# STRUCTURAL EVALUATION, USING 2D SEISMIC DATA OF DHULIAN AREA, POTWAR, PAKISTAN


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# ABSTRACT

Dhulian is located in the Central Potwar Zone and is broad east-west trending, doubly plunging anticline. The aim of the study is to identify structures present in the area of Dhulian through the interpretation of the Seismic data. A total number of 5 seismic lines PDK-101, PDK-103, PDK-104, PDK-112 and PDK-113, well logs of Dhulian-43 and a base map were provided to us by Directorate General of Petroleum Concession (DGPC) from a Seismic survey conducted by O.G.D.C. in 1981 in the area of Dhulian. Four prominent reflectors R1 (Chorgali Formation), R2 (Sakesar Formation), R3 (Lockhart Formation) and R4 (Basemaent) are marked on the Seismic sections and mapped.

Two way travel time for each reflector was calculated and the average velocity for each line was calculated by using Mean Line Method. Time and depth contour maps were made for the four horizons and then plotted on computer software Rock Works to view time and depth surfaces. These contour maps show a faulted anticline subsurface structure favourable for hydrocarbon accumulation. Geoseismic sections, representing seismic structures in terms of depth were prepared for the line PDK-104 and PDK-113 by using depth of horizons picked and formation thicknesses encountered in well Dhulian-43.

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We pay our humble regards to the co-superviser Dr.Mohammad Zafar, Head of Department Earth and Environmental Sciences, Bahria University Islamabad, who steered and piloted our thesis and his extraordinary guidance throughout the academics.

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# CONTENTS


| | | | |
|---|---|---|---|
| ABSTRACT | | | i |
| ACKNOWLEDGEMENT | | | ii |
| CONTENTS | | | iii |
| LIST OF FIGURES | | | v |
| LIST OF TABLES | | | vii |
| **Chapter 1** | **INTRODUCTION** | | 1 |
| | 1.1 | Location of study area | 1 |
| | 1.2 | Exploration History of Dhulian Oilfield | 4 |
| | 1.3 | Data used | 4 |
| | 1.4 | Objectives and Methodology | 4 |
| **Chapter 2** | **GENERAL GEOLOGY AND TECTONICS OF POTWR PLATEAU** | | 6 |
| | 2.1 | Northwestern Himalayan Fold and Thrust Belt | 7 |
| | 2.2 | Potwar Plateau | 7 |
| | 2.2.1 | Structural Style of Potwar Plateau | 10 |
| | 2.2.2 | Major Faults in Potwar Plateau | 10 |
| | 2.2.3 | Major Folds in Potwar Plateau | 11 |
| **Chapter 3** | **STRATIGRAPHY OF DHULIAN AREA** | | 14 |
| | 3.1 | Stratigraphy of Dhulian Area | 14 |
| | 3.2 | Hydrocarbon Occurrence | 18 |
| | 3.3 | Petroleum Geology of Dhulian Area | 20 |
| | 3.3.1 | Source | 20 |

3.3.2 Reservoir 20

3.3.3 Seal 22

3.3.4 Trap 22

3.4 Dhulian Structure 23

**Chapter 4 SEISMIC DATA ACQUISITION AND PROCESSING** 24

4.1 Seismic Data Acquisition 24

4.1.1 Field Crew 25

4.1.2 Energy Sources 25

4.1.3 Seismic Spread 26

4.1.4 Geophone Interval 26

4.1.5 Geophone Base 26

4.1.6 Geophone Code 27

4.1.7 Multiplicity of Data 28

4.1.8 Recording ParameterS 28

4.2 Seismic Data Processing 30

4.2.1 Steps involved in Seismic Data Processing 32

**Chapter 5 SEISMIC DATA INTERPRETATION** 35

5.1 Seismic Time Section 35

5.2 Interpretation of the given Seismic Data 36

5.2.1 Identification of horizons 36

5.2.2 Identification of faults 37

5.2.3 Identification of Structure from Interpreted Seismic section

5.2.4 Calculating two way travel time 43

5.2.5 Calculating velocities by Mean Average Velocity Line Method 44

5.2.6 Time Contour Map 50

5.2.7 Depth Contour Map 50

5.2.8 Preparation of Geoseismic Section 57

5.3 Conclusions 62

APPENDICES 64

REFERENCES 74

# LIST OF FIGURES


| | | |
|---|---|---|
| Figure 1.1 | Map showing tectonic zones of Pakistan. Inset showing the Potwar sub-basin. | 2 |
| Figure 1.2 | In the inset Pakistan map is showing the location of the Dhulian Anticline. | 3 |
| Figure 2.1 | Geological and Structural Map of Potwar Plateu. Study Area (Dhulian) is highlighted by the box. | 9 |
| Figure 3.1 | Generalized Stratigraphy of Potwar Area | 16 |
| Figure 3.2 | Map showing hydrocarbon potential of Potwar Plateau. (Siddiqui et al., 2006). | 18 |
| Figure 4.1 | Seismic Reflection Acquisition | 24 |
| Figure 4.2 | Geophone array layout used to acquire study area data. | 27 |
| Figure 4.3 | Fold Coverage | 28 |
| Figure 4.4 | Generalized flowchart for reflection data processing (From Kim et al., 2001) | 31 |
| Figure 4.5 | Diffraction pattern in ”Unmigrated” line PDK-112 highlighted by the box | 34 |
| Figure 5.1 | Seismic Interpretation Flowchart for the Study Area | 36 |
| Figure 5.2 | Study Area (Dhulian) Base Map | 38 |
| Figure 5.3 | Seismic Section of line PDK-101 | 39 |
| Figure 5.4 | Seismic Section of line PDK-103 | 40 |
| Figure 5.5 | Seismic Section of line PDK-104 | 41 |
| Figure 5.6 | Seismic Section of line PDK-113 | 42 |

| | | |
|---|---|---|
| Figure 5.7 | Two Way Time VS Velocity plot along with the Average Velocity of Seismic line PDK-101. | 45 |
| Figure5.8 | Two Way Time VS Velocity plot along with the Average Velocity of Seismic line PDK-103 | 46 |
| Figure 5.9 | Two Way Time VS Velocity plot along with the Average Velocity of Seismic line PDK-104original Base Map of Dhulian | 47 |
| Figure 5.10 | Two Way Time VS Velocity plot along with the Average Velocity of Seismic line PDK-112 | 48 |
| Figure 5.11 | Two Way Time VS Velocity plot along with the Average Velocity of Seismic line PDK-113. | 49 |
| Figure 5.12 | Time Contour Map of Reflector R1 | 51 |
| Figure 5.13 | Time Contour Map of Reflector 2 | 52 |
| Figure 5.14 | Time Contour Map of Reflector 3 | 53 |
| Figure 5.15 | Depth Contour Map of Reflector 1 | 54 |
| Figure 5.16 | Depth Contour Map of Reflector 2 | 55 |
| Figure 5.17 | Depth Map of Reflector 3 | 56 |
| Figure 5.18 | Surface Topographic map of Dhulian area | 58 |
| Figure 5.19 | Surface Geological map of Dhulian and adjoining area (Siddiqui et al., 2006). | 59 |
| Figure 5.20 | GeoSeismic Section of Dip line PDK-104 | 60 |
| Figure 5.21 | GeoSeismic Section of Strike Line PDK-113 | 61 |

# LIST OF TABLES


| | | |
|---|---|---|
| Table 1 | Stratigraphic Section of Dhulian | 17 |
| Table 2: | Table 2: Field Crew for the Seismic lines of Dhulian Anticline | 25 |
| Table 3 | Source Parameters used for the Seismic lines of Dhulian Anticline | 26 |
| Table 4 | Spread Geometry used for lines PDK -101, 103, 104, 112 and 113 | 26 |
| Table 5 | Receiver parameters used for the lines PDK-101,103,104,112 and 113 | 27 |
| Table 6 | Recording parameters used for the lines PDK-101, 103, 104, 112 and113. | 29 |
| Table 7 | Different Processing steps and their purpose | 33 |
| Table 8 | Probable Formation thickness measured from Well Data Dhulian-43 for Strike line PDK-113. | 57 |
| Table 9 | Probable Formation thickness measured from Well Data Dhulian-43 for Dip line PDK-104. | 57 |

# Chapter 1

# INTRODUCTION

Pakistan has high potential of hydrocarbons in its northern (like Potwar, Kohat) and southern (like Badin, Mari etc.) parts. The Indus basin, including the Kohat-Potwar (study area) depression, belongs to the category of extra continental downward basins which account for 48% of the world's known petroleum resources (Riva, 1983). The Potwar sub-basin in dominated by the structural traps and mostly Seismic data is incorporated for the delineation of these structures.

## 1.1 Location of Study Area

Dhulian (Study Area) is located in the Potwar Area. The location of the Potwar Plateau is shown by a map in Fig. 1.1.The area under study Dhulian Anticline bounded by latitude $33^0$ $12^/$ $41^{//}$ and longitude $72^0$ $12^/$ $00^{//}$ lies in the central part of Potwar sub-basin as shown in the figure 1.2.

The Naryal and Toot Oilfields are located on the western side of Dhulian Oilfield. Soan Syncline is present in the South. Khaur Anticline is located in the North-East of Dhulian Anticline. In the North-West of Dhulian we have Meyal Oilfield and in the NNW is situated the Ratana Oilfield as shown in the Figure 1.2 and 6.20.

In 1993 POL acquired Seismic data which revealed that in the subsurface the Dhulian structure is a broad symmetric compressional fold with faulted compartments. It is salt cored with a wrench induced major thrust to the North separating it from the Khaur pop-up structure.

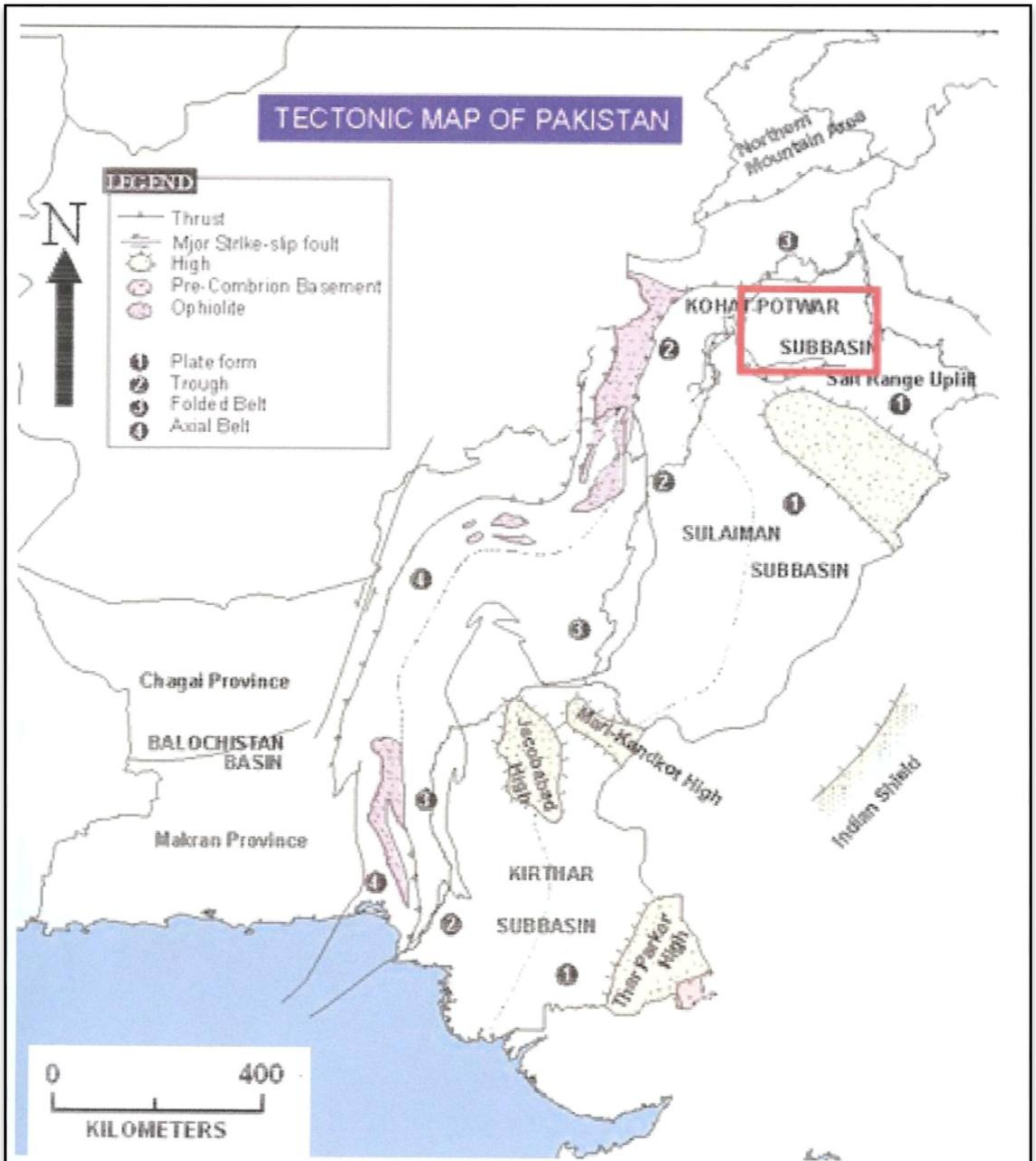
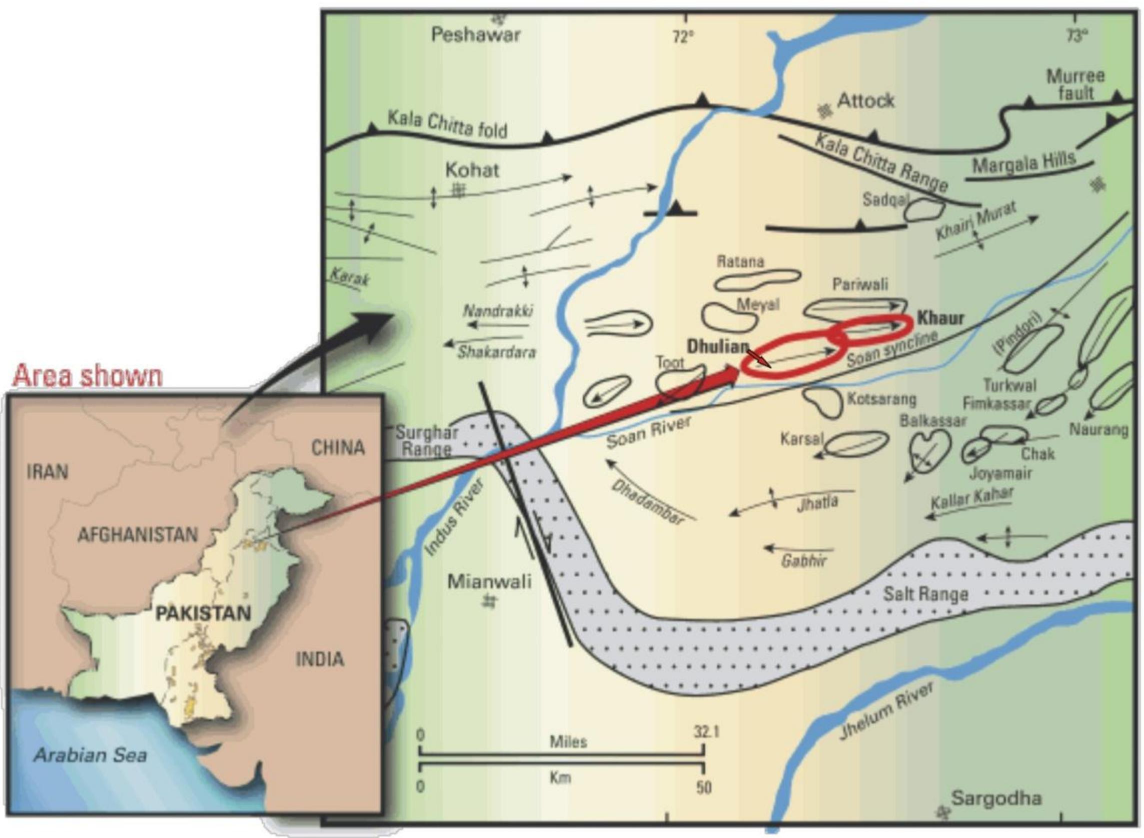


Figure 1.1: Map showing tectonic zones of Pakistan. Inset showing the Potwar sub-basin.


Area shown
IRAN
CHINA
AFGHANISTAN
PAKISTAN
INDIA
Arabian Sea
Peshawar
72°
73°
Murree fault
Attock
Kala Chitta fold
Kala Chitta Range
Margala Hills
Kohat
Sadqal
Khairi Murat
Karak
Ratana
Pariwali
Meyal
Khaur
Nandrakki
Shakardara
Dhulian
Toot
Soan syncline
(Pindori)
Turkwal
Fimkassar
Kotsarang
Surghar Range
Soan River
Karsal
Balkassar
Naurang
Chak
Joyamair
Indus River
Dhadambar
Jhatla
Kallar Kahar
Gabhir
Mianwali
Salt Range
Jhelum River
0
Miles
32.1
Km
50
Sargodha

## 1.2 Exploration History of Dhulian Oil Field

The Dhulian oilfield located in the central part of the Potwar Plateau about 90 km South-West of Islamabad. Wynne mapped the surface structure in 1877 as a broad East-West trending, doubly plunging anticline.

In 1918, the Attock Oil Company limited started exploration on the surface structure. First commercial production was obtained in 1937 from the fractured shelf carbonates of Eocene Chorgali-Sakesar Formation. First oil discovery in Pakistan from Paleocene reservoir was made during 1951 in Dhulian. In 1960 Pakistan's first Jurassic oil-bearing reservoir was also discovered in the Dhulian 39 well. A total of 49 wells were drilled till 1966. The average well depth in the field is about 8,500 feet, but Dhulian 43, the deepest well, was drilled to a depth of 12,428 feet into Infra-Cambrian. The Permian and Cambrian objectives were water bearing.

## 1.3 Data Used

Seismic data has been incorporated in the present work. A total of five seismic lines, a base map and well data of Dhulian-43 were obtained from Landmark Resources (LMKR) with prior approval from the Directorate General of Petroleum Concession (DGPC).

## 1.4 Objectives and Methodology

The foremost objective of the thesis work is to understand the Seismic Data Interpretation required for the mapping of subsurface structure for the exploration of hydrocarbons. To achieve the desired goal, the study was carried out in the following systematic manner:

1. Study the acquisition and processed parameters of the project Seismic lines
2. Picking of the prominent reflectors on the Seismic sections.
3. Correlate all the marked horizons over all the dip and strike lines.
4. Identifications of faults and geologic features observed on the section as a result of tectonic activity in the area.

5. Correlate the faults on base map.
6. Preparation of Time contour map of the recognized horizons.
7. Preparation of Depth structure map for each reflector.
8. Preparation of Geoseismic Section for each Seismic line for the better understanding of the geologic model of the study area.

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# Chapter 2

# GENERAL GEOLOGY OF POTWAR PLATEAU

Pakistan possesses the North-Western boundary of the Indian lithospheric plate. The underthrusting of Indian Plate beneath the Eurasian Plate is producing compressional thin-skinned tectonic features since Eocene time on the northern and North-Western fringes of the Indian Plate. The continued underthrusting of the Indian Plate since Cretaceous produced the spectacular mountain ranges of the Himalaya and a chain of foreland fold-and-thrust belts and thick sheets of sediments thrusted over the Indian craton (Kemal, 1991).

In northern Pakistan, the Himalayan trend is divided into four major subdivisions. Karakoram ranges and Hindukush lie in the North of the Main Karakoram Thrust (MKT). South of the MKT and North of Main Mantle Thrust (MMT) lies the Kohistan block. Low ranges of Swat, Hazara and Kashmir that are analogous to the Lesser Himalayas of India lie between the MMT and the Main Boundary Thrust (MBT). The Potwar Plateau, bounded on the South by the Salt Range Thrust (SRT), represents the marginal foreland fold-and-thrust belt of Indo-Pakistan Subcontinent, equivalent to the Sub-Himalayas in India (Pennock et at, 1989).

Thrusting in the Indian Plate is certainly the main accommodation method of shortening in the Himalayas. Fault plane solutions of earthquakes give evidence that these are linked to the thrusts. However, in the North-West Himalayas (the study area is the part of which), complications arise as earthquake fault planes do not follow the thrusts which change in orientation, suggesting that other accommodation features besides simple thrusting are occurring in the North-West Himalayas (Spencer, 1992). Kazmi and Jan (1997) named the North-West Himalayas as the North-western Himalayan Fold-and-Thrust Belt, in their tectonic division of Pakistan.

## 2.1 Northwestern Himalayan Fold-And Thrust Belt

The North-West Himalayas fold-and-thrust belt consists of irregularly shaped mountainous region and it covers a wide area about 250x560 $km^2$. It extends from the Afghan border near Parachinar upto the Kashmir Basin. Its eastern boundaries are the Hazara-Kashmir Syntaxis and Nanga Parbat Syntaxes, whereas MMT in the North and the SRT in the South are its structural limits. The Nanga Parbat, Hazara, southern Kohistan, Swat, Margalla Kalachitta, Kohat, Koh-i-Sufaid, Salt Range and its western extension are also covered by it.

The belt is divisible into two parts i.e. hinterland zone and foreland zone by a major thrust i.e. Panjal-Khairabad Fault. The study area belongs to the foreland zone, which is further comprised of the Hazara-Kashmir Syntaxis, Salt Range and Kohat-Potwar fold belt, and the Kurram-Charat – Margala thrust belt. Below is the tectonic/geological description of the Potwar area only.

## 2.2 Potwar Plateau

Physiographically, the Plateau is a low relief surface, except where dissected by major rivers. Potwar Plateau is an elevated nearly flat region located about 100 km North of the Salt Range. The Kalachitta and Margala Hills bound the Potwar Plateau to the North, the Indus River and Kohat Plateau to the West, and the Jhelum River and the Hazara-Kashmir syntaxis to the East. It is largely covered by the Siwalik sequence, though at places upper Eocene shales and limestones crop out locally in folded inliers. The wide and broad Soan Syncline divides the Potwar Plateau into Northern Potwar Deformed Zone (NPDZ) and Southern Potwar Platform Zone (SPPZ).

The NPDZ is more intensely deformed that the southern part. It is a belt of Neogene deformation, extending South ward from the MBT to the Soan Syncline. The zones are shown in Fig. 2.1. Formation outcrops and faults are generally East-North-East trending, approximately perpendicular to the tectonic transport direction. The highly dissected NPDZ is an area of wide synclines, compressed folds and closely spaced imbricate thrusts. The deformation style of NPDZ abruptly changes from East to West (Figure. 2.1).

The eastern NPDZ represents a burled thrust front with the development of foreland syncline on the back of Dhurnal Fault, passive roof duplex (triangle zone) and hinterland dipping imbricate stack farther North (Kemal, 1991). While the western NPDZ which is characterized by compressed and faulted anticlines separated by large synclines, representing the emergent thrust (Kemal, 1991). Jaswal et al (1997) calculated about 55 km of horizontal shortening for the zone between the Soan syncline and a point near MBT.

