2D SEISMIC REFLECTION DATA

INTERPRETATION INTEGRATED WITH ROCK PHYSICS

(ACOUSTIC PROPERTIES) OF

LINE: 93-MN-09

OF MINWAL JOYAMAIR AREA

Quaid-i-Azam University
Reference Section

BY:
MUHAMMAD SAJJAD
M.Sc GEOPHYSICS
2006-2008

DEPARTMENT OF EARTH SCIENCES
QUAID-I-AZAM UNIVERSITY
ISLAMABAD

بسم الله الرحمن الرحيم

CERTIFICATE

The dissertation submitted by *MUHAMMAD SAJJAD S/O MUHAMMAD IBRAHIM* is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the requirements for the Degree of **MASTER OF SCIENCES (M.Sc) in GEOPHYSICS.**

RECOMMENDED BY:

Supervisor: -

(Dr. MONA LISA)

Chairman: -

(Dr. Zulfiqar Ahmad)
(Earth Sciences Department)

External Examiner: -

Date:___________2008.

DEPARTMENT OF EARTH SCIENCES
QUAID-I-AZAM UNIVERSITY
ISLAMABAD.

DEDICATED

TO MY

AMMI AND ABU

ABSTRACT:

A seismic reflection line 93-MN-09 of MINWAL,JOYAMAIR was provided by the department of Earth Sciences, Quaid-i-Azam University for interpretation. The given line is oriented in NW- SE direction. The line is fully processed.

Total five reflectors & two faults were marked.

Lithological interpretation has been made on basis of reflection co-efficient.

Other parameters relating Rock physics like Vp Vs--, bulk modulus, shear modulus, Vp/Vs ratio, Poisson ratio acoustic impedance of P & S waves and lame's parameter were calculated.

.

ACKNOWLEDGEMENT:

All praises for Almighty ALLAH, the most beneficial .the most merciful, compassionate the creator of the Universe who blessed me with the knowledge and enabled me to complete the research work. Without the kind blessing of whom, I could not be able to complete my work and to be at such place.

All respect to Holy Prophet Hazrat Muhammad (P.B.U.H) who appeared and blossomed as model for whole of humanity.

I specially acknowledge the help the encouragement, endless love and prayers of my family specially my loving and caring **Father** and **Mother**, which have always been a source of inspiration and guidance for me all the way, and especially my **brothers** who helped and support me morally as well as financially. Without their efforts, I can't reach up to this position. And my **sisters** whose invaluable prayers kept my sprit alive to reach this milestone.

I am especially thankful to my kindhearted supervisor **DR. MONA LISA** who encouraged me every time not only during my thesis work but throughout my course work. Without their valuable advices and cooperation I can't do this work.

I am also indebted to **Dr. Zulfiqar Ahmad**, Chairman of Earth sciences department Q.A.U Islamabad and **Sir MATLOOB HUSSAIN**, lecturer Department of Earth sciences Q.A.U Islamabad for giving me an initiative to this study.

I pay my thanks to whole faculty of my department specially the teacher's whole valuable knowledge, assistance cooperation and guidance enabled me to take initiative and furnished my academic carrier.

I am especially thankful to MY friends who are always there to help me whenever I face difficulties during my study period.

I am very very grateful to MR.AAMIR IQBAL whose prayers and cooperation in each and every matter of my life raised me so high to this status.

I am extremely thankful to all my class fellows and seniors for their moral support and respect given to me during the M.SC, their help, discussions and comments in completing this dissertation and showing with me unforgettable and ever lasting memories which we had in the University. I especially acknowledge the efforts and support of my class-fellows Mansoor Malangi, Mujahid Abbas, Mudassar, Imran, Syed Tallatuf Shah, Wajahat, Abid Hafiz Sohaib & Zaheem Abbas for their whole hearted cooperation.

Finally I am thankful to all my well-wishers and my friends specially my Best friends Iftikhar Ahmed and Sheikh Ammar for his moral encouragement and invaluable prayers and remarkable contribution.

MUHAMMAD SAJJAD

TABLE OF CONTENTS

NTRODUCTION TO DISSERTATION: 9
DATA RECORDING: 9
DATA PROCESSING: 10
DISPLAY PARAMETERS:. 12
OBJECTIVES OF DISSERTATION: 13
CHAPTER 2 15
2.1 INTRODUCTION 15
2.2 TECTONIC ZONES OF PAKISTAN 15
2.3 SEDIMENTARY BASINS OF PAKISTAN 16
2.4 INDUS BASIN: 17
2.4.1 NORTHERN INDUS BASIN: 17
2.4.2 CENTRAL INDUS BASIN: 18
2.4.3 SOUTHERN INDUS BASIN: 18
POTWAR BASIN:- 18
2.5.1 REGIONAL DEPOSITIONAL HISTORY OF POTWAR BASIN 19
2.6 SALT RANGE & KOHAT-POTWAR FOLD BELT 24
STRATIGRAPHY OF THE AREA 25
I. Basement complex *26*
II. Salt range formation *26*
III. Platform section *26*
IV. Molassic section *26*
CHINGI FORMATION 26
KAMLIAL FORMATION 26
MUREE FORMATION 27
2.8 EOCENE SUCCESSION 27
CHORGALI FORMATION 27
SAKESAR LIMESTONE 27
NAMMAL FORMATION 28
2.9 PALEOCENE SUCCESSION 28
PATALA FORMATION *28*
LOCKHART LIMESTONE *29*
HANGU FORMATION (DHAK PASS BEDS) 29
EARLY PERMIAN SUCCESSION 29
Amb formation *29*
Sardahi formation *29*
Warcha sandstone *29*
Dandot formation *30*
Tobra formation *30*
2.10.2 CAMBRIAN SUCCESSION 30
3.1 NTRODUCTION TO SEISMIC METHODS: 36
3.2 TYPE OF SEISMIC METHODS: 36
3.2.2 REFRACTION METHOD: 37
3.4 BASIC LAWS SEISMIC WAVES: 42
3.5 LAWS GOVERNING SEISMIC WAVES: 45
1) Huygens's Principal *45*
2) Fermat's Principal *46*
3) Snell's Law *46*
3.6 REFLECTION- AND TRANSMISSION-COEFFICIENTS 46
Reflection and transmission in terms of energy *47*
Reflection coefficient in terms of energy *47*
Transmission coefficient in terms of energy *47*
Fig3.7Angle dependent reflection and transmission coefficients for P and S-waves *48*

3.7 Wave Conversion *48*
3.9.1 Acquisition Setup *50*
3.9.1.1 The Spread Configuration *51*
(1) Symmetric shooting .... ***Error! Bookmark not defined.***
(2) Asymmetric shooting .... ***Error! Bookmark not defined.***
(3) End shooting .... ***Error! Bookmark not defined.***
(4) Roll- in shooting .... ***Error! Bookmark not defined.***
3.9.1.5 Selection of Shooting & Recording Parameters *53*
3.9.3 Detection and Recording *54*
3.10.1 PRIMARY STAGES OF SEISMIC DATA PROCESSING 56
3.10.2 PROCESSING SEQUENCE 57
1) Data Reduction *57*
a) Demultiplexing *57*
b) Correlation *58*
3.11.1 DEPENDENCE OF SEISMIC VELOCITIES UPON THE PHYSICAL PROPERTIES OF THE ROCK 68
I) POROSITY 68
II) AGE OF ROCKS 68
III) TEMPERATURE 68
IV) NATURE OF INTERSTITIAL FLUIDS 68
V) SHALE CONTENT AND SAND CONTENT 68
VI) DOLOMITIZATION 68
VII) LIME CONTENT 68
3.11.2 P-WAVE VELOCITIES OF DIFFERENT ROCKS 68
3.11.3 VELOCITY ANALYSIS 69
3.11.4 DIX FORMULA 69
3.11.5.2 INTERVAL VELOCITY 69
3.11.5.3 INSTANTANEOUS VELOCITY 69
3.11.5.4 ROOT-MEAN-SQUARE VELOCITY 69
3.11.6.1 POROSITY 70

CHAPTER 4

INTERPRETATION 72
METHOD FOR INTERPRETATION OF SEISMIC DATA: 72
Structural Analysis: *72*
Stratigraphic Analysis: *73*
STUDTY OF LINE 93-MN-09 MINWAL JOYA MIR *74*
SEISMIC SECTION 75
Seismic Time Section *76*
AVERAGE VELOCITY GRAPH *79*
MEAN VELOCITY GRAPH *82*
ISO VELOCITY SECTION *84*
SEISMIC DEPTH SECTION *85*
ROCK PHYSICS 87
Study of Rock Physics Properties: *87*
REFLECTION COEFFICIENT 98
CONCLUSION: 104
REFRENCES: 105

CHAPTER 1

INTRODUCTION TO THE LINE

INTRODUCTION TO DISSERTATION:

The given Project is to interpret the Seismic Section along the seismic line 93-MN-09.The Department of Earth Sciences provided the pre-stacked time migrated seismic section of MINWAL JOYAMAIR area. This dissertation is based on the interpretation of a seismic time section. A fully processed filtered migrated along the line 93-MN-09 is provided for analysis and interpretation.

Seismic section ranges from VIBROSIES POINTS 101-274. The survey was conducted by PAKISTAN OILFIELDS LIMITED(P.O.L) in the Minwal Joyamair area in JANUARY 1994. The acquisition and processing of the data has been done carefully with the selection of appropriate field and processing parameters, which are given as under:

SEISMIC LINE: 93-MN-09
VIBROSIES POINT's: 101-274
DATUM: 400 m
VR: 2100 m/s

Basically, sequence comprises:

- **Data Recording**
- **Processing Sequence**
- **Display Paramters**

Data Recording:

Recording parameters are designed and selected keeping in mind the following objectives:

- Geological objectives for delineation of sub surface structures.
- Seismological conditions of the area where seismic operations are to be carried out.

↯ Recording Parameter:

Recorded By:	**CGG**
Date:	January 1994
Record Length	5.0 SEC
Field Filters	Low: 8 HZ 18 DB/OCT
	High: 177.6 HZ 72 DB/OCT
Group Interval	40 M
Geophone Type	N/A
Geophones /Group	36
Array Length	40 M
Source:	Vibroseis
Sweeps /V.P	12 AT 3.5 M
Sweep Frequency	9-72 Hz
Array Length	52.5 M
Party Number	213 34 42
Instruments	SN 368-LXU
Sample Rate	2 MSEC
Notch	Out
No. Of Channels	240
Geophone Frequency	10 HZ
Array Type	Inline
Source Interval	80 M
Sweep Length	14 SEC

Spread Diagram:

Channel:	1	120	V.P 121	240
Offset:	-4900 M	-140 M	140 M	4900 M

Data Processing:

After the data has been acquired, it passes through the whole processing sequence that includes different data processing techniques that are used to enhance the quality of the data.

This data has passed through a desirable processing sequence and finally a "Time Section" was prepared. The time section gives the position of different reflectors in terms of two way reflection times; therefore first we have to convert it in to depth section to get the true picture of subsurface. Later on time section was converted in to depth section by estimation velocities so the processing sequence is given below.

Processing Parameters:

1. Demultiplex And Gain Recovery
2. Geometry Description And Application
3. Trace Edits
4. Spherical Divergence And Inelastic Attenuation Compensation
5. Refraction Statics Application(Relative)

   Relative Datum : Smoothed Surface Elevations

   Replacement Velocity : 2100 M/SEC
6. Convert To Minimum Phase
7. F-K Noise Reject Filter
8. Deconvolution-Surface Consistent

   Operator Type : Spiking

   Operater Length : 260 msec

   Added White Noise : 1.0%
9. Common Mid Point Sort
10. Velocity Analysis

    Type: CVS Discrete Panels

    Spacing: 1/Kilometers
11. Surface Consistent Residual Statics
12. Velocity Analysis

    Type: CVS Discrete Panels

    Spacing: 1/Kilometers
13. Surface Consistent Residual Statics

14. Time Variant Scaling

500 MSEC

15. Space Variant First Break Suppression Mute

16. Refraction Statics Application(Mean)

Final Datum: 400 M

Replacement Velocity: 2100 M/SEC

17. Pre stack Time Migration And Velocity Analysis

Offset 0-4000 M

18. Paint (Variable Velocity Prestack Migration Reconstruction)

19. Bandpass Filter-Butterworth(Time Variant)

Frequency/Slope	Time (msec)
12/18-60/72	0-500
12/18-50/72	1000-1500
10/18-35/72	2000-2500
8/18-35/72	3000-5000

20. Time Variant Scaling (Square Root)

1000 MSEC. Windows

DISPLAY PARAMETERS:

Wed Mar	8 10 : 18: 49 1995
Traces/Inches	16
Gain Set:	0.55
Gain Constant	699.947
Bias:	0 %
Polarity:	Normal
Static Shift	0
Inches/Second	5
Clip Limit	4
RMS Amplitude	1.42868

Objectives of DISSERTATION:

The major objectives of this dissertation are:

1. To understand the processing and interpretation procedure for structural interpretation of the migrated seismic section to obtain a reliable picture of the subsurface.
2. To calculate the average velocity from Dix average velocity formula using the interval velocity and RMS velocity.
3. To determine the average velocities at certain constant interval of time from each CDP data (the average velocities).
4. To determine the mean of all average velocities determined for each constant frame of time.
5. To Prepare The Mean Average Velocity Graph, Iso Velocity Graph, Average Velocity Graph

   To prepare time section to analyze the structure.

CHAPTER 2

GEOLOGY OF THE AREA

MINWAL JOYAMAIR

CHAPTER 2

GEOLOGY AND STRATIGRAPHY OF THE MINWAL, JOYAMAIR AREA

2.1 Introduction

The information about geology of an area plays very important role for a precise interpretation of seismic data, because same velocity effects can be generated from formations of different lithologies. Also different velocity effects can be generated from same lithological horizons. Therefore as long as we don't know about geological formations in the area we cannot recognize different reflectors appearing in the seismic section.

The information about location of faults, their penetration in subsurface and the presence of unconformities between rocks of different ages is also very important from interpretation point of view

2.2 Tectonic zones of Pakistan

On the basis of plate tectonics, geological structures, orogenic history Pakistan is divided into following broad tectonic zones (Figure 2.1).

1. Indus Platform and foredeep.
2. East Balochistan fold-and thrust belt.
3. NW-Himalayan fold and thrust belt.
4. Kohistan-Ladakh magmatic arc.
5. Karakoram block.
6. Kakar khorasan flysch basin and Makaran acceretionery zone.
7. Chagai magmatic arc.
8. Pakistan offshore.

Tectonic Map of Pakistan

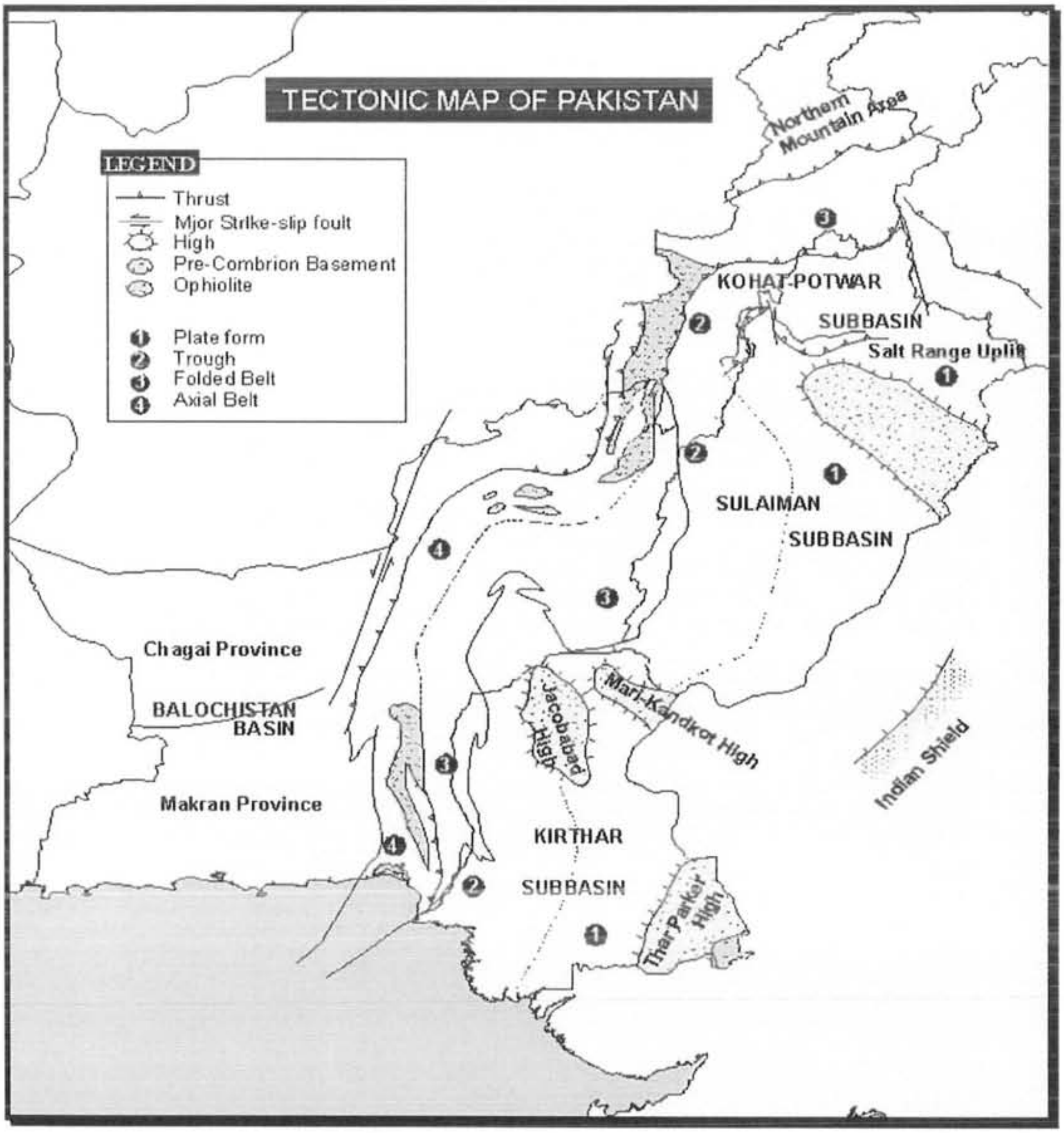


Figure 2.1, showing tectonic zones of Pakistan. (Kazmi,A.H, 1997)

2.3 Sedimentary Basins of Pakistan

Sedimentary basins of Pakistan includes:

Indus Basin.

Indus Basin is further divided in to following parts:

- Upper Indus Basin.
- Middle Indus Basin.
- Lower Indus Basin.

2. Baluchistan Basin.
3. Kakar Khorasan Basin (Qadri, 1995).
4. Pishin Basin.

Basin Architecture of Pakistan

Figure 2.2, Showing Basin Architecture of Pakistan,(www.thefreedictionary.com)

2.4 Indus Basin:

The Indus basin belongs to a class of extra continental trough downwarp basin. it is the largest and so far the only producing sedimentary basin of pakistan. The basin is oriented in NE-SW direction. Basement is exposed at two places, one in NE (Sargodha high) and second in SE corner (Nagar parkar high). It is characterized by large easterly platform region that dip gently and monoclinally toward NW (a ring of trough in which platform dips) and a westerly folded and thrusted topographically uplifted region.

The convergence between Indian and Eurasian plate has resulted in partitioning of the basin into three parts, upper, middle, lower called as northern, central and southern respectively. Some basement highs present over platform area serves as dividers. (Riaz Ahmed, 1998)

2.4.1 Northern Indus Basin:

This basin is characterized by complex structural styles and Stratigraphic sequence ranging from PreCambrian to Recent. A number of oil fields occur in this zone. The Dhurnal oil field is the largest and has reserves of about 52 million Barrel of oil and 0.13 TCF of gas. This basin contains all the source, reservoir and cap rocks. (Kazmi and Jan, 1997)

2.4.2 Central Indus Basin:

This basin is comprised of duplex stucture characterized by large anticlines and domes in the passive roof sequense of sulaiman fold belt followed eastward by gently dipping strata of Punjab monocline. The basin contains a sedementary sequence ranging from precambrian to recent. It contains one of the biggest gas field called Sui gas field with 8.6 TCF. Central Indus basin is bounded by Jacobabad high in south, Sargodha high in north, sulaiman foredeep in west and Indian shield in east. (Kazmi and Jan, 1997)

2.4.3 Southern Indus Basin:

As already mentioned the study area, Southern Indus Basin is located just south of Sukkur Rift, a divide between Central and Southern Indus basins. Based on the variation in the deformational style and various post depositional processes the basin can be subdivided into the following main units:

Thar Platform

Karachi Trough

Kirthar Foredeep

Kirthar Fold Belt

Offshore Indus

Potwar Basin:-

Potwar sub-basin is located at the northern margin of the Indian Plate and is characterized by thick Infra-Cambrian evaporites, relatively thin stratigraphic section from Cambrian to Eocene time and thick Miocene-Pliocene molasse deposits with extremely severe deformation during Himalayan orogeny in Pliocene to Middle Pleistocene. To develop understanding of various structural features, fault types, decollement levels and influence of tectonics, various transects have been developed in a grid fashion, and a regional time structure map at base Miocene level has been generated, which is also more or less conformable for deeper horizons.

The Potwar sub-basin is structurally very complex and in some cases surface geological features do not reflect the subsurface structures. At least two decollement levels are identified on seismic, within Neogene molasses and in the Pre-Cambrian Salt Range Formation, causing offset and variation in structural manifestation between different levels above and below decollement. Beneath the Potwar sub-basin lies a low angle thrust within Salt Range Formation, that has carried the entire sedimentary section southward. The structures were formed as a result of fault propagation and salt movement activated by southward thrusting of sedimentary wedge. The

structural style in the central, western and the eastern parts of the Salt Range / Potwar Plateau exhibit conspicuous difference, which are attributable to the amount of salt, detachment levels and faults and flexures in the basement. Subsurface picture of the Potwar subbasin

demonstrates that structures are regionally bounded by foreland verging thrust faults, which are trending northeast–southwest in its eastern part while in the north-western part their orientation is almost east west.

The Potwar fold region is a prolific area with multiple structural leads. Attempt has been made to relate hydrocarbon entrapment in various areas of Potwar sub-basin with distinctive structural domain, which defines orientation, styles and geographic distribution of structures and migration from the source rock to reservoir via fault plane. For the carbonate reservoirs, there exists a relationship between the occurrence of fractures with the proximity to faults and flexures, which in turn may

be related with release or absorption of stresses by neighbouring major fault systems. Authors have also tried to identify sub-thrust play fairway in different parts of the Potwar sub-basin. There are leads of popup, "snake-headed" and salt-cored anticlines, along with leads in imbricate and triangle zones in different parts of this sub-basin.

2.5.1 REGIONAL DEPOSITIONAL HISTORY OF POTWAR BASIN

The Potwar Basin is characterized by thick Infra-Cambrian evaporite deposits overlain by relatively thin stratigraphic section of the Eocene to Cambrian. Thick Miocene-Pliocene molasse deposits are related to severe deformation in Late Pliocene to Middle Pleistocene

(Himalayan orogeny). The generalized stratigraphy of the Potwar is shown in Figure-2.3. All of these formations are exposed in the Salt Range from east to west. The depositional sequence in the Potwar sub-basin may be summarized as follows:

(1) Deposition of Infra-Cambrian evaporite sequence upon the Pre-Cambrian basement took place in an intra-cratonic setting in a basin that extended from Pakistan to Turkey through Iran and Oman.

