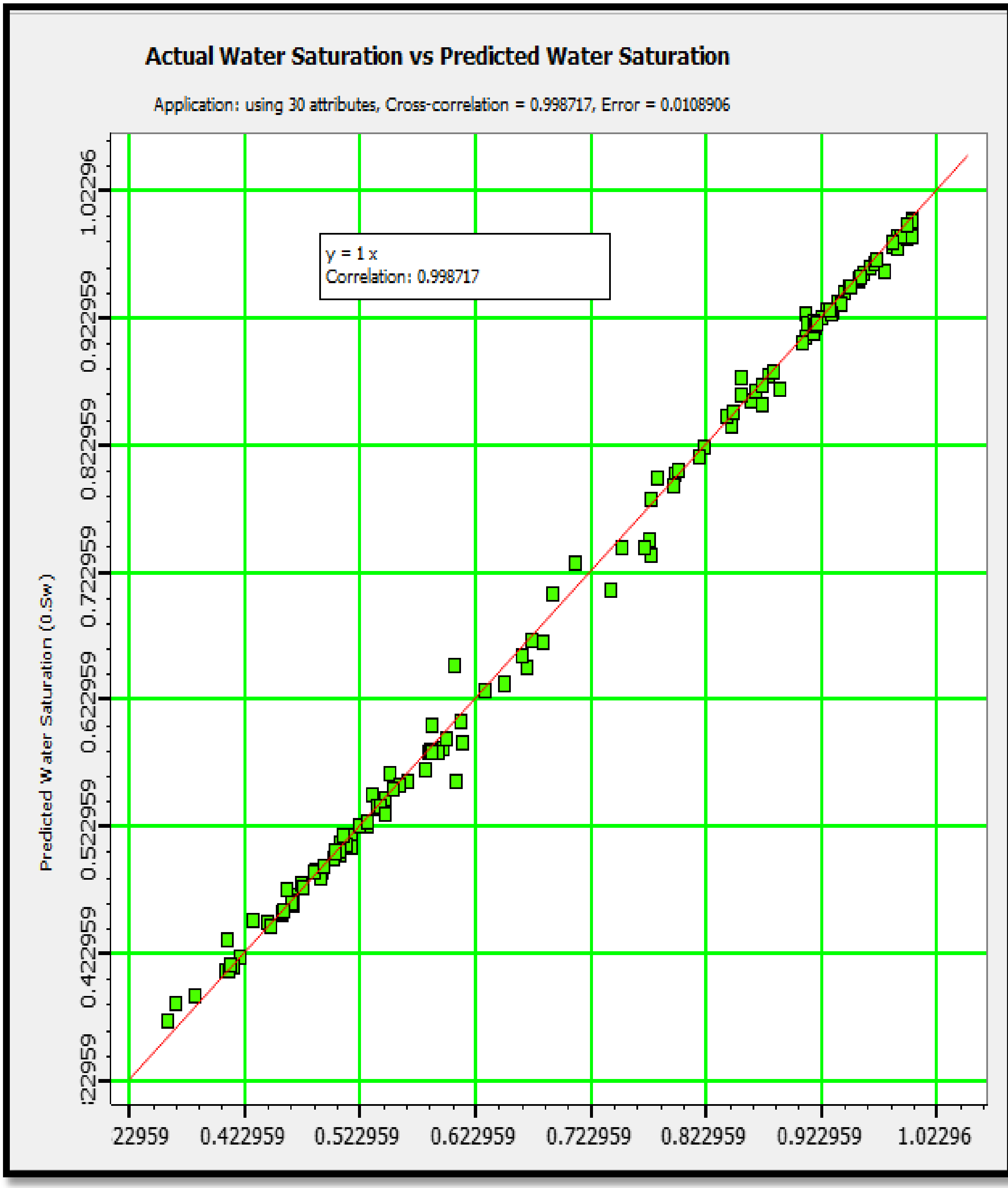


**Figure 8.8** Cross plot of Actual Water Saturation with Predicted Water Saturation (modeled).

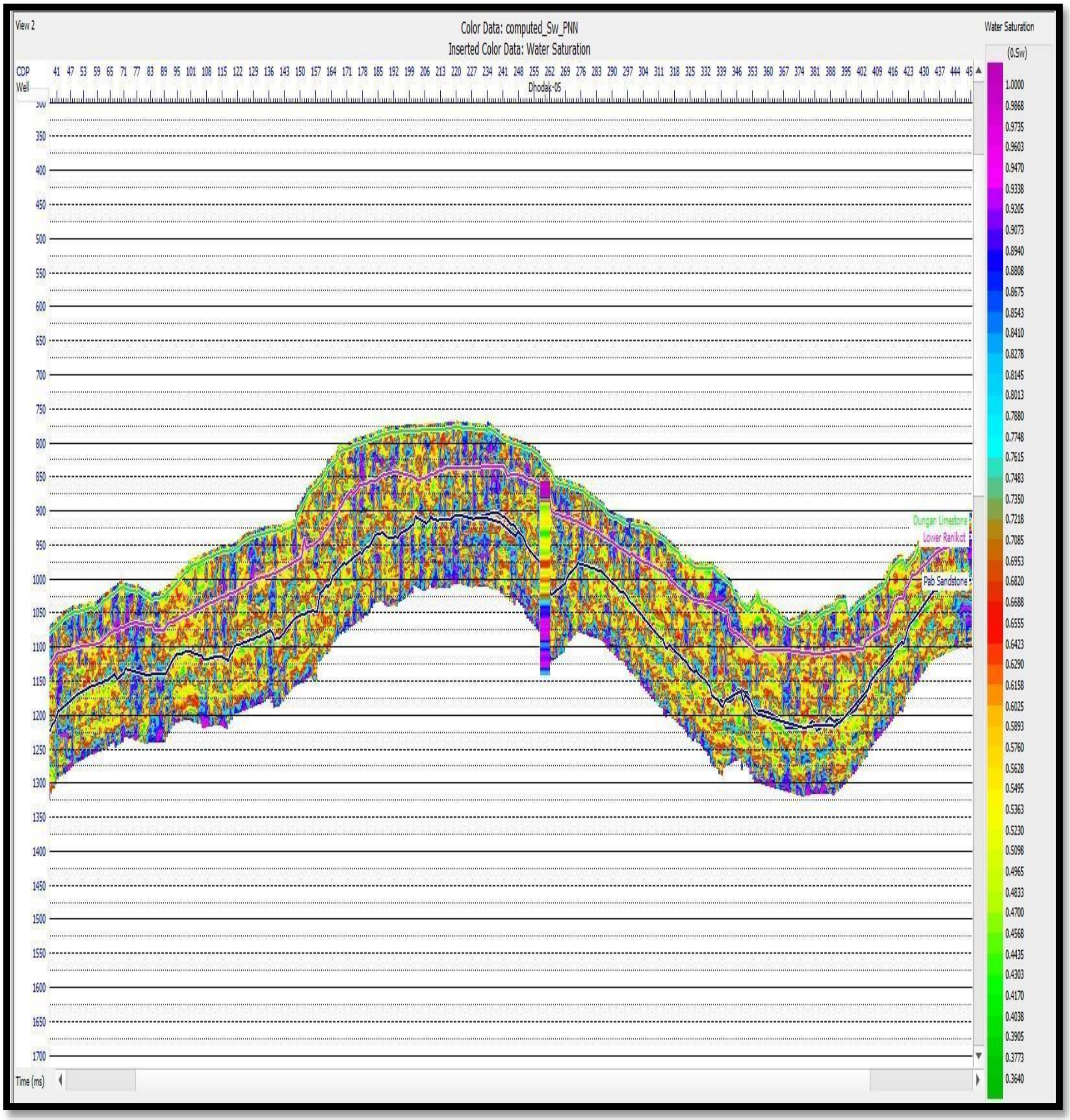


**Figure 8.9** Depicts values ranging from 0.04% to 0.52% of predicted Sw of Dhodak-05.

# CONCLUSIONS

1. Seismic data interpretation illustrates that the Dhodak structure is asymmetrical anticline with the eastern limb which is dipping more steeply as compared to western limb. Time and depth contour maps shows decreasing values of time and depth over Dhodak anticline. The study area comprises of many reverse faults that makes the pop up structures. Faults of area are dominantly east-west trending reverse fault.

2. The petro physical interpretation illustrates that the Lower Ranikot Formation shows good hydrocarbon potential which have about 75 % hydrocarbon saturation in Zone-2 and economically viable.

3. Rock physics analysis helps in the verification of the results of the petro-physical analysis which helps the demarcation of the zone of interests basis, while Zone 2 is more promising.

4. Model based inversion illustrated the Porosity and Litho-Facies model of reservoir is viable and economical.

5. Volume of clay, water saturation and average porosities have been accurately predicted by machine learning algorithms.

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