The NPDZ is followed to the South by asymmetrical wide and broad Soan Syncline, with a gently northward dipping southern flank along the Salt Range and steeply dipping northern limb along NPDZ (Figure. 2.1). The eastern part of the Southern Potwar Platform Zone represents strong deformation as compared to the central and western parts. The thrusts and back thrusts bounded salt cored anticlines represents both foreland and hinterland verging minor deformation is present within the overthrusted Phanerozoic sedimentary section, due to effective decoupling within Eocambrian evaporates above the basement.

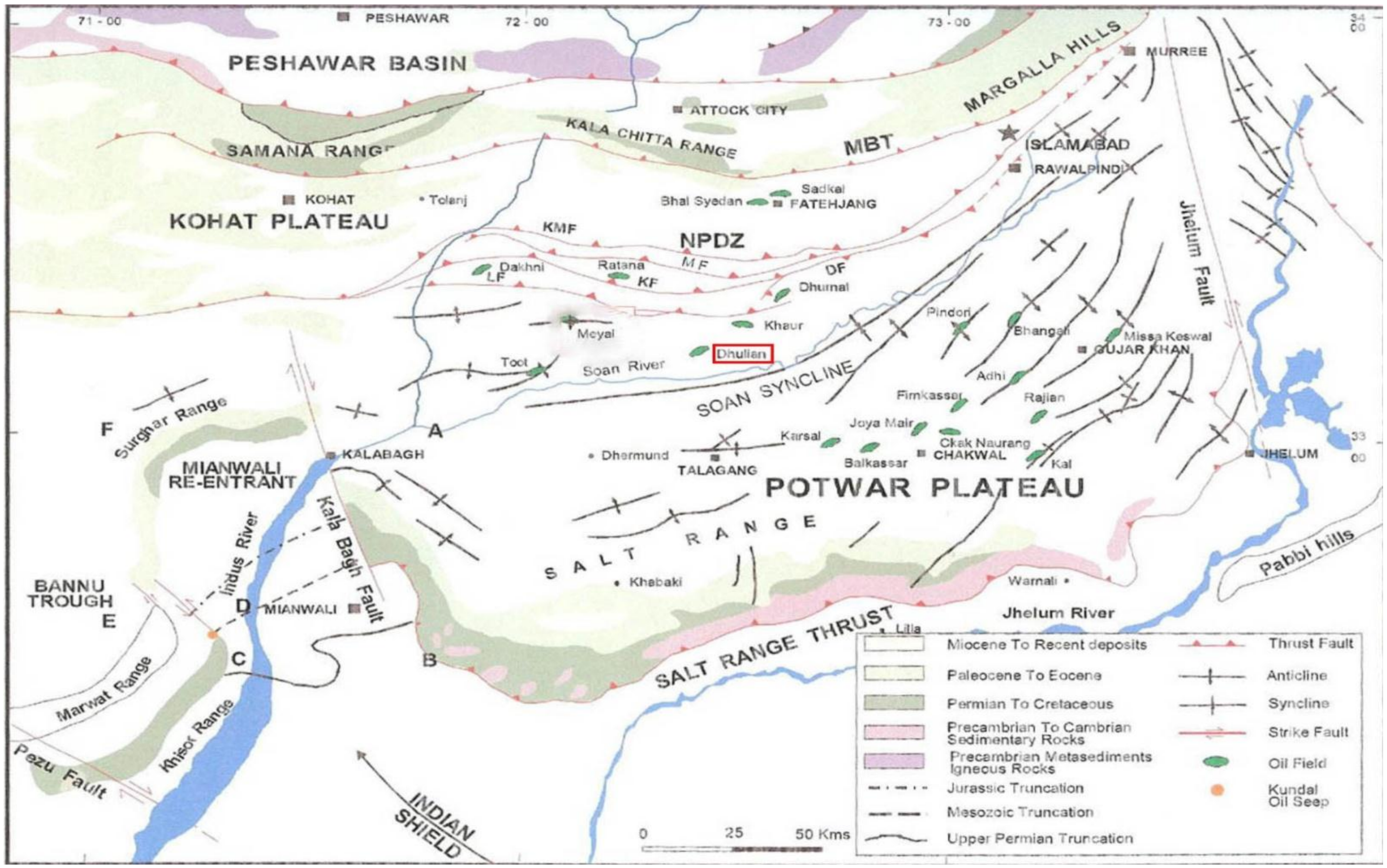



Figure 2.1: Geological and Structural Map of Potwar Plateu. Study Area (Dhulian) is highlighted by the box.

### 2.2.1 Structural Style of Potwar Plateau

The structural style of the central eastern and western parts of Potwar Plateau shows a marked difference. In the central western parts of Potwar Plateau, the deformation appears to have occurred by south-verging thrusting, whereas in the eastern part the deformation is mainly in North-East-South-West direction with tight and occasionally overturned anticlines separated by broad synclines. This difference may be related to lesser thickness of Eocene-Cambrian sequence and more thickness of Salt Range Formation in the eastern areas and very low dip of the basement ($1^{o}$-1.5) as compared to central Potwar ($2^{o}$-$3^{o}$).

In central Potwar, structures are mainly fault bounded mostly by thrusts and backthrusts, while at some places, asymmetric anticlines are mainly fault bounded mostly by thrusts and back thrusts, while at some places, asymmetric anticlines are bound by a single fault. Based on the seismic interpretation, the structures in Potwar area may be divided into: Pop-up anticlines, Snake-head anticlines, Salt cored anticlines and Triangle zones (Siddiqui et al, 2006).

### 2.2.2 Major Faults in Potwar Plateau

As Potwar Plateau represents the southern margin of the Himalayan collisional zone, a variety of faults and folds can be seen in the area which is shown in Figure. 2.1. Some of the major faults of the area are described as given below:

**Khair-i-Murat Fault (KMF)**

Khair-i-Murat Fault (KMF) is a North-dipping major emergent thrust in the NPDZ as shown in Figure.2.1, along which high velocity Eocene Carbonates are thrusted southward over low velocity molasses (Jaswal et al., 1997). It solves out in the basal decollement at a depth of about 9 km (Jadoon et al., 1999). Due to back rotation, fault having steep dips at the surface and contains highly faulted beds of Murree Formation to its North, where most of the area is covered by the alluvium (Jaswal et al., 1997).

**Dhurnal Back Thrust (DBT)**

Dhurnal Back Thrust (DBT) a passive roof back thrust, had been considered previously as the Eastward extension of the Kanet Fault (KF), but recent work has shown the Dhurnal Fault as a different fault with different sense of motion as can be seen in Figure.2.1. It joins the KF West of Dhurnal and then diverts towards the South-West, gradually dying out at the surface. According to Jadoon et a. (1999), the steep Dhurnal back thrust becomes shallower to the South and dies out at a depth of 2 to 4 km, where it merges with a North-dipping blind thrust that propagates up section as a ramp from a layer of Eocambrian evaporates at a depth of about 8 km and forms a flat along a politic horizon in Miocene molasses strata.

**Kanet Fautl (KF)**

Kanet Fault (KF) is a North-dipping emergent thrust in the western part of the NPDZ, developed in the direction of tectonic transport, and in the eastern part of the NPDZ, it is underthrusted beneath the DBT at shown in Figure. 2.1. KF bound the Kanet syncline from the North (Jaswal et al., 1997).

**Riwat Fault (RF)**

Riwat Fault (RF) is a passive roof thrust South of Soan Syncline in the eastern Potwar Plateau (Figure. 2.1), and is a hinterland-dipping fault rather than foreland. As its southward terminus, the Riwat Fault dies out along the southern flank of the Chak Beli Khan anticline and to the North-East it dies out near the Soan Syncline axis (Pennock et al., 1989).

### 2.2.3 Major Folds in Potwar Plateau

Besides major faults, other structures present in the area include several anticlinal and synclinal features which are shown in Figure. 2.1 are given as follows;

**Soan Syncline**

Soan Syncline is a broad, wide and asymmetrical syncline that divides the Potwar Plateau into NPDZ and SPPZ. Soan River marks its axis. Soan Syncline developed at 2.1 to 1 8 Ma (Shami and Baig, 2002). Dhok Pathan Formation overlying the Nagri Formation crops out South of Dhumal area on the northern limb of Soan Syncline. The area North of Soan Syncline is characterized by horizontal shortening and imbricate thrust faulting (Jaswal et al., 1997).

**Chak Naurang Anticline**

Chak Naurang Anticline is an excellent example of a fault-propagation fold. The Southward-verging Anticline has a steeply dipping southern limb and a moderately dipping northern limb. No fault has been mapped at the surface. Reflection data shows a strong Northward dipping basement reflector overlain by a thick evaporate section. Above the evaporates, the strongly reflective platform sequence is offset, and the fault appears to lose displacement up section the Rawalpindi and Siwalik molasses.

**Mahesian Anticline**

Mahesian Antcline exposes Chinji rocks in its core. The fold is cut by two small faults, neither of which shows surface displacement of more than a few meters. The southern end of the fold has an overturned limb (60-75) and a moderately dipping western limb ($30^0$-$40^0$) (Pennock et. Al 1989).

**Tanwin –Banis Anticline**

Tanwin-Banis Acticline has a salt-thicked core. However strong reflectors, similar in seismic character to the platform sequence, appear to be over ridden by thrusts on both North-West and South-East. This geometry is interpreted as incipient triangle zone. This triangle zone can be mapped a minimum of 9 km to the southwest.

**Adhi Gungril Anticlines**

Adhi Gungri Anticlines are relatively symmetrical structures. Their crestal region dips more gently than their moderately dipping flanks. Seismic reflection data indicates the Adhi Gungril structure is a popup bounded by reverse faults to the North-West and South-East. Adhi-5 well confirms the presence of salt in the core of the fold and thins to nearly zero beneath the adjacent synclines (Pennock et al., 1989).

**Joya Mair Anticline**

Joya Mair Antcline is a doubly plunging anticline and plunges $10^0$ South-West and $4^0$ North-East. The fold axis of anticline trends North-East-South-West and is cross folded to from North-West-South-East trending Joya Mair antiformal syncline. The Chinji Formation is exposed in the core and the Nagri Formation lies along the limbs. The geologic, structural, borehole and seismic data shows that the Joya Mair structure is a triangle zone in the subsurface. (Shami and Baig, 2002).

**Dhurnal Anticline**

Dhurnal Anticline is a thrust formed anticline in a triangle zone hidden under an adjacent, foreland syncline as shown in Fig. 2.1. The surface expression is an East treding monocline, which forms the northern limb of Soan Syncline. At Eocene level the Dhurnal structure is an East North-East trending, pop-up structure bounded by forward and back thrust on the South-East and North-West, respectively. This is also the largest producing oil field in Pakistan (Jaswal et al., 1997).

**Dhulian Anticline**

The Dhulian surface structure is an almost symmetrical anticline with maximum dips of $30^o$ to $35^o$ (Figure. 6.20). The fold axis trends ENE-WSW and plunges about $4^o$-$5^o$ at both ends, running en-echelon to the nearby Khaur fold. Dhulian fold is flanked by the Soan Syncline to the South and by the tight Pindi Gheb Syncline to the North.

# Chapter 3

# STRATIGRAPHY OF DHULIAN AREA

## 3.1 Stratigraphy of Dhulian Area

Rocks from Pre-Cambrian to Quaternary age are present in the Potwar Plateau. These rocks with a total thickness of more than 26,000 feet represent a variety of environments of depositions, ranging from marine to fluvial. Periods of uplift and erosion were quite extensive, as indicated by several major unconformities (Figure. 3.1 ).

The oldest rocks penetrated by Dhulian-43, are the Pre-cambrian evaporates of the Salt Range Formation. These were deposited unconformably on a Pre-Cambrian basement in a restricted hypersaline basin of Gondwanaland interior (Jaswal et al., 1997). Dhulian-43 drilled 511 feet of Salt Range Formation, which consists of massive salt deposits grading from gypsum through marl to dolomite. The overlying Cambrian rocks of the Jhelum Group, which are present in the eastern Potwar, gradually thin out towards west and are missing in Dhulian Field. The unconformity above Salt Range Formation extends from Ordovician to Upper Carboniferous. Erosion during this time resulted in the removal of Cambrian rocks in the western Potwar sub-basin including Dhulian area.

Sedimentation was re-established in Early Permian with the accumulation of Tobra Formation in glacio-fluvial environments. The Permian sequence shows a gradual transition into marine facies indicating a wide spread transgression. In Dhulian area, marine conditions persisted until the end of Permian. In Dhulian Field, Permian rocks are represented by Nilawahan Group (Tobra, Dandot, Warcha and Sardhai Formations) and Zaluch Group (Amb, Wargal and Chidru Formations).

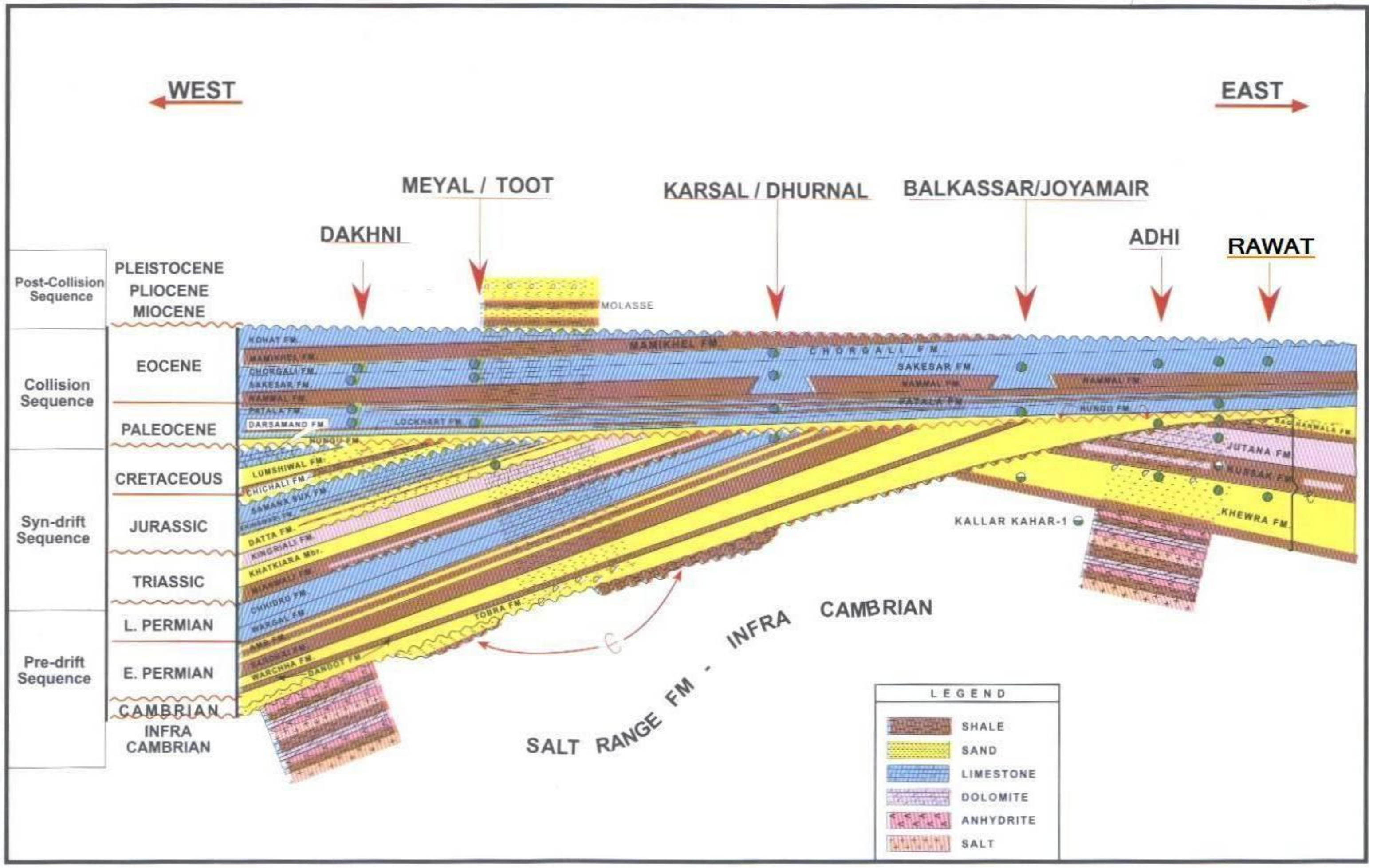
The Permian and Triassic strata are separated by an unconformity, reflecting a regression of the sea and emergent conditions persisted during Late Permian / Early Triassic, followed by yet another marine transgression in the Triassic. The rocks of Triassic, Jurassic and Cretaceous age were deposited on a West-Northwest facing passive margin after the breakup of Gondwanaland with maximum development of Mesozoic rocks in the western Potwar and Salt Range, overlapped by Paleocene strata towards east (Yeats and Hussain, 1987). In Dhulian area, Mesozoic sediments comprise a thin sequence of Triassic and Jurassic sands and shales (Mianwali and Datta Formations) overlain unconformably by

Plaeocene strata. The Jurassic sequence, however, is also missing over the eastern part of Dhulian Field, as it wedge out in the NE-SW direction, and as a consequence, Hangu Formation (Dhak Pass) directly overlies the Mianwali Formation.

During Paleocene, shallow marine deposition ensued, which was dominated by bioclastic and micrite carbonates of Lockhart Limestone (Khairabad Limestone). The overlying Patala Formation represents alternations of deeper outer and shallower inner shelf facies. This is followed by another period of Paleocene carbonate build-up represented by Upper Ranikot and Oyster Beds and this sedimentation was terminated with the onset of apparently more anoxic deep water deposition of Nammal Formation.

During Eocene, shallow marine sedimentation resumed with deposition of a mainly calcareous / argillaceous sequence of Sakesar and Chorgali Formation. The overlying Kuldana Formation, which consists of red claystones and shales, was deposited in open-marine to partially restricted environments.

The last period of uplift and erosion corresponds to major collision between the Indo-Pakistan and Eurasian plates probably in Late Eocene. Oligocene rocks are not present in the Potwar region. During the main orogenic phase in Miocene and Pliocene, thick fluvial sediments represented by Rawalpindi Group (Murree and Kamlial Formations) and Siwalik Group (Chinji, Nagri, and Dhok Pathan Formations) were deposited in the Potwar Foredeep, in response to the continued uplift in the North.


WEST
EAST
MEYAL / TOOT
KARSAL / DHURNAL
BALKASSAR/JOYAMAIR
DAKHNI
ADHI
RAWAT
Post-Collision Sequence
Collision Sequence
Syn-drift Sequence
Pre-drift Sequence
PLEISTOCENE
PLIOCENE
MIOCENE
EOCENE
PALEOCENE
CRETACEOUS
JURASSIC
TRIASSIC
L. PERMIAN
E. PERMIAN
CAMBRIAN
INFRA CAMBRIAN
MOLASSE
KALLAR KAHAR-1
SALT RANGE FM - INFRA CAMBRIAN
LEGEND
SHALE
SAND
LIMESTONE
DOLOMITE
ANHYDRITE
SALT

| ERA | PERIOD | EPOCH | GROUP | FORMATION | DEPOSITIONAL SETTING | THICKNESS (FT.) | HYDRO-CARBONS | LITHOLOGY |
|---|---|---|---|---|---|---|---|---|
| CENOZOIC | TERTIARY | PLIO. | R.PINDI SIWALIK | NAGRI | FLUVIAL, CHANNEL | | | Greenish grey Sst. and clay, conglomeratic |
| | | MIOCENE | | CHINJI | FLUVIAL, STREAMS CHANNEL | 2413-3520 | | Bright red clays with Sst. |
| | | | | KAMLIAL | FLUVIAL | 380-684 | | Massive red and brown Sst., dark red clays |
| | | | | MURREE | | 4005-4716 | R/C | Interbedded light grey Sst. |
| | | OLIGO | | | | | | |
| | | EOCENE | | KULDANA (Red Clays) | RED BEDS, COASTAL PLAINS | 90-106 | C | Interbedded quartzose Sst. grad to conglom. with sltst. and sh |
| | | | | CHORGALI | SHALLOW MARINE SUPRATIDAL LAGOONAL | 140-200 | S/R | Dark - med. grey argillaceous Lst, minor Evaporites |
| | | | | SAKESAR | | 270-340 | S/R | Massive and nodular Lst. with marls : chert in upper part |
| | | | | NAMMAL | SHALLOW MARINE RESTRICTED ANOXIC | 155-200 | S/C | Dark grey calcareous sh. light grey Lst. pyrite and glauconite |
| | | PALEOCENE | Patala Group | OYSTER BEDS | SHALLOW MARINE | 15-20 | | Grey Lst. abundant mollusk, echinoids shells |
| | | | | U.RANIKOT | | 100-120 | R/S | Dark grey calcareous sh. light grey Lst. pyrite and glauconite |
| | | | | PATALA | | 73-243 | R/S | Dark. grey greenish sh and Ls |
| | | | | LOCKHART | SHALLOW MARINE (DISTAL TO PROXIMAL) | 185-300 | R/S | Massive light - dark grey Lst. with minor sh, pyrite |
| | | | | HANGU | V.SHALLOW MARINE LITTORAL TO PALUDAL | 0-138 | C | Light grey sdst and dark grey s |
| MESOZOIC | CRETACEOUS | | | | | | | |
| | JURASSIC | | | DATTA | Shallow Marine To Deltaic | 0-223 | R | Massive Sst. & Variegated Sh. & M Lateritic zones, common gy mottli |
| | TRIASSIC | | | MIANWALI | MARINE | 149 | S/C | Olive - green & grey shales, th Limestone / dolomite |
| PALEOZOIC | LATE PERMIAN | | ZALUCH | CHIDDRU | SHALLOW MARINE | 257 | | Limestone, marl and calcareous Sst |
| | | | | WARGAL | SHALLOW MARINE PLATEFORM | 450 | R | Massive grey Lst.thin carbanaceous sh. |
| | | | | AMB | SHALLOW MARINE TO PLUDAL | 248 | | Calcareous Sst., carb Sh. |
| | EARLY PERMIAN | | NILAWAHAN | SARDHAI | V.SHALLOW MARINE TO ESTURINE | 252 | S | Dark purple & Lavendor clays Streaks of Sst. |
| | | | | WARCHA | FLUVIAL,SUB AERIAL, PALUDAL LAGOONAL | 494 | | Red & Light colored Sst. and grit |
| | | | | DANDOT | SHALLOW MARINE LAGOONAL | 218 | | Olive - green and gray Sst. & Sh. |
| | | | | TOBRA | GLACIAL TO FLUVIAL | 407 | | Conglomeratic Sst. boulders, Sh. |
| | CARBONIF. | | | | | | | |
| | DEVONIAN | | | | | | | |
| | SILURIAN | | | | | | | |
| | ORDOVICIAN | | | | | | | |
| | CAMBRIAN | | | | | | | |
| PRECAMBRIAN | | | | SALT RANGE | RESTRICTED MARINE HYPERSALINE | + 511 | | Red gypsum marl, rock salt, Evaporites |
| | | | | BASEMENT INDIAN SHIELD | | | | Biotite schist, quartzitic, rhyolite |

R: RESERVOIR ROCK S: SOURCE ROCK C: CAP ROCK

Author : TARIQ HASANY CAD by : M.F.QAZI MAY,1998

Table 1: Stratigraphic Section of Dhulian

Figure 3.1: Generalized Stratigraphy of Potwar.