(2) The Infra-Cambrian evaporite sequence are overlain by Cambrian rocks termed as the Jhelum Group which comprises Khewra Sandstone,

Kussak, Jutana and Bhaganwala Formations.

(3) Deposition of the Jhelum Group was followed by a period of limited deposition from Middle Cambrian to Early Permian. Therefore, the strata belonging to these periods are missing in Potwar sub-basin.

(4). The early Permian formations, termed as the Nilawahan Group are restricted to the eastern part of Potwar / Salt Range and is predominantly of continental origin. This group includes Tobra Formation deposited in predominantly glacial environments, olive green sandstones and claystones of Dandot, red sandstone of Warcha

And lavender claystone of Sardhai Formations.

(5). The Zaluch Group restricted to the western and northern/central part of Potwar / Salt Range includes marine limestones and claystones of the Amb, the Wargal and the Chhidru Formations which were deposited during the Late Permian.

(6). The Triassic formations include Mianwali, Tredian and the Kingriali Formations. The former two formations were deposited in deep to shallow marine environment, whereas the latter is composed of shallow water dolomite.

(7). The Jurassic formations are divided into Datta Sandstone, Shinawari (limestone and shale sequence) and the Samana Suk (Limestone) Formations.

(8). The Cretaceous sequence is represented by the clastics of Chichali and Lumshiwal and the carbonates / clays of Kawagarh Formations, later beingrestricted to the northern Kohat Basin, while former present in western SR/PP and Kohat Basin

(9). Mesozoic sediments are present only in the western part of the Potwar/Salt Range, as the Base Tertiary unconformity progressively oversteps Jurassic, Triassic and Permian formations to the east. In the eastern-most Salt Range this sequence directly overlies Cambrian.

(10). Shallow marine foraminiferal limestones and dark grey shale with large foraminifera were deposited during the Paleocene and Eocene time. A laterite bed marks base of this succession. The Paleocene formations include shales, siltstones and sandstones of Hangu, limestone of the Lokhart and shale and limestone of the Patala formations.

(11). Deposition of calcareous claystone of the Nammal Formation marking the beginning of Lower Eocene was followed by massive shelfal limestones of the Sakesar Formation which is overlain by dolomitic limestones and calcareous claystones of the Chorgali Formation.

(12). Continental collision in the Middle Eocene resulted in uplift of the Sargodha High, which ended marine deposition in the area and started erosion to the south.

(13). Oligocene age sediments are missing in the Potwar Basin, as during this time the Higher Himalayas were building for the subsequent

molasse sedimentation.

(14). The foreland sedimentation in the Potwar Basin commenced in Early Miocene, which is represented by fluvial and fluvio-deltaic lithology of Rawalpindi and Siwalik Groups including Murree, Kamlial, Chingi, Nagri, Dhok Pathan and Soan formations. The thickness of the Molasse sequence generally increases towards North.

The studied area is a part of the Potwar plateau where the topography is undulating and char-acterized by a series of parallel ridges and valleys. Generally they trend in E-W direction. Geo-logically it forms part of the foreland zone of the NW Himalayan fold and thrust belt. This fore-land zone, comprising of Salt range, Potwar plateau/Kohat plateau and Hazara ranges, is an area bounded by the Salt range thrust in the south and the Panjal-Khairabad fault in the north (Figure 2.5). At its eastern end is the nearly N-S running left lateral Jhelum fault (Kazmi, Jan, 1997).

In this zone of convergence, intense de-formation has resulted in the formation of complex structures. The northern part of Pot-war plateau, also referred to as the northern Potwar deformed zone (NPDZ), lies between the main boundary thrust and the Soan syn-cline (Figure 2.4). It is more intensely de-formed than the southern Potwar and the Salt range. Mostly E-W trending tight and com-plex folds are seen with their southern limbs overturned with steep angle faults.

The area contains a series of thrusts. Lil-lie, et al (1987) described the northern Potwar as an imbricate stack of thrust faults with some being on the surface and the others oc-curring at depths as blind thrusts. General trend of these thrusts changes from E-W to NE-SW direction in the eastern part of the NPDZ. Some of these thrusts are shown in Figure 2.4. A number of researchers have described these faults (Lillie, et al, 1987; Jadoon, et al, 1995; Jaswal, et al, 1997).

The studied area is a part of the Potwar plateau where the topography is undulating and char-acterized by a series of parallel ridges and valleys. Generally they trend in E-W direction. Geo-logically it forms part of the foreland zone of the NW Himalayan fold and thrust belt. This fore-land zone, comprising of Salt range, Potwar plateau/Kohat plateau and Hazara ranges, is an area bounded by the Salt range thrust in the south and the Panjal-Khairabad fault in the north (Figure 3). At its eastern end is the nearly N-S running left lateral Jhelum fault (Kazmi, Jan, 1997).

In this zone of convergence, intense de-formation has resulted in the formation of complex structures. The northern part of Pot-war plateau, also referred to as the northern Potwar deformed zone (NPDZ), lies between the main boundary thrust and the Soan syn-cline (Figure 2.4). It is more intensely de-formed than the southern Potwar and the Salt range. Mostly E-W trending tight and com-plex folds are seen with their southern limbs overturned with steep angle faults.

The area contains a series of thrusts. Lil-lie, et al (1987) described the northern Potwar as an imbricate stack of thrust faults with some being on the surface and the others oc-curring at depths as blind thrusts. General trend of these thrusts changes from E-W to NE-SW direction in the eastern part of the NPDZ. Some of these thrusts are shown in Figure 2.4. A number of researchers have described these faults (Lillie, et al, 1987; Jadoon, et al, 1995; Jaswal, et al, 1997).

Important structures, which are considered to have played significant role in the development of the tectonic style that appears in the northern Potwar and described by various researchers, from south to north are the Soan Syncline, Soan (Dhurnal) back thrust and the Khair-i-Murat imbricate zone.

Soan syncline is the major structural feature of Potwar. Its southern limb is less steep than the northern limb.

According to Johnson, et al (1986) the de-velopment of the southern limb took place due to thrusting along the Riwat thrust. This NE-SW thrust lies about 20 km south of Rawalpindi. Jadoon, et al (1995) believed that cessation of move-ment along the Riwat thrust stopped at about 2.7 Ma BP.

Soan (Dhurnal) backthrust is a distinctive feature of the eastern northern Potwar deformed zone. It is on the northern limb of the Soan syncline immediately south of Rawalpindi (Figure 2.4). The dip of the back thrust is nearly vertical in contrast to being nearly horizontal along axis of the Soan syncline. The top of Kamlial formation marks its location. To the north of the back thrust till the high angle Mianwala fault, highly deformed Murree formation rocks with steep to vertical dips appear, where, as further north till the Khair-i-Murat fault, steeply dipping Siwalik group litholo-gies are representative.

Khair-i-Murat and Golra imbricate zone is an area between the Soan syncline and the main boundary thrust (MBT). The Khair-i-Murat thrust named after the range of this name lies to the southwest of Rawalpindi. It is about 22 km long and 2 km wide. Golra is a name of village, now part of Islamabad. Eocene rocks are exposed along these two thrusts and have moderate to vertical dips. Overturning also exists. In the Khair-i-Murat range, the moderatly to steeply dipping Murree formation with small bedding parallel slip and related splay is imbricated. Golra fault merges eastwards in the MBT. This and other minor faults like the Shah Allah Ditta fault that lies north of the Golra fault, are probably splaying branches of the MBT. The MBT itself is represented by many high angle thrusts along which Eocene and older rocks have been thrusted over the molasses of the NPDZ.

According to Pennock, et al (1989) the basement along the Soan syncline is at a depth of about 6 km. It increases towards north and is at about 8 km near the MBT (Jaswal, et al, 1997). Most researchers consider the NPDZ to be a thin-skinned tectonic feature, in which the basal de-collement is in the Eocambrian Salt range formation. In this interpretation the Dhurnal fault is a passive back thrust and the area bounded by it and the Khair-i-Murat fault (Figure 2.4) is a triangle zone of complex geology (Jadoon, et al, 1999).

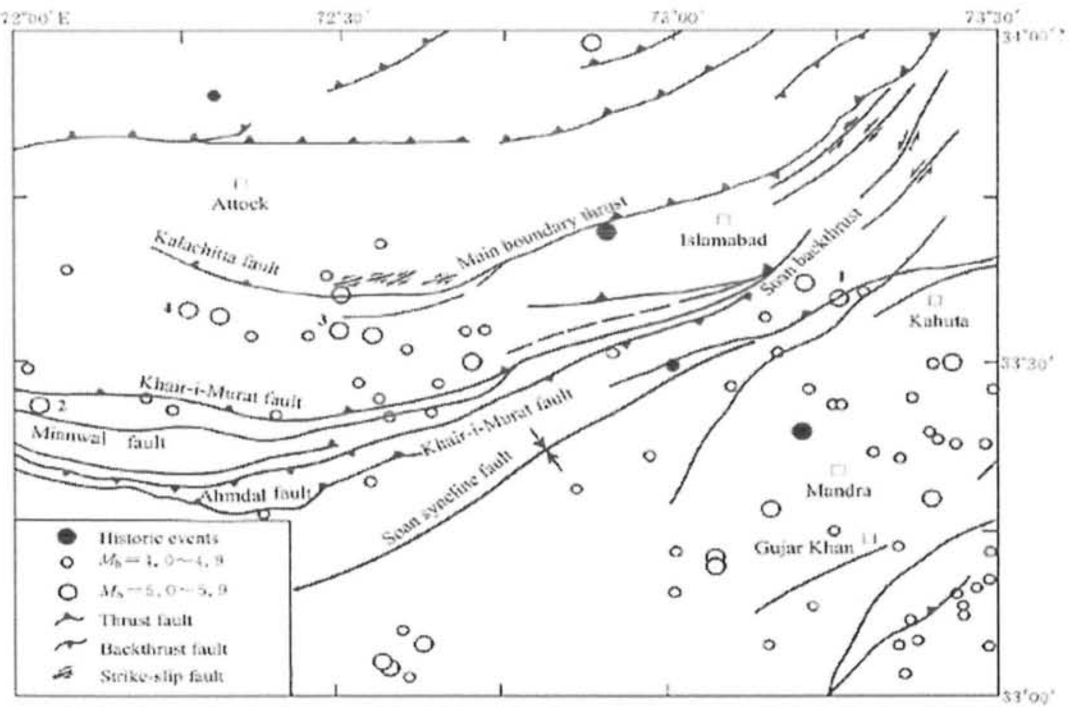


Fig 2.4 Map pf Seismicity and structures of Potwar Basin. The locations of events whose focal mechanism solutions have been determined are number 1-4 (Jadoon, et al, 1999).

The models invoking duplex structure have recently been questioned (Pivnik, Sercombe, 1993; Sercombe, et al, 1998). These researchers recognize the presence of strike-slip faults on the surface and even in the basement. They relate the structures (high angle strike-slip faults and associated flower structures) to transpressional deformation

Figure 2.5 Regional map showing major tectonic divisions of Pakistan KM denotes Kashmir (Mona Lisa.et, al., 2004)

2.6 Salt Range & Kohat-Potwar Fold Belt

This east-west trending fold belt comprises the low rolling hills and valleys of the uplifted Kohat-Potwar Plateau, the Salt Range and its west ward extensions. It is about 85 km wide and extends for about 200km; it is a discreet structural zone bounded in the north by the north dipping MBT. Southward the Salt Range Thrust, Kalabagh Fault and the Surghar Thrust from its southern boundary, west and east ward it is terminated by the north-south oriented Kurram Thrust and Jhelum Fault respectively.

(Kazmi & Jan, 1997)

The area of study (Potwar) is bounded by numerous faults, of which main deformational faults are;

Jhelum Fault

Kazmi (1977) pointed out that the fault along the western margin of axial zone of syntaxis was a left-lateral strike-slip fault and he named it the Jhelum Fault. The Jhelum Fault apparently dislocates the MBT (Main Boundary Thrust) and terminates the eastward continuation of some of the structures of NW Himalayan fold-and-thrust belt which shows that it is the youngest major tectonic feature in syntaxial zone.

A number of east-west trending faults join the Jhelum fault at an acute angle pointed northward, indicating a relative left left-lateral strike-slip movement. (Kazmi & Jan, 1997)

Kalabagh Fault

This part forms the western margin of the Salt Range and extends NNW from near Mianwali for a distance of 120 km. It has been described as an active dextral wrench fault associated with several recoded earthquake epicenters.

Southward the Kalabagh fault apparently displaces the Salt Range thrust. Near its southern end (north of Khairabad), the Kalabagh fault splays out and form two additional sub-parallel faults, the Dinghot and Ainwan Faults. Near its northern end, the Kalabagh fault bends westward and branches out into a number of smaller, north dipping thrust faults. (Kazmi & Jan, 1997)

Salt Range Thrust

This thrust fault runs along the southern margin of the Salt Range between the Jhelum and Indus River and it has pushed the older rocks of the Salt Range upon the less deformed Tertiary sequence of the south lying Jhelum Plain, the thrust zone is largly covered by recent fanglomerates. However at the places (i.e near Jalalpur and Kalabagh), the thrust is exposed and shows the Paleozoic rocks overlying the Neogene or Quaternary deposits of the Jhelum Plain.

(Kazmi & Jan, 1997)

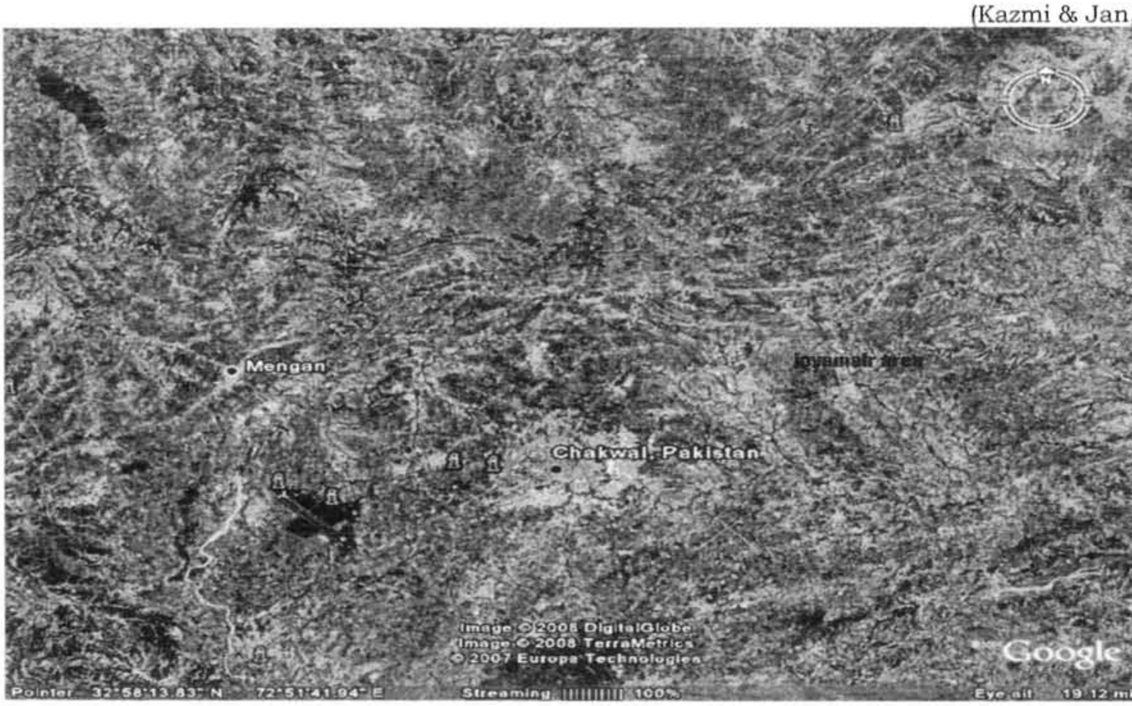


FIG2 .3a:SATELLITE IMAGE SHOWING POSITION OF JOYAMAIR
(image source:www.earth.google.com)

STRATIGRAPHY OF THE AREA

- Chinji formation
- Kamlial formation
- Murree formation
- Chorgali formation
- Sakesar limestone
- Patala formation
- Lockhart Limestone
- Sardhai limestone
- Warcha limestone
- Dandot Formation
- Tobra Formation
- Kussak Formation
- Khewra Sandstone
- Salt-Range Formation

2.7 STRATIGRAPHY OF THE AREA.

Sedimentation in the Potwar Basin started in late Precambrian and lasted until the Pleistocene. The deposition was however interrupted several times, with the two major breaks, between the Cambrian and Precambrian and between Eocene and Miocene.

From bottom to top, the stratigraphic section can be divided into four groups.

I. Basement complex

II. Salt range formation

III. Platform section

IV. Molassic section

The basement complex is of Precambrian age and consists of metamorphic and volcanic rocks of Indian shield. The Eocambrian salt range formation is evaporates and sedimentary until that forms the level of decollement for the fold and thrust belt. The platform section consists of Cambrian to Eocene shallow water sediments. The Molassic section consists of terrigenous fluvitile sediments. Various cycles of subsidence and uplift, caused by non-organic movements, affected the Pre-Eocene deposition, where as orogenic movements (Himalayan Uplifts) affected Post-Eocene fluvial sedimentation.

CHINGI FORMATION

Lewis (1937) proposed the name Chingi formation and the same was accepted as such by the stratigraphic committee of Pakistan. The section south of Chingi village in the Attock district has been designated as a type locality.

Broadly the formation is divided into two divisions, the lower predominantly is red claystone sequence while the upper predominantly is subordinate ash gray or brownish sandstone. The red claystone of the typical Chingi formation are brighter than those of the Kamlial, this formation shows fluvial environment of deposition (Jaswal et.al 1997).

KAMLIAL FORMATION

The stratigraphic committee of Pakistan has formally established the name Kamlial bed. The term "Kamlial formation" was established by the Pinfold (1918) the section southwest of the Kamlial village has been designed as the type locality.

In Meyal the formation consists of purple gray and dark brick-red sandstone, which is medium to coarse grained and contains interbeds of hard purple intraformation conglomerates. Due to faulting, its base on muree formation is not exposed. The formation in the subsurface exhibit more or less the same characteristics as are observed at the outcrops. Most wells are drilled in the partly eroded Nagri formation penetrates the complete sequence of Chingi and Kamlial formations.

MUREE FORMATION

The stratigraphic committee of Pakistan has formally named the Muree series of pilgrim (1910) as Muree formation (S.M.Ibrahim, 1977). A section exposed on the north of the Dhok Maike in the Attock district has been designated as the type locality.

This formation composed of repetitive sequence of dark red, purple clay and greenish gray sandstone with subordinate intraformational conglomerate. The main body of the formation is poorly fossiliferous.

2.8 EOCENE SUCCESSION

CHORGALI FORMATION

The term "Chorgali beds" by Pascoe (1920) has formally been designated as Chorgli formation by the stratigraphic committee of Pakistan (S.M.Ibrahim, 1977).

The section exposed in Chorgali pass on the Khair-e-Murat Range has been chosen as the type locality.

The top of this formation consists of turquoise colored marls and light bluish green shales underlain by the gray, argillaceous and fractured limestone with thin, black splintery occasional bituminous shale partings. The limestone contains veins, inclusions and nodules of white to pink anhydride. The basal part consists of grey, highly fractured dolomitic limestone with veins and irregular thin layer of gray to black shale showing bituminous luster. This formation in Meyal is about 73 meters thick and its lower boundary with Sakesar lime stone is not only conformable but also lithologically arbitrary and based upon microfossil evidence (G.R.Gardazi, 1983-83).

SAKESAR LIMESTONE

The term Sakesar limestone was introduced by Gee (1935) for the most prominent Eocene limestone unit in the Salt and Trans Indus Ranges. The Sakesar peak in the Salt range has been designated as the type locality.

The formation is dominantly composed of limestone with subordinate marl generally the formation consists of gray to dark gray, argillaceous, to moderate dolomite, massive to occasionally nodular, at some places highly fossiliferous, fractured limestone. The black occasionally bituminous carbonaceous and at some places highly fossiliferous shale partings are present in the sequence. Calcite and anhydrite veins are quite common and some open fractures are lined with calcite crystallization.

Sakesar limestone in Meyal field thickness south-westwards and varies from 86-106 meters.

NAMMAL FORMATION

The term Nammal Formation has been formally accepted by the stratigraphic committee of Pakistan for the Nammal limestone and shale of Gee (in Fermor, 1935), Nammal marl of Danilchik and shah (1967) occurring in the salt and Trans Indus ranges.

The section exposed in the Nammal gorge is the type locality. This section is fossiliferous and contains pelagic planktons including Globorotalia and Globogerinas (Haque 1956). The lower part of the formation predominately consists of gray to dark gray, very argillaceous, pyrite, fossiliferous limestone and marls with thin bands of greenish gray, splintery shales. The Nammal formation is about 33 meters thick in Meyal and conformably overlies the upper Ranikot formation of Paleocene age.

2.9 PALEOCENE SUCCESSION

the Paleocene succession in Meyal oil field consists of the following four formations.

- Patala Formation
- Lockhart Limestone (khairabad limestone)
- Hangu Formation (Dhak Pass Beds)

PATALA FORMATION

The stratigraphic committee of Pakistan formalized the term Patala formation for the Patala shale of Davies and Pinfold in 1935. (S.M Ibrahim 1945)

The section exposed in Patala Nala in the Salt range has been designated as type locality. The Patala formation is predominantly shale facies and its lithological characters are similar to the shales occurring in the basal part of upper Ranikot formation. Therefore the fixation of its upper boundary has always been difficult. Generally it consists of dark gray to black fissile and splintery shales with this and occasionally bands of marly limestone. Its thickness varies from 15-19 meters and lies conformably over the Lockhart lime stone. It shows shallow marine lagoonal environment of deposition.

LOCKHART LIMESTONE

Daves (1930) introduce the term Lockhart Limestone for a Paleocene Limestone unit in the Kohat area and the stratigraphic committee of Pakistan has extended this usage. The section exposed near Fort Lockhart in the Samana Range has been designated as type locality of the unit. The Lockhart limestone is mainly gray to dark gray, occasionally brownish gray, hard compact and highly fossiliferous limestone with thin bends of ash gray marls. The limestone is also occasionally dolomitic and shows nodular structure. In its basal part, the Lockhart limestone becomes marly and it is interlayered with dark to black splintery shale. It shows shallow marine environment of deposition.

HANGU FORMATION (DHAK PASS BEDS)

The Hangu shale and Hangu sandstone of Daves (1930) from the Kohat area have been formalized by the stratigraphic committee of Pakistan as Hangu formation. This was earlier called Dhak Pass Beds.

Early Permian succession

Amb formation

Teichert sugetsed the name Amb formation which was later formalized by Stratigraphic commite of Pakistan.the name has been derived from Amb village in the central salt range.

The formation is composed of sandstone limestone and shale.the sandstone is brownish grey and medium bedded.and also have some limestone beds are present.

It has confirmable contact with Wargal limestone and is placed above plant bed.

Sardahi formation

The formation is given name by Startigraphic Commite of Pakistan after the Noetling upper Waarcha Group.and type section is Sardhai gorge in eastern salt range.

The formation is compsed of bluish and greenish gray clay and some sand siltstone beds,with some carbonaceous shales.

It has lower contact conformable with Warcha sandstone and upper contact confirmable with Amb formation.

Warcha sandstone

The formation is mainly distributed in the Saltrange and Khisor ranges.and thickness of the formation is 70-165 meters.

The lower contact with Dandot is conformable and upper contact with Sardhai formation is transitional.

The formation is mainly composed of redish brownish sandstone and is medium to tchik bedded and fine to coarse grained and dark brown shales.and it also conatains carbonaceous shales with irruegular coal seams also found

Dandot formation

The formation is well exposed in Eastern salt range and thins out westward.its absent in western salt range and Khisor ranges.its maximum thickness in eastern salt range is 50 m and towards west it is 10-15m.
The upper and lower contact with Warcha sandstone and Tobra Foramtion are conformable.
The formation is mainly composed of silt stone ,sand stone and clays.

Tobra formation

The formation is lowest in the Nilwahan group and widely spread in Potwar and surface exposures are from eastern salt range to Khisor ranges.

The lower contact of the formation with Baghanwala formation and is unconformable. And upper contact with Dandot Formation is conformable.

The formation thickness is 140 m in western salt range and 30m in eastern salt range.

The formation mainly composed of boulders , cobbles , pebbles and gravels of acid igneous rocks in a silty , sandy, argelliceous matrix.and shales are greenish in colour.

2.10.2 Cambrian Succession

Baghanwala formation

Pascoe (1959) named the formation as Baghanwala stage and its given name as Baghanwala formation by stratigraphiic comite of Pakistan.

The formation is composed of red shale and flaggy sandstone and it exhibits various colours especially is lower part of the formation.Mudcracks and ripples are observed in the formation.

The presence of casts of salt pseudomorphs coupled with absence of fossils indicate lagoonal environment and arid climatic conditions for the deposition of the formation.

The upper contact with Tobra formation is unconformable and lower contact with Jutana formation is conformable.

Jutana formation

Noetling described the formation as Jutana stage.and its type locality is in eastern salt range.

The formation is compoed of sandy dolomite and upper part is composed of light green and hard massive partly sandy dolomite and upper part is composed o light green to dirty white massive dolomite.

The formation has 80m thick at its type locality and it has upper &lower contact confirmable with Kussak formaton and Baghanwala formation.

Kussak Formation

Noetling (1894) proposed the name Kussak group and finally stratigraphic committee of Pakistan proposed Kussak Formation.

The formation is composed glauconitic, micaceous , sandstone and siltstone and dolomite, oolitic arenaceous dolomite.pink gypsum lenses are present in the formation.

The thcknes is 70m at its typre locality, and it has upper and lower contact both conformable.

Khewra sandstone

Noetling (1894) named the formation as Khewra group and later its formalized as Khewra sandstone by Stratigraphic committee of Pakistan.

The formation is composed of mainly fine grained sandstone and lower portion is shale.where as sandstone is massive.

Sedimentary features like ripple marks, mudcrakcs are common in the formation.the lower contact with salt range is uncertain and overlying Kussak formation is confirmable.

2.10.3 Infra-Cambrian

Salt range formation :-

Exposure and Extension

The formation is exposed along the periphery of the salt range from the Kalabagh in the west to eastern salt range and in subsurface formation is encountered in subsurface in potwar(Dhulian,Joyamir) but further in south its occurance is not sure as there lies thick deposits of sedimentary cover overlie it.

Asrarullah (1967) gave the name as Salt Rnage formation and eastern salt range is its type locality.the formation has lower part composed of gypserous marl and salt seams and also oil shales in upper part of formation are also found..

There are 3 members of the formation :-

Sahwal marl member

Its bright red marl and dull red marl beds with some salt seams.

Bhandar Kas gypsum :-

Massive gypsum with minor beds dolomite and clay.

Billianwala salt member :-

Ferrigenous red marl with thck seam of salt (650 m)thick.

The upper contact with overlying Khwera sandstone is conformably placed.

AGE	FORMATION		SYMB.		VEL.	DESCRIPTION	THICKNESS	OIL
PLEISTOCENE	POTWAR SILT							
PLEISTOCENE	Siwalik Group	SOAN	Qs	QTs	3000 m/sec	conglom. & ss and varicolored claystone (Lei Conglomerate)	1800+ m	
PLIOCENE	Siwalik Group	DHOK PATHAN	Tdp	QTs	3000 m/sec	orange to red clay-stone and gray ss	1000 m	
PLIOCENE	Siwalik Group	NAGRI	Tn	QTs	3000 m/sec	green-gray, cross-bedded ss & subordinate red to brown clay	1000 m	
PLIOCENE	Siwalik Group	CHINJI	Tc	QTs	3000 m/sec	red clay with subordinate gray ss	1500 m	
MIOCENE	Rawalpindi Group	KAMLIAL	Tk	Tr	2300 m/sec	red to purple ss & clay with intraformational conglomerates	100-150 m	
MIOCENE	Rawalpindi Group	MURREE	Tm	Tr	2300 m/sec	red to purple clay & ss with intraformational & basal conglomerates	approx. 2000 m	yes
EOCENE		BHADRAR	Te	C-E	4000 m/sec	limestone and shale	50-150 m	yes
EOCENE		SAKESAR	Te	C-E	4000 m/sec	limestone	50-150 m	yes
EOCENE		NAMMAL	Te	C-E	4000 m/sec	limestone	50-150 m	
PALEOCENE		PATALA	Tp	C-E	4000 m/sec	shale	20-60 m	
PALEOCENE		LOCKHART	Tp	C-E	4000 m/sec	limestone	20-60 m	yes
PERMIAN		AMB	P	C-E	4000 m/sec	limestone	0-275 m Truncated to the west by an unconformity	yes
PERMIAN		SARDHAI	P	C-E	4000 m/sec	sandy shale, siltstone	0-275 m Truncated to the west by an unconformity	
PERMIAN		WARRCHHA	P	C-E	4000 m/sec	sandstone	0-275 m Truncated to the west by an unconformity	
PERMIAN		DANDOT	P	C-E	4000 m/sec	shale	0-275 m Truncated to the west by an unconformity	
PERMIAN		TOBRA	P	C-E	4000 m/sec	conglomerate	0-275 m Truncated to the west by an unconformity	yes
CAMBRIAN		BAGHANWALA	€	C-E	4000 m/sec	shale, salt pseudo...	110-350 m Truncated to the east by an unconformity	
CAMBRIAN		JUTANA	€	C-E	4000 m/sec	sandy dolomite	110-350 m Truncated to the east by an unconformity	
CAMBRIAN		KUSSAK	€	C-E	4000 m/sec	sandy shale	110-350 m Truncated to the east by an unconformity	
CAMBRIAN		KHEWRA	€	C-E	4000 m/sec	red-brown sandstone	110-350 m Truncated to the east by an unconformity	yes
INFRA-CAMBRIAN		SALT RANGE FORMATION	SRF		4400 m/sec	red marls and gypsum with interbeds of anhydrite and dolomite and thick seams of massive halite	0 to >2000 m	
PRE-CAMBRIAN		BASEMENT OF INDIAN SHIELD	PC		3000 m/sec	biotite schist		

Figure 2.4 Generalized stratigraphic column of eastern SR/PP.

(Kadri, I.B. ,1995)

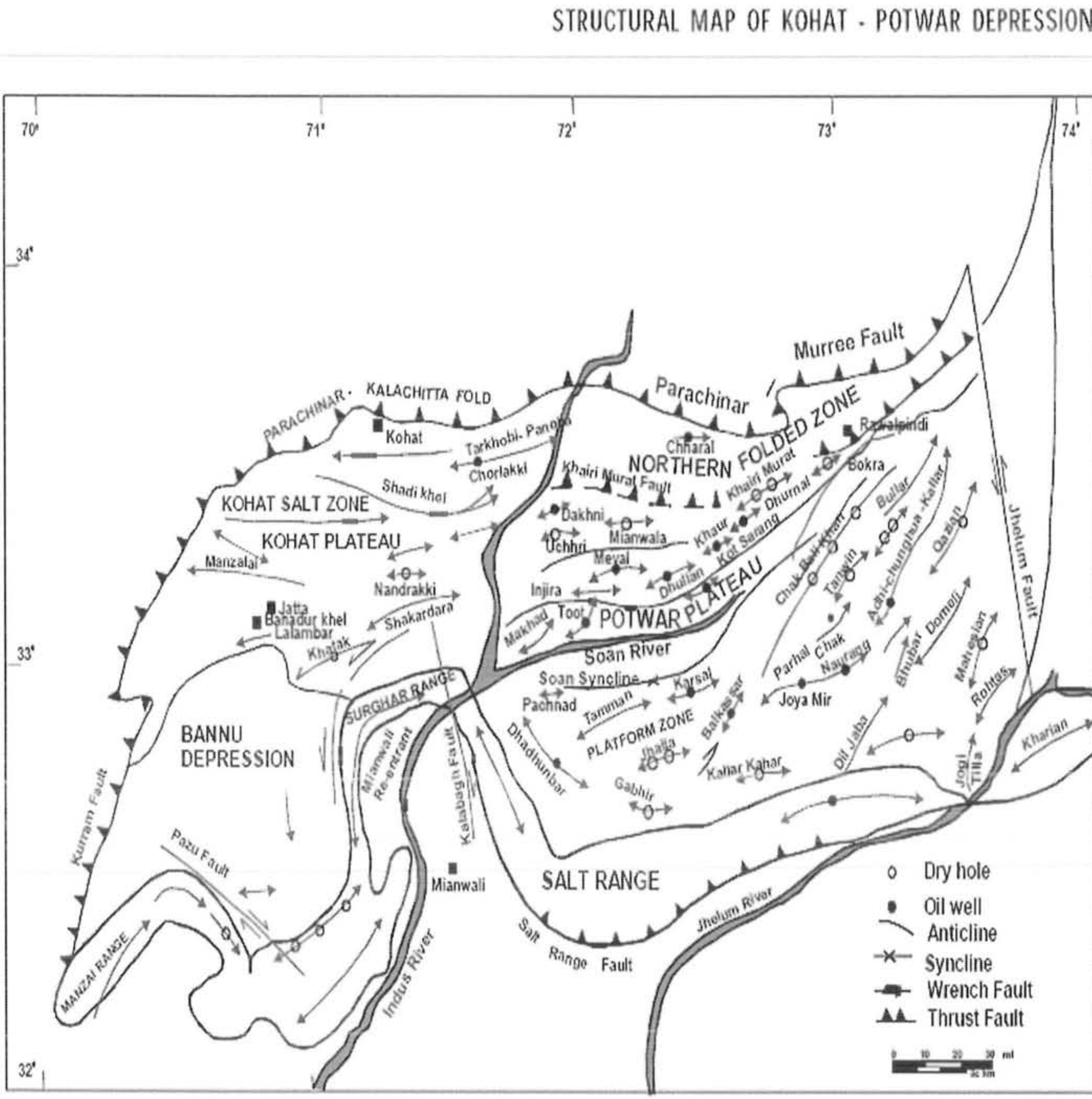


Fig 2.5: structural map of chakwal area potowar.((Kazmi & Jan, 1997)

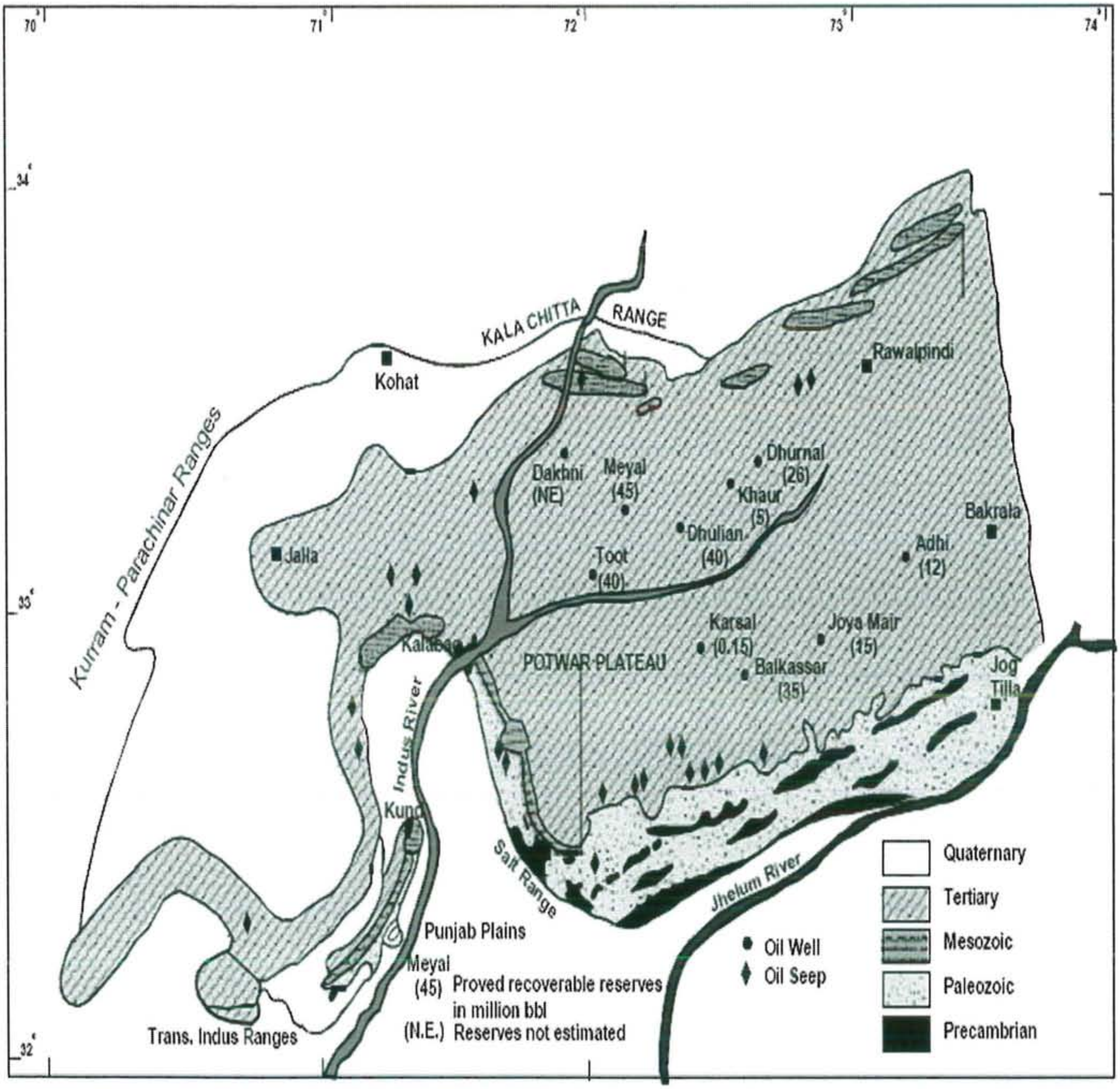


Fig 2.6: geological map of chakwal area potowar (Kazmi & Jan, 1997)

Quaid-i-Azam University

CHAPTER 3

SEISMIC METHODS

DATA ACQUISITION
DATA PROCESSING
SEISMIC VELOCITIES

3.1 Introduction to Seismic Methods:

Seismic method is one of the most commonly used geophysical techniques for investigating the subsurface. The predominance of the Seismic method over other geophysical method is due to various factors, the most important of which are the high accuracy, high resolution and great penetration of which the method is capable. The widespread use of seismic method is principally in Exploration of petroleum.

The basic technique of seismic exploration consists of generating Seismic waves and measuring the time required for the waves to travel from the source to a series of geophones usually disposed along a straight line directed towards the source.

If the rock layers are horizontal or gently dipping seismic waves follow uncomplicated path. The two kinds of paths are followed by reflection seismic waves and refraction seismic waves.
The reflected waves have traveled downward to borders between rock layers where they bounce or echo back to the surface. In contrast, the refracted waves follow paths that bend at each border.
(Robinson & Coruh, 1988)

Energy sources are used to generate the seismic waves, which penetrate the earth's crust and undergo reflection and refraction at different elastic discontinuities. An array of geophones is used to detect them, which are infect, one of electromechanical devices capable of converting the up and down motion of ground into electrical signals. The data is usually recorded on magnetic tape, or any other medium.

In seismic method actually a relation is developed between the Seismic velocity and the subsurface lithology. The results obtained are interpreted in geological terms and the lithology of subsurface is studied.

3.2 Type of Seismic Methods:

There are two types of seismic methods:

- **Reflection method**
- **Refraction method**

3.2.1 Reflection Method:

The Seismic reflection method is based on the study of elastic waves reflected from the interface between the geological layers. This method is base on Law of reflection which is that when a wave is propagating through a medium. It bounces back with the same angle in which it incident. This is very useful in oil exploration finding out deep structure such as anticline, salt domes and trusted anticlines. This method is preferred on other geophysical method because it has long penetration in subsurface.

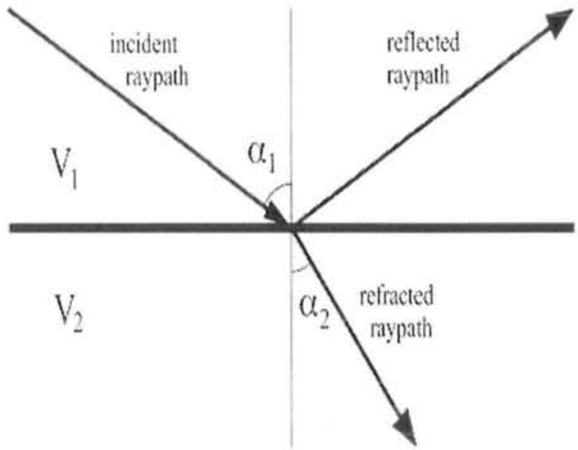


fig (a):reflection and refraction of seismic wave

3.2.2 Refraction Method:

The Seismic Refraction method is based on the study of the elastic waves refracted along the geological layers in which the velocity of propagation of elastic waves is greater than the overlying strata. This method is base on Snell's law which is when wave is incident in a medium some part of it is bounces back while the other is transmitted to another medium

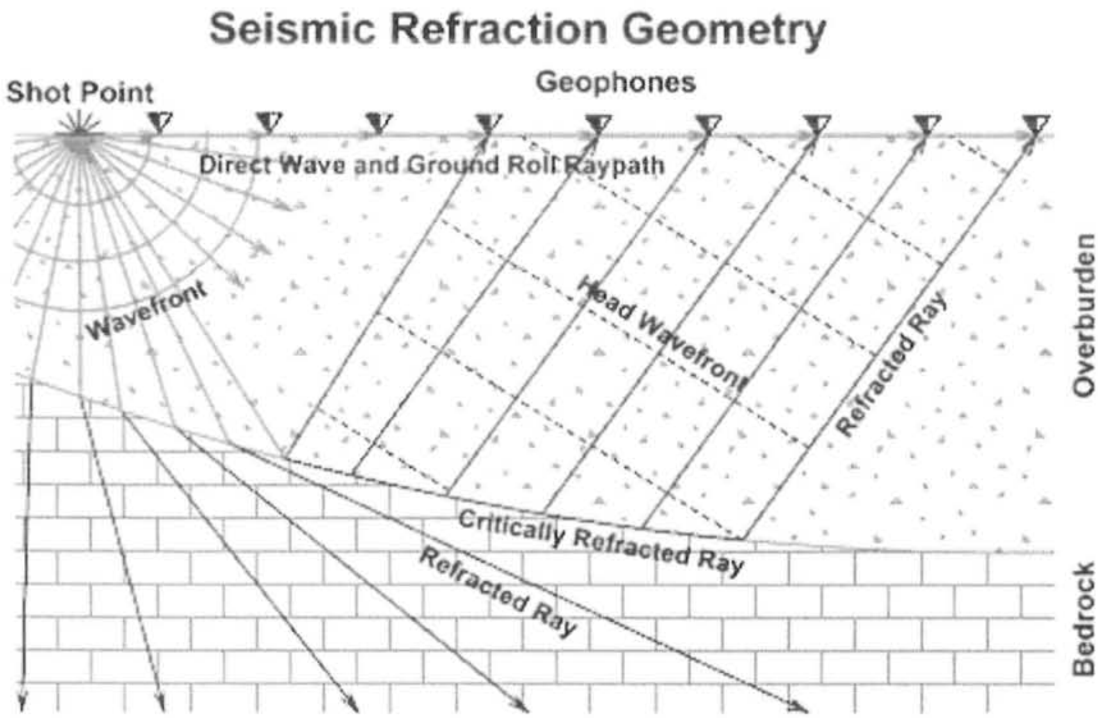


Fig (b):seismic refraction geometry

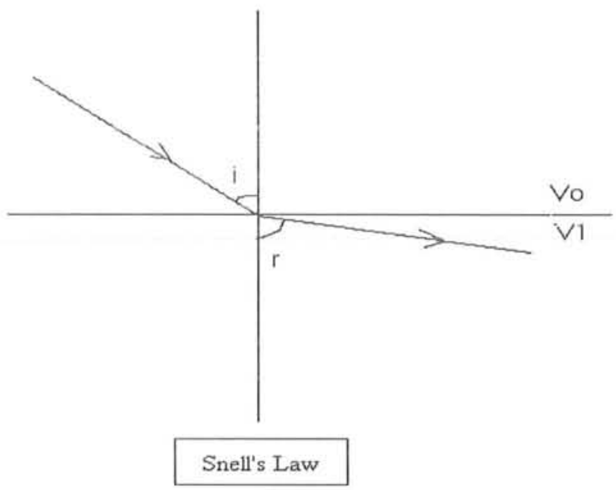


Fig (c): Snell's law

Applications of Seismic Methods:

Seismic methods are used

- To find out the structural traps (such as anticlines, faults, salt domes and reefs).
- To investigate the Stratigraphic features like discontinuous layers.
- Reflection data can be used to determine the average velocities of seismic waves provide a good indication of Lithology. (Dobrin and Savit, 1988)

- Seismic method is also used in search for ground water, in civil engineering, mineral exploration and locating subsurface features. (Robinson and Coruh, 1988)

3.3 Types of Seismic Waves:

Seismic waves are messengers that convey information about the earth's interior. Basically these waves test the extent to which earth materials can be stretched or squeezed some what as we can squeeze a sponge. They cause the particles of materials to vibrate which means that passing seismic waves temporarily deforms these particles can be described by its properties of elasticity. These physical properties can be used to distinguish different materials. They influence the speeds of seismic waves through those materials.

These waves are generated by Earth's material as a result of an earthquake or an explosion. Seismic waves are of two types; the body waves and surface waves. When a stress is suddenly applied to an elastic body or when stress is suddenly released the corresponding displacement is propagated outward as an elastic wave. Different types of propagation give rise to different waves. So seismic waves can be divided into two parts,

1) **Body waves**
2) **Surface waves**

3.3.1 Body Waves:

These are those waves, which can travel though the earth interior and provide vital information about the structure of the earth. The body waves can be further divided into the following;

- **P- waves (Primary waves)**
- **S- waves (Secondary waves)**

P –waves (Primary Waves):

The particular kinds of waves of most interest to seismologists are the compressional or P-waves also called as compressional waves, longitudinal waves, primary waves, pressure waves, and dilatation waves (see Figure 3.1). In this case the vibrating particles move back and forth in the same direction as the direction of propagation of waves. P-waves can pass through any kind of material - solid liquid or gas. The P-waves velocity depends upon density and elastic constants. (Dobrin and Savit, 1988) The seismic velocity of a medium is a function of its elasticity and can be expressed in

terms of its elastic constants. For a homogeneous, isotropic medium, the seismic P-wave velocity Vp is given by;

$$Vp = \sqrt{\frac{(4/3)\mu + k}{\rho}},$$

Where μ is the shear modulus, k is the bulk modulus and ρ is the density of the medium.