## 3.2 Hydrocarbon Occurrence

The Potwar sub-basin is one of the oldest oil provinces of the world, where the first commercial discovery was made during early last century in 1914 at Khaur. So far, about 150 exploratory wells have been drilled in the area but many of these were pre-maturely abandoned, as these could not reach their target depths due to drilling problems related to extremely high-pressure water in molasse deposits, which may be related to structural complexities. The Potwar region is an important oil- and gas-producing area. The oil and gas discoveries in the Potwar Plateau, are mostly from NE-SW elongated anticlines. The Eocene-to-Cambrian (E-C) platform deposits are about 400 m thick in the Potwar area. Throughout Potwar, oil production has been established from Eocene-Permian, and Cambrian-age rocks. Exploration in the Potwar began by drilling simple surface anticlines. With the improvement of seismic acquisition and processing, the search for additional petroleum reserves has entered a new phase. (Siddiqui et al., 2006).

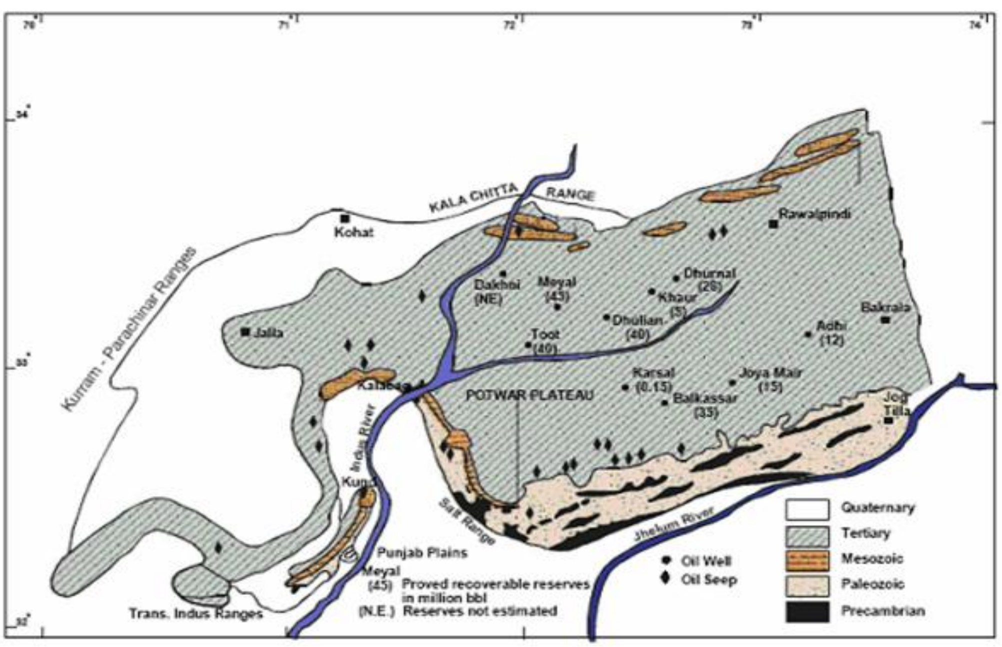



Figure 3.2: Map showing hydrocarbon potential of Potwar Plateau. (Siddiqui et al., 2006).

The Kohat-Potwar depression has several features that makes it a favourable site for hydrocarbon accumulations. Located on a continental margin, the depression is filled with thick deposits of sedimentary rocks, including potential source reservoir and cap rock. It contains a thick overburden (about 3000m) of fluvial sediments, which provide the burial depth and optimum geothermal gradient for seeps found in this area (Khan et al., 1986). The sedimentary rocks are deformed during thin-skinned Himalayan tectonics, forming site for hydrocarbon accumulation (Coward and Buttler , 1985).j

This foreland basin is filled with thick sequence of sedimentary rocks. The source, reservoir and cap rocks are present in SRPFB. It contains thick overburden of 1980 m to 3050 m of fluvial sediments, which provide burial depth and optimum geothermal gradient for the formation of oil in SRPFB (Shami and Baig, 2002). Simple and translated fault-propagation folds from important structural traps in fold and thrust belts. The most important traps in fault propagation folds are in the crests of major anticlines. These fault traps may be present along backlimb thrusts, between the imbricates in the forelimbs and in upturned beds in the footwall. Secondary traps may also be present within the major thrust sheets, particularly at the leading edge of the thrust sheet and above footwall ramps (Mitra, 1990).

The SRPFB belongs to the category of extra continental down wrap basins, this accounts for 48% of the world known petroleum (Riva, 1983). It has several features suitable for hydrocarbon accumulation including continental margin, thick marine sedimentary sequence, potential source, reservoir and cap rock. The thick overburden of 3047 m of mollase provides burial depth and optimum geothermal gradient of $2^0$ C/100 m is producing oil from the depth of 2750-5200 m (Shami and Baig, 2002). The presence of an optimal combination of source, reservoir and trap within the oil window resulted in oil and gas accumulation in Joya Mair, Toot, Meyal and Dhulian oil fields ( Kozary et al., 1968)

## 3.3 Petroleum Geology of Dhulian Area

Petroleum Geology refers to the specific set of geologic disciples that are applied to the search for hydrocarbons. Petroleum geology is principally concerned with the evaluation of seven key elements in sedimentary basins

1. Source
2. Reservoir
3. Seal
4. Trap
5. Timing
6. Maturation
7. Migration

## 3.3.1 Source

Evaluation of the source uses the methods of geochemistry to quantify the nature of organic-rich rocks which contain the precursors to hydrocarbons, such that the type and quality of expelled hydrocarbon can be assessed. The data from Dhulian and nearby fields, where source rock studies were carried out, indicate that the Patala Formation and to some extent the Lockhart Formation, are proven source rocks. These source rocks are rich in organic matter and are mature at Dhulian area. (Kadri, 1995).

## 3.3.2 Reservoir

The reservoir is a porous and permeable lithological unit or set of units that holds the hydrocarbon reserves. Analysis of reservoirs at the simplest level requires an assessment of their porosity (to calculate the volume of in situ hydrocarbons) and their permeability (to calculate how easily hydrocarbons will flow out of them). Some of the key disciplines used in reservoir analysis are the fields of Stratigraphy, Sedimentology and Reservoir Engineering.

**Dhulian Reservoirs**

**Eocene**

The initial production at Dhulian was obtained from limestone of Eocene age near the contact of Chorgali and Sakesar Limestone. This oil bearing horizon was remarkably consistent and it became known as the “Main Oil Horizon”. Pressure migrates to the crest of the structure to form a secondary gas cap. This expanding gas cap displaces the oil and helps maintain high oil saturation and therefore an elevated relative permeability to oil, in an oil-bearing zone. The oil which enters the well bore then contains only that gas which remains in solution at the current reservoir pressure. All of the crestal wells produced a large volume of gas from the secondary gas cap.

**Jurassic**

Dhulian 39 was Pakistan's first oil discovery from a Jurassic reservoir (Datta Formation). Dhulian-41 bottomed in Permian and Dhulian-43 was drilled down to Slat Range Formation. Dhulian-41 drilled a very thin section of Jurassic while Dhulian-43 did not encounter this formation, which indicated that the regional truncation edge of Jurassic is located between Dhulian-41 and 43, near the crest of the fold.

Datta Formation can be divided into two parts. The upper part consists of mudstone, claystone and shale with minor sandstone and has been termed as "Variegated Beds" in the Potwar region. The lower unit called "Main Oil Sand" is more or less a massive, coarse to medium grained, and sometimes gritty, quartzose sandstone. Most of the oil from Jurassic was produced from "Main Oil Sand. The primary porosity of Jurassic is quite variable and ranges from 2.9% to 11.6%. The average porosity is about 8.5%. Permeability ranges from 1.2 to 869 milli darcys.

### 3.3.3 Seal

The seal, or cap rock, is a unit with low permeability that impedes the escape of hydrocarbons from the reservoir rock. Common seals include evaporites, chalks and shales. Analysis of seals involves assessment of their thickness and extent, such that their effectiveness can be quantified.

**Dhulian Seal**

**Kuldana Formation**

The Kuldana Formation consists of red and purple coloured claystone and shale with occasional silty / sandy streaks. This formation is present all over the Dhulian field and ranges in thickness from 90 to 120 feet. The basal part of Kuldana is composed of green compact shales which is about 10-20 feet thick. Due to its impermeable character Kuldana Formation forms an effective seal over the Eocene reservoir of the Dhulian Field.

**Nammal Formation**

Nammal Formation consists of shales with thin bands of argillaceous limestone bands. Shales of Nammal Formation (155 to 200 feet thick) are developed all over the Dhulian Field and provide top seal for the Paleocene (Ranikot) reservoir.

**Shale of Datta Formation**

The top part of the Datta Formation is Dhulian consists of varicoloured shale, siltstone, mudstones and claystone with thin sand beds (“Varigated Beds”). These beds overlie the “Main Oil Sand” horizon of the Datta Formation and are believed to be the top seal of the Jurassic reservoir.

### 3.3.4 Trap

The trap is the stratigraphic or structural feature that ensures the juxtaposition of reservoir and seal such that hydrocarbons remain trapped in the subsurface, rather than escaping (due to their natural buoyancy) and being lost. Analysis of maturation involves assessing the thermal history of the source rock in order to make predictions of the amount and timing of hydrocarbon generation and expulsion.

## 3.4 Dhulian Structure

The Dhulian surface structure is an almost symmetrical anticline with maximum dips of $30^o$ to $35^o$ (Figure. 6.19). The fold axis trends ENE-WSW and plunges about $4^o$-$5^o$ at both ends, running en-echelon to the nearby Khaur fold. Dhulian fold is flanked by the Soan Syncline to the South and by the tight Pindi Gheb syncline to the North. The sandstones of Nagri Formation form the flanks of the Dhulian anticline whereas Chinji Formation is exposed in the core of the fold.

The Dhulian structure was originally thought to be a conventional anticline with a fold axis trending NE-SW. Based on surface geology, Dhulian was recognized to have been genetically related to the adjacent Khaur structure, which was known to have originated by thrusting. Consequently the development of the Dhulian field was carried out without Geophysical surveys and all subsurface geological maps and cross-sections were constructed based on borehole information.

The multifold seismic acquired by OXY and POL demonstrated that Dhulian subsurface structure is more complicated than what was originally thought. Based on this new seismic evidence, Dhulian structure was proved to be a thrust bounded salt cored anticline. The foreland thrust in the western fault block is located to the south while in case of the eastern fault block the thrust is on the northern side (hinterland verging thrust). It is suspected that the wrench is responsible for this counter thrust movement, which has resulted in the disappearance of the Pindi Gheb syncline in between Dhulian and Khaur in the East.

# Chapter 4

# SEISMIC DATA ACQUISITION AND PROCESSING

## 4.1 Seismic Data Acquisition

The purpose of seismic data acquisition is to record the effects produced by mechanical disturbance somewhere at the surface or close to the surface of the earth, and observing its effects at the number of locations along the surface in such a manner that their relation with the initial disturbance can be interpreted. It includes all those steps which yields final output to be processed and interpreted. The instruments so adopted to acquire seismic data nowadays differ from those used in the past, but essential principle for all the instruments is same. Energy sources like dynamite or vibrators are used to generate waves. These waves are penetrated inside the ground and after reflection from different rocks are recorded on the surface through geophones. The data is recorded in digital as well as analogue form on magnetic tape in the recording truck.

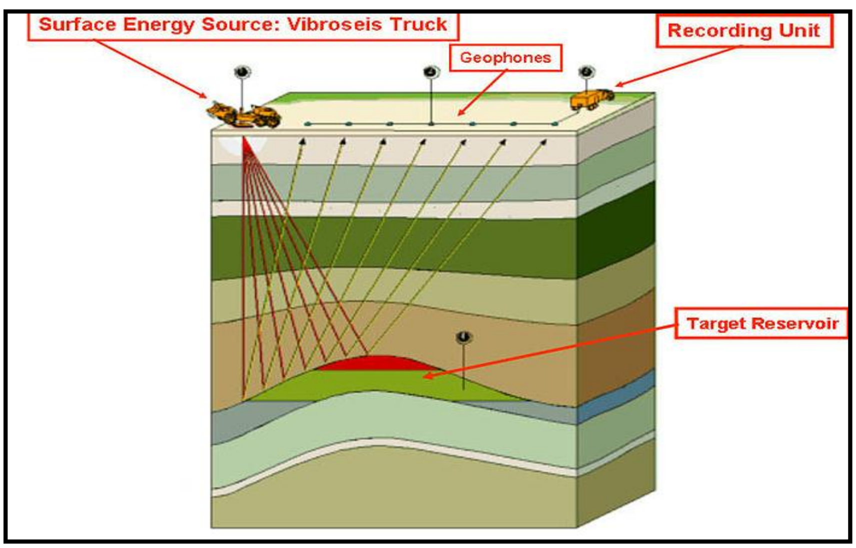


Figure 4.1: Seismic Reflection Acquisition

### 4.1.1 Field Crew

Seismic information is acquired by field crews.

| | |
|---|---|
| RECORDED BY | O.G.D.C |
| PARTY NO. | VSP- 1 |
| DATE | 1981 |
| DATUM | 400 M |

Table 2: Field Crew for the Seismic lines of Dhulian Anticline

### 4.1.2 Energy Sources:

There are different ways for generating Mechanical Disturbance on land or in water. Dynamite and Vibroseis are two sources of seismic energy mostly used on land**.** Our data was acquired by using Vibrosies.

**Vibroseis**

Vibrosies is based on vibrating plate. The wave put into the earth by a vibroseis source is oscillatory rather than impulse and persists for many seconds (about 12 sec), the frequency changing slowly over the duration of the signal (between 10 to100 hz). Therefore controlled vibration of the plates injects into the ground an oscillatory waveform of varying frequencies, for a fixed time duration. This is known as sweep. A sweep way be up-sweep or down-sweep depending on whether the frequency increases or decreases with time. The duration of vibration is referred to as the sweep time

The returned signals in the field cannot be interpreted directly, the recorded data, therefore, must be processed by cross-correlation of the signals received by the geophones with the oscillatory source signal itself. Vibroseis source is safer can be undertaken in populated areas. It is easy to deploy a vibroseis system than using explosives which require special arrangements for storage, transportation and drilling of shot holes for their use. In production recording vibroseis survey normally 2 to 5 vibrators are vibrated in phase so that sufficient energy could be generated.

| | |
|---|---|
| SOURCE | VIBROSEIS |
| NUMBER OF VIBRATORS | 2/3 |
| NO. OF SWEEPS/UP | 42 |
| SOURCE PATTERN | INLINE |
| TYPE OF VIBRATORS | MERTZ(MODEL SHV-10) |
| VIBRATION LENGTH | 100M |
| SWEEP FREQUNCY | 7-42 HZ |
| SWEEP DURATION | 25000 MILLI SECONDS |

Table 3: Source Parameters used for the Seismic lines of Dhulian Anticline.

### 4.1.3 Seismic Spread

There are three types of seismic spreads used for seismic data acquisition

1. Symmetric: In this type of spread equal numbers of channels are recorded on both sides of the shot point/vibration point.
2. Asymmetric: In this case there are not an equal numbers of channels on both sides of the shot/vibration point.

3. End-shooting: In this type of spread all the channels are recorded on one side of shot/vibration point.

| | |
|---|---|
| SYMMETRIC | 2450- 150- * -150 -2450 m<br>1- 24- * -25 -48m |
| ASSYMETRIC | 1250- 150- * -150 -3650 m<br>1- 12- * -13 -48 m |

| | |
|---|---|
| NO. OF GROUPS | 48 |
| GROUP LENGTH | 159M |

Table 4: Spread Geometry used for lines PDK -101, 103, 104, 112 and 113

### 4.1.4 Geophone Interval

It refers to the distance between successive geophone groups in a seismic profile. It is kept constant and is given by the field geophysicist .The geophone interval used for recording PDK- 101,103,104, 112 and 113 was 100m.

### 4.1.5 Geophone Base

It means the total length over which the geophones connected to a channel/trace are spread/ planted on the ground. Spread configuration of the geophone spread over the total base length can be of linear, parallelogram or star pattern. The geophone base used was 159m and had a parallelogram shape.

| | |
|---|---|
| GROUP INTERVAL | 100M |
| GROUP PATTERN | PARALLELOGRAM |

Table 5: Receiver parameters used for the lines PDK-101,103,104,112 and 113

### 4.1.6 Geophone Code

The general pattern of the layout of geophone group used in recording data can be described by the geophone code 031203.

1. 03 means three strings of geophone for each group (Normally 9 to 12 geophones are connected in series to give combine output and this is called a string)
2. 12 stands for 12 geophone for each string and
3. 03 means shift of geophone in the layout

3 inline strings of 12 geophone each

```
o o o o o o o o o o o o
   o o o o o o o o o o o o
      o o o o o o o o o o o o
```

Figure 4.2: Geophone array layout used to acquire study area data.

### 4.1.7 Multiplicity of Data

The number of common depth points which sample essentially the same portion of the reflector but with different offset. Seismic data acquired was 24 fold data. The 24 fold data means recording of each subsurface point 24 points, one from each of the different offset distances. The signals recorded for the CDP on each separate trace are summed by stacking in processing to improve the signal to noise ratio.

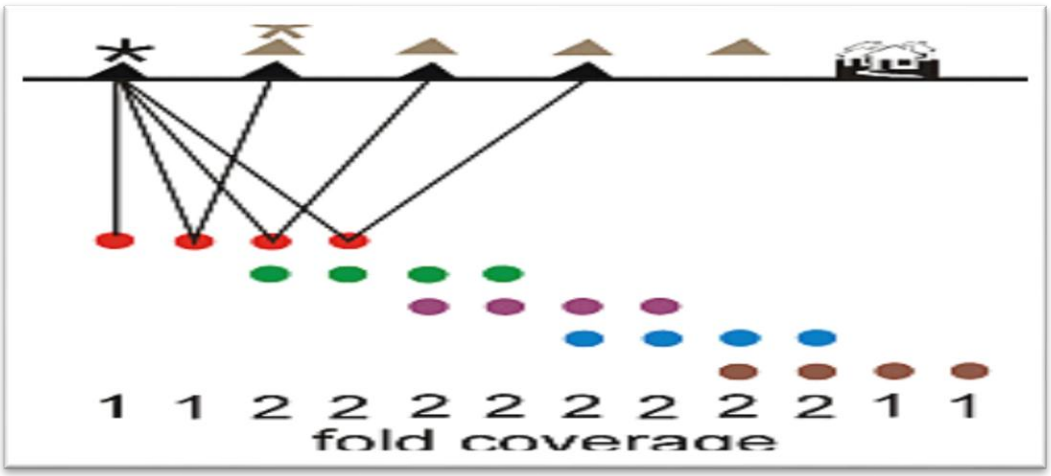



Figure 4.3: Fold Coverage

### 4.1.8 Recording Parameters

The field equipment/recorder is required to record reflected Seismic signals as detected by arrays of geophones. The recording parameters of our seismic data are given in the table below:

| | |
|---|---|
| SUMMING COMPUTER | COBA-II |
| LOW-CUT FILTER | OUT |
| NOTCH FILTER | OUT |
| HIGH-CUT FILTER | 62 HZ AND 78 DB/OCT |
| SAMPLING INTERVAL | 4 ms |
| RECORD LENGTH | 4000 ms |

| | |
|---|---|
| PRE-AMPLIFIER GAIN | $2^7$ |
| MAIN AMPLIFIER GAIN | I.F.P |
| SUMMING | DIVERSITY AVERAGE |
| RECORDING FORMAT | SEG-C |
| DENSITY | 1600 BPI |
| NO. OF CHANNELS | 62 |
| NO. OF RECORDING CHANNEL AT A TIME | 48 |

Table 6: Recording parameters used for the lines PDK-101, 103, 104, 112 and113.

## 4.2 SEISMIC DATA PROCESSING

Seismic data are recorded in the field on magnetic tape. About three to six weeks later the information is transmitted to the interpreter as a seismic section. All of the intervening steps comprise the data processing phase of seismic exploration.

Processing Seismic data consists of applying a sequence of computer programs, each designed to achieve one step along the path from field tape to record section. From ten to twenty programs are usually used in a processing sequence, and these are selected from a library of several hundred programs. So, data processing can be defined as,” An approach by which the raw data recorded in the field is enhanced to the extent that it can be used for the geological interpretation”.

Seismic data processing strategies and results are strongly affected by field acquisition parameters. Additionally, surface conditions have a significant impact on the quality of data collected in the field. Besides surface conditions, the factors that contribute to influence the quality of data are environmental conditions, demographic restrictions, weather condition and condition of recording equipment.

Processing may be systematically shown as

**Observational data → Processing System → Useful Information**

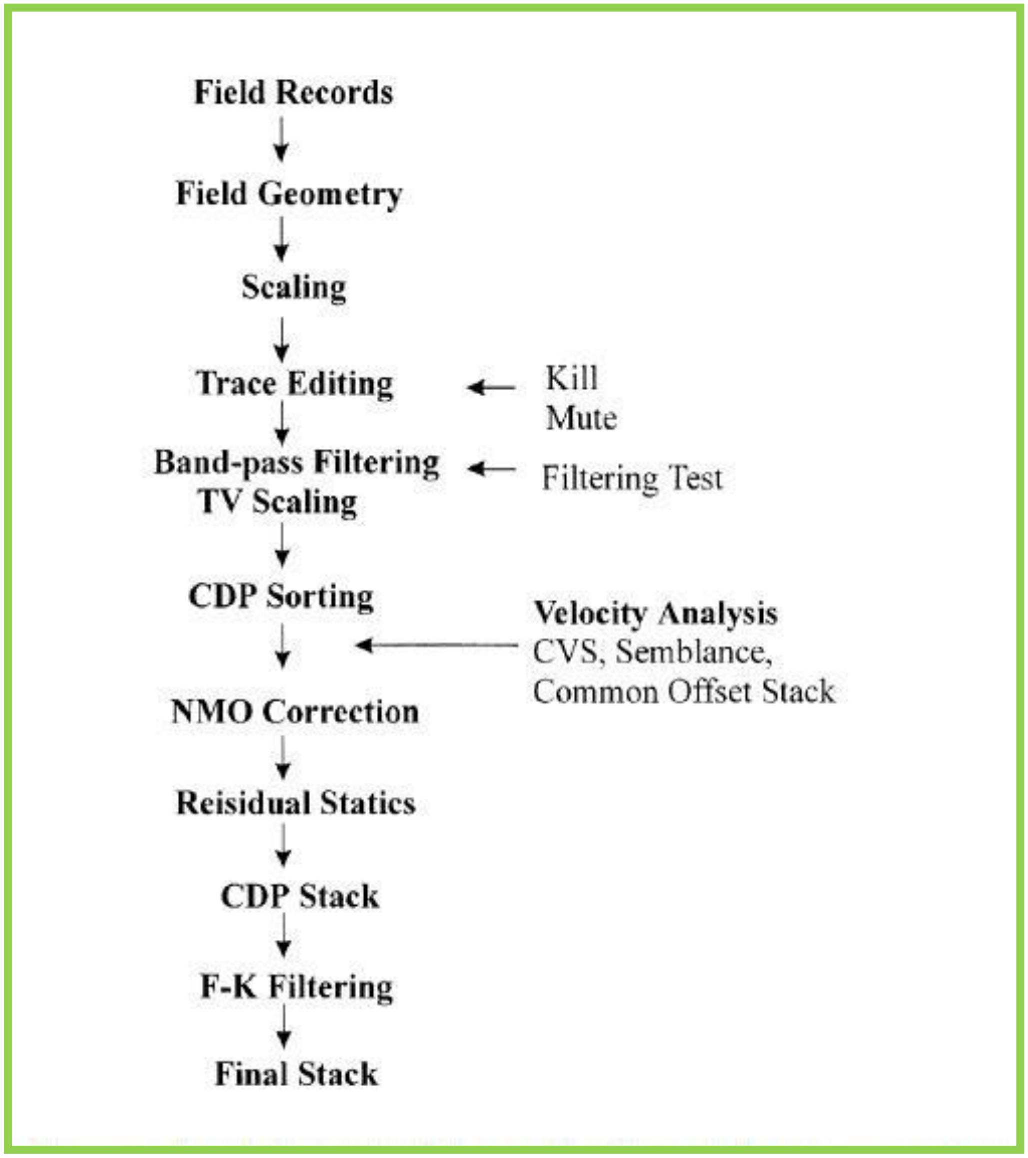



Figure 4.4: Generalized flowchart for reflection data processing (From Kim et al., 2001)

### 4.2.1 Steps involved in Seismic Data Processing

Seismic data processing is composed of basically five types of corrections and adjustments: time, amplitude, frequency-phase content, data compression (stacking) and data positioning (migration). These adjustments increase the signal–to-noise ratio, correct data for various physical processes that obscure the desired (geologic) information of seismic data, and reduce the volume of data that the geophysicist must analyze. The various processing steps involved in the processing of our Seismic Data are as follows:

| Processing Steps | Purposes |
|---|---|
| 1. Transcription | The data of the seismograph is converted into SEG-Y format by the software for processing. |
| 2. Demultiplexing | Unscrambling a multiplexed array into a trace sequential form. It is accompanied by a simple computer sorting program. |
| 3. Geometry | Crooked line geometry installation. Some mistakes in the introduction of geometry are a very common source of problem in Seismic Reflection. |
| 4. Editing | Editing of bad and dead traces. |
| 5. Vibroseis Correlation | Correlation of the vibroseis pulse with the signal. Data reduction. |
| 6. Mute | Deadens high amplitude noise spike. |
| 7. Amplitude Gain Control | Automatic gain control is the adjustment of amplitude within a trace.<br>Its effect is the suppression of stronger arrivals, coupled with the |

| | |
|---|---|
| | enhancement of weaker once, and its goal is the improvement of event continuity and visual standout. |
| 8. Filter | To eliminate certain types of unwanted energy from the data. Remove noise having frequency outside of signal band. |
| 9. Deconvolution | To compress the pulse data resulting in sharper, clearer seismic images i.e. it increases data resolution. Remove reverberations. |
| 10. Static Correction | Vertical time correction. A common static correction is the Weathering Correction that compensates for a layer of low velocity. Whereas the Elevation Correction provides floating datum. |
| 11.CDP Sort | Arrange traces according to common depth point. |
| 12. Velocity Analysis | To optimize NMO and stacking velocity function. |
| 13. Normal Moveout | To compensate for the effect  f the separation between the source and receiver on the arrival time of reflection |
| 14. Stacking | Traces from different shot records having common depth point are stacked to form a single trace to reduce noise and improve overall data quality. |
| 15. Migration | Move events to true spatial position relative to shot and receiver point. Remove diffractions. |
| 16. Display Scale | Giving horizontal and vertical scale to the Seismic Section |

Table 7: Different Processing steps and their purpose

In our Seismic data line PDK-112 is unmigrated and is showing diffraction pattern as indicated in fig 4.5.

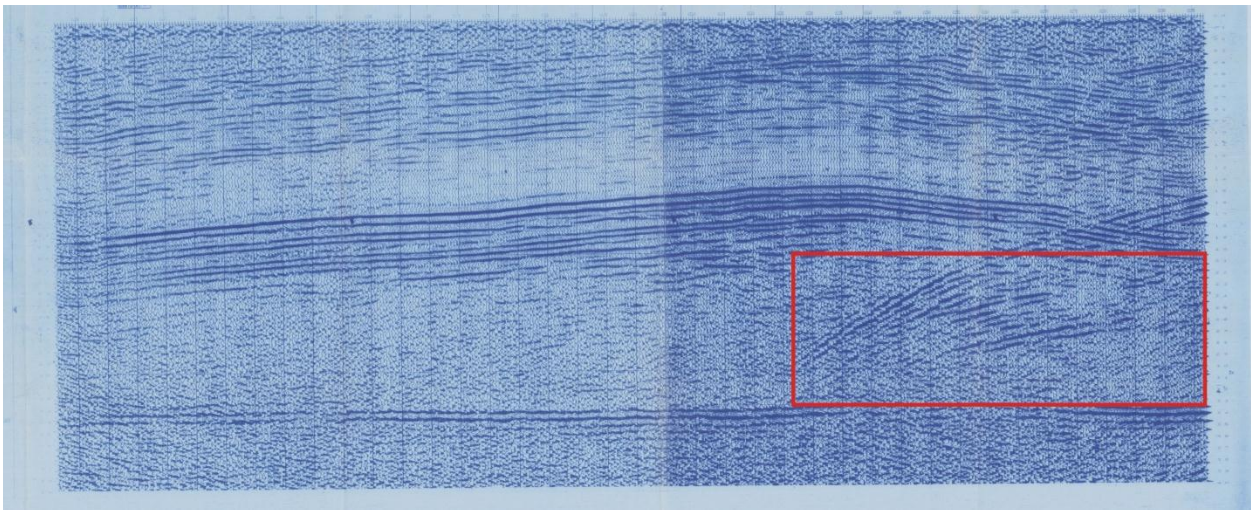


Figure 4.5: Diffraction pattern in **"Unmigrated"** strike line PDK-112 highlighted by the box.

# Chapter 5

# SEISMIC DATA INTERPRETATION

The interpretation of the reflection data involves its expressions in geological terms. When completely carried out, it requires the fitting together of all pertinent geological and geophysical information into an integrated picture that is more complete and more reliable than either source is likely to give alone. Ideally, this integration would be accomplished most efficiently if a single person highly competent both in geophysics and geology.

The Seismic reflection interpretation usually consists of calculating the position of and identifying geologically concealed interfaces or sharp transition zones from seismic pulses return to the ground surface by reflection. The influence of varying geological condition is eliminated along the profiles to transform the irregular recorded travel times into acceptable subsurface models. This is very important for confident estimation of the depth and geometry of the bed rock or target horizons. The main purpose of seismic reflection survey is to reveal as clearly as possible, the structures and stratigraphy of the subsurface. The geological meanings of seismic reflection are simply an indication of different boundaries where there is a change in acoustic impedance. These observed contrasts are associated with different geological structures and stratigraphic contacts.

There are two main approaches for the interpretation of Seismic section.

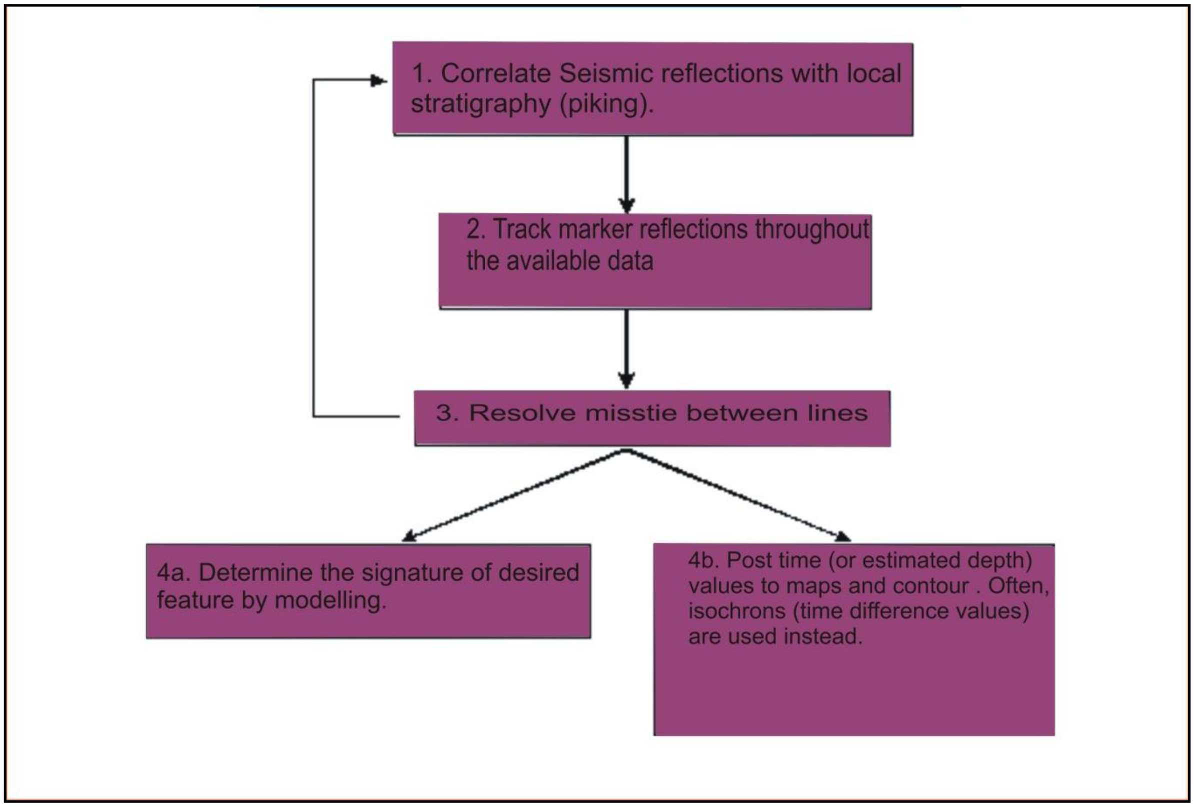
1. Structural analysis
2. Stratigraphic analysis

Extracting from seismic data the geological structures, such as folding and faulting are referred to as structural interpretation (Dobrin & Savit 1988). On the other hand, extracting stratigraphic information from seismic data is called, "Seismic Facies Analysis".

## 5.1 Seismic Time Section

It consists of two scales; horizontal scale consists of SPs/CDPs while the vertical scale consists of two-way time in seconds or miliseconds. The time for each reflector is marked from the seismc section. In the given data, the total length of the section is 4s. Each reflector's depth, according to the time has been read and interpreted in terms of velocity and depth.

## 5.2 Interpretation of the given Seismic Data




\ Figure 5.1: Seismic Interpretation Flowchart for the Study Area

### 5.2.1 Identification of horizons

The first step when starting the interpretation process is to judge the reflections and unconformities, if present on the Seismic time section. Those reflectors are selected which are real, show good character and continuity, and can be followed throughout the area.

On the time section horizons are marked by picking the continuous train of wavelets running across the section. Confusion arises in marking the continuity because the wavelets or the traces tend to mix up or the sequence might break due to subsurface structural changes or abrupt lithological changes or the most common problem faced is the presence of different types of noises, such noises cause the distortion of the signal. Therefore, in order to decide that whether the sequence continues towards the upper horizon or the lower, a broader view of the interpreter, knowledge about the area and the considerable experience would help in marking a correct pick.

Four horizons $R_1$ (Probable Chorgali Formation), $R_2$ (Probable Sakesar Formation), $R_3$ (Probable Lockhart Formation) and $R_4$ (Basement) marked by yellow, orange, green and red colour respectively were picked up in the lines PDK-101,103, 104, 112 and 113 of Dhulian area. The reflectors were strong enough to be picked due to variation in acoustic impedance that is eventually caused by changes in lithology. Once a reflector was marked on a line this information was passed on to the other lines by tieing at the intersection point of two lines. Therefore a complete horizon was traced down on the five lines. There was mistie on the line PDK-112 where it was intersected by line PDK-101 and PDK-103.The miss tie probably due to inaccurate processing as the Seismic line PDK 112 was not migrated. The mistie was adjusted so that the horizons can be picked and marked accurately.

### 5.2.2 Identification of faults

Second phase of interpretation is to mark the faults on the Seismic section. Faults are marked on the basis of break in continuity of the reflections. Thrust faults were marked on the dip lines PDK-103 and PDK-104 and strike line PDK 113. Normal faulting was observed in the basement marked by red reflector.

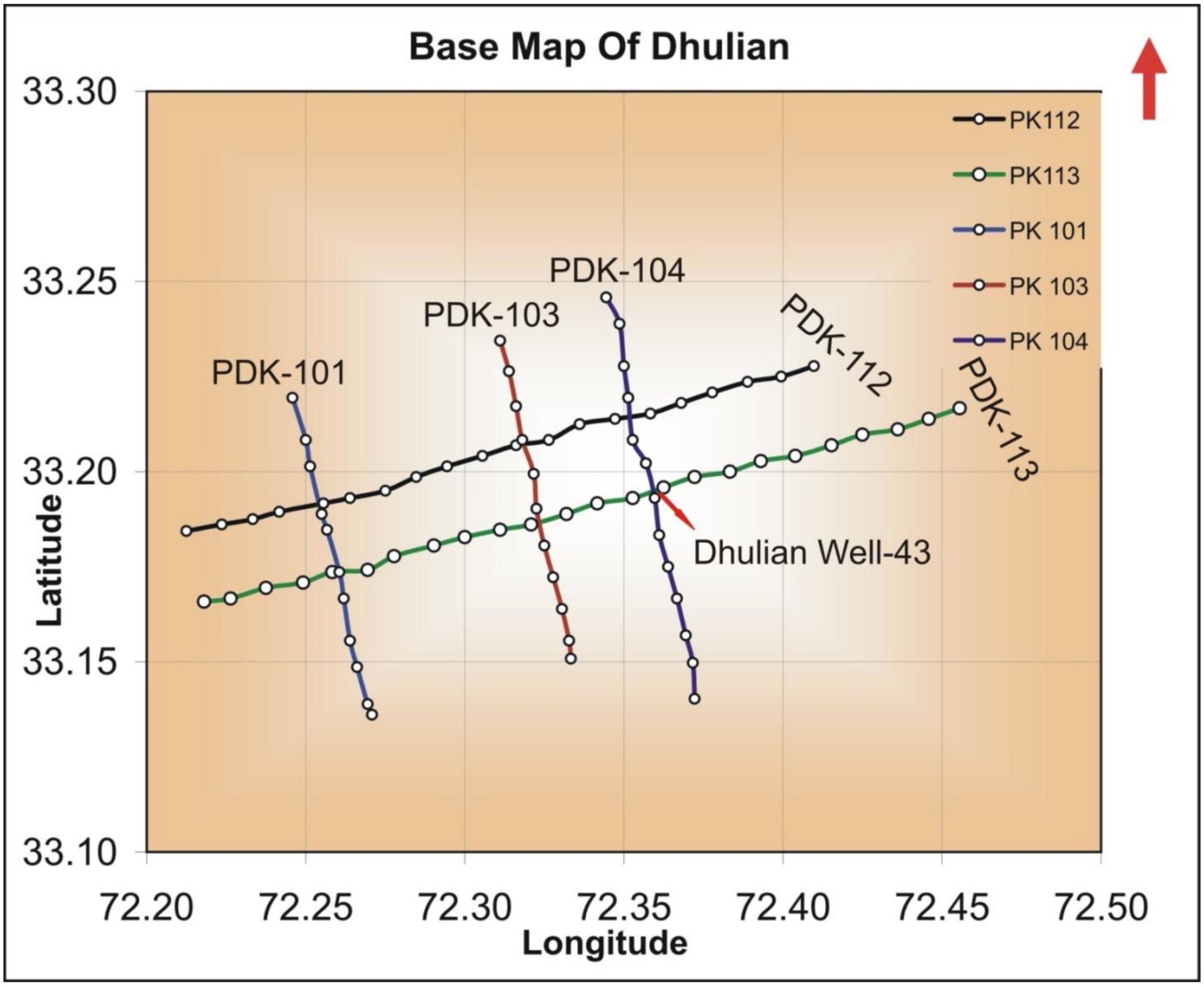



Figure 5.2: Showing Base map of Dhulian drawn from the latitude and longitude values of shot points from original Base map of Dhulian (Appendix 11-15). Generated using MS Excel.