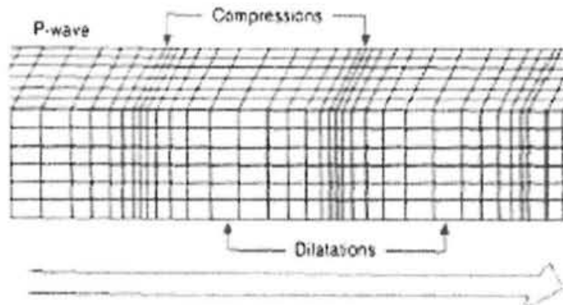


Fig 3.1 Propagation of P-waves in an elastic medium

S waves (Secondary waves):

In shear waves, the particles vibrate in a direction perpendicular to the direction of propagation of waves.

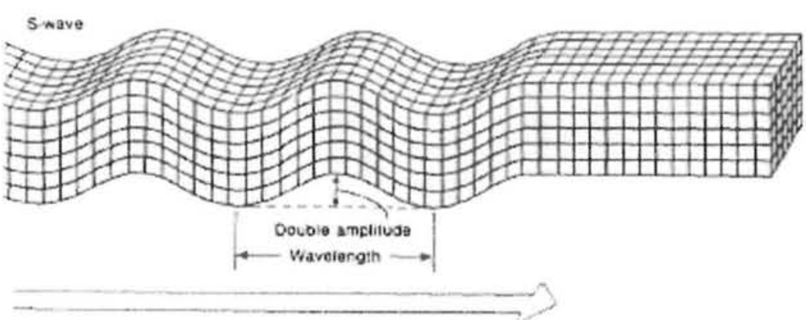


Fig 3.2 Propagation of S-waves in an elastic medium

They are also called as shear waves, transverse waves, and converted waves. For ideal gases and liquid μ=0. S-waves cannot pass through fluids (Dobrin and Savit, 1988). The velocity of S-waves is given by (using the same notation as of V_p);

$$Vs = \sqrt{\frac{\mu}{\rho}}.$$

Characteristics of Body Waves:

These travel with low speed through layers close to the earth's surface, as well in weathered layers. (Robinson & Coruh, C, 1988)

Frequency of body waves in exploration vary from 15Hz to 100 Hz . (Parasnis, 1997).

3.3.2 Surface Waves:

A part from body waves more complicated patterns of vibration are observed as well. These kinds of vibrations can be measured only at locations close to the surface. Such vibrations must result from waves that follow paths close to the earth's surface, hence known as surface waves.

In bounded elastic solid, surface waves can propagate along the boundary of the solid. Frequency of surface waves is less than 15Hz (Parasnis, 1997). Surface waves are also of two types;

- Raleigh waves
- Love waves

Love Waves:

A type of surface waves having a horizontal motion i.e. transverse to the direction of propagation (Kearey, Brooks & Hill, 2002). The velocity of these waves depends on the density and modulus of rigidity and notdepends upon the bulk modulus (k).

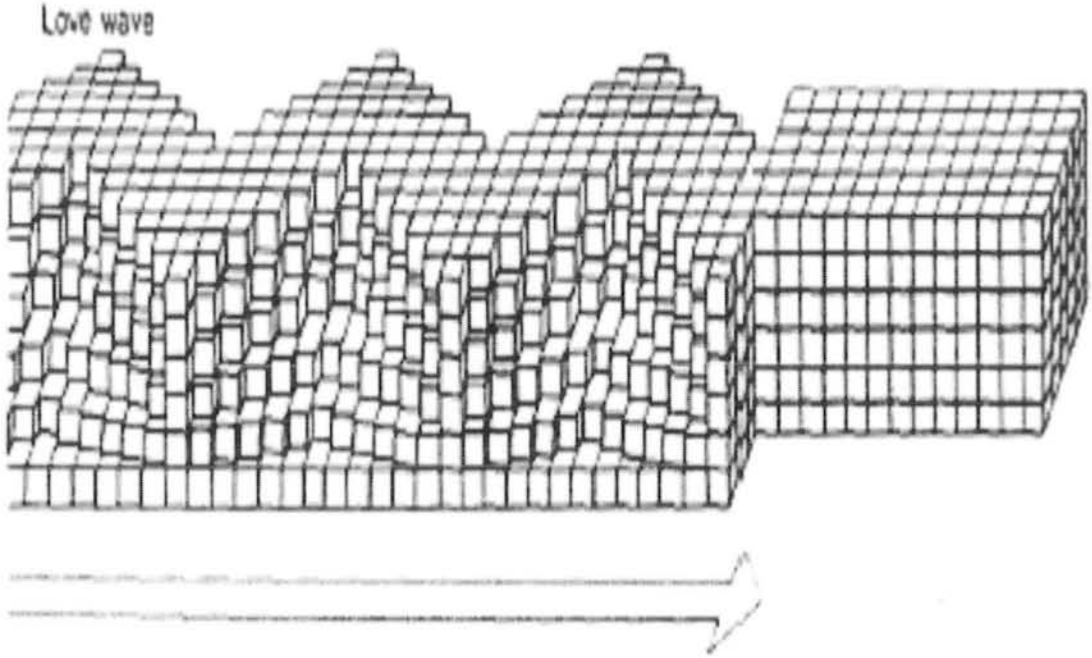


Fig 3.3 Propagation of Love waves in an elastic medium

Raleigh Waves

Type of surface waves having a retrograde, elliptical motion at the free surface of a solid and it is always vertical plane. Raleigh waves are principal component of ground roll (Kearey, Brooks & Hill, 2002).

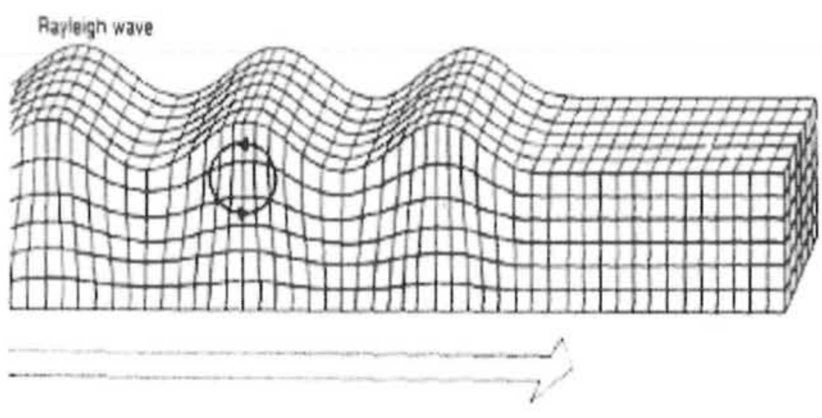


Fig3.4 Propagation of Raleigh waves in an elastic medium

3.4 Basic Laws Seismic Waves:

Theory of Elasticity:

The seismic method utilizes the propagation of waves through the earth, since this propagation depends upon the elastic properties of the rock so it is necessary to know the elastic properties of the subsurface material.

The size of a solid body can be changed by applying forces to the external surface of the body. These external forces are opposed by internal forces, which resist the changes in size and shape. As a result, the body tends to return to its original condition when the external forces are removed. Similarly, a fluid resist changes in size (volume) but not changes in shape. This property of resisting changes in size or shape and of returning to the undeformed condition when the external forces are removed is called elasticity.

Stress

"The force (F) applied per unit area (A) of the body"

Its unit in SI system is Pascal and one Pascal is equal to one Newton per square meter. Mathematically;

$$\textbf{Stress} = \mathbf{F/A}$$

Strain

Strain can be defined as:

"the change in size and shape of the body when external forces are applied on that body"

These changes are called Strain. It has four types.

- Longitudinal Strain
- Transverse Strain
- Shear Strain
- Dilation

Hooke's Law

This law states that

" Stress is the directly proportional to strain provided the elastic limit of the body is not exceeded. This limiting value depends upon the nature of rock body".

Mathematically

$\text{Stress} \propto \text{Strain}$

Elastic Modules

The linear relationship between stress and strain in the elastic filed is specified for any material by its various elastic modules, each of which expresses the ratio of a particular type of stress to the strain and provides a measure of rigidity. There are certain types of elastic modules as given below;

- Bulk Modulus
- Shear Modulus
- Young's Modulus
- Poisson's Ratio

Bulk Modulus (K)

It is the ratio of stress to the volumetric strain and is given by the relation

$$K = \frac{\text{volume stress}}{\text{volume strain}}$$
$$= \frac{P(\text{pressure})}{\Delta V/V}$$

Mathematically it can be represented as,

$$k = \frac{1}{\kappa} = \frac{P}{\Delta V / V}$$

Where k is the compressibility coefficient

Shear Modulus (μ)

The shear modulus is defined as

"The ratio of shearing stress "τ" to the resulted shear strain "tanθ". It is also called as rigidity modulus. It is denoted by "μ". For liquids and gases, shear modulus (μ) is zero

$$\mu = \frac{\text{shear stress}}{\text{shear strain}}$$
$$= \frac{F/A}{\tan\phi}$$
$$= \frac{F/A}{\Delta L/L}$$

Mathematically it can be represented as (where τ is the shear stress);

$$\mu = \frac{\tau}{\tan\theta}$$

Young's Modulus (E)

It is defined as the

"The ratio between longitudinal stress and longitudinal strain. It is also called stretch modulus". It is denoted by "E"

$$E = \frac{\text{longitudinal stress}}{\text{longitudinal strain}}$$
$$= \frac{F/A}{\Delta L/L}$$

- Poisson's Ratio (σ)

It is used to show that the change in diameter (d) is proportional to the change in length (l). Poisson's ratio varies from 0 to ½ and has the value ½ for fluids.

$$\sigma = \frac{\text{transverse strain}}{\text{longitudinal strain}}$$
$$= \frac{\Delta D/D}{-\Delta L/L}$$

Mathematically it is represented as Bulk modulus (k) and Shear modulus (μ);

$$\sigma = \frac{3k - 2\mu}{2(3k + \mu)}$$

- Relationship between Elastic Module

The all four module can be interrelated in the following way (Dobrin and Savit, 1988)

$$K = E / 3(1-2\sigma)$$
$$\mu = E / 2(1+\sigma)$$

3.5 Laws governing seismic waves:

There are three fundamental laws that govern the seismic wave propagation.

1) Huygen's principle
2) Fermat's principle
3) Snell's law

1) Huygens's Principal

"Every point on a wave front is a source of new wave that travels away from it in all directions"

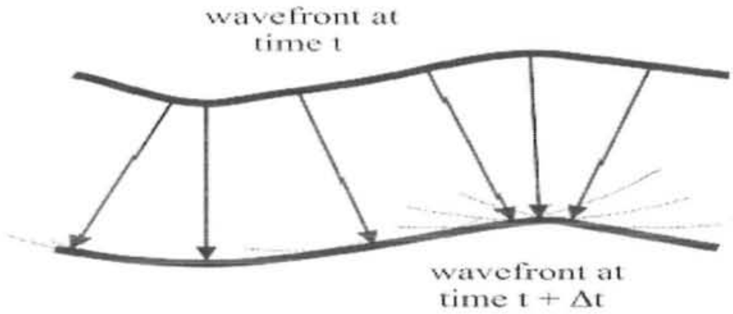


Fig 3.5 Huygens's Principle

2) Fermat's Principal

It states that

"Elastic waves travel between two points along the paths requiring the least time"

3) Snell's Law

According to this law

"Direction of refracted of reflected waves traveling away from a boundary depends upon the direction of the incident waves and the speed of the waves"

Mathematically,

$$\frac{\sin(\alpha_1)}{V_1} = \frac{\sin(\alpha_2)}{V_2},$$

Where V_1 and V_2 are velocities in the upper and lower layers, α_1 is the angle of the incident ray-path with respect to the vertical, and α_2 is the angle of transmission of the refracted ray-path with respect to the vertical.

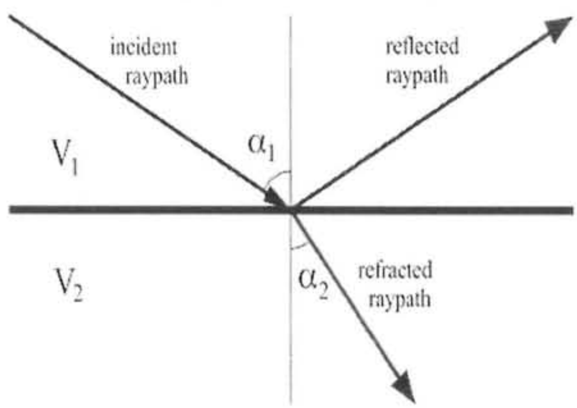


Fig 3.6 Refraction and reflection of an incident wave

3.6 Reflection- and transmission-coefficients

The Reflection- and Transmission coefficient give the ratio between the incident amplitude A_0 and the reflected (A_R) and transmitted (A_T) amplitude, respectively. In the special case of a incident wave perpendicular at an interface for a P-wave, a simple expressions for the reflection and transmission coefficient is obtained.

3.6.1 Reflection coefficient

These coefficients compare the amplitude of incident wave and reflected wave. Value of reflection coefficient varies from -1 to +1(Khan, 1989). For R=0, there will be no reflection, wave will be transmitted. It can be mathematically represented as;

$$R = \frac{A_R}{A_0} = \frac{v_2\rho_2 - v_1\rho_1}{v_2\rho_2 + v_1\rho_1} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

3.6.2 Transmission coefficient

Transmission coefficients are those, which compare the amplitude of incident wave and refracted wave. Value of transmission coefficient varies from 0 to2 (Khan, 1989).

If Ai is the amplitude of incident wave and At is the amplitude of transmitted wave, then transmission coefficient T is given as follow;

$$T = \frac{A_T}{A_0} = \frac{2v_1\rho_1}{v_2\rho_2 + v_1\rho_1} = \frac{2Z_1}{Z_2 + Z_1}$$

The product $Z = v\,\rho$ is known as the acoustic impedance.

Reflection and transmission in terms of energy

Sometimes the coefficients, which describe the energy and not the amplitudes, are introduced as Reflection- and Transmission coefficients

Reflection coefficient in terms of energy

$$E_R = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$$

Transmission coefficient in terms of energy

$$E_T = \frac{4Z_1Z_2}{(Z_2 + Z_1)^2}$$

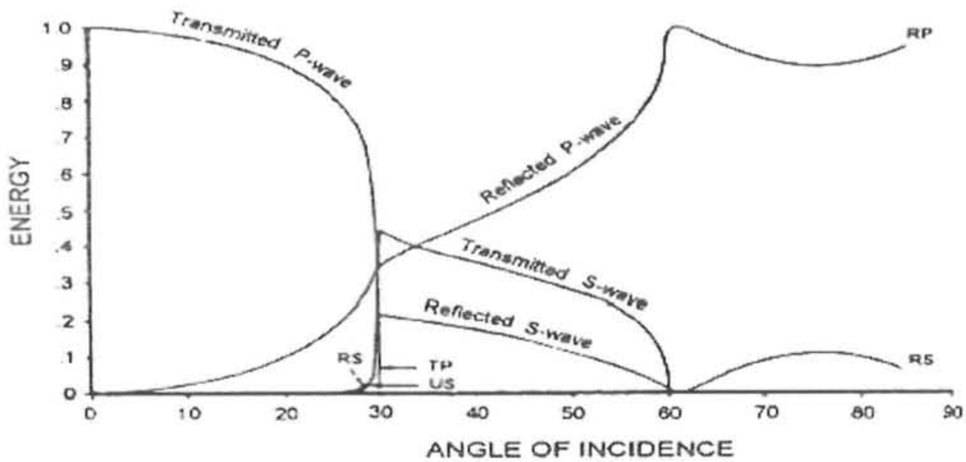


Fig3.7Angle dependent reflection and transmission coefficients for P and S-waves

3.7 Wave Conversion

When a wave reaches the boundary between two substances having velocities, it divides up into waves that reflect from the boundary or refract across the boundary. So an incident wave is converted into reflected and refracted waves. An incident wave can be P-wave, S_V- wave or S_H-wave. (Robinson & Coruh, 1988)

- When incident wave is P-wave then it is reflected and refracted as P-wave and S-wave as shown in fig 3.8a
- When incident wave is S_V-wave then it is reflected and refracted as P-wave and S_V-wave shown in fig 3.8b
- When incident wave is S_H-wave then it is reflected and refracted as S_H-wave shown in fig 3.8c

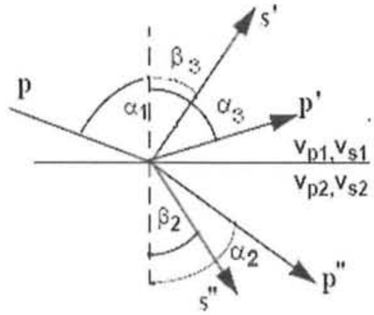


Fig 3.8a Wave conversion of P-wave into various waves

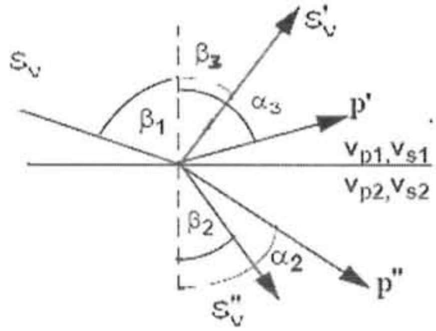


Fig 3.8b Wave conversion of SV-wave into various waves

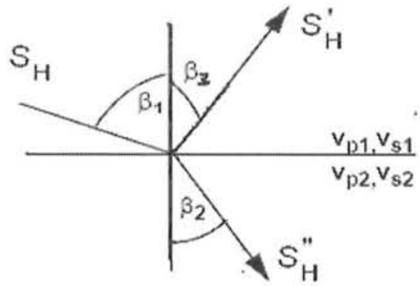


Fig 3.8c: Wave conversion of SH-wave into various waves

There are three basic steps for interpolating seismic data:

1-SEISMIC DATA ACQUISITION

2-SEISMIC DATA PROCESSING

3-SEISMIC DATA INTERPRETATION

3.9 SEISMIC DATA ACQUISITION

Fundamental purpose of seismic data acquisition is to record the ground motion caused by a known source in a known location. First step in seismic data acquisition is to generate a seismic pulse with a suitable source. Second is to detect and record the seismic waves propagating through ground with a suitable receiver (geophone/seismometer), digital or analogue form. Third is the registration of data on a chart or tape recorder.

(Kearey, Brooks & Hill, 2002)

The record of ground motion with time is called as seismogram. It is the basic information to be used in seismic data interpretation. During the seismic data acquisition certain operations are to be applied, such as conversion of the ground motions into electrical signals, amplification of these signals and filtering of the signals as well.

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

After this survey layout procedure is decided. Surveyor start to lay out the seismic line according to the prescribed programme. While doing this surveyor has to mention the pickets and shot points as well. Numbers are assigned to these pickets. Pickets are the small heaps of soil or stones on the ground at some constant distance. In seismic survey these pickets represents the seismic channels.

Shot points are those pickets on which shots are recorded. Distance between pickets and shot points is selected by QC geophysist in crew.

While doing seismic data acquisition, chainage sheets (surveyor's log) are also prepared. This sheet contains information about vegetation, water resources, etc. These sheets are very useful for geometry development of the survey area in seismic data processing.

Another important aspect of seismic data acquisition is drilling up of the shot holes. This drilling can be done with

(1) Rotary rigs.

(2) Flushing unit.

These holes can be used for shooting as well as for well velocity surveys (Down hole and Up hole surveys). (Al-Sadi, 1980)

3.9.1 Acquisition Setup

It includes

(1) The spread configuration.

(2) Shooting types.

(3) Shooting parameters.

(4) Recording parameters.

3.9.1.1 The Spread Configuration

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

(1) End Spread.
(2) In-Line Offset Spread.
(3) Split Spread/Centre Shooting.
(4) Cross Spread.
(5) L Spread.

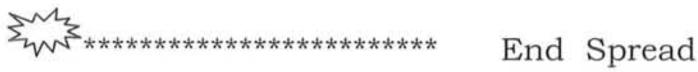


Fig 3.9a: End spread

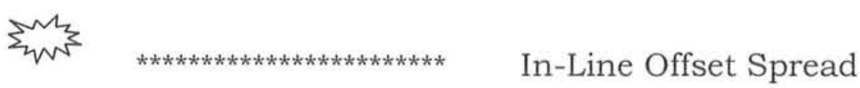


Fig 3.9b: In-Line Offset Spread

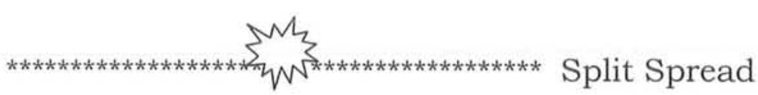


Fig 3.9c: split spread

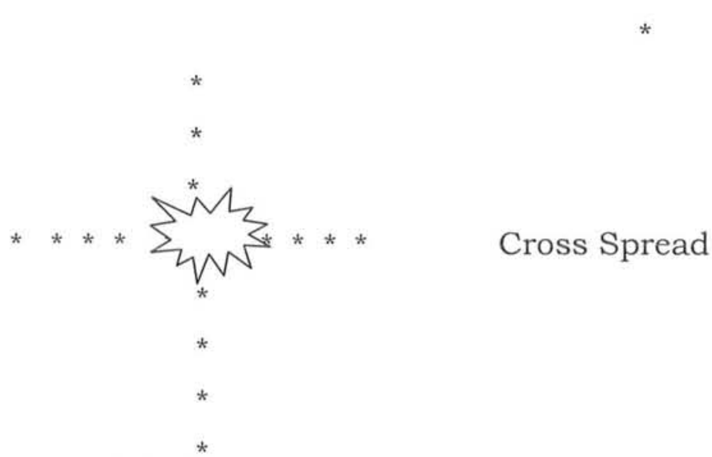


Fig 3.9d: cross spread

L- Spread

Fig 3.9e: L- spread

Along with these basic spreads, another technique called as Fan shooting can also be used. In this technique, geophones are arranged in an arc, fanning out in different directions from the source. (Robinson &Coruh, 1988)

Fan shooting is used in Transmission method. Transmission method differs from normal refraction method in the sense that it does not involve critical incidence of waves over the interface. In Transmission method, source and detector are on opposite sides of the investigated interface.

Other techniques used in transmission method in velocity logging (well shooting, continuous velocity logging (CVL) and uphole survey).Fan shooting is used for determination of the dimensions of velocity anomalous structures. (Al-Sadi, 1980)

3.9.1.4 Recording Parameters

The recording parameters include:

a) Group interval.

b) Group base.

c) No of channels.

d) No of geophones in a group.

e) Geophone array (linear or weighted).

f) Sample rate.

g) Record length.

h) Coverage (folds).

i) Near and far offset.

a) Group Interval

Group is defined to be as combination of a certain no of geophones. Group interval is the interval between the mid points of two consective group.

b) Group Base

It is the total length of that collectively feed a channel. Group base can act for the suppression of noise.

c) No. of Channels

Total no. of recording units used in the survey.

d) No. of Geophones in a Group

Total no. of geophones in a group.

e) Geophone Array

It can be linear, weighted or arial. Linear array means that all geophones are arranged along a line. Weighted array means that geophones in a group are arranged in form of parallel lines. In this array sensitivity of each geophone is made different. In arial array, geophones are laid over an area around the line.

f) Sample Rate

The time in digital recording, during which discrete samples are recorded.

g) Record Length

The total length of for recording one short is called as record length.

h) Coverage

Coverage means how many fold data will be obtained from the multifold profiling survey. No of folds from a survey can be determined as follows

$$\text{No. of Folds} = N/2(\triangle x/\triangle s)$$

Where N: the number of recording channels along a spread.

$\triangle$X: the geophone interval.

$\triangle$S: the source interval.

(Robinson & Coruh, 1988)

3.9.1.5 Selection of Shooting & Recording Parameters

The initial stage of seismic survey involves field trails in the survey area to determine the most suitable combination of source, offset, recording range, array geometry and detector spacing to produce good seismic data.

Quality of field data can be achieved if field parameters (shooting and recorder) are appropriately selected. This selection is done by conducting different experiments in field. This selection of parameters is dependent on four variables. These variables are source size, source depth, no. of holes and group base. By changing these Variables, the best combination is selected for recording and shooting parameters.

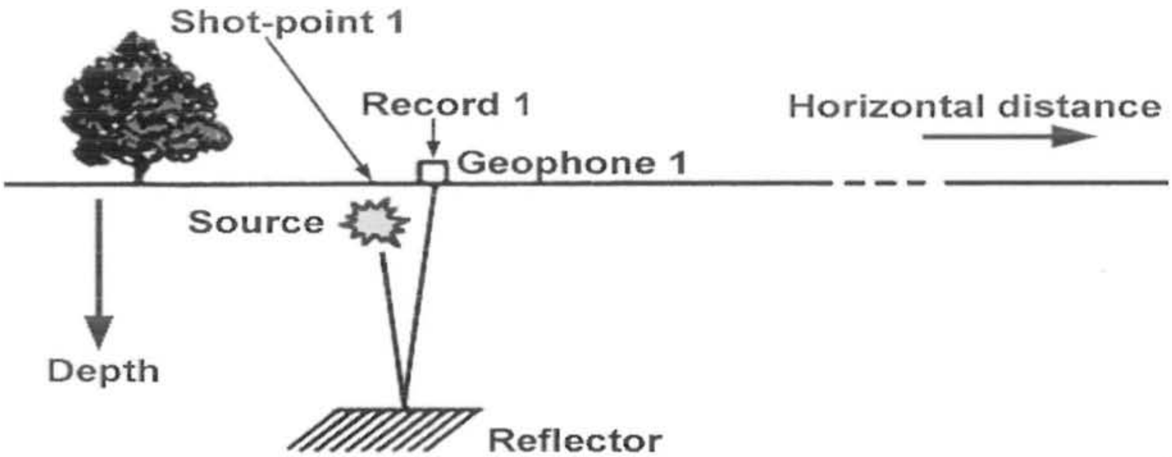


Fig 3.10 : The basic layout for a seismic reflection acquisition Dobrin & Savit, 1988

3.9.1.6 Seismic Energy Sources

Energy sources are designated to generate vibrations in the ground. There are different sources of energy, each having different level of frequencies. Suitable seismic source for a particular survey is selected on the basis of lithology, area accessibility and cost.

Energy sources used in seismic survey on land are

(1) Dynamite.

(2) Vibroseis.

(3) Geograph.

(4) Dinoseis.

(5)Geoflux. (Al-Sadi, 1980)

Energy sources used in marine seismic survey are

(6) Air- gun.

(7) Stream- gun .

(8)Gas-gun (Al-Sadi, 1980)

3.9.3 Detection and Recording

The most important and necessary step of data acquisition is detection and recording of data. It is described as follow:

3.9.3.1 Seismic Detectors

Similar to the source, special receiver/detectors are used for the measurement of the seismic waves on land and in water:

(1) Geophones - on Land.

(2) Hydrophones - in Water.

(1) Geophone

Most of the geophones are based on the principle of a moving coil. The cylindrical coil is suspended in a magnetic field by a leaf-spring. The passage of a seismic wave at the surface causes a physical displacement of the ground, which moves the geophone case and magnet in sympathy with the ground but relatively to the coil because of its inertia. This relative movement of the magnet with respect to the coil results in a small voltage being generated across the terminals of the coil in proportion to the relative velocity of the two components. Geophones thus respond to the rate of movement of the ground (i.e. particle velocity) not to the amount of movement or displacement.

To amplify the wanted signals and to suppress the unwanted signals like surface waves, more geophones are used in one group. The signal of the separate geophones is added to one signal for the whole geophone group. (Al-Sadi, 1980)

(2) Hydrophone

Hydrophone/Pressure Phone is the standard receiver in Marine Seismic Survey and responds to variations in pressure. Principle of the measurement is the measurement of the change in pressure with a piezoelectric crystal placed in the hydrophone. Due to the bending of the crystal, a voltage occurs. (Robinson & Coruh, 1988)

3.9.3.2 Seismic Recording

There are two types of recording system.

(1) Analogue-recording system.

(2) Digital-recording system.

(1) Analogue-Recording System

This system is made up of an assembly of electronic unit normally housed in a specially adapted truck called as recording station or dog house. The function of the system may be divided into two main stages.

a) The amplification stage.

b) The recording stage.

3.10 SEISMIC DATA PROCESSING

Data processing is a sequence of operations, which are carried out, according to a predefined program to extract useful information from a raw data set (Al-Sadi, 1980). Indeed the whole set of seismic data processing is to message, seismic data recorded in the filed into a coherent cross-section, indicating significant geological horizons into the earth subsurface, related to hydrocarbon detection and seismic Stratigraphy (Dobrin and Savit, 1988). The purpose of data processing is to produce a perfect seismic section by applying a sequence of corrections so that it is interpretable.

Seismic data processing consist of applying a sequence of computer programs, each designed to achieve one step along the path from field tape to record section. The processing sequence consisting of corrections and adjustments which increases the signal-to-noise ratio corrects the data for various physical processes that obscure the desired geological information of seismic data and reduce the volume of data.

Schematically:

INPUT → **PROCESSING SYSTEM** → ***OUTPUT***

Data collected → useful information

3.10.1 Primary Stages of Seismic Data Processing

There are three primary stages in Seismic Data processing, each aimed to improve the seismic resolution (ability to separate two reflection events that lie very close to each other). These three stages in their usual order are:

A- Deconvolution

B- Stacking

C- Migration

Besides these primary steps, other processing techniques may be considered as secondary as these help to improve the effectiveness of the primary processes. (Yilmaz, 2001)

3.10.2 Processing Sequence

Briefly, we can describe the data processing procedure in the following five major categories:

1) Data Reduction
2) Geometric Corrections
3) Data Analysis and Parameter Optimization
4) Data Refinement
5) Data Presentation

1) Data Reduction

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

Demultiplexing

Correlation

Header generation

Display

Editing and muting

Amplitude adjustment

a) Demultiplexing

Demultiplexing in the geophysical sense is the unscrambling of multiplexed field data to trace sequential form. The demultiplexed data results in a separate trace for each shot point, sampled at what ever interval has been used during recording (often 4ms) (Badley, 1985). Mathematically Demultiplexing data is seen as transposing a big matrix so that the columns of the resulting matrix can be read as seismic trace, recorded at different offsets, with common shot point.

Actually the multiplexed data is in time sequential format and demultiplexed data is in trace sequential format which is a convenient format that is used throughout processing. The principle of multiplying in field is adopted when the capacities of the AD converter are not sufficient to digitize and save all channels at the same time. This is common in older measurement systems or for measurements with a large time window and a lot of channels per shot. The separate values of all channels are sorted by samples and not by channels:

$[T_1S_1][T_2S_1][T_3S_1] \cdots [T_nS_1][T_1S_2][T_2S_2] \cdots [T_nS_2] \cdots [T_nS_m]$

T_i = Trace i; S_j = Sample j

Now, it is difficult to process the data in this form. It is more convenient and illustrative when the data is sorted by traces i.e. demultiplexed:

$[T_1S_1] \cdots [T_1S_n][T_2S_1] \cdots [T_2S_n] \cdots [T_nS_1] \cdots [T_nS_m]$

T_i = Trace i; S_j = Sample j

Now we have obtained the data in such a format that it can be used for further processing.

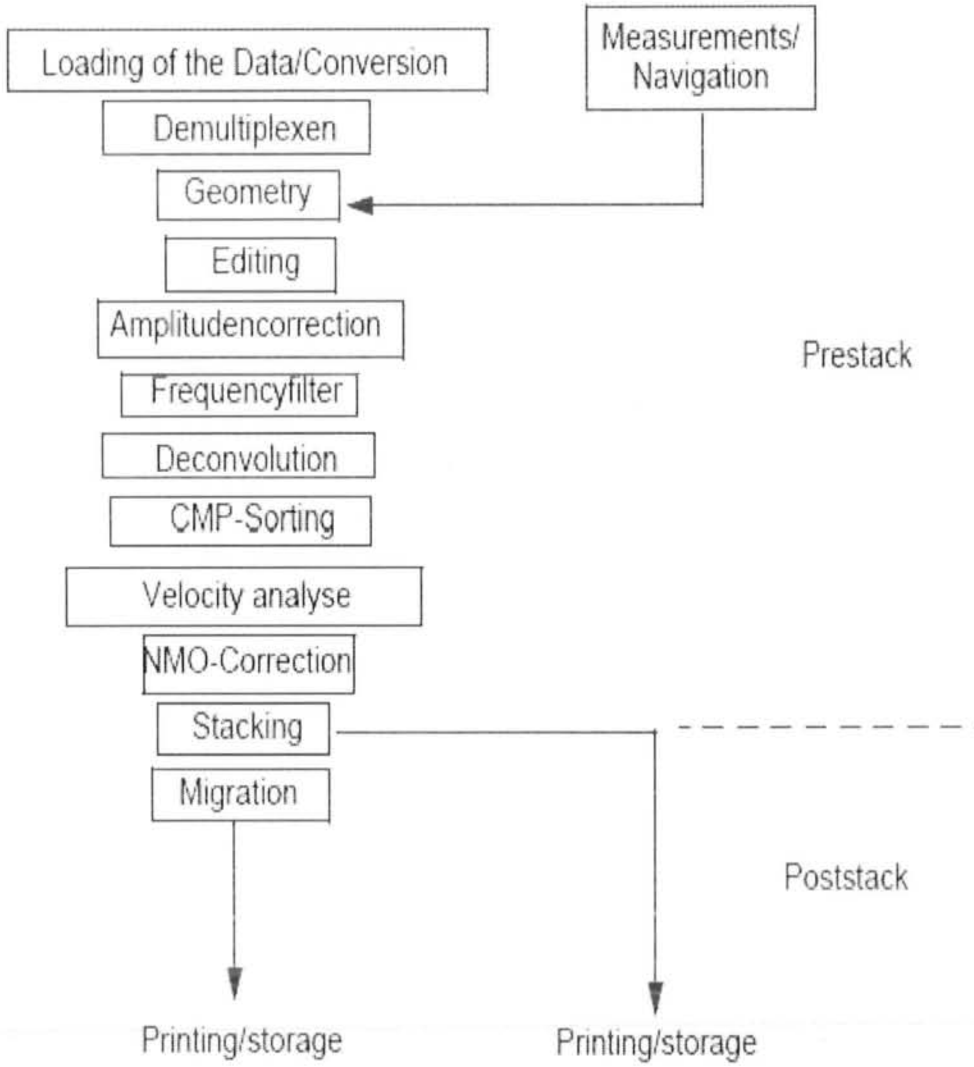


Fig. 3.11: Detailed processing sequence flow chart.

b) Correlation

Correlation is simply the measurement of similarity or time alignment of two traces. Since correlation is a convolution without reversing the moving array, a similar frequency domain operation also applies to correlation. Two types of correlation are:

Cross Correlation

Auto Correlation

Cross Correlation

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

II. Auto Correlation

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

Vibroseis correlation

The signal so obtained by non-impulsive source is called sweep, which may be either upsweep or down sweep. Vibroseis correlation enables us to extract from each of the long overlapping sweep signals a short wavelet much like those obtained with impulsive sources (Robinson and Coruh, 1988), because all reflected and refracted signals in a Vibroseis seismogram, overlap and another extensively which is not readable. Another, computer processing is needed to obtain a recognizable record. To make Vibroseis record, useable, we "compress" the reflection into short wavelets. This procedure is called "Vibroseis correlation". This is done by cross correlating the data with original input sweep .so that each reflection is compressed to a wavelet which can be used directly to examine subsurface structure. (Badley, 1985)

Procedure for Vibroseis Correlation

In Vibroseis correlation, we cross multiply, point by point the digitized values of the Vibroseis trace with the digitized values of the input sweep. Then we sum up these products to obtain first correlated value for the correlated seismogram trace. Now we advance one point on the Vibroseis trace and repeat the process. We plot these correlated

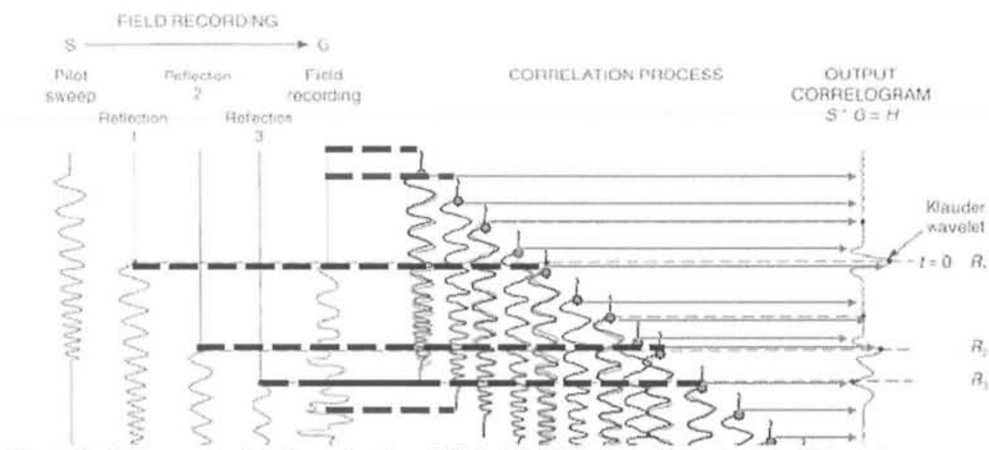


Fig. 3.12: Detailed Process Of Correlation With Field Recording Sweep Signal

values to obtain correlated seismogram. This seismogram represents a short pulse or wavelet rather than the long sweep/wave train, centered at arrival time for each wave indicated on the original trace. The particular type of wavelet produced by the Vibroseis correlation is called "Klauder Wavelet". These Klauder wavelets are then used to develop the correlogram. (Robinson & Coruh, 1988)

c) Header Generation

After that all of the sample from a given field trace are assembled into an array, a large amount of archival information is placed in a reserved block called a trace header, which is located on the just ahead of the data samples. Trace header information may include location and elevation of source and receiver, field record number, trace number etc .A real header block is also placed at the head of each reel, for recording line number, reel number etc.

d) Display

At the end of the processing sequence, and sometime at the intermediate stages, it

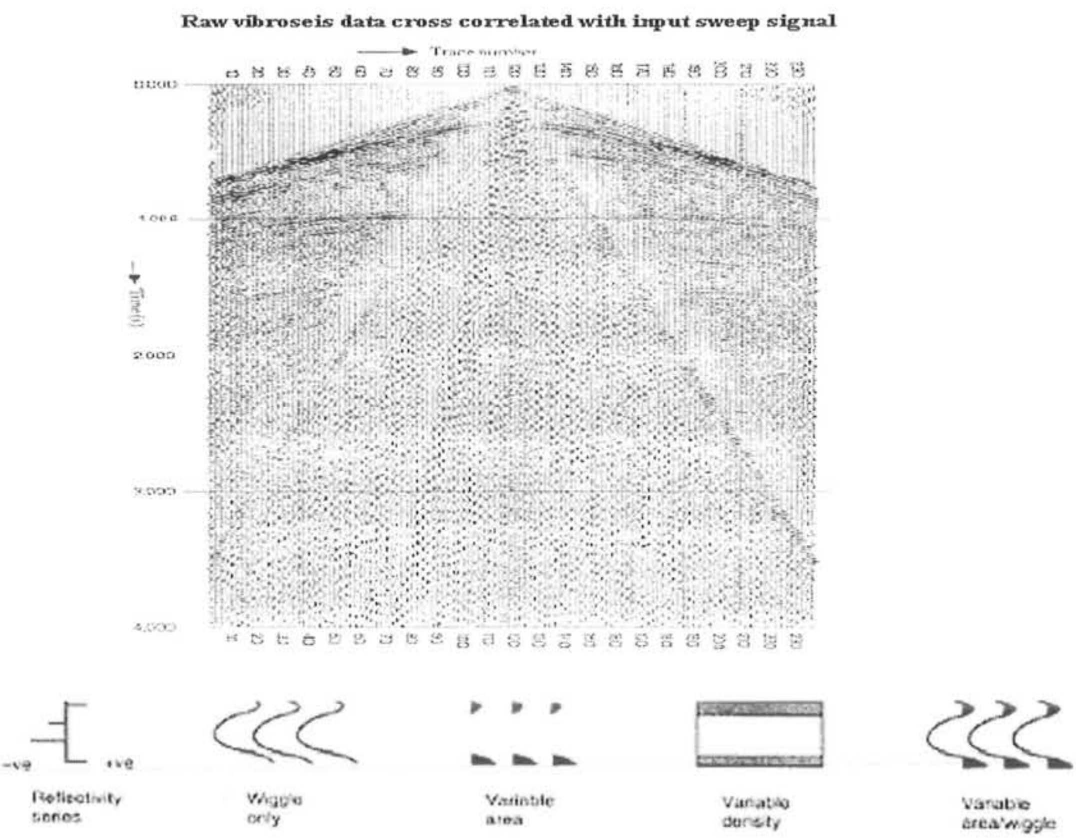


Fig. 3.13: Common display types for seismic trace.

is necessary to reconvert the digitized data to analog format, in wiggle trace or other modes, then examined visually. There are several methods of plotting digital data in analog form. The most common method is to pass the digital trace through a sample and hold device, which produce an output voltage proportional to each sample and which holds the voltage constant until the next sample arrives. This procedure produces a "stair step" type of analog output, which can then be smoothened into a continuous trace by their passage through a low pass filter.

e) Editing and Muting

Due to certain unfavorable field-conditions, some of the recorded data are not useful. Part of a trace or the whole trace and occasionally the whole shot point record may come out very weak or over-ridden by abnormally high energy events. There may be noisy traces,

traces with transient glitches, some dead traces and mono frequency signals on the record Data editing involves complete removal of all undesired data before proceeding further in data processing. This is done by setting to zero, the all undesired trace-samples.

Some time in the field the electrical connections of some traces are inverted by mistake. As the result, the peak-trough sense of such traces comes out reversed with respect to the rest of the record. This is called as polarity reversal. Rectification of polarity reversal of such traces is an important part of data editing. Otherwise if it could not be done these traces must be zeroed.

After doing this all the contributing traces per each CDP are gathered together. Each trace in one CDP is identified by its shot point and receiver numbers. The CDP-gathers may be displayed as such for direct inspection and checking of edited data. Muting is useful to remove useless information from the processing stream in a way that first identifies the information to be removed and then blanked. Muting is categorized as initial muting, to remove first arrivals; usually done later in processing, and surgical muting, to remove air waves or ground roll energies.

f) Amplitude adjustment

Amplitude of the seismic wavelet is adjusted because it dies out as the input wave travels down to the earth and losses it energy due to the spatial spreading of the wave or absorption. Besides, spherical spreading and energy dissipation in earth, there are other reasons for the observable decay in seismic amplitude with time. Under the knowledge of such reasons amplitude of the seismic wavelet is adjusted:

(a) Trace Normalization

(b) Trace Balancing

2) Geometric Corrections

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

a) Static correction

b) Dynamic correction

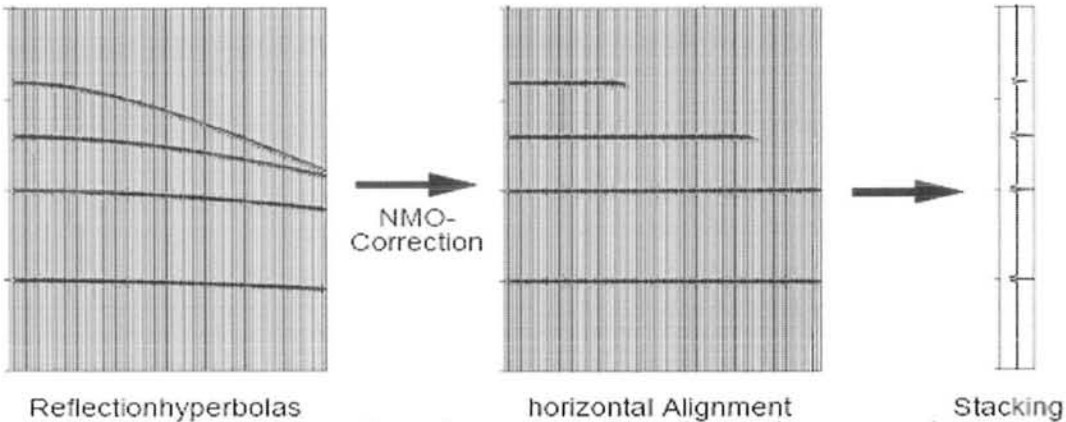
(a) Static correction

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

(i) Elevation correction

(ii) Weathering correction

Principle:



Principle of NMO-Correction. The Reflections are alligned using the correct velocity, such that the events are horizontally. Then all the separate traces are stacked (summed).

Fig. 5.5 Principle of Dynamic Correction.

3) Trace Gathering (CDP sort)

Traces are routinely gathered into groups having some common elements. The types of gathers usually made are:

- (i) Common shot - all traces that belong to the same shot.
- (ii) Common midpoint (CMP) - all traces with the same midpoint.
- (iii) Common receiver - all traces, recorded with the same geophone.
- (iv) Common offset - all traces with the same offset between shot and geophone.

For a horizontal layered earth the reflection point lies between source and receiver (midpoint).Using more shots with different positions of the source and receivers several combinations of source and receivers exist which have the same midpoint.

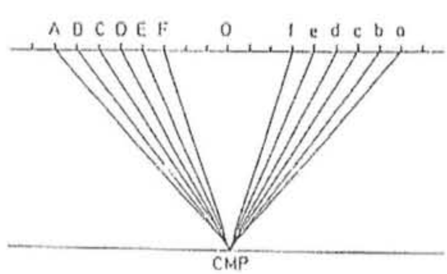
When a horizontal layering is present the reflection then also comes from an equal point in the subsurface (Common depth point- CDP). For an inclined layer the point of reflection for traces with the same midpoint are not equal anymore. The nomenclature CDP is not valid anymore. However, several processing programs still use the word CDP in stead of CMP.