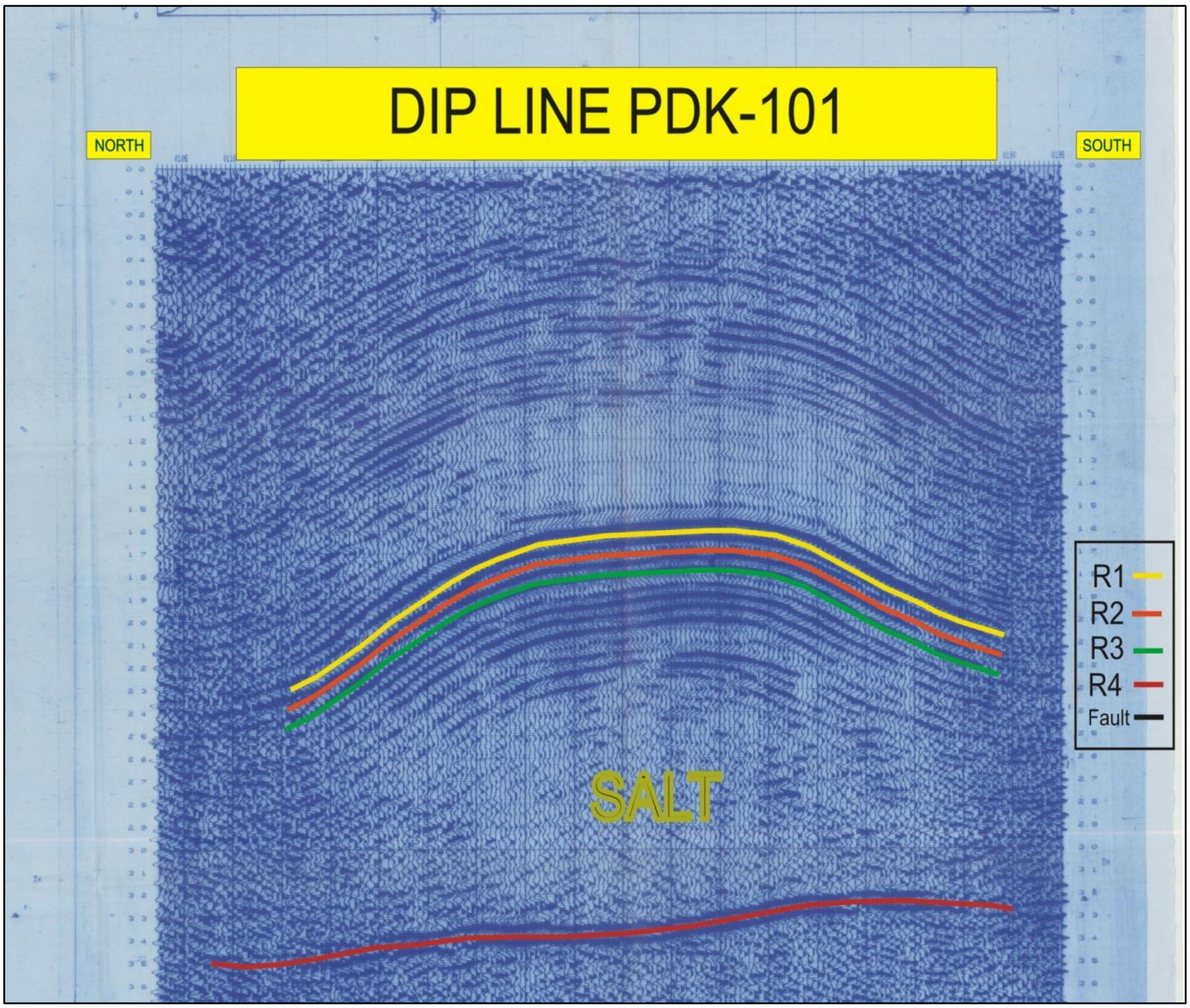



Figure 5.3: Seismic Section of line PDK-101

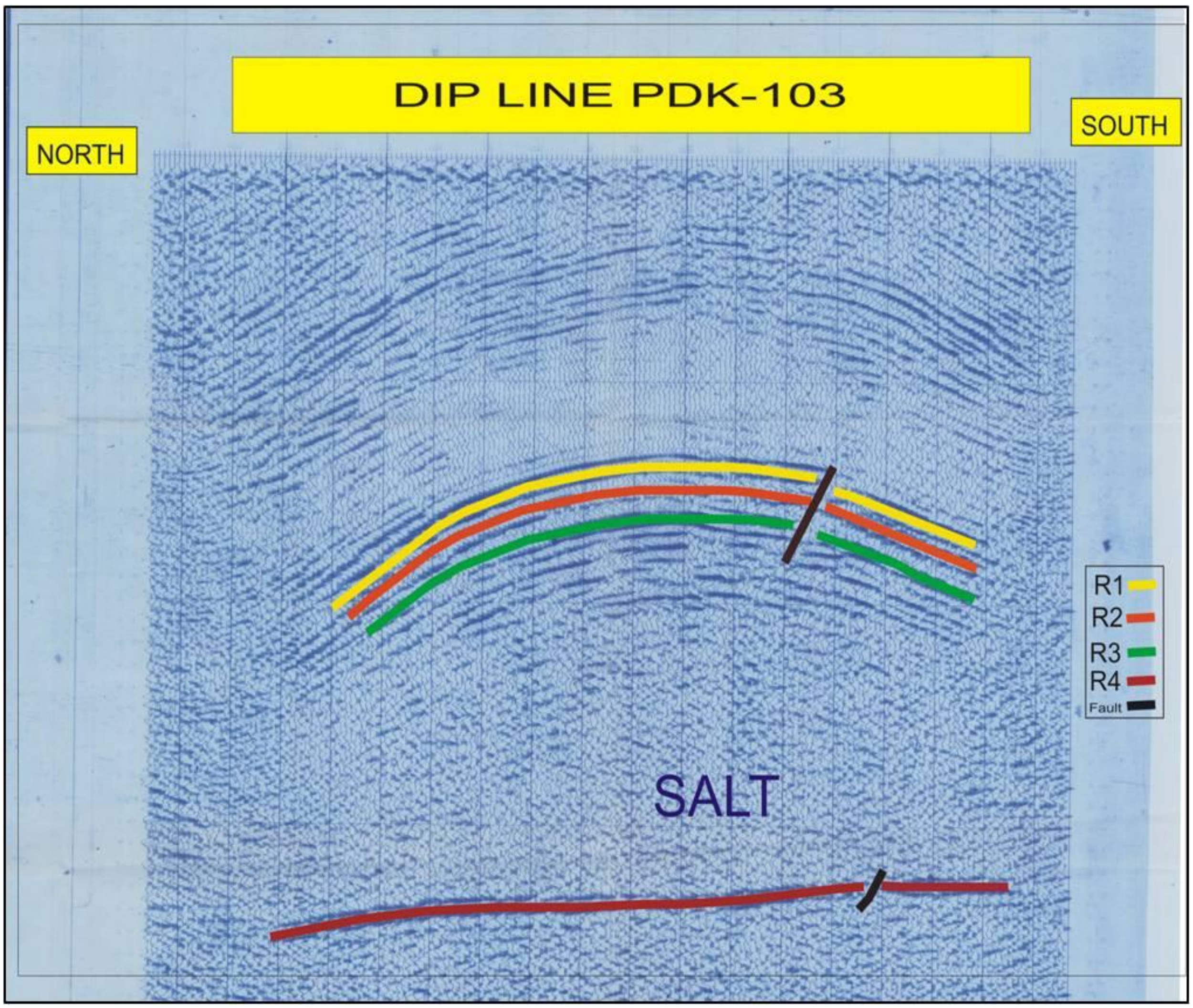



Figure 5.4: Seismic Section of line PDK-103

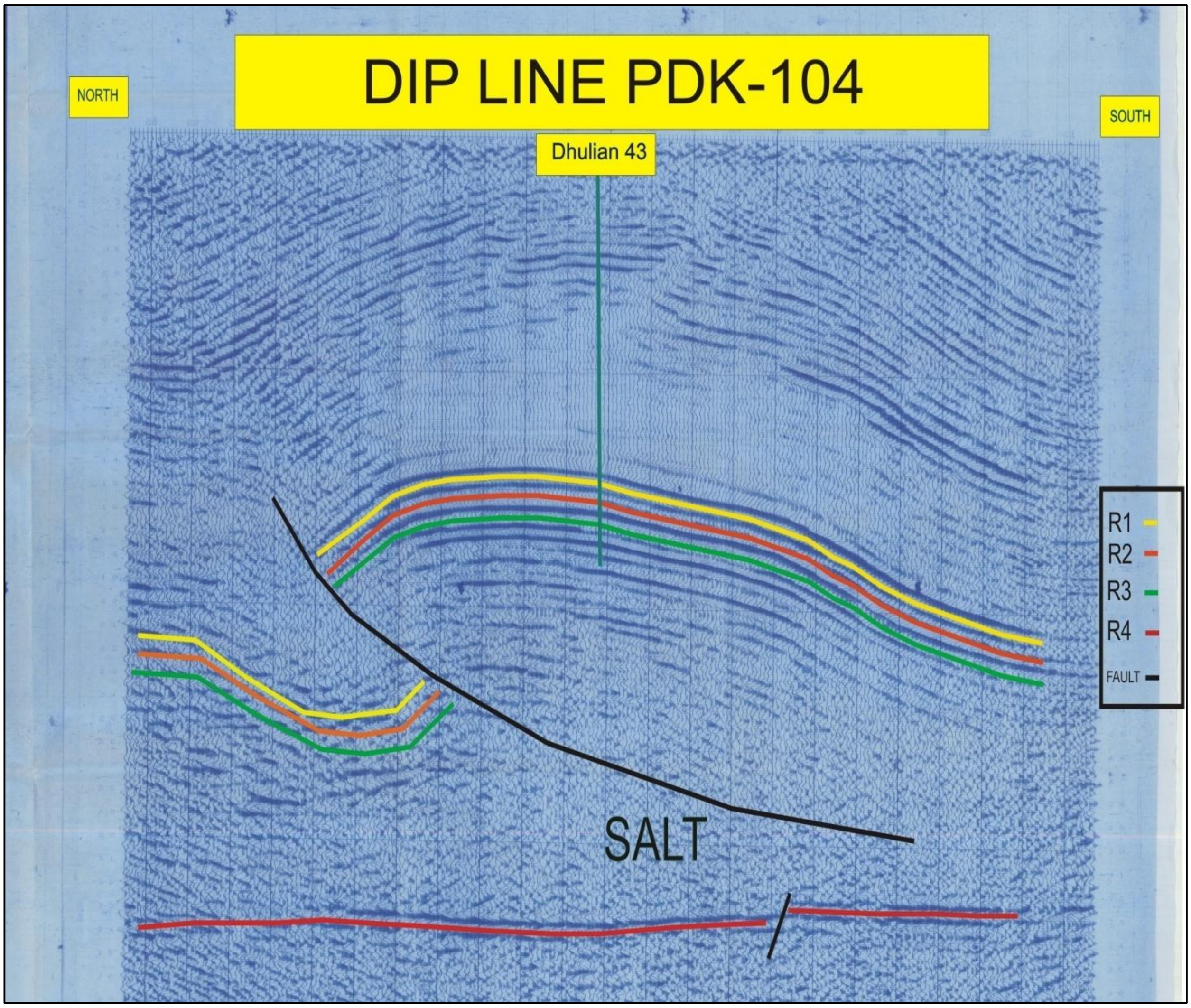



Figure 5.5: Seismic Section of line PDK-104

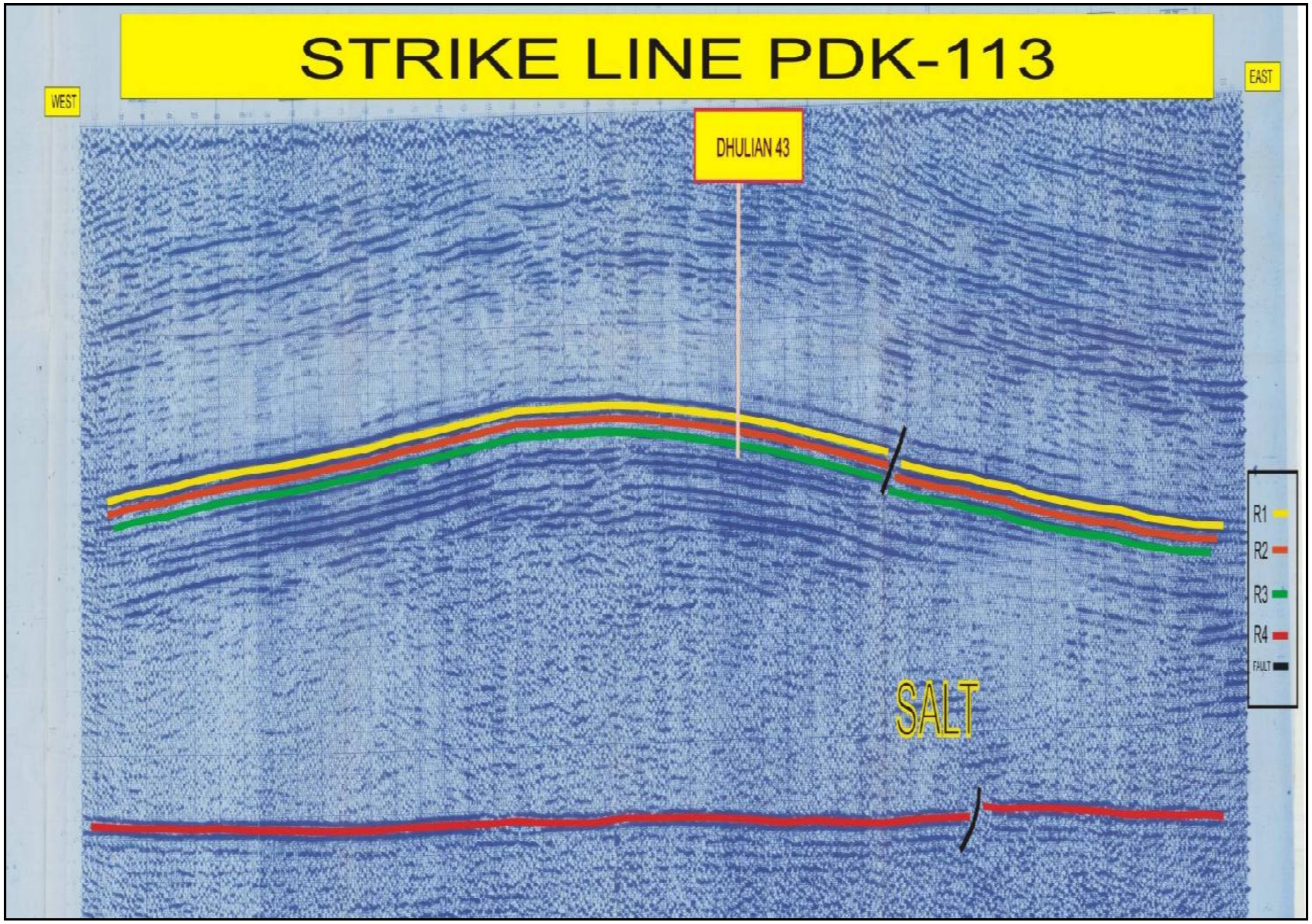



Figure 5.6: Seismic Section of line PDK-113

### 5.2.3 Identification of Structure from Interpreted Seismic Section

The direction of the dip line PDK-104 is North-South and is showing an anticlinal feature due to compression. We marked four horizons (R1, R2, R3, R4) indicated by Yellow, Orange, Green and Red colors respectively. The reflector R1 is probably Chorgali Formation, Reflector R2 is probably Sakesar Formation, Reflector R3 is probably Lockhart Formation and Reflector R4 is Basement. As we can see from the base map (Fig.5.2) there is well Dhulian 43 on the line PDK-104 at shot point 158. Dhulian 43 was drilled to 12,428 feet and is the deepest well in Dhulian. The well was drilled down to the Salt Range Formation of Infracambrian age. We also marked the South dipping thrust fault. There is also a North dipping normal fault in the Basement. This line is passing over Dhulian anticline East of the crestal part.

The dip line PDK-101 is showing the North-South picture of the Dhulian anticline in the western plunge of the structure. Whereas in the dip line PDK-103 we marked the North dipping thrust fault and North dipping normal fault in the basement .The direction of the strike line PDK-113 is West-East and showing an anticlinal feature. The well Dhulian 43 was also drilled on the strike PDK-113 at shot point 236. We also marked the West dipping thrust fault. There is also a West dipping normal fault in the Basement.

### 5.2.4 Calculating Two Way Travel Time

For each of the four identified reflectors on the five lines, their TWT corresponding to the respective shot point was calculated. Therefore tables (appendix 1-5) were constructed in which TWT corresponding to the respective shot point were picked and noted for the four reflectors on each of the Seismic lines. This TWT will be used to construct time contour maps. Later the TWT would be converted to depth by using average velocity and the depth values would be used to create depth contour maps and geoseismic sections.

### 5.2.5 Calculating velocities by Mean Average Velocity Line Method

An accurate measurement of the seismic velocities is an important step in Seismic interpretation. Mean average velocity line method was used to calculate the average velocities for the five lines. Mean average velocity graph is obtained by plotting the velocities, given in the velocity panels at different CDPs of the Seismic section.

The time was plotted on the x-axis and the velocity on the y-axis. An average or best-fit line was drawn through the plots of the Seismic velocity panels given. This is the Average Velocity line of the Seismic section. In the graphs (Figure 5.7-5.11) the average velocity line is indicated by the red colour. These velocities were later used to convert the two-way times of the reflectors into depth, for the formation of the depth sections. Therefore the picked times and the average velocities of the reflectors were used to construct the depth sections.

The velocity graphs (Figure 5.7-5.11) prepared shows that velocity is increasing with the increase in time. This is equivalent to saying that velocity is increasing with depth. The difference in different CDP velocity plots is the result of the variation in velocities horizontally and vertically. There are several factors effecting seismic velocities which include:

1. Matrix and structure of the rocks
2. Lithology
3. Porosity
4. Pore filling interstitial fluid
5. Temperature
6. Degree of compaction

The remarkable change in the average velocity appears with the lithological changes. An accurate measurement of the seismic velocity is an important step in the process of interpretation because the average velocity would then be used to calculate the depth of different horizons. The depth is found by multiplying two way travel time with average velocity.

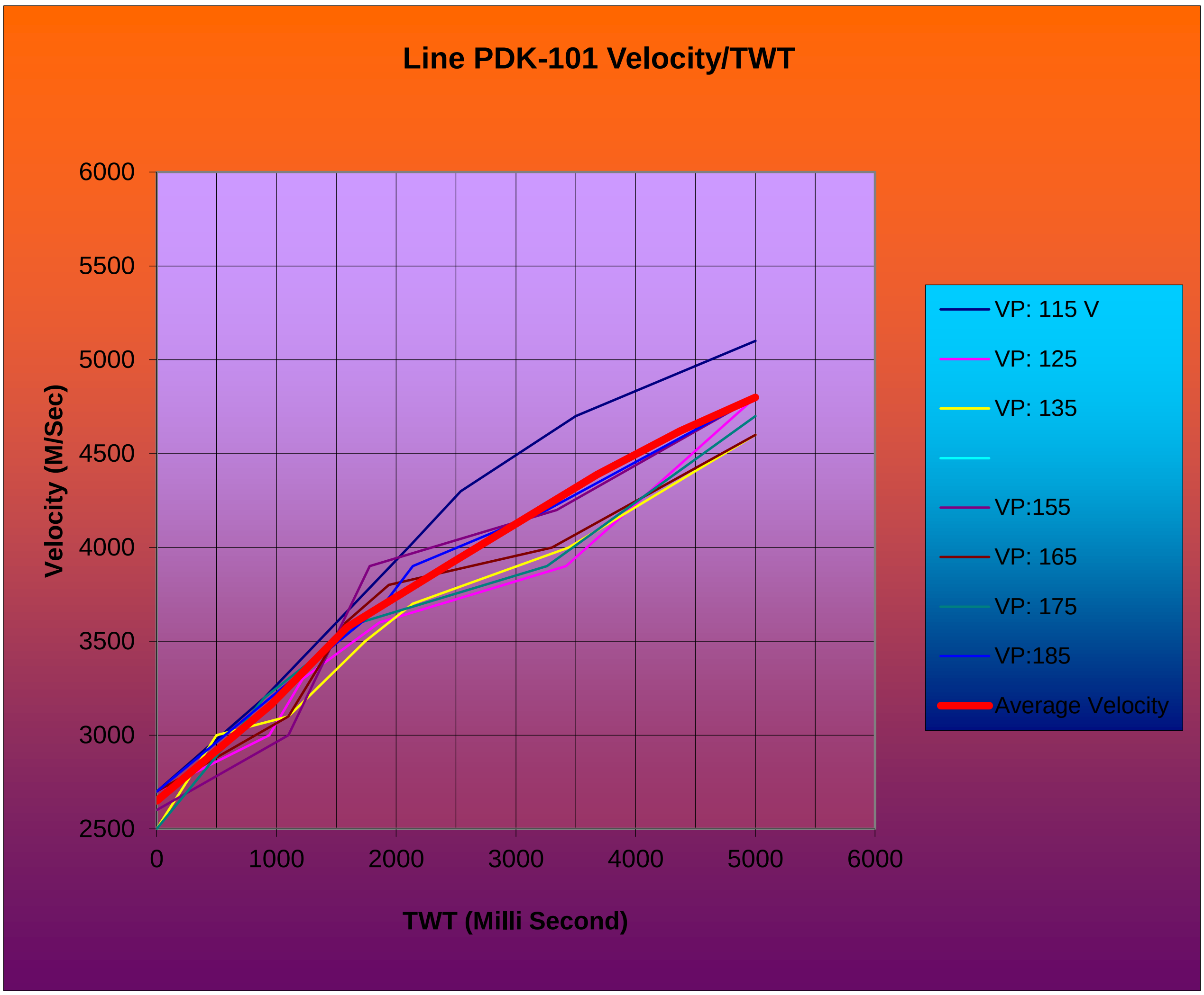



Figure 5.7: Two Way Time VS Velocity plot along with the Average Velocity of Seismic line PDK-101.

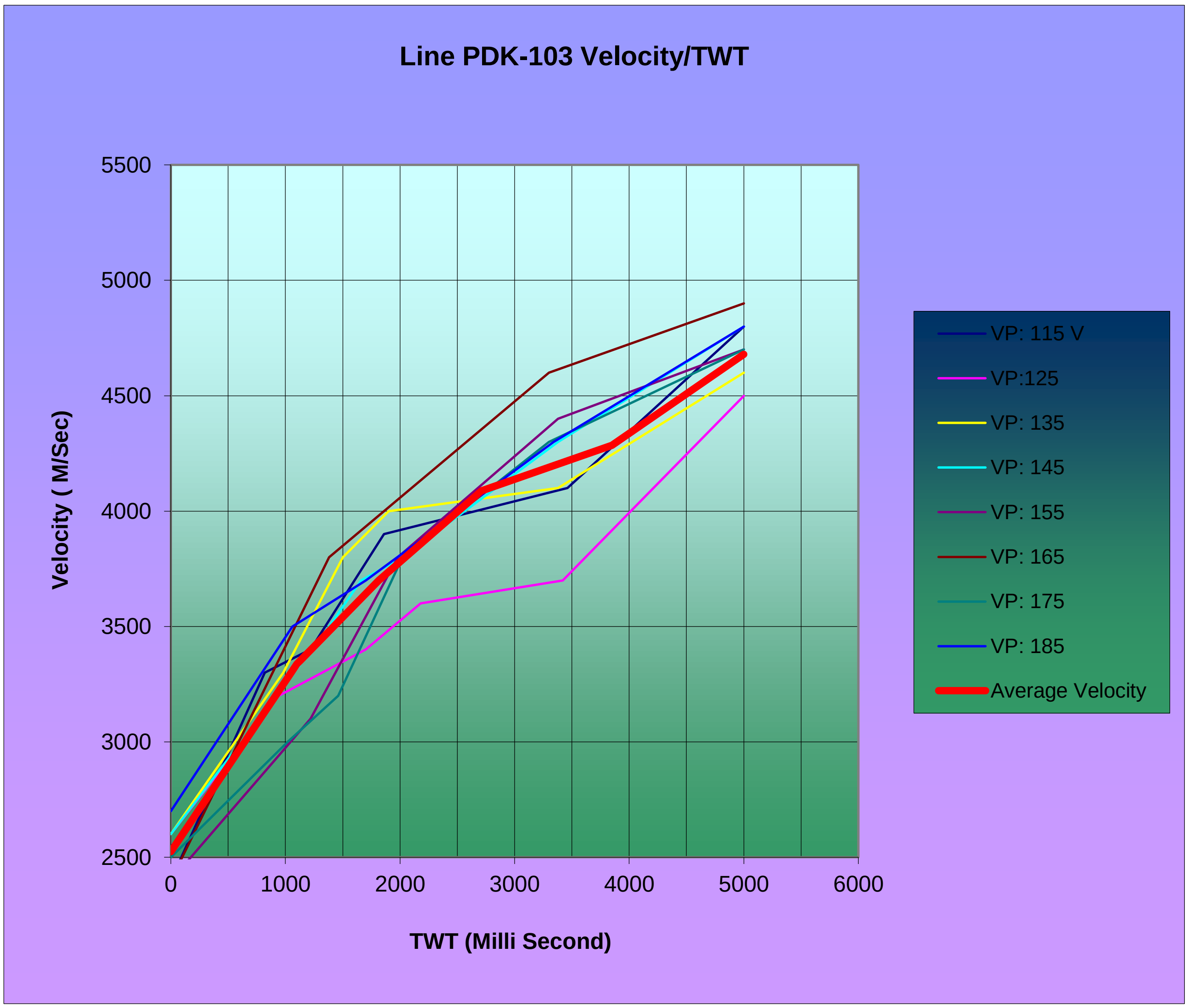



Figure 5.8: Two Way Time VS Velocity plot along with the Average Velocity of Seismic line PDK-103.

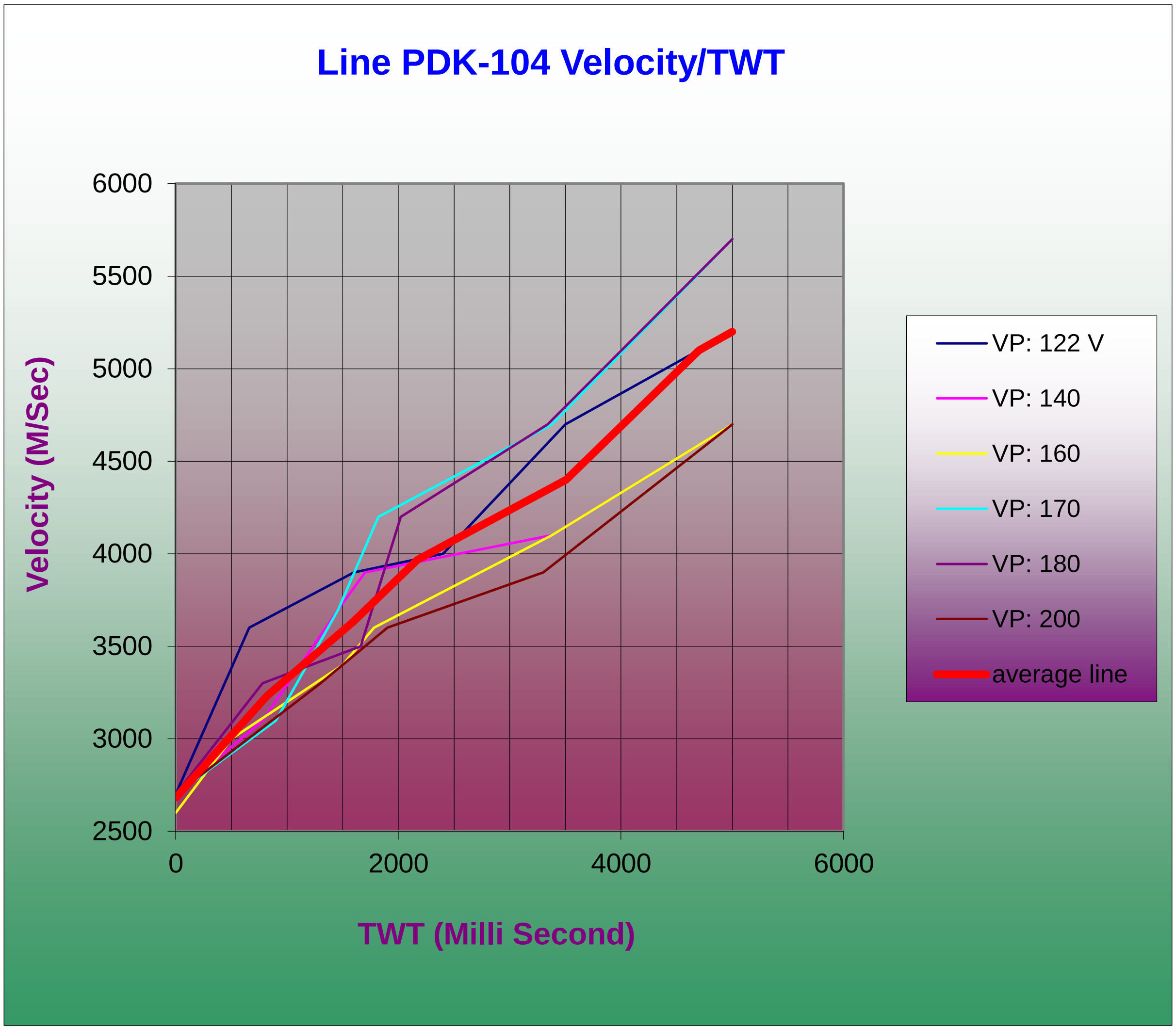

Line PDK-104 Velocity/TWT
6000
5500
5000
4500
4000
3500
3000
2500
0
2000
4000
6000
Velocity (M/Sec)
TWT (Milli Second)
VP: 122 V
VP: 140
VP: 160
VP: 170
VP: 180
VP: 200
average line

Figure 5.9: Two Way Time VS Velocity plot along with the Average Velocity of Seismic line PDK-104.