Fold

The fold indicates the number of traces per CDP. This is often the number of traces in a CMP.The theoretical formula for the fold is given by: The number of traces which are measured at a certain geophone position is called "surface fold" as below:

$$\text{Fold} = \frac{\text{Numberof Geophones} \cdot \text{Distance between Geophones}}{2 \cdot \text{Distance between shots}}$$

CMP Gathers



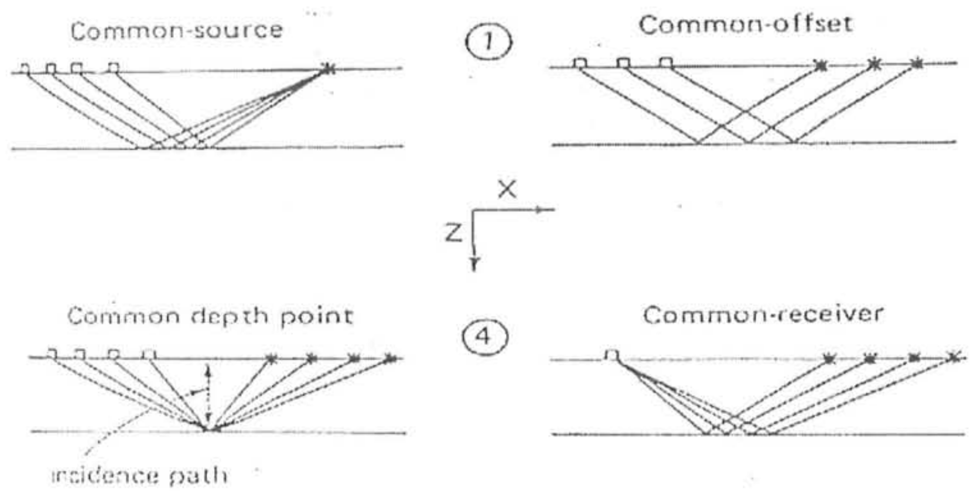


Fig. 5.6 Diagrammatic representation of different trace gathers

3) Data Analysis And Parameter Optimization

Three steps are involved in this procedure:

(i) Filtering

(ii) Deconvolution/ Inverse Filter

(iii) Velocity Analysis

(i) Filtering

Filtering is an operation by which the amplitude and/or phase spectrum of a time signal are altered. Purpose of a filter is to enhance primary reflections by attenuating ambient and source-generated noise whose frequency spectra are separated in tow ways are identical mathematically (OGTI manuals, 1988). In general the aim of filtering is to improve signal to noise ratio (Kearey and Brooks, 2002). There are two basic methods of filtering:

(a) Frequency Domain Method (b) Time Domain Method

Table3.1

Type of filter	Application
Fk –filters	Suppression of noise signals with specific slopes (Interface waves), multiple reflections and Elimination of Artifacts in stacked Sections (post-stack)
Alias filter	Removes those frequencies which are above Nyquist frequency.
Band pass Filters	Passes on specified band of frequency
Low pass and high pass filters	Passes specific frequency either low or high
Notch Filters	To analog before digitizing, removes specified narrow notch frequency e.g. of power lines 60 Hz.
Tau Filters	time-dependent velocity filter; Suppression of multiples, interpolation between traces, analysis of Guided Waves

Velocity Filters/fan filters/pie slice filtering	Remove coherent noise event on the basis of particular angle at which the event dips (March & Bailey 1983).

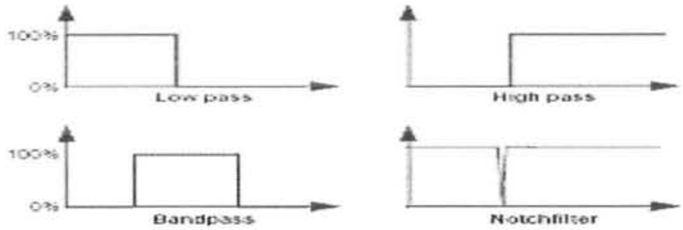


Fig. 314: Example of various types of filters.

Seismic Noise

Noise is the undesired information contained on a seismic record which one does not wish to use and are to be filtered .There are two types of seismic noises encountered in seismic survey are:

(a) Coherent Noise

(b) Incoherent Noise

(a) Coherent Noise

It displays some regular patterns on seismogram. It is seismic energy which aligns from trace to trace or record to record on seismic record .Often, it is very similar to the signal and usually more difficult to overcome than the incoherent/random noise. By examining the patterns of coherent noise, we can devise field procedures to reduce it. It has various sources as discussed below:

(i) Ground Rolls

(ii) Guided waves

(iii) Multiples

(iv) Noise due to the Air wave

(v) Cable Noise

(vi) Side-scattered Noise

(vii) Noise due to power lines (Yilmaz, 2001)

(b) Incoherent Noise

It is also known as Random Noise. It is the seismic energy that does not align up from trace to trace or record to record on seismic record. It displays no systematic pattern. This noise is uncorrectable. We can overcome random noises by recording more than one trace from the same location. It has various sources such as given below:

(i) Wind Noise

(ii) Transient/Small movements in vicinity of seismic cable

(iii) Water flow Noise

(iv) Electrical Noise from instruments

(v) Bad Geophone Noise (improperly planted)

(vi) Short wavelength propagation Noise. (Yilmaz, 2001)

(ii) Deconvolution / Inverse Filter

It is the process by which the wavelet associated with the significant reflections is compressed and reverberatory energy that trails behind each reflection is largely attenuated. It is a filtering process designed to improve resolution and suppress multiple Deconvolution, showing how Deconvolution compress and resolves the input signal so that reflections are prominent after the suppression of noises and multiples between 1 and 2 seconds.

Deconvolution can be considered either in the time domain or in the frequency domain. In the time domain the object is to convert each wavelet with its reverberations and multiples, into a single spike. If we know the shape of the wavelet, we can design an operator which, when convolved with the seismic trace, with convert each wavelet into a single spike. Key parameters for Deconvolution are:

- Type of Deconvolution-spiking or prediction
- Portion of trace to be the source of the autocorrelation
- Length of filter operator
- White noise factor

Two main types of Deconvolution are:

(I) Deterministic Deconvolution

(II) Predictive Deconvolution

Deterministic Deconvolution is capable of producing a pulse of any designed shape with an appropriate band width.

Predictive Deconvolution attempts to predict event shapes, obtained by statistical studies of the seismic traces. (Badley, 1985)

Velocity-Spectrum

The velocity spectrum is obtained when the stacking results for a range of velocities are plotted in a panel for each velocity side by side on a plane of velocity versus two-way travel-time. This can be plotted as traces or as iso-amplitudes. This method is commonly used by interactive software to determine the velocities.

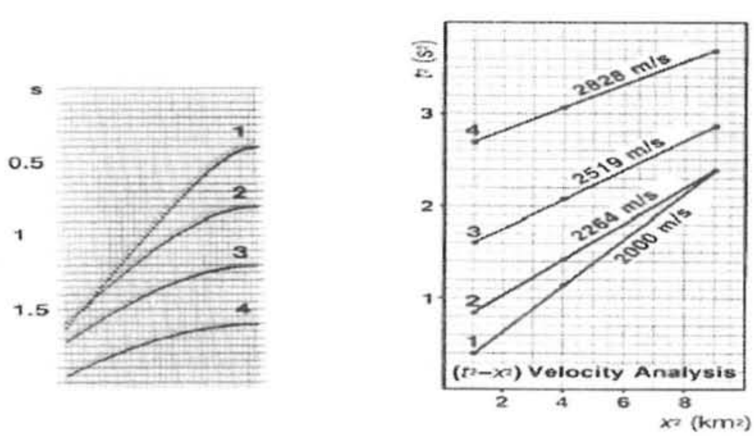


Fig. 3.15: An example of t^2-x^2 graph.

4) Data Refinement

The processes described till now are used to make data free of the factors that decrease its quality. Also these processes are used to reformat the data and to diagnose its characteristics. Data refinement consists of the following three main stages:

(i) Stacking

(ii) Residual Statics

(iii) Migration.

(i) Stacking

Stacking is simply a method to improve signal-to-noise ratio, by adding reflections together in phase and adding noise, out of phase, so that it cancels. According to Badley 1985, stacking discriminates against multiples provided that the velocity of the multiples is such that during stacking, it has a normal-move-out significantly different from primaries arriving at the same time (Badley, 1985). Stacking is performed by summation of the NMO-corrected data. The result is an approximation of a zero-offset section, where the reflections come from below the CMP position.

(ii) Residual Statics

The process of residual Statics consists of shifting the separate traces in such a way that the optimal reflections are obtained. To make sure that the traces of a single CMP are not shifted randomly, the shift is divided in a value for the source ("source static") and a value for the receiver ("receiver static"). For each source and receiver a value is determined. All traces with a certain source are corrected with the value for that source.

(iii) Migration

"The process of shifting the reflection points to the positions that correctly image the reflector and remove diffraction images so that we may get an accurate picture of underground layers."

If the reflector is flat, the reflection point will be located directly beneath the shot/receiver station, and the record section displays the event in its true position, plotted in time rather than depth. However, if the reflector is not flat, the reflection point will not lie directly beneath the shot/receiver position, and the true position of the reflector will differ from its apparent position.

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

Important features of Migration

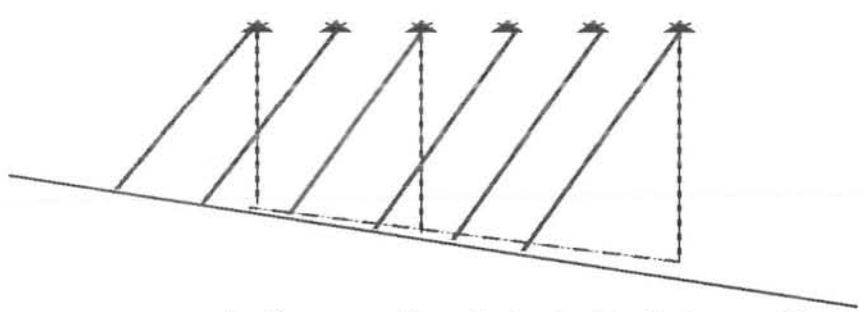
- Migration steepens the reflectors as the dip angle of the reflector in the geologic section is greater than in the time section.
- Migration shortens the reflectors as the length of the reflector on the geologic section is shorter than in the time section; thus,
- Migration moves reflectors in the up dip direction.
- When migration is applied in case of the undulating reflector the crests become narrower and troughs become broad.

Types of Migration

- With respect to the stage when migration is applied on the seismic data during processing, there are two important methods of migration.
- a) Pre-Stack Migration
- b) Post-Stack Migration

a) Pre-Stack Migration

Pre-stack migration is essentially when seismic data is adjusted before the stacking sequence occurs. The popular form of pre-stack migration is depth migration (PDM). PDM requires the user to know more about velocities of the layers.



- **Fig 3.16** Effect of migration moves the reflector back to its true position

b) Post-Stack Migration

Post stack migration is the process of migration in which the data is stacked after it has been migrated. This process is better for many reasons, mainly because of its reasonable cost compared to pre-stack migration.

3.11 SEISMIC VELOCITIES

Seismic Velocities are the most important parameter in Seismic technique for interpretation processing. Seismic velocities are generally needed for the inspection of lithology, physical nature of the rocks and also for the calculation of dip and depth interfaces. The Seismic interpretation has been described as the process of solving for a velocity distribution from the data measured in terms of time, which must be presented in geologic terms (as in structural & lithological interpretation). Velocity varies both in lateral position and with depth, depending upon the medium. According to Dobrin & Savit, (1988) Seismic velocities vary largely in sedimentary rocks as compared to igneous and metamorphic rocks. In terms of lithology, whenever there is a change in grain size and mineralogical composition of the sock, velocity behavior changes. An increase in grain size will result in the increase in velocity.

3.11.1 Dependence Of Seismic Velocities Upon The Physical Properties Of The Rock

The velocities of propagating waves depend upon the following physical characteristics of rocks

i)Porosity

"Porosity decrease with depth as the result velocity increases".

ii) AgeOf Rocks

"Seismic velocity increases to one-sixth power of age".iii) *Temperature*

"Seismic velocity decreases slightly with temperature but freezing of pores fluids increase the velocity".

iv) Nature Of Interstitial Fluids

"Sand containing water in pore space has higher seismic velocity then containing the oil and if containing gas has lower velocity".

v) Shale Content And Sand Content

"Shale content tends to have lower seismic velocity and more in sand content".

vi) Dolomitization

"It tends to increase S-wave velocity".

vii) Lime Content

"It increases the seismic velocity".

3.11.2 P-Wave Velocities Of Different Rocks

TABLE 3.2:VELOCITIES OF p-wave in DIFFERENT MEDIUM

Type of Medium	Velocity Rang (m/Sec)
Air	330
Water	1400-1600
Shale	1100-3000
Sandstone	2000-3500
Limestone	3500-4500
Dolomite	3500-6900
Granite	4200-6000
Gabbro	6450-6700
Dunite	7500-8100
Basalt	5500-6300

3.11.4 Dix Formula

Dix (1955) showed that for uniform horizontal layers and small offsets compared with reflector depth, the stacking velocity Vst closely approximates the root-mean-square velocity Vrms, the time-weighted root-mean-square value for a series of layers. Values of Vrms, down to different reflectors can then be used to compute interval velocities using the Dix formula. To compute the interval velocity Vn, for the nth interval.

3.11.5 Velocity Terminology

According to Dobrin and Savit (1988) and Sheriff (1973), the different kinds of velocities enter into seismic-data reduction and interpretation, discussed as under.

3.11.5.1 Average Velocity

It is the ratio of the vertical depth "z" of a reflecting surface below a datum to the observed one-way reflection time "t" from the datum to the surface, so that

$$V_{nv} = \frac{z}{t}$$

If the section is made up of parallel flat layers of velocity "Vi" and thickness "z i", so that the travel time across each layer is:

$$t_i = \frac{z_i}{t_i}$$

Then,

$$V_{nv} = \frac{\Sigma v_i t_i}{\Sigma t_i} = \frac{\Sigma z_i}{\Sigma z_i \underline{V_i}}$$

The average velocity is used for time-to-depth conversions and for migration.
The average velocity is used for time-to-depth conversions and for migration.

3.11.5.2 Interval Velocity

It is the average velocity measured for a defined depth-interval perpendicular to the velocity layers, which are assumed to be parallel. If two reflectors at depths z1 and z2 give reflections having respective one-way times of t1 and t2, the interval velocity between zi and Z2 is defined as

$$V_{int} = \frac{z_2 - z_1}{t_2 - t_1}$$

Average velocity and interval velocity are the same for shallow horizons.

3.11.5.3 Instantaneous Velocity

It refers to the speed of a wave front in the direction of the energy propagation (perpendicular to the wave front for isotropic media). If the velocity varies continuously with depth, its value at a particular depth z is obtained from interval velocity by contracting the interval z2-z1 to an infinitesimally thin layer having a thickness dz. The interval velocity then becomes the derivative of z with respect to t, which is the instantaneous velocity defined as

$$V_{inst} = \frac{dz}{dt}$$

3.11.5.4 Root-Mean-Square Velocity

When velocity layers are horizontal with respective interval velocities of v1,v2,v3,...,vn, and one-way interval travel tunes t1,t2,t3 .... tn,, the root-mean- square velocity of the section of ground down to the nth interface is given by

$$V_{rms\,n} = \left[\frac{\sum v_i t_i}{\sum t_i}\right]^{1/2}$$

The rms velocity is always greater than the average velocity.

3.11.5.5 Stacking Velocity

It is the velocity obtained from normal move out measurements, used to maximize events in common-depth-point stacking.

Stacking velocity Vt is based on the relation

$$T2 = T2_0 + \frac{X^2}{V^2_{st}}$$

Where,

X= source-receiver offset for a CMP sequence of shots.

T= travel time of the reflection at X.

T0= travel time at the zero offset.

Stacking velocity is almost always greater than the average velocity.

3.11.6 Factors Affecting Seismic Velocities

The velocity of P-waves in a homogeneous solid is a function only of the elastic constants and the density of the medium. By virtue of their various compositions, textures (e.g., grain shape and degree of sorting), porosities and contained pore fluids, rocks differ in their elastic modulae and densities and, hence, in their seismic velocities.

Factors such as porosity, fracturing, fluid content, and chemical composition of the medium, which affect the value of density, brings about a corresponding change in velocity. The velocity appears to increase with density.

3.11.6.1 Porosity

Beyond the depth where consolidation is reached, the influence of variation in pressure on velocity becomes small, and then porosity and mineral composition of the grains become dominant in governing velocity. Principally the existing differential pressure and the maximum depth of burial determine porosity. Empirical data suggest that the maximum depth to which a rock has been buried is a measure of the irreversible effect on porosity. The empirical time-average equation is used to relate velocity V and porosity

$$\frac{1}{V} = \frac{\acute{o}}{V_f} + \frac{1-\acute{o}}{V_m}$$

Where Vf and Vm are the velocities of the fluid content and matrix material of the porous rock respectively.

3.11.6.2 Pore Fluids

In actual rocks, the pore spaces are filled with a fluid whose elastic constants and density also affect the seismic velocity. The fluid in rock pore spaces is under pressure, so that the effective pressure on the granular matrix is the difference between the overburden and fluid pressures. Where formation fluids are under abnormally high pressures, the seismic velocity is exceptionally low.

3.11.6.3 Depth and Age

With depth of burial and geological age, material becomes more compact, due to the overburden pressure. This results in an increase in elasticity (Sadi, 1980), which in turn makes a corresponding increase in the velocity. Faust (1951) studied independently the variations of velocity for an average shale and sandstone section, with depth and time, in order to develop a quantitative relationship given by

$$V = 125.3(ZT)^{\frac{1}{6}}$$

CHAPTER 4

INTERPRETATION

CHAPTER 4:

INTERPRETATION

INTRODUCTION:

Seismic Interpretation means the conversion of seismic data into useful geologic information. The interpretation of reflection data requires the fitting of all geological and geophysical information into an integrated picture that is more complete and reliable than any other source is likely to give alone.

In seismic method measurement are made at the surface by using different geophysical instruments which are then interpreted in terms of what might be in the subsurface. The behavior of different interfaces which give rise to reflection events is calculated from arrival times of seismic waves from these interfaces. Reflection arises at boundaries across which acoustic impedance changes given by the product of interval velocity & density.Greater the difference in the acoustic impedance across an interface, stronger will be the reflection generated.

According to Dobrin and Savit (1988) interpretation is the transformation of seismic reflection data into a structural picture by the application of corrections, migration and time depth conversion.

METHOD FOR INTERPRETATION OF SEISMIC DATA:

Two approaches have been applied for the interpretation of given seismic section, one is the Structural Analysis Approach and second is Stratigraphic Analysis Approach

Structural Analysis:

The main application of Structural analysis of seismic sections is in the search for Structural traps containing hydrocarbons. The structural interpretation uses two way reflection time rather depth and time. Structural maps are constructed to display the geometry of selected reflected events. Discontinuous reflections clearly indicate faults and undulating reflections reveal folded beds.

According to Badley (1990) the cross section is representative of the structure being studied. Much structural information is based on the interpretation of seismic section .Usually it is difficult to make a certain structural interpretation on the basis of only one seismic section. Grids of seismic data are required to determine the 3-D geometry.

Such an analysis usually take place against background of continuing exploration activitity and associated increase in amount of information referred to subsurface geology. The most common structural features associated with the Oil are anticlines and faults . Faults are mainly of three types:

Normal faults

Reverse faults

Thrust faults

The area is identified as an extensional regime resulting from an inferred fossil-rift crustal feature overlain by thick sedimentary sequence. Based on magnetic anomaly trends, the Indus basin fossil rift feature is characterized by Horst and Graben structures. (Bulletin, v. 84, No 11(Nov 2000), pp. 1833). Normal faults making Horst and Graben structures are marked in the given seismic section and are attributed to the same extensional regime.

Stratigraphic Analysis:

Seismic Stratigraphy is used to find out the depositional processes and environmental settings, because genetically related sedimentary sequence normally consists of concordant strata that show discordance with sequence above and below it. It also helps to identify formations, stratigraphic traps and unconformity.

Seismic Stratigraphy analysis involves the subdivision of seismic sections into sequence of reflections that are interpreted as the seismic expression of genetically related sedimentary sequences. Different types of reflection configuration are diagnostic of different sedimentary sequences. On a regional scale, for example, parallel reflections characterize some shallow water shelf environment. On the other hand the oblique cross beds show deeper water environment. The ability to identify particular sedimentary environment and predict lithofacies from analysis of seismic section can be of great value to exploration programmers which provide a pointer to the location of potential source, reservoir and seal rocks.

Stratigraphic analysis therefore greatly enhances the chances of successfully locating hydrocarbon traps in sedimentary basin environments. Hydrocarbon accumulations are some times revealed directly on true amplitude seismic sections by localized zones of anomalous strong reflections known as "Bright Spots". These high amplitude reflection events are attributable to the larger reflection coefficients at the top and bottom of gas zones, within a hydrocarbon reservoir. In the absence of bright spots, fluid interfaces may nevertheless be directly recognizable reflection events discordant to the local geological dip.

Stratigraphic analysis of the provided seismic section is provided as northing and eastings of the line. A generalized stratigraphic picture of the explored area was available from the literature on the basis of which the horizons have been correlated with the Stratigraphy of the area.

STUDTY OF LINE 93-MN-09 MINWAL JOYA MIR

Base map has covered the area of Minwal Joyamir. The scale of base map is 1:25000 and it is bounded by latitudes 32°56'00" North to 33°03'00" and longitudes 72°42'00" East to 72°53'00" East. Base map is shown in fig. 7.1.This map consist of following lines.

93-MN-01 **(Dip line)**
93-MN-02 **(Dip line)**
93-MN-04 **(Dip line)**
93-MN-05 **(Dip line)**
93-MN-06 **(Dip line)**
93-MN-07 **(Dip line)**
93-MN-08 **(Dip line)**
93-MN-09 **(Dip line)**
93-MN-10 **(Strike line)**
93-MN-11 **(Strike line)**

BASE MAP OF THE AREA

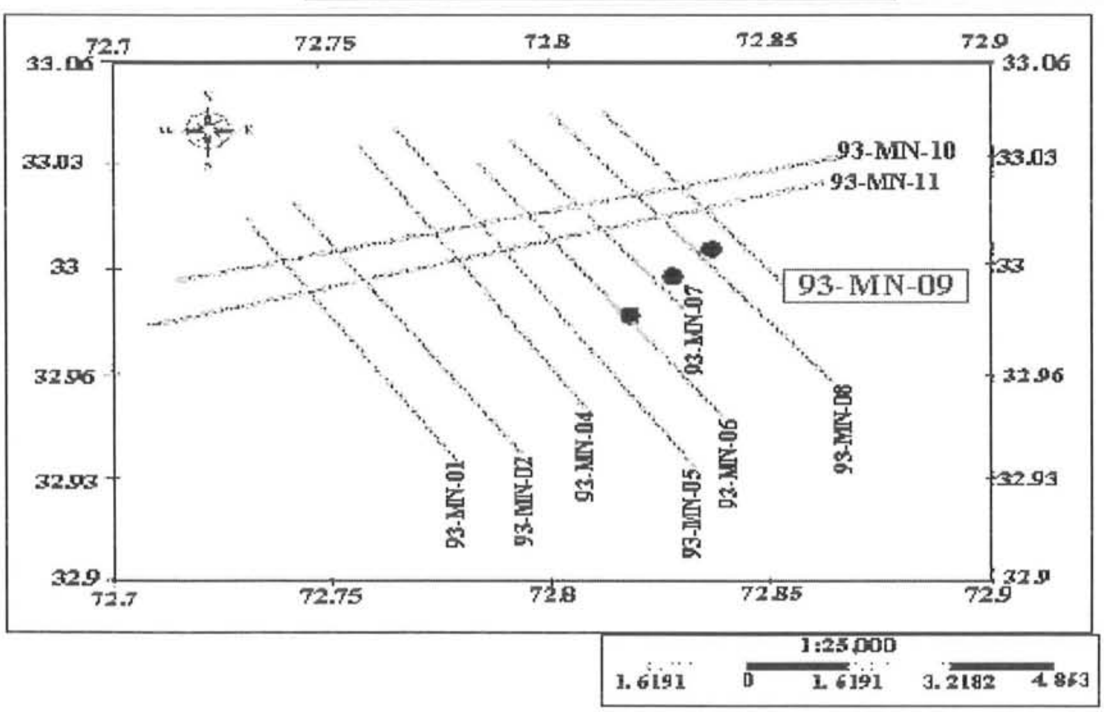


FIG 4.1:BASE MAP OF JOYAMAIR

From above lines, line number 93-MN-09(VP 190-VP 270) is allotted for present study which is a dip line and other lines are interpreted by other class fellows.

SEISMIC SECTION

Seismic section is prepared by plotting side by side all the traces from a CDP reflection profile. Each trace is drawn as a vertical wiggly line.

INFORMATION ABOUT SEISMIC SECTION OF LINE NUMBER 93-MN-09

CALCULATION OF LENGTH COVERED BY SEISMIC SECTION

Length of a section can be calculated by proceeding in the following way. First of all measure the shot points. Then multiply total number of shot points with 40

In case of line 93-MN-09

Shot points = 173

And Length of section = 173*40

=6920m

OR Length = 6.92 Km

It means that this section cover an area of 6.92km.

DIRECTION:

Direction of line number 93-MN-09 is northwest.

DATA TYPE

Seismic section consists of 50 fold data. It means that we get 50 reflections from a single point.

DATUM FOR RECORDING

From observation of section it is clear that data is recorded at 400m height from mean sea level

GERNAL VIEW OF A SEISMIC SECTION

A seismic section consists of velocity windows which contain time in mille second and root mean square velocities in meter per second.

For example

TABLE 4.1:VELOCITY WINDOW

CDP:250	
Time(ms)	Vrms(m/s)
0	2994
509	3178
1168	3393

1546	3494
1911	3630
2324	3718
2732	3800
5000	4165

By using these columns interval velocity and average velocity can be calculated by applying certain formulas.

CDP:250			
Time(ms)	Vrms(m/s)	Vint(m/s)	Vav(m/s)
0	2994	2994	2994.00
509	3178	3178	3178.00
1168	3393	3550	3387.98
1546	3494	3789	3486.06
1911	3630	4157	3614.21
2324	3718	4101	3700.66
2732	3800	4237	3780.74
5000	4165	4566	4136.98

TABLE 4.2:AN EXMPLE OF A SOLVED VELOCITY WINDOW.

These velocities are used to draw velocities (average, mean and is velocity) graphs and for further interpretation.

Seismic Time Section

An ordinary seismic section is actually a time section.We can also say that time section is the reproduction of reflectors marked on the given seismic section.

How we can prepare a seismic section? It is quite simple to prepare it.

First we calculate time of each reflector from seismic section corresponding to shot point given on seismic section.

Then we plot time of each reflector verses shot points by keeping time along Y-Axis in mille seconds and shot points along X-Axis.

DATA FOR THE PREPARATION OF TIME SECTION

	R 1(sec)	R 2(sec)	R3(sec)	R 4(sec)	R5(sec)	FAULT 1	FAULT 2
VP 110	1.435	2.05	2.13	2.37	2.62		
VP 120	1.5	2.15	2.23	2.42	2.65		
VP 130	1.49	2.2	2.29	2.46	2.7		
VP 140	1.45	2.21	2.33	2.48	2.705		
VP 150	1.42	2.22	2.34	2.5	2.72	0.64	

VP 160	1.25	2.21	2.32	2.5	2.73	1.26	
VP 170	1.18	2.14	2.29	2.46	2.72	1.86	2.59
VP 180	1.17	1.83	1.98	2.38	2.85	2.27	2.925
VP 190	1.19	1.83	1.96	2.13	2.86	2.6	3.17
VP 200	1.2	1.83	1.96	2.13	2.86		
VP 210	1.2	1.83	1.96	2.12	2.86		
VP 220	1.19	1.84	1.97	2.13	2.88		
VP 230	1.19	1.85	1.98	2.14	2.89		
VP 240	1.18	1.84	1.96	2.14	2.89		
VP 250	1.16	1.84	1.96	2.13	2.89		
VP 260	1.14	1.82	1.94	2.12	2.88		
VP 270	1.09	1.81	1.95	2.1	2.85		

SEISMIC TIME SECTION

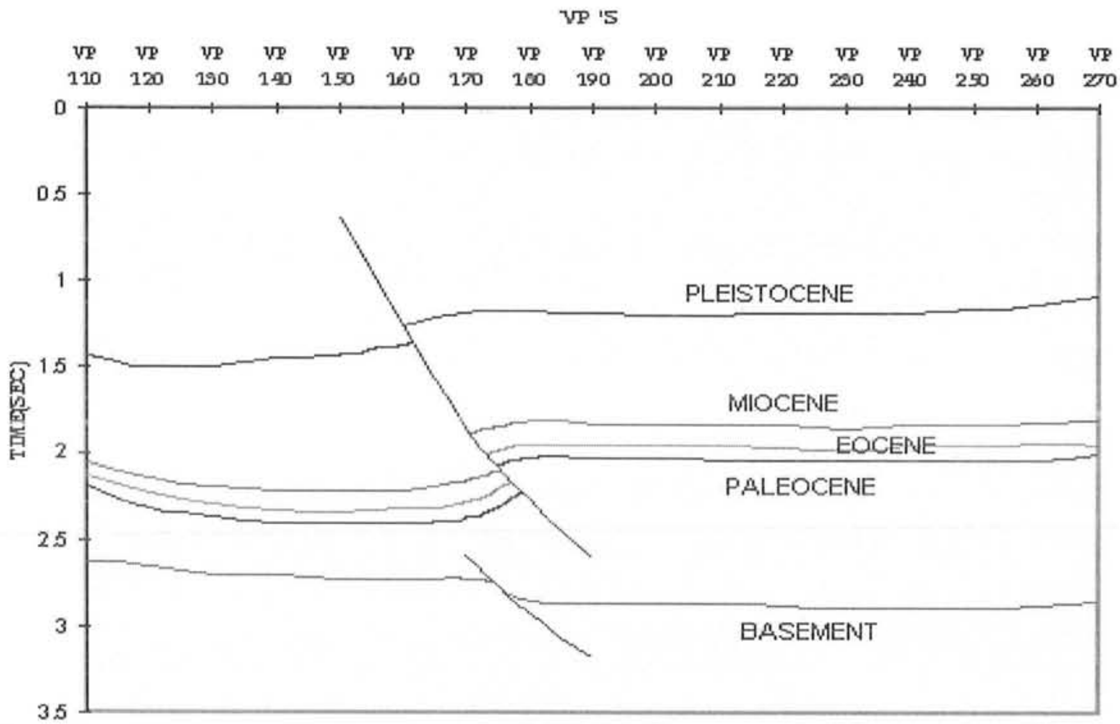


Figure4.2: indicate the time section of line number 93-MN-09 of Minwal Joyamir

Time section of 93-MN-09 indicates different reflectors which are representative of different geological formations.
From bottom to top these are following formations.
Basement marked as R5
Lockhart formation as R4 of Paleocene age.
Chorgali Formation as R3 of Eocene age.
Murree Formation as R2 of Miocene age.
And
Top most is may be Siwaliks R1 of recent age(Pleistocene).

SEISMIC VELOCITIES

VELOCITY:

Rate of change of speed in a particular direction is called velocity.

SEISMIC VELOCITY:

Seismic velocity is defined as "Rate at which seismic waves travel through a medium". Seismic interpretation has been described as the process of solving the velocity distribution from data, measured in terms of time, and conversion of that into meaningful subsurface geology. As seismic wave propagate in subsurface its velocity changes. These changes are used to measure different physical properties of subsurface material.
Seismic velocities are generally used for the following purposes

Determination of different subsurface lithologies
Determination of different physical properties of subsurface material
For the calculation of dip and depth of interfaces
Calculation of depth for the preparation of depth section
Seismic velocity is affected by the following factors.

- DENSITY OF ROCK
- POROSITY OF ROCK
- AGE OF ROCK
- OVER BURDEN PRESURE OR DEPTH OF BURIAL
- FLUID CONTENT IN PORES
- COMPOSITION OF ROCK (MINERALOGICAL &LITHALOGICAL)
- TEMPRATURE OF ROCK

Seismic velocities which are used for interpretation are following:

ROOT- MEAN- SEQUARE (RMS) VELOCIT

INTERVAL VELOCITY

AVERAGE VELOCITY

& MEAN VELOCITY

These velocities are used to prepare different velocity graphs. Now we will discuss all of these velocities and related graphs one by one.

ROOT MEAN SEQUARE(RMS) VELOCITY :

Weighted average velocity along the path of a reflected wave is called root-mean-square velocity or RMS velocity. It is related to velocities, thicknesses and travel path direction through the layers above the reflector.

INTERVAL VELOCITY:

Interval velocity is defined as "thickness of a stratigraphic layer divided by travel time by which a wave travels from top of layer to the bottom".

If we suppose that ΔZ is the thickness of layer and Δt is time taken by a wave to travel from top of layer to the bottom than interval velocity can be written as

Vint =Δ Z/Δt m/sec
ΔZ = Z2-Z1
Δt = t2-t1

Interval velocity can also defined as "velocity of an interval in subsurface measured by determining the travel time over a depth interval along some ray path."
OR
"The average velocity of the interval in the subsurface between two reflections"

AVERAGE VELOCITY:

If "Z" is the depth of a reflector from datum and "t" is one way reflection time from datum to surface, than average velocity is given as

$V_{avg} = Z/t$ m/sec

If we have more then one layer suppose there are N numbers of layers than average velocity is given as

V = ∑Zi /∑t

Where

∑Z i= Z1 +Z2+Z3............. +ZN

Average velocity is true vertical velocity in ground therefore it is used for calculation of depth for the preparing of depth section.

MEAN VELOCITY:

It is define as "sum of average velocities at constant interval of time divided by total number of velocities which are being added". If we have N number average velocities then mean of average velocities is calculated by following relation.

Vmean = (Vave1+Vave2+Vave3............. +VaveN)/N

Mean velocity is used to calculate depth which is further used for the preparation of a depth section.

AVERAGE VELOCITY GRAPH

Average velocity graph can be prepared by proceeding in the following way. First of all we calculate average velocity by using time and interval velocity For this purpose we use following formula

VAVE = ((VINT i-1) (t i – t i-1) – (VAVE i-1) (t i -1))/ t i

Now we plot average velocity against time by keeping average velocity along Y-Axis and time along X-Axis.

Table 4.3:PREPARATION OF AVERAGE VELOCITY GRAPH

TIME	CDP 250	CDP 295	CDP 340	CDP 385	CDP 430	CDP 475	CDP 520
100	3030.15	3044.26	3060.79	3101.19	3074.76	3110.19	3158.72
200	3066.30	3071.62	3083.58	3129.52	3129.52	3151.38	3192.44
300	3102.45	3098.97	3106.38	3157.85	3184.24	3192.56	3226.15
400	3138.60	3126.33	3134.57	3186.17	3238.29	3233.75	3258.65
500	3174.75	3154.83	3168.40	3217.04	3292.33	3274.94	3290.06
600	3207.00	3184.05	3202.22	3253.84	3336.65	3305.87	3321.48
700	3238.86	3213.27	3238.79	3290.64	3362.10	3333.91	3352.89
800	3270.73	3242.49	3276.18	3320.61	3387.55	3361.95	3382.39
900	3302.60	3271.71	3313.57	3348.86	3413.00	3389.99	3408.49
1000	3334.46	3300.98	3350.96	3377.12	3437.25	3418.03	3434.58
1100	3366.33	3330.34	3388.35	3405.38	3461.51	3445.95	3460.68
1200	3396.30	3359.70	3424.93	3433.64	3486.91	3473.83	3486.77
1300	3422.22	3389.06	3454.28	3461.89	3514.74	3501.70	3512.87
1400	3448.15	3418.42	3483.63	3493.60	3550.17	3529.57	3544.37
1500	3474.07	3453.12	3512.98	3529.87	3597.97	3562.16	3578.77
1600	3504.94	3489.07	3542.33	3567.13	3645.78	3598.03	3613.18
1700	3540.01	3525.02	3573.90	3605.39	3693.59	3633.89	3647.59
1800	3575.07	3560.97	3607.70	3643.64	3741.39	3669.76	3682.00
1900	3610.14	3592.29	3641.51	3679.30	3770.71	3705.62	3715.97
2000	3632.75	3622.86	3675.31	3714.53	3795.96	3735.95	3744.18
2100	3653.81	3653.44	3709.11	3749.03	3816.55	3765.31	3772.39
2200	3674.88	3684.01	3742.92	3769.57	3836.24	3794.67	3800.60
2300	3695.94	3714.58	3768.21	3790.11	3856.43	3824.03	3828.81
2400	3715.90	3745.15	3791.63	3810.66	3878.56	3853.39	3857.02
2500	3735.51	3773.75	3815.05	3831.20	3900.69	3882.75	3885.22
2600	3755.12	3795.35	3838.47	3851.74	3922.83	3912.11	3913.43
2700	3774.73	3816.95	3861.89	3872.28	3944.96	3941.47	3941.64
2800	3791.67	3838.54	3885.32	3892.83	3967.10	3970.82	3974.00
2900	3807.37	3857.46	3905.52	3912.09	3989.23	4000.18	4007.33
3000	3823.07	3875.87	3924.93	3928.52	4007.54	4020.42	4030.09
3100	3838.76	3894.27	3944.33	3944.94	4025.51	4039.30	4049.14
3200	3854.46	3912.68	3963.73	3961.36	4043.48	4058.18	4068.18
3300	3870.16	3931.09	3983.14	3977.79	4061.46	4077.06	4087.23
3400	3885.85	3949.49	4002.54	3994.21	4079.43	4095.94	4106.27
3500	3901.55	3967.90	4021.94	4010.64	4097.40	4114.82	4125.32
3600	3917.25	3986.31	4041.35	4027.06	4115.37	4133.70	4144.37
3700	3932.94	4004.71	4060.75	4043.49	4133.35	4152.58	4163.41
3800	3948.64	4023.12	4080.16	4059.91	4151.32	4171.45	4182.46
3900	3964.34	4041.53	4099.56	4076.33	4169.29	4190.33	4201.50
4000	3980.03	4059.93	4118.96	4092.76	4187.27	4209.21	4220.55

4100	3995.73	4078.34	4138.37	4109.18	4205.24	4228.09	4239.59
4200	4011.43	4096.75	4157.77	4125.61	4223.21	4246.97	4258.64
4300	4027.12	4115.15	4177.17	4142.03	4241.19	4265.85	4277.68
4400	4042.82	4133.56	4196.58	4158.45	4259.16	4284.73	4296.73
4500	4058.52	4151.97	4215.98	4174.88	4277.13	4303.61	4315.77
4600	4074.21	4170.37	4235.39	4191.30	4295.11	4322.48	4334.82
4700	4089.91	4188.78	4254.79	4207.73	4313.08	4341.36	4353.86
4800	4105.61	4207.19	4274.19	4224.15	4331.05	4360.24	4372.91
4900	4121.30	4225.59	4293.60	4240.58	4349.03	4379.12	4391.95
5000	4137.00	4244.00	4313.00	4257.00	4367.00	4398.00	4411.00

This data is plotted by keeping average velocity along Y-Axis and time against X-Axis. This gives average velocity graph

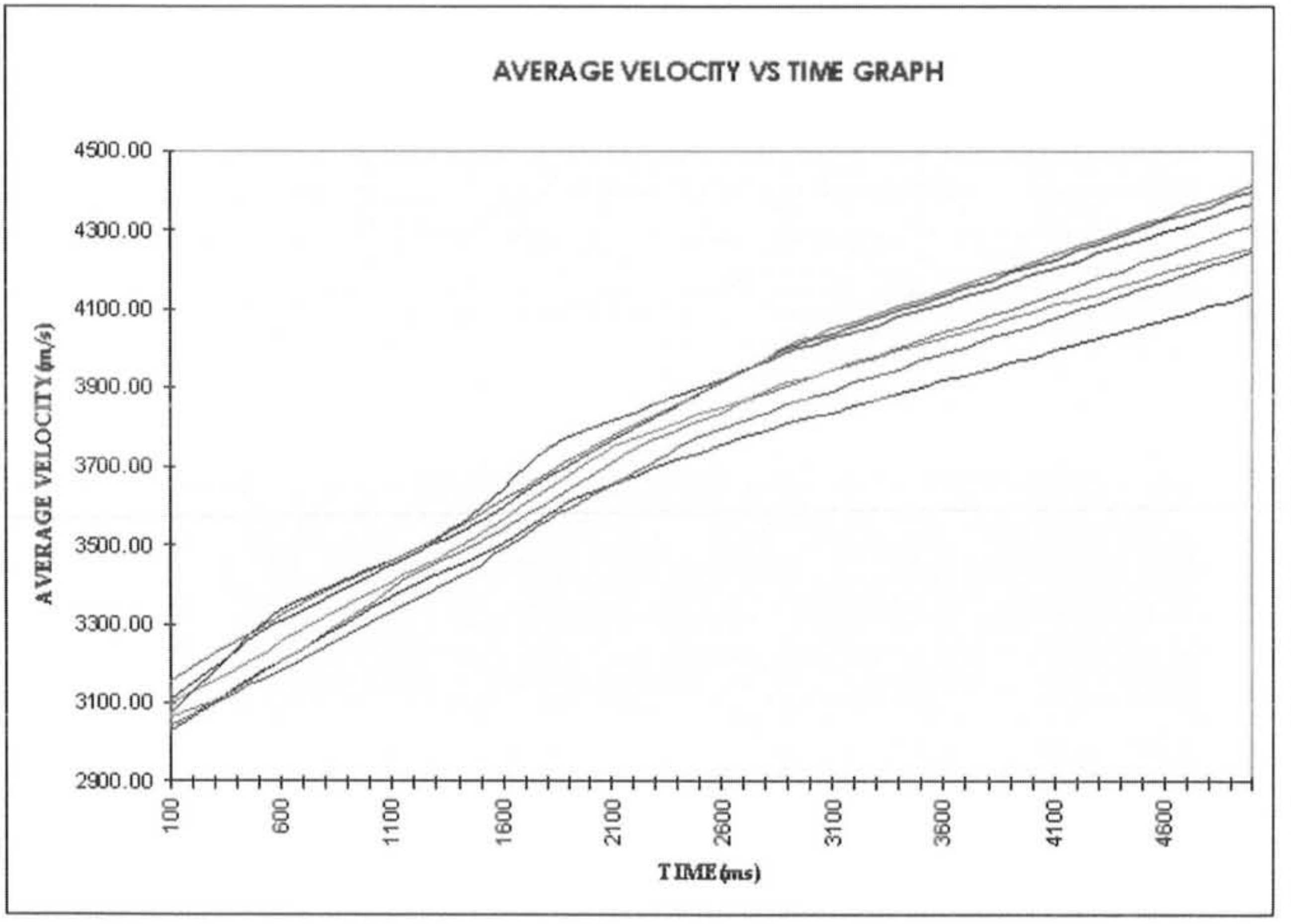


Figure4.3: indicate average velocity graph the vertical variation of average velocity from top to bottom.

Average velocity graph is prepared to observe the vertical variation of average velocity with time from top to bottom. Average velocity is used to calculate the depth of reflector. From which a depth section is drawn.

MEAN VELOCITY GRAPH

Mean velocity graph can be prepared by proceeding in the following way First of all we calculate mean of average velocity by adding average velocities and than divided by total number of velocities which are being added. That is if we have N numbers of average velocities than mean of average velocity is calculated as,

V mean = Vave1+Vave2+Vave3................. +VaveN/N

No we plot mean velocity against time by keeping mean velocity along X-Axis and time along y-axis.

DATA GIVEN FOR MEAN VELOCITY GRAPH IS AS FOLLOW

TIME(msec)	MEAN average velocity(m/s)
100	3082.87
200	3117.76
300	3152.66
400	3188.05
500	3224.62
600	3258.73
700	3290.07
800	3320.27
900	3349.75
1000	3379.06
1100	3408.36
1200	3437.44
1300	3465.25
1400	3495.41
1500	3529.85
1600	3565.78
1700	3602.77
1800	3640.08
1900	3673.65
2000	3703.08
2100	3731.38
2200	3757.56
2300	3782.59
2400	3807.47
2500	3832.03
2600	3855.58
2700	3879.13
2800	3902.90
2900	3925.60
3000	3944.35
3100	3962.32
3200	3980.30
3300	3998.27

3400	4016.25
3500	4034.22
3600	4052.20
3700	4070.18
3800	4088.15
3900	4106.13
4000	4124.10
4100	4142.08
4200	4160.05
4300	4178.03
4400	4196.00
4500	4213.98
4600	4231.96
4700	4249.93
4800	4267.91
4900	4285.88
5000	4303.86

By plotting this data ,mean velocity graph is obtained which is given as.