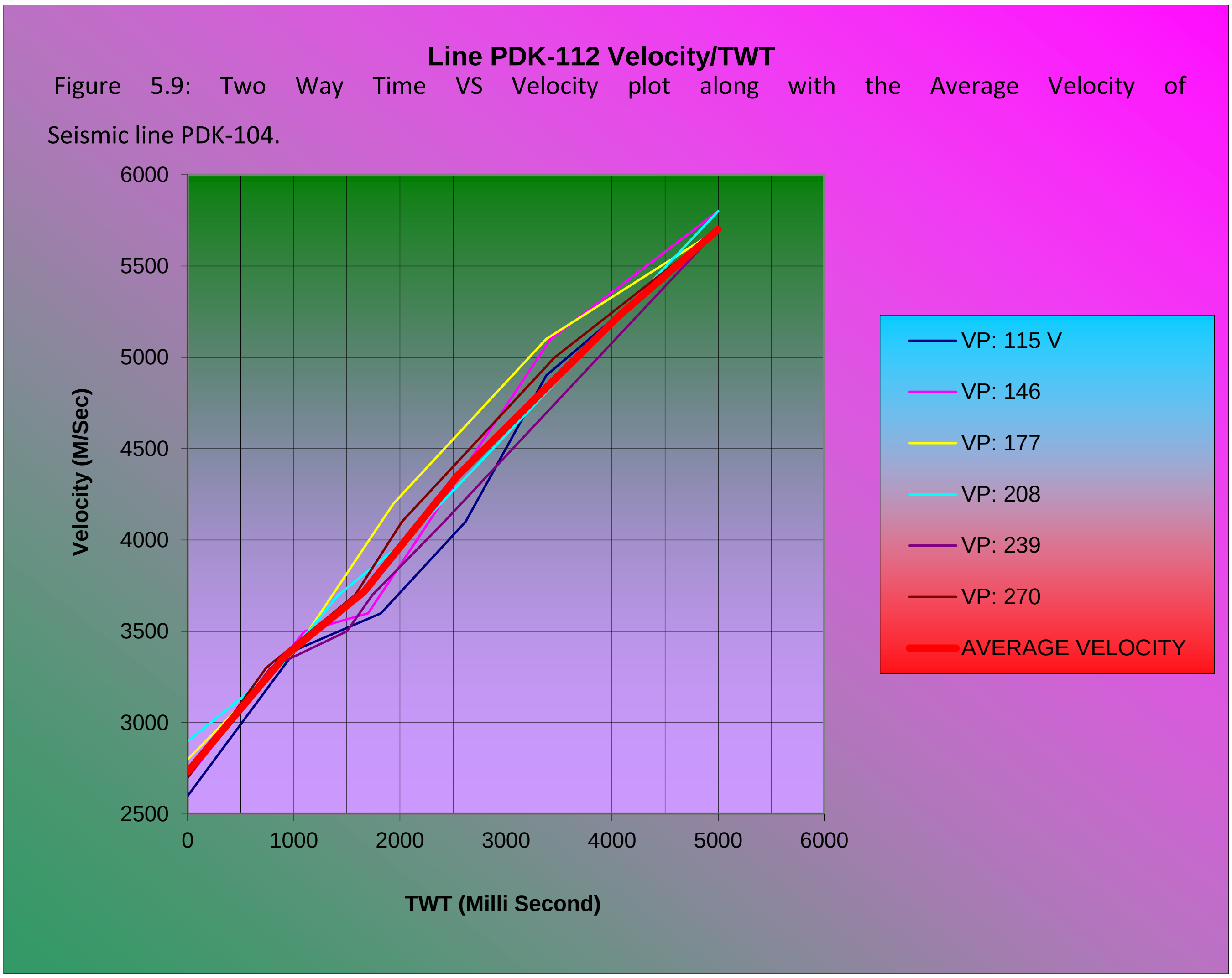



Figure 5.10: Two Way Time VS Velocity plot along with the Average Velocity of Seismic line PDK-112.

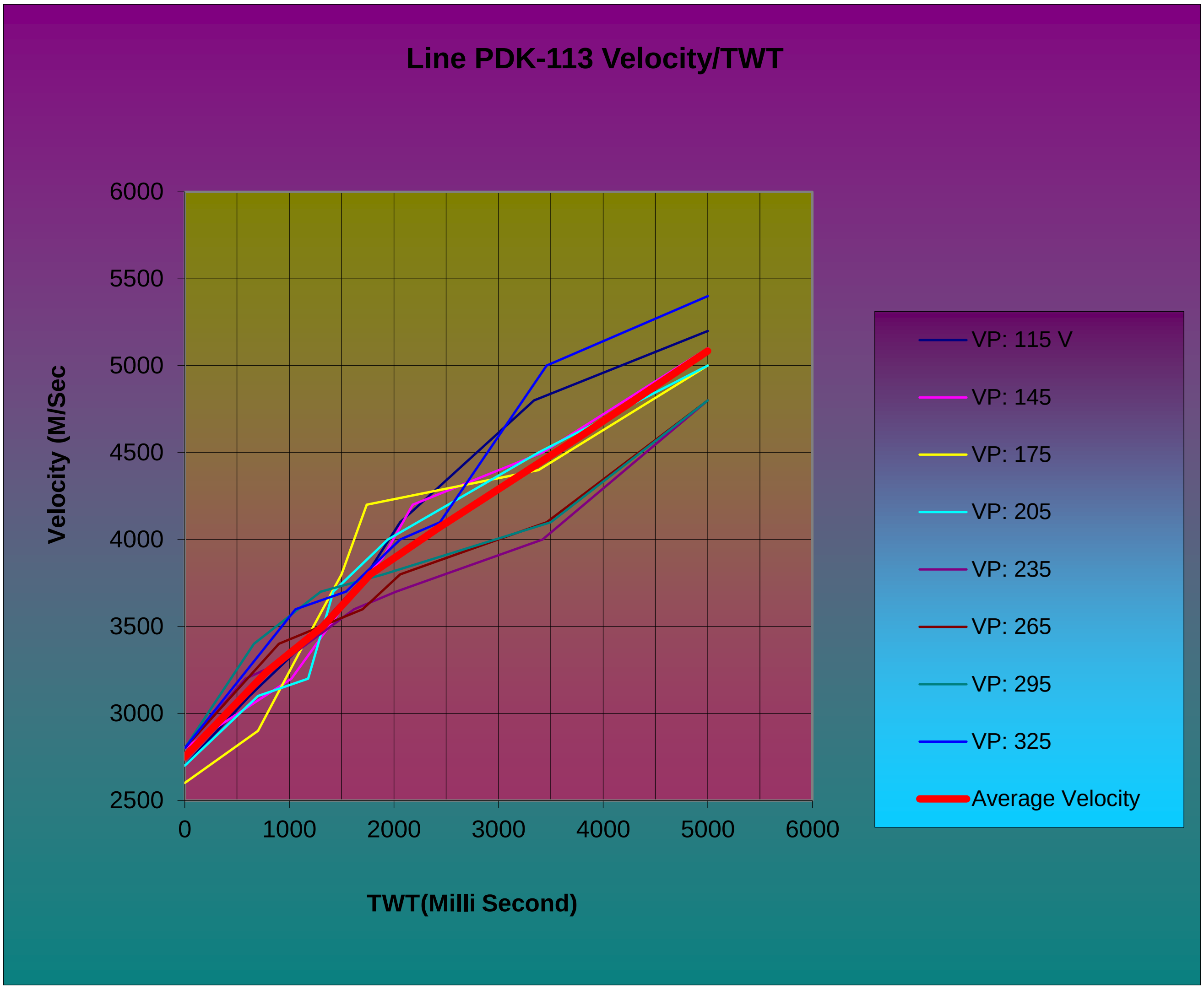



Figure 5.11: Two Way Time VS Velocity plot along with the Average Velocity of Seismic line PDK-113.

### 5.2.6 Time Contour Maps

Time contour maps are prepared one for each of the four reflectors. The TWT was plotted on the base map and contoured manually. The time contour map is made by the following procedure:

- Transfer faults from the tine section to their respective Seismic lines present on the base map.
- Join the similar and adjacent faults of different lines together.
- Transfer the time readings from Seismic time section to their respective Seismic line on the base map after a specific interval.
- Join the points of equal values on the Seismic lines to construct Iso-contour line.

We also prepared the time contour maps by using the software ROCK WORKS (figure 5.12-5.14). Data for time is given in appendix 1-5.

### 5.2.7 Depth Contour Maps

Generally the depth section gives the configuration of reflectors in the same way as the time section. To determine the depth of the marked reflectors on the seismic section, the formula employed is:

$$S = (V * T)/2$$

Where, S = Depth of the reflector

V = Average velocity

T = Two-way time of the reflector read from the seismic section.

We also prepared the depth contour maps manually as well by using the software ROCK WORKS (figure 5.15-5.17). Data for depth is given in appendix 6-10.

Time and depth structure maps are prepared for imaging of subsurface geological structures and trend. We observed that the time and depth maps are giving similar configuration in the subsurface. Looking at the depth map we can measure the top of the horizons for which that map has been prepared. Whereas in time structure map we talk in terms of two way travel time. From the time and depth maps we see that the subsurface is a faulted anticline.

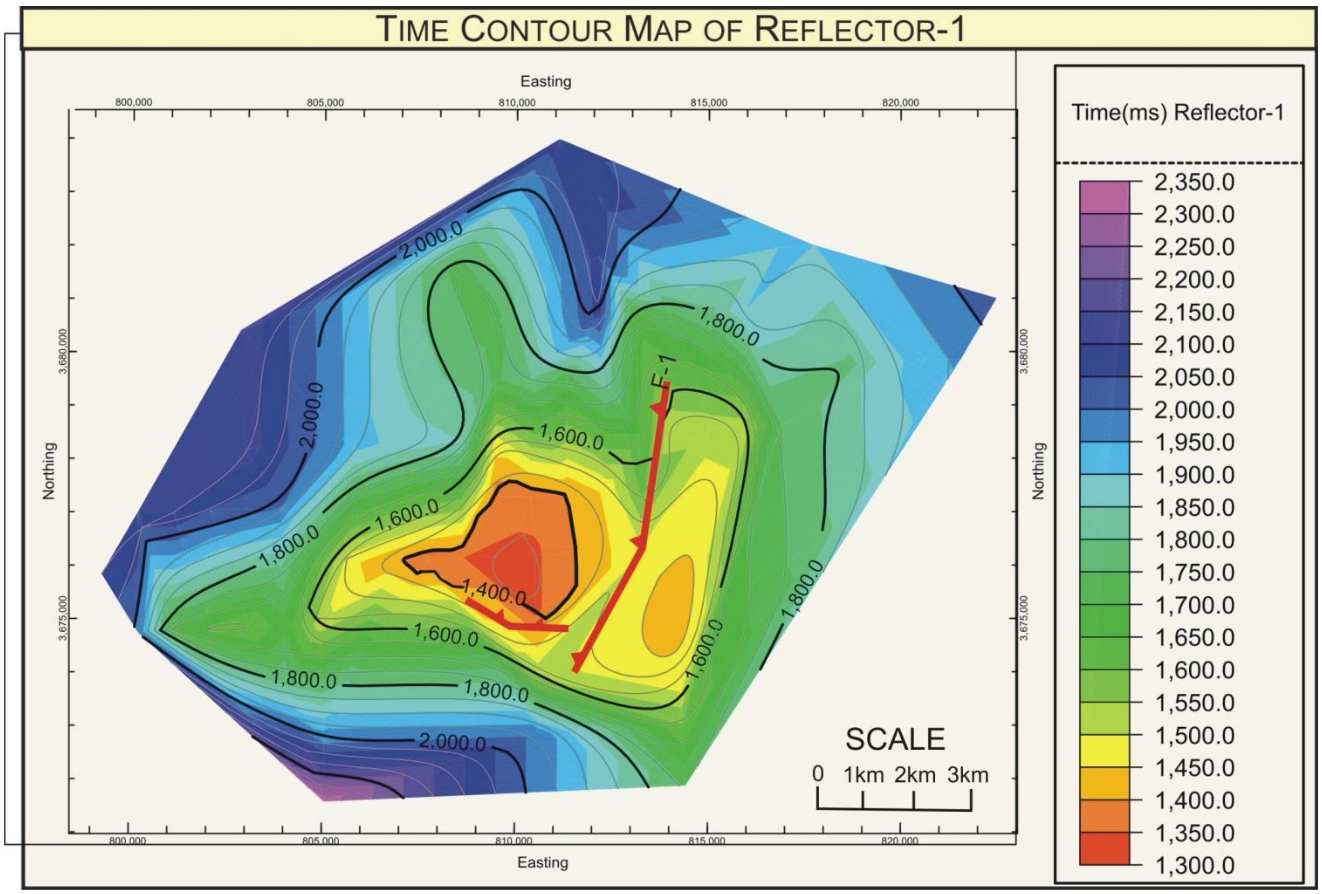



Figure 5.12: Time Contour Map of Reflector R1.

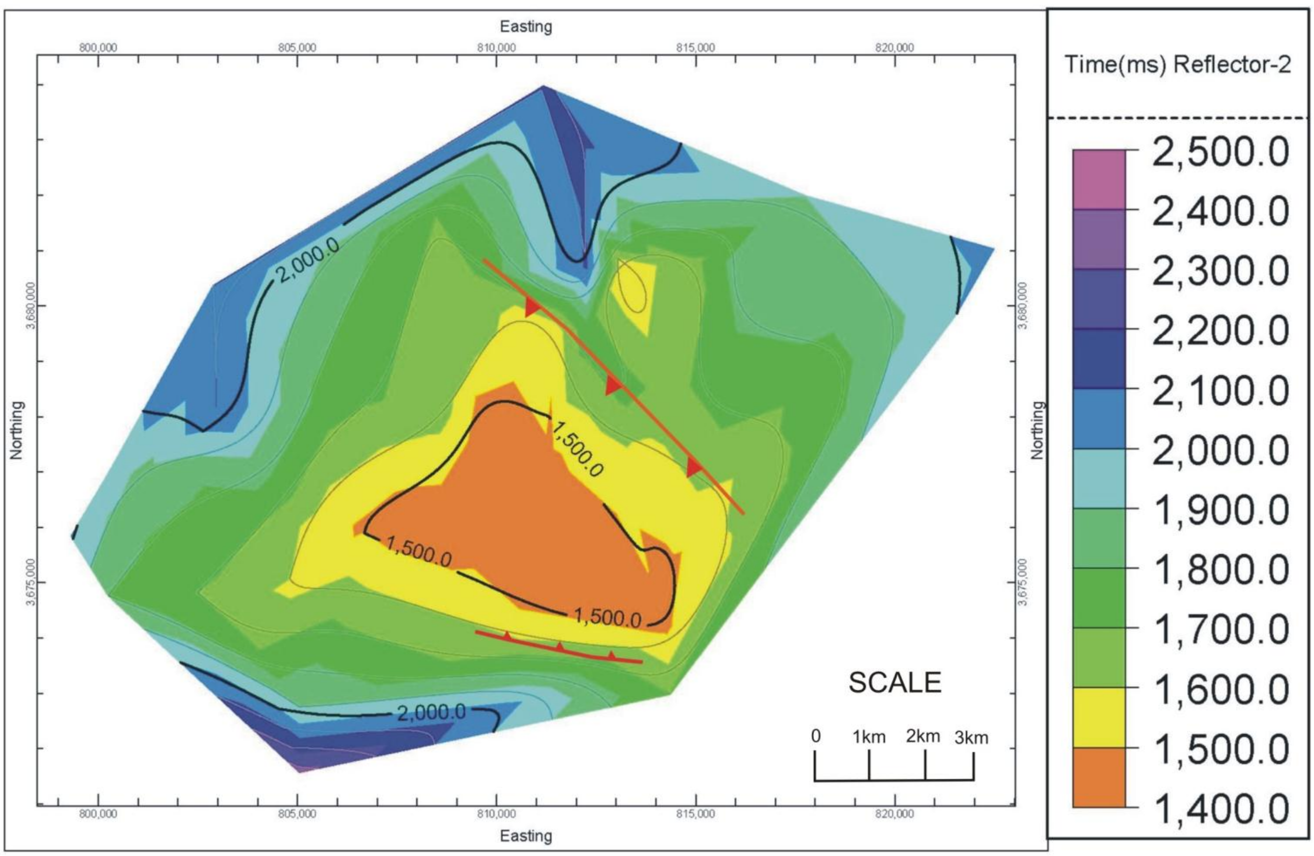



Figure 5.13: Time Contour Map of Reflector 2

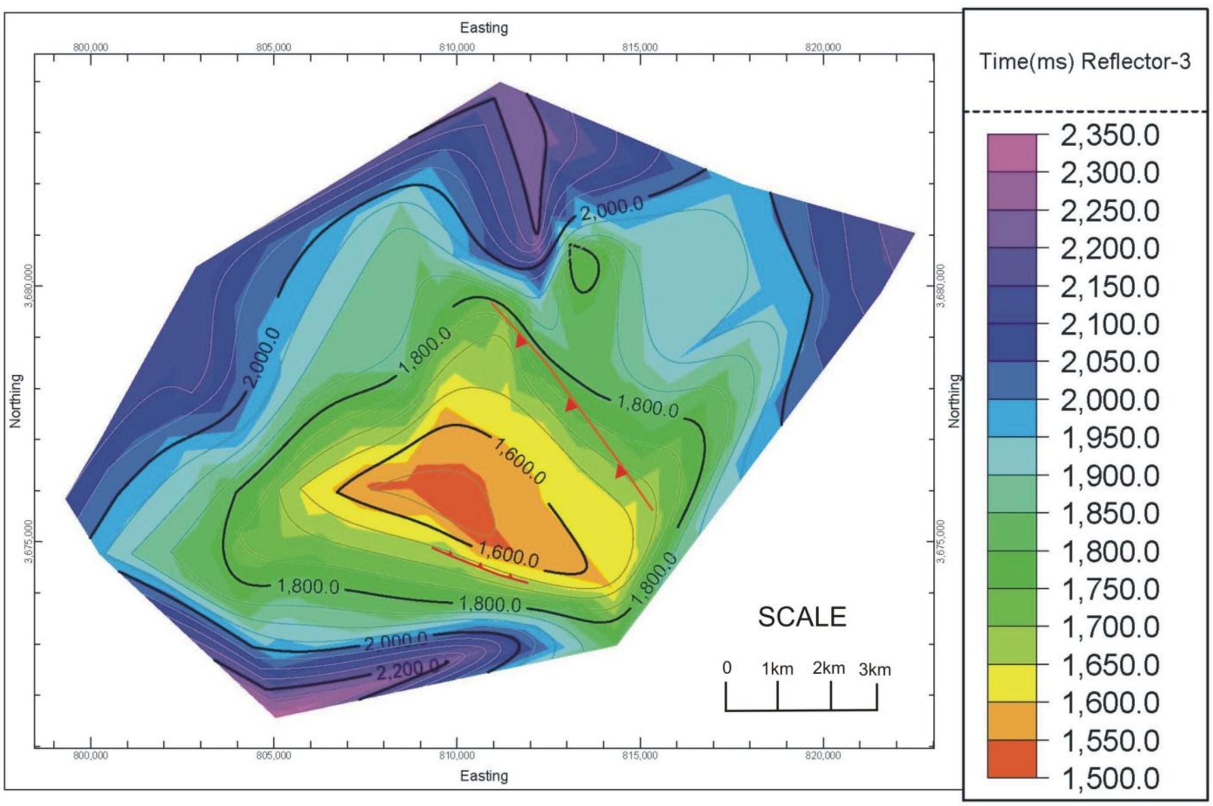



Figure 5.14.: Time Contour Map of Reflector 3

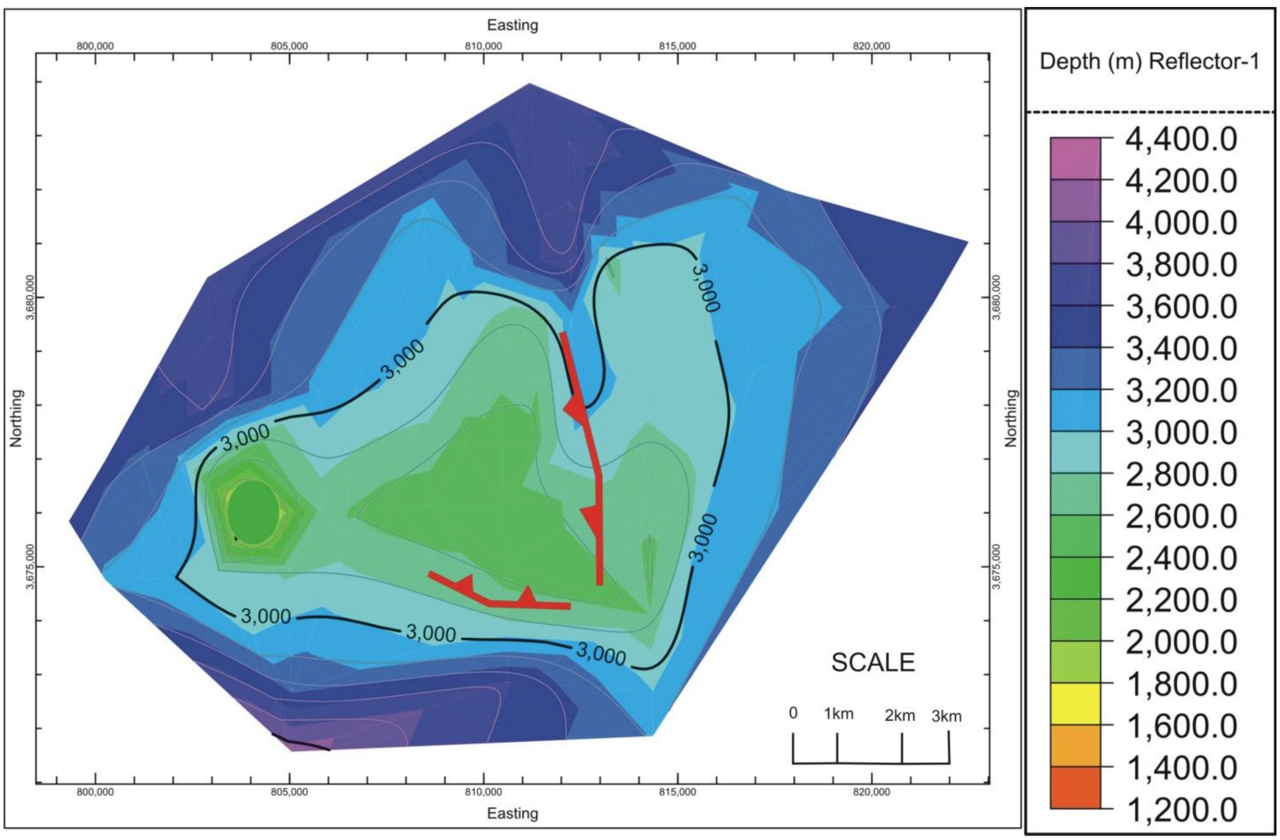



Figure 5.15: Depth Contour Map of Reflector 1

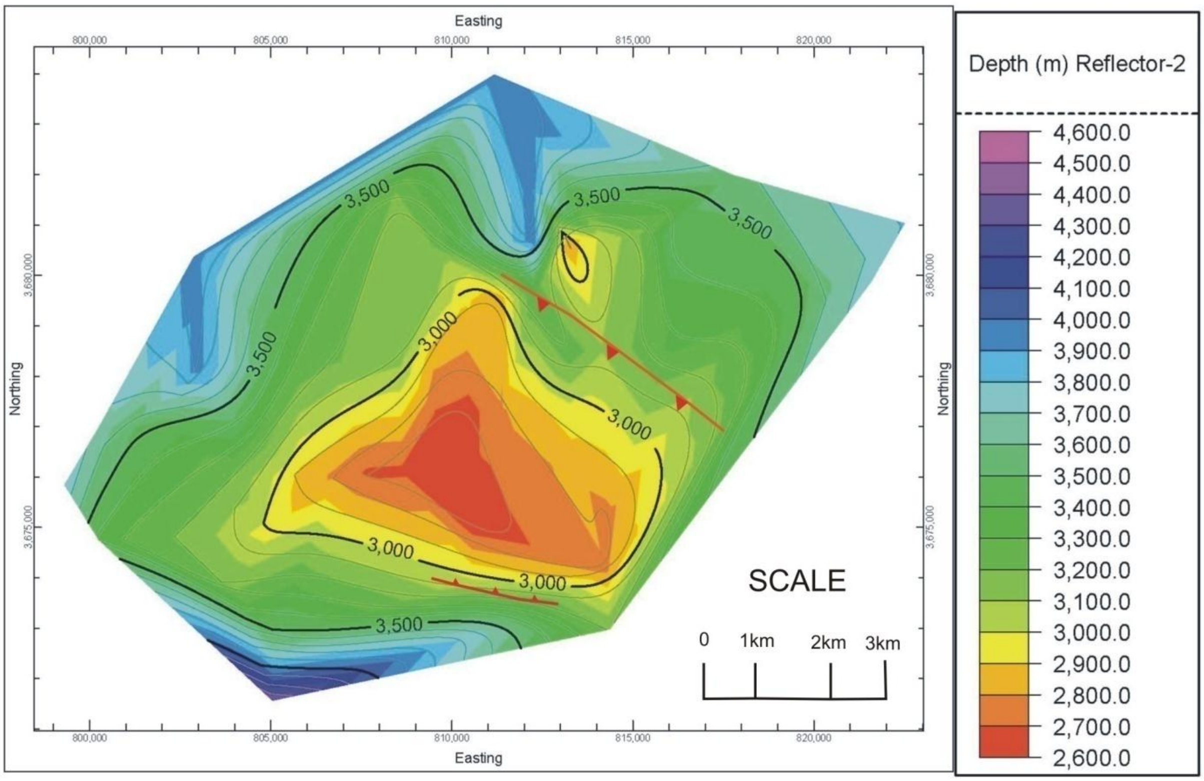



Figure 5.16: Depth Contour Map of Reflector 2

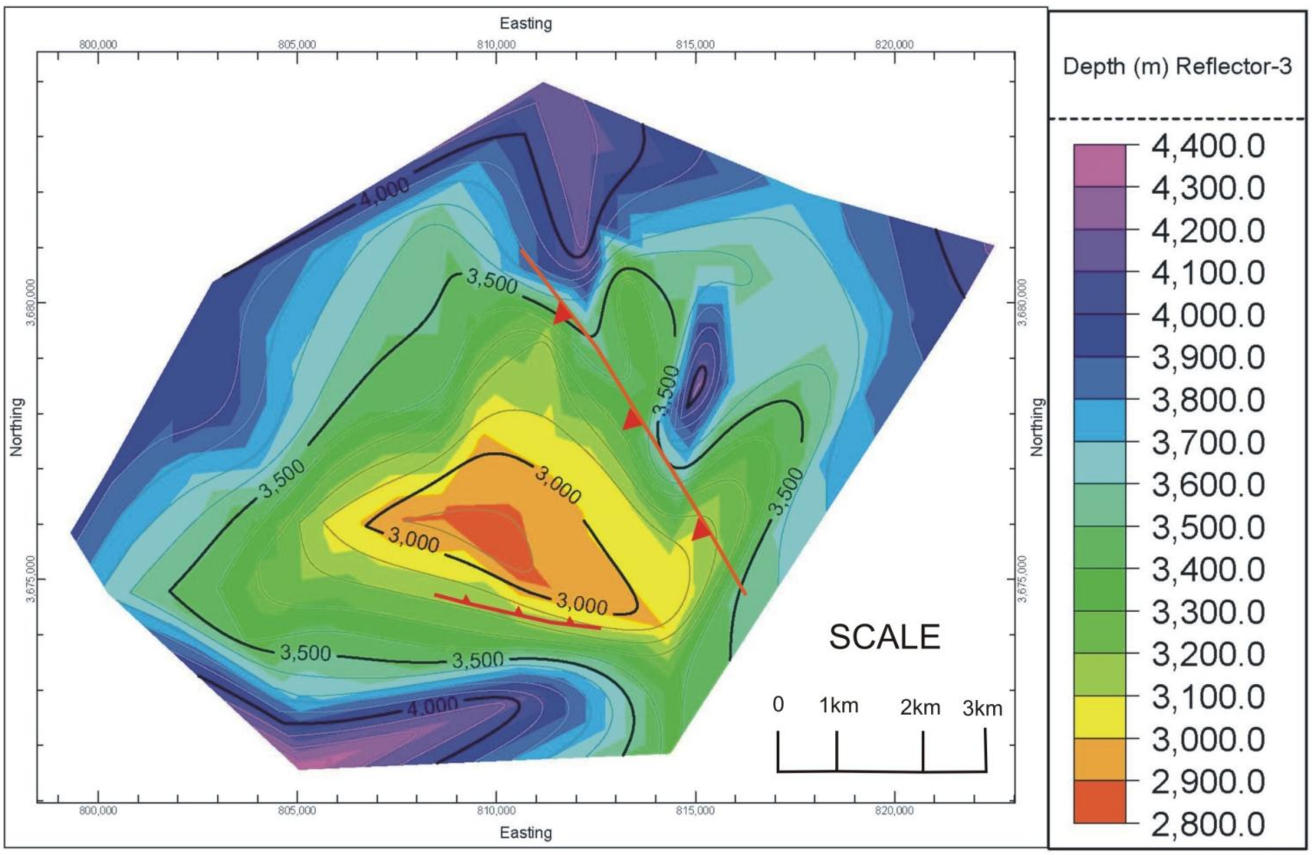



Figure 5.17.: Depth Map of Reflector 3

### 5.2.8 Preparation of Geoseismic Section

Geoseismic sections represent vertical cross section of the earth. Geoseismic sections were prepared for the line PDK-104 and PDK-113 as shown by Figure 5.20 and 5.21 respectively. It is the final representation of the seismic section in terms of depth and stratigraphy. The responsibility of an interpreter is to convert the data from time to depth i.e. to convert it into a form that is as geologically meaningful as possible. Geoseismic section along seismic lines should be prepared on 1 to 1 scale i.e. the horizontal and vertical scale must be the same. The reflector R1 (Chorgali Formation) converted into depth, the depth value against every tenth shot point were posted on the graph paper and by joining the points surface of the reflector R1 obtained in depth domain. The faults were marked by the help of the seismic interpreted lines. Similarly the basement reflector was also plotted in the depth domain.

The Eocene to Cambrian thicknesses obtained in the area by drilling information were measured to plot the Eocene to Cambrian section below R1.Whereas the thickness of Murree and Siwaliks were plotted on the top of reflector R1 by using the drilling information. The available well in the area, near the seismic lines PDK 104 and PDK-113 is Dhulian No.43. The well picks were correlated with the seismic horizons. For more accurate construction of the geoseismic section basemap (Figure 5.2) and surface geological map (Figure 5.19) are incorporated.

| FORMATIONS | AGE | THICKNESS (m) |
|---|---|---|
| Siawliks (Chinji, Nagri) | Pliocene | 1700m |
| Murree | Miocene | 1500m |
| Khuldana-Tobra | Eocene-Cambrian | 1100m |

Table 7: Probable Formation thickness measured from Well Data Dhulian-43 for line PDK-113 (Strike line)

| FORMATIONS | AGE | THICKNESS(m) |
|---|---|---|
| Siwaliks(Chinji, Nagri) | Pliocene | 2000m |
| Murree | Miocene | 1700m |
| Khuldana – Tobra | Eocene-Cambrian | 1300m |

Table 8: Probable Formation Thickness measured from Well Data Dhulian-43 for line PDK-104 (Dip line)

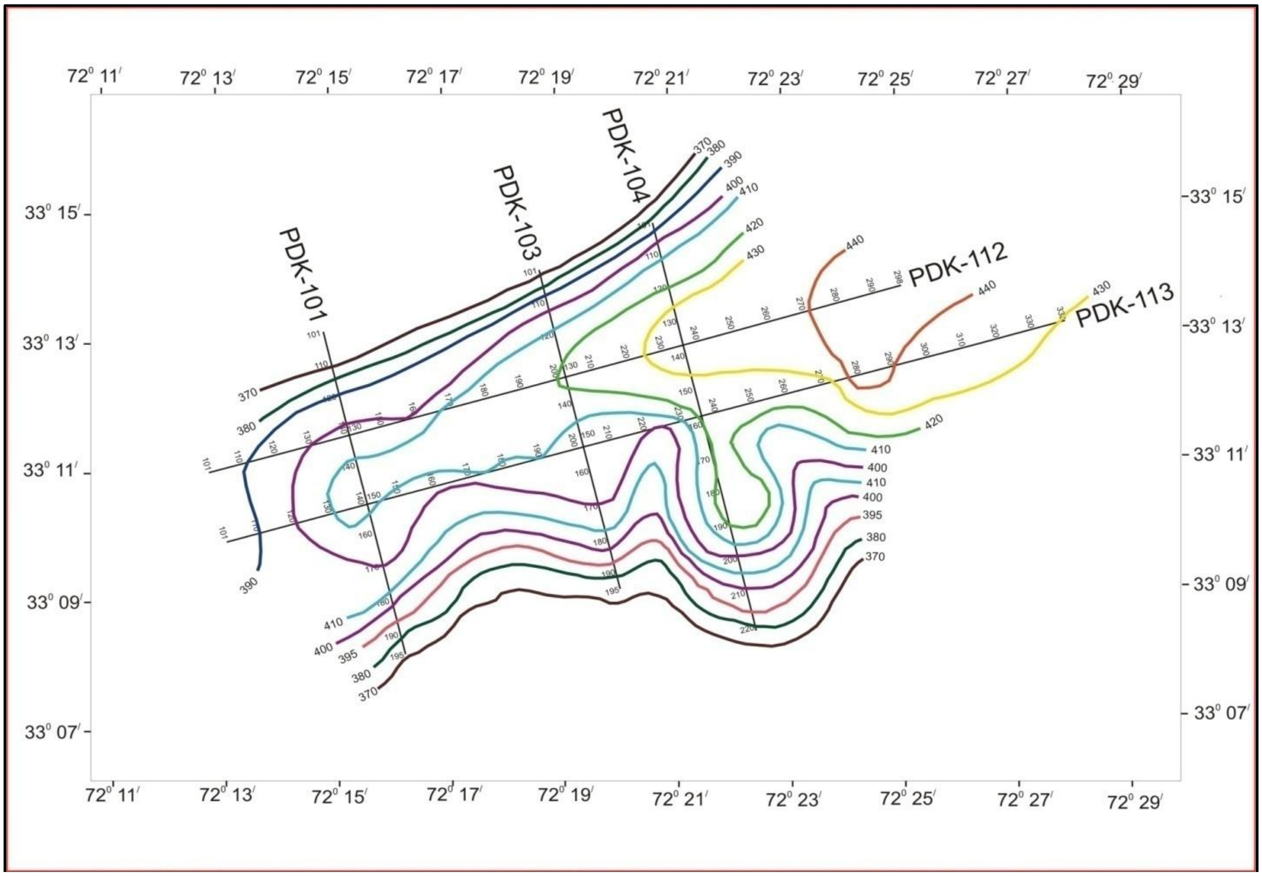



Figure 5.18: Surface Topographic map of Dhulian Area.

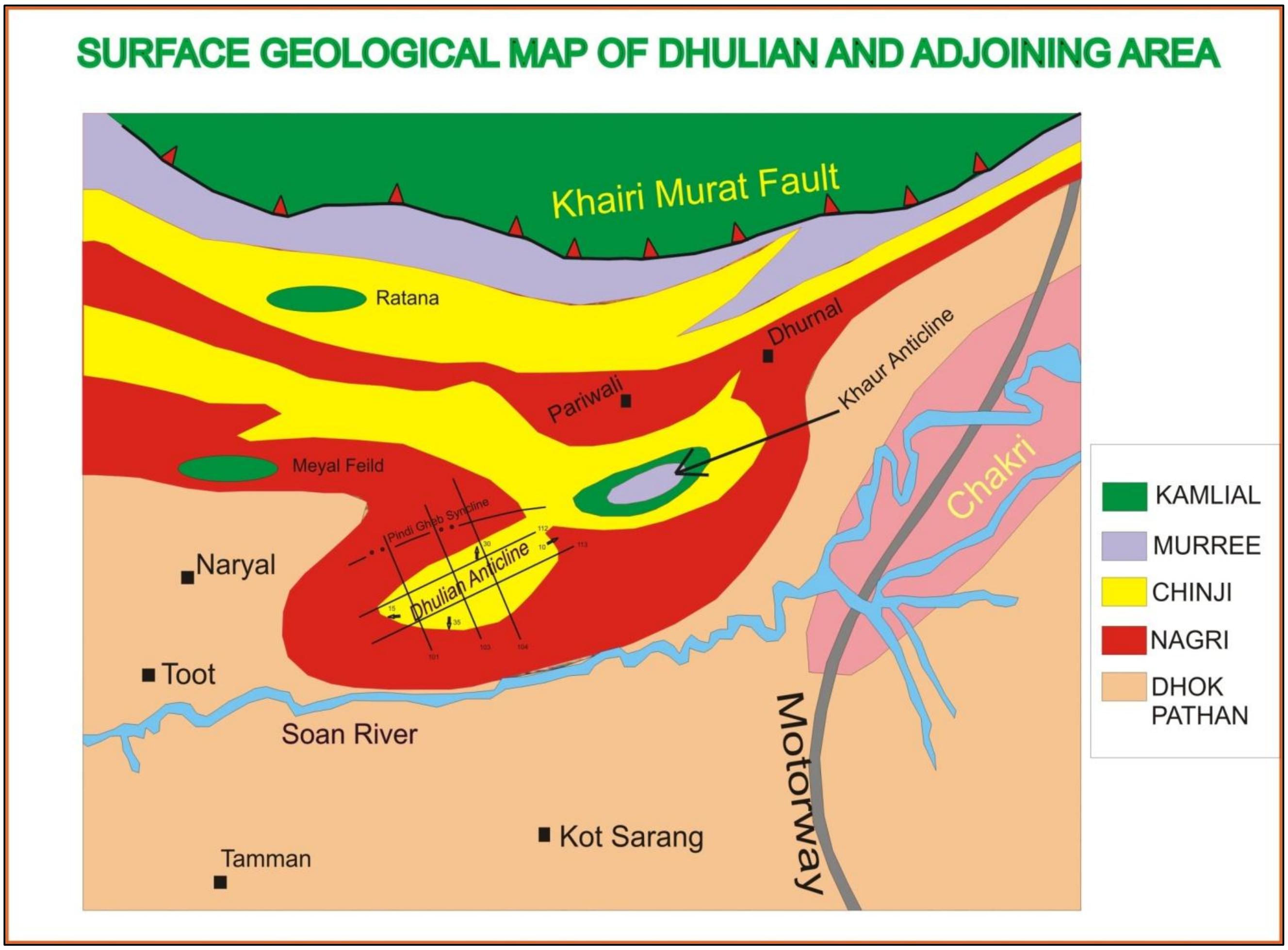



Figure 5.19: Surface Geological map of Dhulian and adjoining area

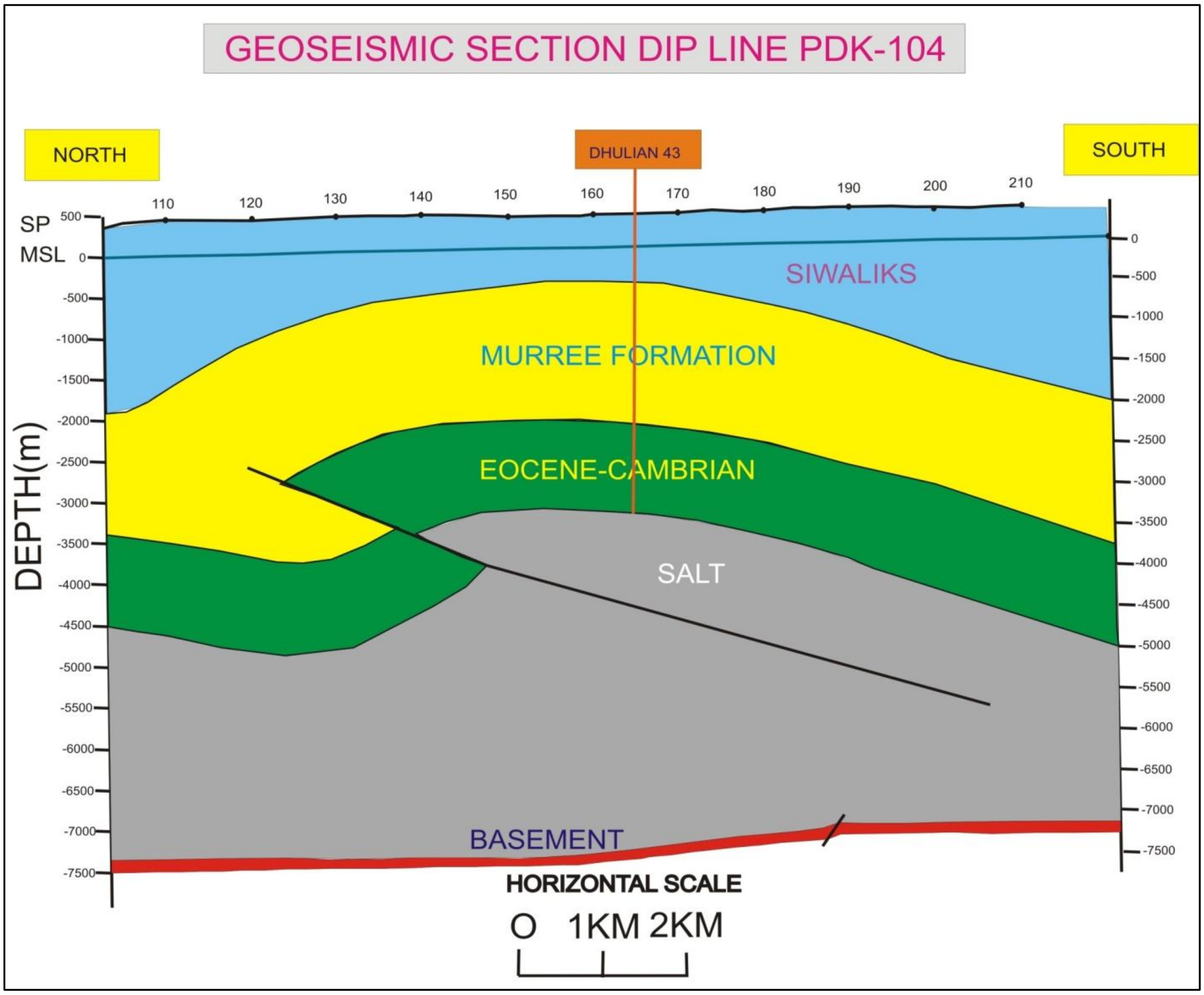



Figure 5.20: Geoseismic Section of Dip line PDK-104

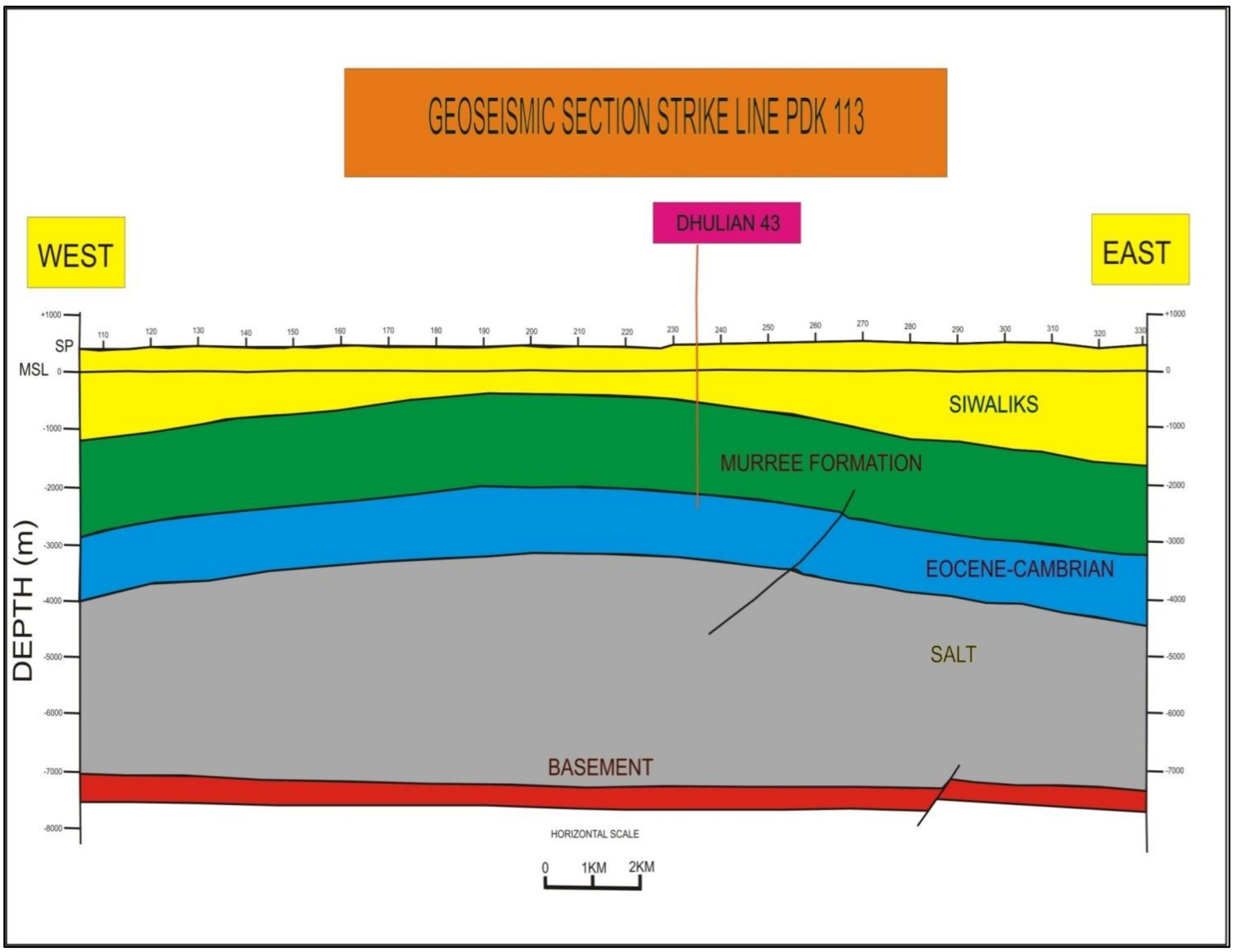



Figure 5.21: Geoseismic Section of Strike Line PDK-113

## 5.3 Conclusions

1. The Time and Depth contour maps (Figure 5.12-5.14 and 5.15-5.17) show that the subsurface structure is a faulted anticline .Thrust faults are almost NS-EW trending. The axis of the anticline is in the East-West direction and the faulted anticline plunges in East- West direction.

2. On the basis well data we can say that Reflector R1 (yellow) is probably Chorgali Formation where as Reflectors R2 (orange) and R3 (green) are probably Sakesar and Lockhart Formation respectively. R4 marked by red colour is the basement.

3. The contour maps suggest very good structural trap for Eocene Reservoir. The Dhulian anticline is a four way dip closure. The capacity of a fold trap to hold oil and gas depends chiefly on structural closure, the thickness of the reservoir rock, the rocks effective porosity, reservoir pressure and the conditions of fluid flow through the rock. Closure is found by subtracting the lowest contour value from the highest contour value. The time closure for R1 and R2 is 500msec and 600msec respectively. Whereas the depth closure for R1 is 100m and for R2 it is 1800m.

4. From the two way travel time and depth values we can find the crest of the anticline which is the highest point on the given stratum along the top of the fold. The crest is indicated by the lowest time and depth values of the reflectors marked. When the particles of oil and gas entrained in the flowing water reach the anticline their buoyancy causes them to tend to resist further movement by the moving water when they reach the crest of the anticline. The net result is that the oil and gas are retained in the highest point of the structure. Water moving across the structural trap thus leaves the oil and gas behind at the point of lowest potential energy or near the highest point in the reservoir rock.
5. The Geoseismic Section for the dip line PDK-104 as shown in the Figure 5.20 indicates a South dipping thrust which ranges from 2500m to 4000m. Age of the thrust is Miocene as the youngest rocks the fault has displaced are of Miocene age. The maximum depth of the

basement is 7500m. There is a North dipping normal fault in the basement at shot point 190.

6. The Geoseismic Section for the strike line PDK-113 as shown in the Figure 5.21 shows a West dipping thrust fault. The depth of the thrust ranges from 2100m to 4800m. Themaximum depth of the basement is 7000m. There is a West dipping normal fault in the basement at the shot point 285.

7. The Patala Formation of Paleocene is the source rock in this area. Its thickness is 71m. The Chorgali and Sakesar Formations of Eocene known as Main Oil Horizon are acting as reservoir rocks. The thickness of Chorgali and Sakesar is 66m and 92m respectively. Mammikhel Formation is the seal rock.
8. Unmigrated strike line PDK-112 is showing diffraction pattern. A mistie of 100 milliseconds exist at the tie point of line PDK-112 and 101 and also at PDK-112 and103
9. Dhulian is a part of the Central Potwar region which is under Compresional Regime. Thus the thrust faulting is due to Compression. The Normal faulting in the basement is as a result of Extensional Regime when the Indian plate was rifting during the Mesozoic.
10. Existence of evaporate layer over basement suggest thin skin tectonics in this area.

# APPENDICES

Appendix 1: Time values of R1, R2, R3 of the Seiemic line PDK-101.

| SP NO. | TWT Reflector # 1 (ms) | TWT Reflector # 2 (ms) | TWT Reflector # 3 (ms) |
|---|---|---|---|
| 110 | 2330 | 2410 | |
| 120 | 2160 | 2250 | 2330 |
| 130 | 1850 | 1910 | 2000 |
| 140 | 1640 | 1700 | 1800 |
| 150 | 1590 | 1620 | 1740 |
| 160 | 1560 | 1590 | 1710 |

| | | | |
|---|---|---|---|
| 170 | 1650 | 1700 | 1800 |
| 180 | 1870 | 1920 | 2030 |
| 190 | 2040 | 2100 | 2130 |

Appendix 2: Time values of R1, R2, R3 of the Seiemic line PDK-103.

| **SP NO.** | **TWT Reflector # 1 (ms)** | **TWT Reflector # 2 (ms)** | **TWT Reflector # 3 (ms)** |
|---|---|---|---|
| 120 | 1980 | 2000 | 2200 |
| 130 | 1620 | 1700 | 1870 |
| 140 | 1450 | 1500 | 1630 |
| 150 | 1340 | 1400 | 1530 |
| 160 | 1340 | 1420 | 1540 |
| 170 (up) | 1380 | 1450 | 1600 |
| 170 (down) | 1490 | 1500 | |
| 180 | 1630 | 1700 | 1800 |
| 185 | 1720 | | 1900 |

Appendix 3: Time values of R1, R2, R3 of the Seiemic line PDK-104.

| **SP NO.** | **TWT Reflector # 1 (ms)** | **TWT Reflector # 2 (ms)** | **TWT Reflector # 3 (ms)** |
|---|---|---|---|
| 125 | 1740 | | |
| 130 | 1610 | 1700 | 1800 |
| 140 | 1420 | 1490 | 1600 |

| | | | |
|---|---|---|---|
| 150 | 1400 | 1470 | 1600 |
| 160 | 1440 | 1500 | 1600 |
| 170 | 1550 | 1520 | 1680 |
| 180 | 1610 | 1590 | 1750 |
| 190 | 1800 | 1880 | 1940 |
| 200 | 1980 | 2020 | 2120 |
| 210 | 2070 | 2110 | 2220 |

Appendix 4: Time values of R1, R2, R3 of the Seiemic line PDK-112.

| **SP NO.** | **TWT Reflector # 1 (ms)** | **TWT Reflector # 2 (ms)** | **TWT Reflector # 3 (ms)** |
|---|---|---|---|
| 110 | 1930 | 2010 | |
| 120 | 1900 | 1950 | 2100 |
| 130 | 1840 | 1870 | 2050 |
| 140 | 1760 | 1840 | 2000 |
| 150 | 1730 | 1810 | 1950 |
| 160 | 1750 | 1790 | 1950 |
| 170 | 1740 | 1770 | 1920 |
| 180 | 1710 | 1730 | 1890 |
| 190 | 1660 | 1710 | 1850 |
| 200 | 1610 | 1670 | 1850 |
| 210 | 1550 | 1620 | 1800 |
| 220 | 1500 | 1550 | 1740 |
| 230 | 1450 | 1510 | 1700 |

| | | | |
|---|---|---|---|
| 240 | 1440 | 1490 | 1690 |
| 250 | 1510 | 1510 | 1750 |
| 260 | 1570 | 1610 | 1790 |
| 270 | 1600 | 1680 | 1900 |
| 280 (up) | 1680 | 1840 | 1900 |
| 280 (down) | 1720 | | |
| 290 | 1840 | 1900 | 1990 |

Appendix 5: Time values of R1, R2, R3 of the Seiemic line PDK-113.

| **SP NO.** | **TWT Reflector # 1 (ms)** | **TWT Reflector # 2 (ms)** | **TWT Reflector # 3 (ms)** |
|---|---|---|---|
| 110 | 1730 | 1800 | 1960 |
| 120 | 1690 | 1740 | 1890 |
| 130 | 1640 | 1710 | 1850 |
| 140 | 1600 | 1680 | 1810 |
| 150 | 1560 | 1640 | 1760 |
| 160 | 1520 | 1580 | 1720 |
| 170 | 1460 | 1530 | 1640 |
| 180 | 1410 | 1480 | 1590 |
| 190 | 1360 | 1430 | 1540 |
| 200 | 1350 | 1430 | 1540 |
| 210 | 1350 | 1420 | 1540 |
| 220 | 1370 | 1420 | 1600 |

| | | | |
|---|---|---|---|
| 230 | 1400 | 1490 | 1620 |
| 240 | 1460 | 1530 | 1650 |
| 250 | 1510 | 1600 | 1730 |
| 260 (up) | 1580 | 1660 | 1850 |
| 260 (down) | | | 1900 |
| 270 (up) | 1640 | 1770 | 1950 |
| 270 (down) | 1700 | | |
| 280 | 1750 | 1820 | 1960 |
| 290 | 1790 | 1850 | 2000 |
| 300 | 1880 | 1930 | 2090 |
| 310 | 1930 | 2000 | 2120 |
| 320 | 1960 | 2030 | 2200 |
| 330 | 2030 | 2090 | 2210 |

Appendix 6: Depth values of R1, R2, R3 of the Seismic line PDK-101

| SP NO | **DEPTH REFLECTOR # 1 (m)** | **DEPTH REFLECTOR # 2 (m)** | **DEPTH REFLECTOR # 3 (m)** |
|---|---|---|---|
| 110 | 4250 | 4520 | |
| 120 | 3940 | 4220 | 4370 |
| 130 | 3380 | 3580 | 3750 |
| 140 | 2990 | 3190 | 3380 |
| 150 | 2900 | 3040 | 3260 |
| 160 | 2850 | 2980 | 3200 |
| 170 | 1360 | 3190 | 3380 |

| | | | |
|---|---|---|---|
| 180 | 1750 | 3600 | 3800 |
| 190 | 3720 | 3940 | 3990 |

Appendix 7: Depth values of R1, R2, R3 of the Seismic line PDK-103

| SP NO | **DEPTH REFLECTOR # 1 (m)** | **DEPTH REFLECTOR # 2 (m)** | **DEPTH REFLECTOR # 3 (m)** |
|---|---|---|---|
| 120 | 3610 | 3750 | 4120 |
| 130 | 2960 | 3190 | 3500 |
| 140 | 2650 | 2810 | 3050 |
| 150 | 2440 | 2630 | 2870 |
| 160 | 2450 | 2660 | 2890 |
| 170 (up) | 2520 | 2720 | 3000 |
| 170 (down) | 2720 | 2830 | |
| 180 | 2980 | 3190 | 3370 |
| 185 | 3140 | | 3560 |

Appendix 8: Depth values of R1, R2, R3 of the Seismic line PDK-104

| **SP NO** | **DEPTH REFLECTOR # 1 (m)** | **DEPTH REFLECTOR #2 (m)** | **DEPTH REFLECTOR # 3 (m)** |
|---|---|---|---|
| 125 | 3180 | | |
| 130 | 2940 | 3190 | 3375 |
| 140 | 2600 | 2790 | 3000 |
| 150 | 2560 | 2760 | 3000 |

| | | | |
|---|---|---|---|
| 160 | 2630 | 2810 | 3000 |
| 170 | 2830 | 2860 | 3150 |
| 180 | 2940 | 2980 | 3280 |
| 190 | 3290 | 3530 | 3640 |
| 200 | 3610 | 3790 | 3980 |
| 210 | 3780 | 3960 | 4160 |

Appendix 9: Depth values of R1, R2, R3 of the Seismic line PDK-112.

| **SP NO** | **DEPETH REFLECTOR # 1 (m)** | **DEPETH REFLECTOR # 2 (m)** | **DEPETH REFLECTOR # 3 (m)** |
|---|---|---|---|
| 110 | 3520 | 3770 | |
| 120 | 3470 | 3660 | 3940 |
| 130 | 3360 | 3510 | 3840 |
| 140 | 3210 | 3450 | 3750 |
| 150 | 3160 | 3390 | 3650 |
| 160 | 3190 | 3360 | 3650 |
| 170 | 3180 | 3320 | 3600 |
| 180 | 3120 | 3240 | 3540 |
| 190 | 3030 | 3210 | 3470 |
| 200 | 2940 | 3130 | 3470 |
| 210 | 2830 | 3040 | 3370 |
| 220 | 2740 | 2910 | 3260 |
| 230 | 2650 | 2830 | 3190 |
| 240 | 2630 | 2790 | 3170 |

| | | | |
|---|---|---|---|
| 250 | 2760 | 2830 | 3280 |
| 260 | 2870 | 3020 | 3560 |
| 270 | 2920 | 3150 | 3560 |
| 280 (up) | 3070 | 3450 | 3560 |
| 280 (down) | 3140 | | |
| 290 | 3360 | 3560 | 3730 |

Appendix 10: Depth values of R1, R2, R3 of the Seismic line PDK-113.

| SP NO | DEPETH REFLECTOR # 1 (m) | DEPETH REFLECTOR # 2 (m) | DEPETH REFLECTOR # 3 (m) |
|---|---|---|---|
| 110 | 3160 | 3380 | 3670 |
| 120 | 3080 | 3260 | 3540 |
| 130 | 2990 | 3210 | 3470 |
| 140 | 2920 | 3150 | 3390 |
| 150 | 2850 | 3080 | 3300 |
| 160 | 2770 | 2960 | 3220 |
| 170 | 2670 | 2870 | 3070 |
| 180 | 2570 | 2780 | 2980 |
| 190 | 2480 | 2680 | 2890 |
| 200 | 2460 | 2680 | 2890 |
| 210 | 2460 | 2660 | 2890 |
| 220 | 2500 | 2660 | 3000 |
| 230 | 2560 | 2790 | 3040 |
| 240 | 2990 | 2870 | 3090 |

| | | | |
|---|---|---|---|
| 250 | 2760 | 3000 | 3240 |
| 260 (up) | 2880 | 3110 | 3370 |
| 260 (down) | | | 4220 |
| 270 (up) | 2990 | 3320 | 3660 |
| 270 (down) | 3100 | | |
| 280 | 3130 | 3410 | 3670 |
| 290 | 3270 | 3470 | 3750 |
| 300 | 3430 | 3620 | 3920 |
| 310 | 3520 | 3750 | 3970 |
| 320 | 3580 | 3810 | 4120 |
| 330 | 3710 | 3920 | 4140 |

Appendix 11: Latitude and Longitude values of Shot points of PDK-101

| **PDK - 101** | | | | | | |
|---|---|---|---|---|---|---|
| **SP NO.** | **LONGITUDE** | | | **LATITUDE** | | |
| 196 | 72º | 16' | 15" | 33º | 08' | 10" |
| 190 | 72º | 16' | 10" | 33º | 08' | 20" |
| 180 | 72º | 15' | 58" | 33º | 08' | 55" |
| 170 | 72º | 15' | 50" | 33º | 09' | 20" |
| 160 | 72º | 15' | 43" | 33º | 10' | |
| 150 | 72º | 15' | 38" | 33º | 10' | 25" |
| 140 | 72º | 15' | 24" | 33º | 11' | 05" |
| 130 | 72º | 15' | 18" | 33º | 11' | 20" |
| 120 | 72º | 15' | 05" | 33º | 12' | 05" |

| | | | | | | |
|---|---|---|---|---|---|---|
| 110 | 72º | 15' | | 33º | 12' | 30'' |
| 101 | 72º | 14' | 45'' | 33º | 13' | 10'' |

Appendix 12: Latitude and Longitude values of Shot points of PDK-103

| PDK - 103 | | | | | | |
|---|---|---|---|---|---|---|
| **SP NO.** | **LONGITUDE** | | | **LATITUDE** | | |
| 196 | 72º | 20' | | 33º | 09' | 03'' |
| 190 | 72º | 19' | 58'' | 33º | 09' | 20'' |
| 180 | 72º | 19' | 50'' | 33º | 09' | 50'' |
| 170 | 72º | 19' | 40'' | 33º | 10' | 20'' |
| 160 | 72º | 19' | 30'' | 33º | 10' | 50'' |
| 150 | 72º | 19' | 21'' | 33º | 11' | 25'' |
| 140 | 72º | 19' | 18'' | 33º | 11' | 58'' |
| 130 | 72º | 19' | 05'' | 33º | 12' | 30'' |
| 120 | 72º | 18' | 58'' | 33º | 13' | 02'' |
| 110 | 72º | 18' | 50'' | 33º | 13' | 35'' |
| 101 | 72º | 18' | 40'' | 33º | 14' | 04'' |

Appendix 13: Latitude and Longitude values of Shot points of PDK-104

| PDK - 104 | | | | | | |
|---|---|---|---|---|---|---|
| **SP NO.** | **LONGITUDE** | | | **LATITUDE** | | |
| 220 | 72º | 22' | 20'' | 33º | 08' | 25'' |
| 210 | 72º | 22' | 18'' | 33º | 08' | 59'' |

| | | | | | | |
|---|---|---|---|---|---|---|
| 200 | 72º | 22' | 10'' | 33º | 09' | 25'' |
| 190 | 72º | 22' | | 33º | 10' | |
| 180 | 72º | 21' | 50'' | 33º | 10' | 30'' |
| 170 | 72º | 21' | 40'' | 33º | 11' | 00'' |
| 160 | 72º | 21' | 35'' | 33º | 11' | 35'' |
| 150 | 72º | 21' | 25'' | 33º | 12' | 08'' |
| 140 | 72º | 21' | 10'' | 33º | 12' | 30'' |
| 130 | 72º | 21' | 05'' | 33º | 13' | 10'' |
| 120 | 72º | 21' | | 33º | 13' | 40'' |
| 110 | 72º | 20' | 55'' | 33º | 14' | 20'' |
| 101 | 72º | 20' | 40'' | 33º | 14' | 45'' |

Appendix 14: Latitude and Longitude values of Shot points of PDK-112

| **PDK – 112** | | | | | | |
|---|---|---|---|---|---|---|
| **SP NO.** | **LATITUDE** | | | **LONGITUDE** | | |
| 101 | 33º | 11' | 55'' | 72º | 12' | 45'' |
| 110 | 33º | 11' | 10'' | 72º | 13' | 25'' |
| 120 | 33º | 11' | 15'' | 72º | 14' | |
| 130 | 33º | 11' | 22'' | 72º | 14' | 30'' |
| 140 | 33º | 11' | 30'' | 72º | 15' | 20'' |
| 150 | 33º | 11' | 35'' | 72º | 15' | 50'' |
| 160 | 33º | 11' | 42'' | 72º | 16' | 30'' |
| 170 | 33º | 11' | 55'' | 72º | 17' | 5'' |
| 180 | 33º | 12' | 5'' | 72º | 17' | 40'' |
| 190 | 33º | 12' | 15'' | 72º | 18' | 20'' |

| | | | | | | |
|---|---|---|---|---|---|---|
| 200 | 33º | 12' | 25" | 72º | 18' | 58" |
| 210 | 33º | 12' | 30" | 72º | 19' | 35" |
| 220 | 33º | 12' | 45" | 72º | 20' | 10" |
| 230 | 33º | 12' | 50" | 72º | 20' | 50" |
| 240 | 33º | 12' | 55" | 72º | 21' | 30" |
| 250 | 33º | 13' | 05" | 72º | 22' | 5" |
| 260 | 33º | 13' | 15" | 72º | 22' | 40" |
| 270 | 33º | 13' | 25" | 72º | 23' | 20" |
| 280 | 33º | 13' | 30" | 72º | 23' | 58" |
| 290 | 33º | 13' | 40" | 72º | 24' | 35" |

Appendix 15: Latitude and Longitude values of Shot points of PDK-113

| PDK-113 | | | | | | |
|---|---|---|---|---|---|---|
| **SP NO.** | **LONGITUDE** | | | **LATITUDE** | | |
| 101 | 72º | 13' | 05" | 33º | 09' | 57" |
| 110 | 72º | 13' | 35" | 33º | 10' | |
| 120 | 72º | 14' | 15" | 33º | 10' | 10" |
| 130 | 72º | 14' | 57" | 33º | 10' | 15" |
| 140 | 72º | 15' | 30" | 33º | 10' | 25" |
| 150 | 72º | 16' | 10" | 33º | 10' | 27" |
| 160 | 72º | 16' | 40" | 33º | 10' | 40" |
| 170 | 72º | 17' | 25" | 33º | 10' | 50" |
| 180 | 72º | 18' | | 33º | 10' | 58" |
| 190 | 72º | 18' | 40" | 33º | 11' | 05" |

| | | | | | | |
|---|---|---|---|---|---|---|
| 200 | 72º | 19' | 15'' | 33º | 11' | 10'' |
| 210 | 72º | 19' | 55'' | 33º | 11' | 20'' |
| 220 | 72º | 20' | 30'' | 33º | 11' | 30'' |
| 230 | 72º | 21' | 10'' | 33º | 11' | 35'' |
| 240 | 72º | 21' | 45'' | 33º | 11' | 45'' |
| 250 | 72º | 22' | 20'' | 33º | 11' | 55'' |
| 260 | 72º | 23' | | 33º | 12' | 00'' |
| 270 | 72º | 23' | 35'' | 33º | 12' | 10'' |
| 280 | 72º | 24' | 14'' | 33º | 12' | 15'' |
| 290 | 72º | 24' | 55'' | 33º | 12' | 25'' |
| 300 | 72º | 25' | 30'' | 33º | 12' | 35'' |
| 310 | 72º | 26' | 10'' | 33º | 12' | 40'' |
| 320 | 72º | 26' | 45'' | 33º | 12' | 50'' |
| 330 | 72º | 27' | 20'' | 33º | 13' | 00'' |

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