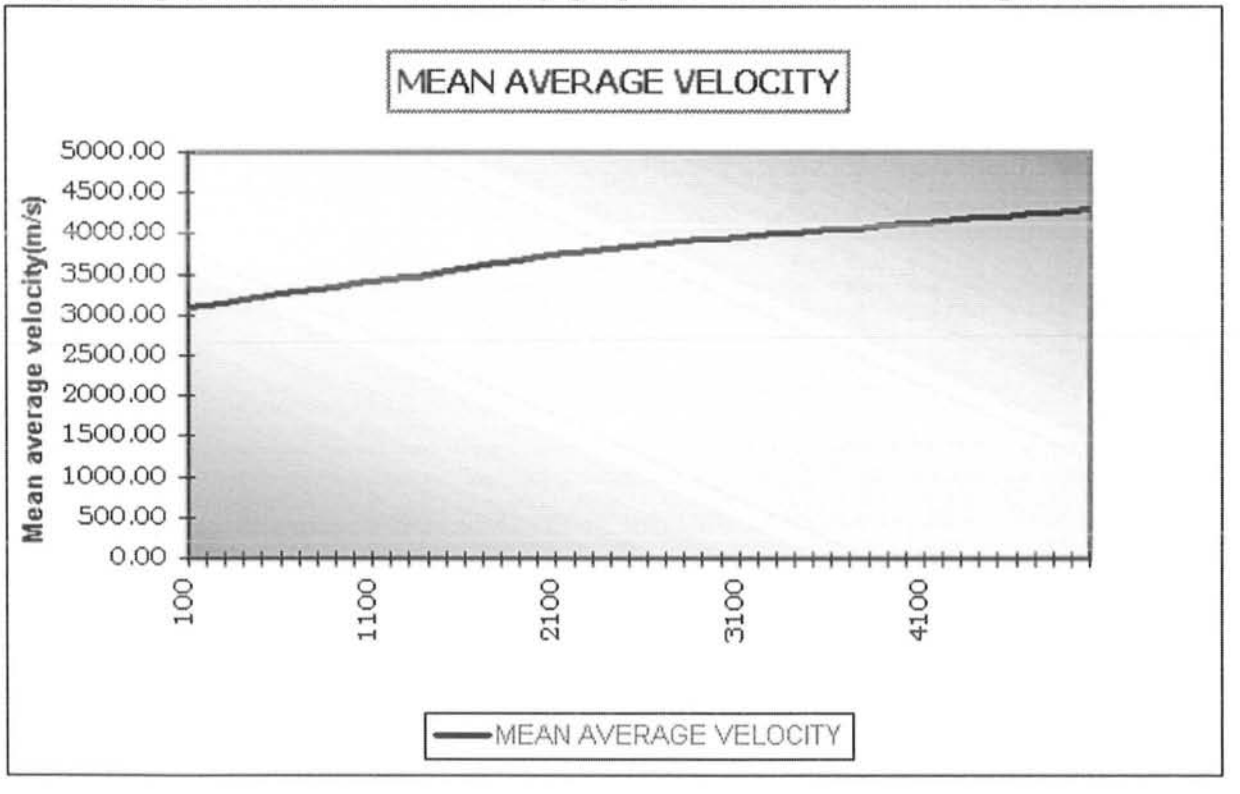


Figure4.4: figure indicate the mean velocity graph it is clear from graph that mean velocity increases with time and depth.

Mean velocity is used to calculate depth of reflectors which is used for the preparation of a depth section.

ISO VELOCITY SECTION

Iso velocity section is actually a velocity contour map which indicates vertical as well as lateral variation of velocity.Vertical variation of velocity is due to following Litho logical changes Over burden pressure AND
Age of formation

Lateral variations in velocity are due to following Folding AND Dipping of strata
Graph which shows velocity contour is called iso velocity map

. **Table 4.4: DATA FOR THE PREPARATION OF ISOVELOCITY MAP**

CDP 295	CDP 340	CDP 385	CDP 430	CDP 475	CDP 520
V ave	V ave	V ave	V ave	V ave	V ave
3018.27	3039.14	3074.28	3022.74	3071.06	3126.69
3018.55	3039.37	3074.57	3023.29	3071.47	3127.02
3018.82	3039.60	3074.85	3023.83	3071.88	3127.36
3019.09	3039.82	3075.13	3024.38	3072.30	3127.70
3019.37	3040.05	3075.42	3024.93	3072.71	3128.03
3019.64	3040.28	3075.70	3025.48	3073.12	3128.37
3019.91	3040.51	3075.98	3026.02	3073.53	3128.71
3020.19	3040.74	3076.27	3026.57	3073.94	3129.05
3020.46	3040.96	3076.55	3027.12	3074.35	3129.38
3020.74	3041.19	3076.83	3027.67	3074.77	3129.72
3021.01	3041.42	3077.12	3028.21	3075.18	3130.06
3021.28	3041.65	3077.40	3028.76	3075.59	3130.39
3021.56	3041.87	3077.68	3029.31	3076.00	3130.73
3021.83	3042.10	3077.97	3029.86	3076.41	3131.07
3022.10	3042.33	3078.25	3030.40	3076.83	3131.41
3022.38	3042.56	3078.53	3030.95	3077.24	3131.74

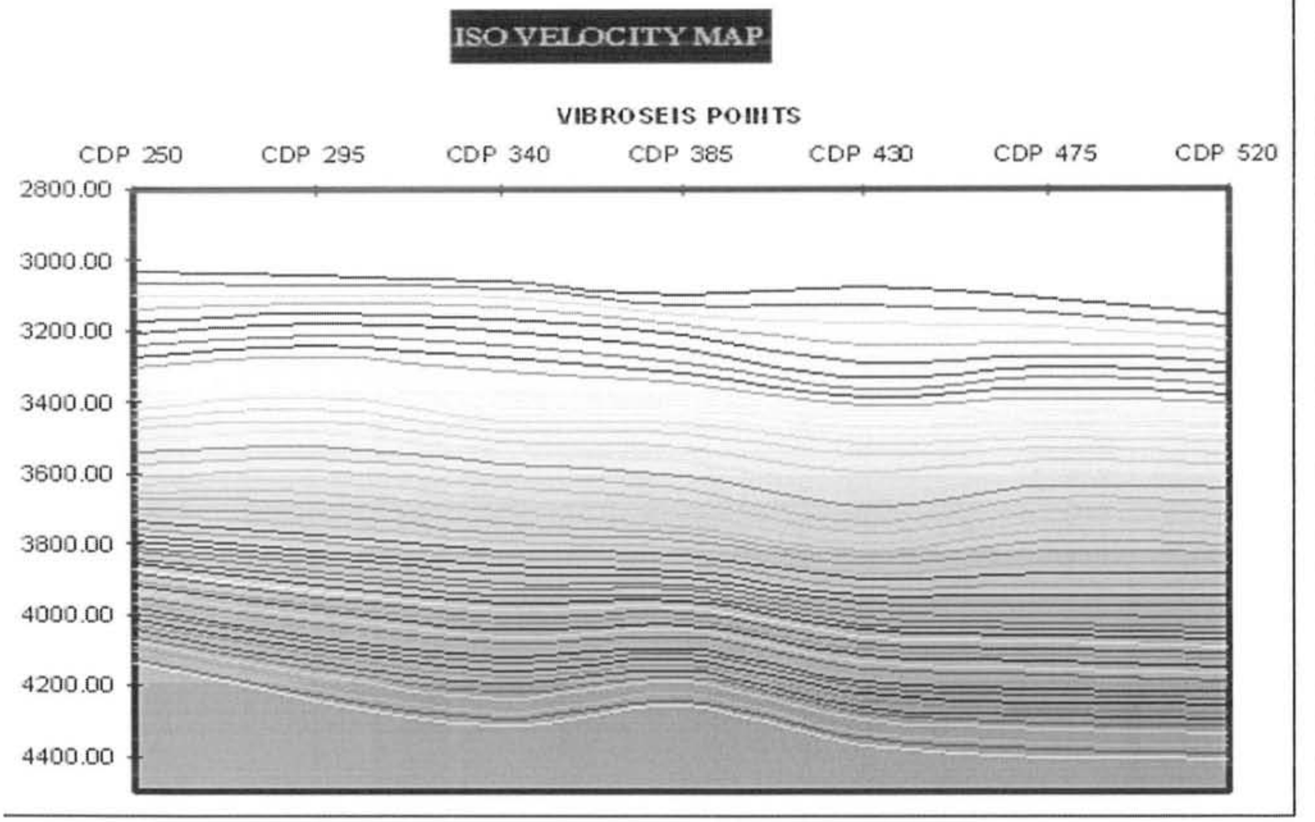


Figure4.5: Isovelocity map indicates the vertical and lateral variation in velocity

Root Mean Square Velocity Method

In this method isovelocity map is plotted by proceeding in the following way Different root mean square velocities are calculated under shot points are calculated

Root mean square velocities are than plotted to obtained isovelocity map. Isovelocity section shows the vertical velocity variation but there is less lateral variation in the velocity. The velocity variation trends are almost smooth indicating the constant change in velocity with time but there are some wavy undulations observed and they are less smoothly curved because it is the true representative of subsurface structure.

SEISMIC DEPTH SECTION

Depth section is obtained by proceeding in following way.
First we calculate mean of average velocity by adding all average velocities And then dividing it by total number of velocities which are being added

Mean average velocity =
Vave1+Vave2+Vave3+.......VaveN/N m/sec

Then multiply mean velocity with time and then divided by 2.time should be taken in seconds in order to obtain depth in meter.
Depth = (Mean average velocity*Time)/2 m.

OR

Depth= (V*t)/2

Where "V" is average velocity and "t" is two way reflection time.

Now we can easily calculate depth of each reflector corresponding to each shot point.

After calculating depth we plot it against shot point by keeping depth along Y-Axis and Shot points along X-Axis.

TABLE 4.6:DEPTH SECTION DATA

	R1(m)	R2(m)	R3(m)	R4(m)	R5(m)	FAULT 1	FAULT 2
VP 110	1186.69	1744.74	1818.77	2043.62	2271.56		
VP 120	1239.54	1837.35	1911.96	2081.33	2309.94		
VP 130	1239.54	1874.60	1968.23	2119.16	2348.55		
VP 140	1204.27	1893.27	2005.89	2138.11	2348.55		
VP 150	1169.09	1893.27	2005.89	2157.09	2367.94	505.54	
VP 160	1029.44	1893.27	1987.05	2157.09	2387.58	1029.44	
VP 170	960.41	1818.77	1968.23	2119.16	2367.94	1561.72	2252.41
VP 180	960.41	1543.58	1671.18	2043.62	2506.37	1949.45	2566.55
VP 190	977.62	1543.58	1652.86	1818.77	2506.37	2252.41	2831.88
VP 200	977.62	1543.58	1652.86	1818.77	2506.37		
VP 210	977.62	1543.58	1652.86	1800.22	2506.37		
VP 220	977.62	1543.58	1671.18	1818.77	2526.34		
VP 230	977.62	1561.72	1671.18	1818.77	2546.42		
VP 240	960.41	1543.58	1652.86	1818.77	2546.42		
VP 250	943.24	1543.58	1652.86	1818.77	2546.42		
VP 260	926.09	1525.47	1634.58	1800.22	2526.34		
VP 270	891.72	1525.47	1652.86	1781.70	2506.37		

DEPTH SECTION

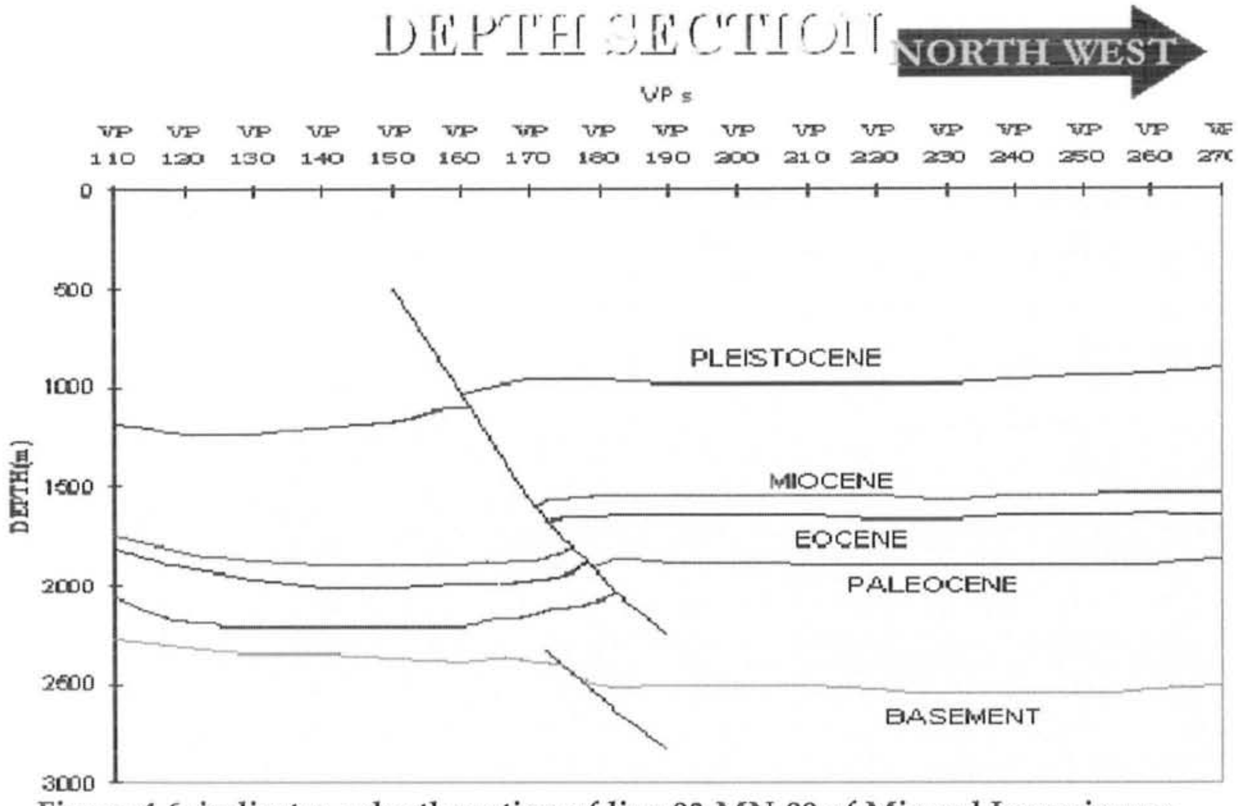


Figure 4.6: indicates a depth section of line 93-MN-09 of Minwal Joyamir area.

When we make a map of seismic time it is intended to show the structure of a horizon in the subsurface. Obviously it does not show the structure directly. Structure is matter of depth and the map is travel time of sound waves. To make a map that is more truly related to the subsurface, depths must be calculated from the times. Here we need true velocities. Generally the depth section gives the configuration of reflectors in the same way as the time section. Remove the kinks of the horizons as much as possible in order to obtain a smoother horizon.

ROCK PHYSICS

Study of Rock Physics Properties:

Rock physics describes a reservoir by rock physical properties such as porosity, rigidity, compressibility, properties that will effect how seismic waves physically travel through the rock & to establish relation between the material properties and the observed seismic response, and to develop a predictive theory so that properties may be detected seismically. Establishing relationship between seismic expression and the physical properties therefore requires a knowledge about the elastic properties of the pore, rock frame & models for rock-fluid interaction.

Thus rock Physics allows to put rock properties together with seismic horizon for a better interpretation because information about porosity, pore-fill, and lithology become available to augment the seismic interpretation.

The rock physics studies uses sonic logs and density logs to establish P-wave (Vp), density, s-wave velocity (Vs), their relationship to elastic modulli k (bulk modulus) and μ (shear modulus), porosity pore fluid, temperature, pressure etc. for lithologies identified on the seismic section.

The Calculations of Rock Physics Parameter

To study the rock physics properties; parameters like; shear modulus, bulk modulus,Vp / Vs ratio, Poisson's ratio and Lame's constant are calculated.

The Calculation of Shear Wave Velocity:

Shear wave velocities has been estimated from castagna's equation (1985)and it is further used to calculate the other rock physics parameters.

$$Vs = (Vp-1.36) / 1.16$$

Vp and Vs are in Km/s

Shear wave velocity is calculated only as a parameter to compute the values of Modulii and Poisson's Ratio as Modulii and Poisson's ratio does not depend upon shear wave velocity but do depends upon compressional wave velocity.

The Density Determination:

Density is a major property of the rock which describes the amount of solid part of the rock body per unit volume. Simply mass per unit volume is called density. Higher denser rocks makes the seismic velocity to drop down. The attenuation is higher for more dense rocks. The case is reverse for the lighter rocks. Seismic velocity is inversely proportional to density.

Direct estimation of density from seismic velocities have been done by using the formula

$$\rho = 0.31 * (Vp)^{0.25}$$

Where ρ = Density, Vp = P-Wave velocity in m/sec.

Density is used in various reflectivity and modulii calculations.

The Bulk Modulus:

Bulk Modulus is also known the modulus of compressibility. This means that this is the measure of how much a rock is compressed when a seismic wave passes through the rock. Certainly different rock types have different values of compressibility due to their porosity, density, mineralogy, grain packing and fluid contents. The fluids in the rock makes the rock stiffer, velocity attenuates in the stiffer zone and hence bulk modulus is increased. Since every fluid has it's own properties and Bulk Modulus values, therefore anomalous zones for hydrocarbons could easily be detected.

Estimation of Bulk Modulus from seismic velocities and density have been done by using the formula

$$K = (Vp^2-1.333*Vs^2)*\rho$$

Where □ =Bulk Modulus, ρ = Density, Vp = P-Wave velocity in m/sec,
Vs =Shear wave velocity

The Shear Modulus:

Shear wave is more anomalous than the compressional waves. But in the case of fluids in the rocks, p-wave become more anomalous than s-waves. Because s-waves cannot pass through fluids and only passes through rock. But p-wave passes through both rock and fluid and hence more anomalous. Estimation of Shear Modulus from shear wave velocity and density have been done by using the formula

$$u=\rho * Vs^2$$

б=Shear modulus, Vs =Shear wave velocity, ρ = Density

The Poisson's Ratio:

Poisson's ratio is defined as the transverse strain divided by longitudinal strain. This means that it is the measure of incompressibility of the rock body.

OR

"it is the measure of transverse distortion as compared to longitudinal distortion." (OGDCL manuals by Zia ur Rehman)

In Post stack data shear wave velocity has been estimated only as a parameter as poststack data do not have shear components. Also Poisson's Ratio is more dependent upon P-wave velocity rather than S-Wave velocity. Estimation of Poisson's ratio from shear wave velocity and density have been done by using the formula

σ = 1/2 (vP2-2vS2)/ (vP2-vS2)).

Where σ =Poisson Ratio, , Vp = P-Wave velocity in m/sec,
Vs =Shear wave velocity.

In other words we can say that the Poisson's Ratio is the measure of the behavior of a seismic wave when it passes through the rock body.

Vp / Vs Ratio:

When a seismic wave passes through the rock body, rock behaves by two ways. One vertical behavior and the other tangential. Vertical behavior is the compressibility (Measure is the Bulk Modulus) and tangential behavior is the rigidity (Measure is the Shear Modulus). Vp / Vs ratio is the combined behavior of the rock body when it passes through through the rock.

Estimation of Vp/Vs Ratio from Bulk modulus and Shear modulus is done by using the formula

Vp/Vs= ((□/ u)+4/3)1/2

Where Vp/Vs= Vp / Vs Ratio, □ =Bulk Modulus , б=Shear modulus

The Calculation of the Lame's Parameter (λ):

It is calculated using the relation

λ = Vp2*ρ-2μ

The Rock Parameters And The Zones Of Interest:

The rock Parameters which used are:
ρ = Density
□ =Bulk Modulus
б=Shear modulus
s =Poisson Ratio
Vp/Vs= Vp / Vs Ratio

The Compressional Wave Impedance:

The Compressional Wave Impedance is estimated by simply multiplying the Compressional Wave velocity with density. mathematically,

Impedance = ρ*Vp

Where ρ = Density, Vp = P-Wave velocity

The Shear Wave Impedance:

The Shear Wave Impedance is estimated by simply multiplying the shear Wave velocity with density. mathematically,

Impedance = ρ*Vs

Where ρ = Density, Vs = S-Wave velocity

The Interval Velocities:

The velocity between two layers or a particular time interval is called interval velocity. Interval velocities are calculated by using the general formula

Interval Velocity =2*((Z2 – Z1) / (T2 – T1))

Where Z2 and Z1 are the depths of bottom and top of the studied interval respectively.
Where as T1 and T2 are the time intervals of bottom and top horizons of the studied interval respectively. The interval velocities for the joyamair area were provided on the seismic section.

The Rock Physics Parameters For Seismic Data:

The Rock Physics parameters for the seismic data have been calculated for each CDP employing the same method as for a well. Poisson's Ratio, Vp / Vs Ratio, Bulk Modulus, Shear Modulus, Velocity, Density, Impedance etc have been calculated.

Vp/Vs Ratio Vs Vp Graph:

Vp/Vs are also the vital parameter of the rock physics. Cross plotting of Vp/Vs ratio with Vp is shown in the following figure4.7

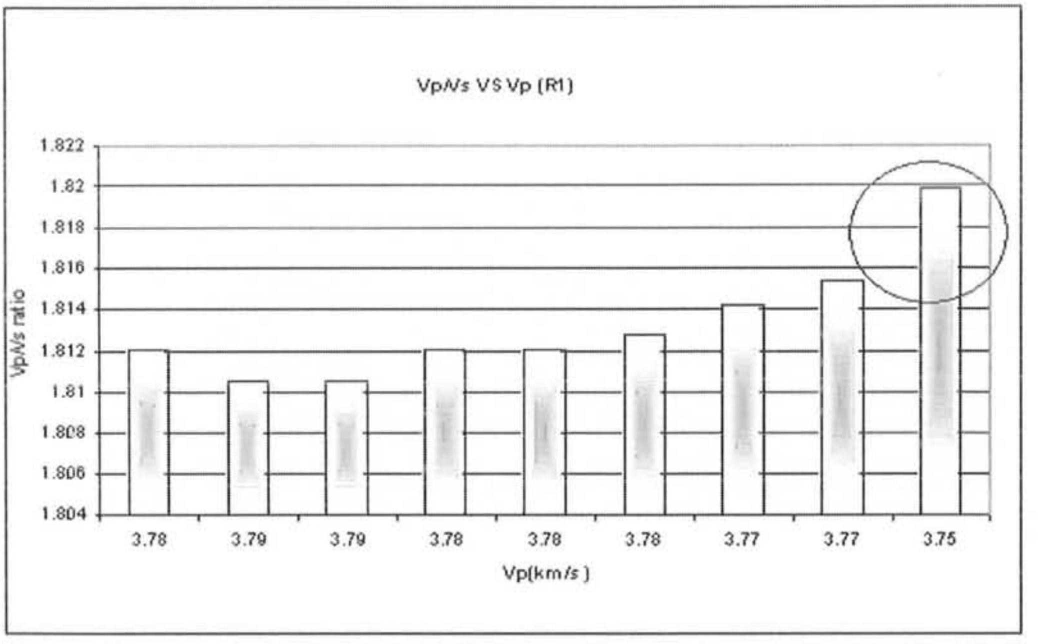


FIG 4.7: showing bar graph of Vp/Vs ratio plotted versus Vp (km/s) for R1 in line 93-MN-09.

As where there is Hydrocarbon. Vp has fewer values as in this case. So., the figure shows the absence of hydrocarbon in the targeted zone.
Where there is chance of hydrocarbon presence, Vp/Vs ratio has higher value because shear waves cannot pass through fluid,so whenever they encounter a hydrocarbon zone,the value of Vs drops abruptly without having effect on p-waves which can pass through all kinds of lithologies.hence Vp decreases while Vp remains normal causing higher value of Vp/Vs ratio.this kind of situation is slightly seen in last encircled portion of graph 4.1 but this is not a very huge change so it is difficult to say that hydrocarbon is present here. As there is unavailability of sufficient amount of data(a half seismic line from VP 190 to VP 270 of 39-MN-09) so this kind of interpretation is difficult.
More graphs of Vp/Vs ratio vs Vs constructed for R2,R3,R4,R5 are shown as fig 4.2,4.3,4.4,4.5 in tables and figures chapter.

Poisson's Ratio Vs Vp Graph:

Poisson's ratio is the important parameter of Rock Physics.Poissons ratio has low values in the Basal sand Formation. Generally Poisson's Ratio has high values in the hydrocarbonzone.Also the values of Vp is high.So there is clear indication of absence of hydrocarbon as shown in the figure 4.6

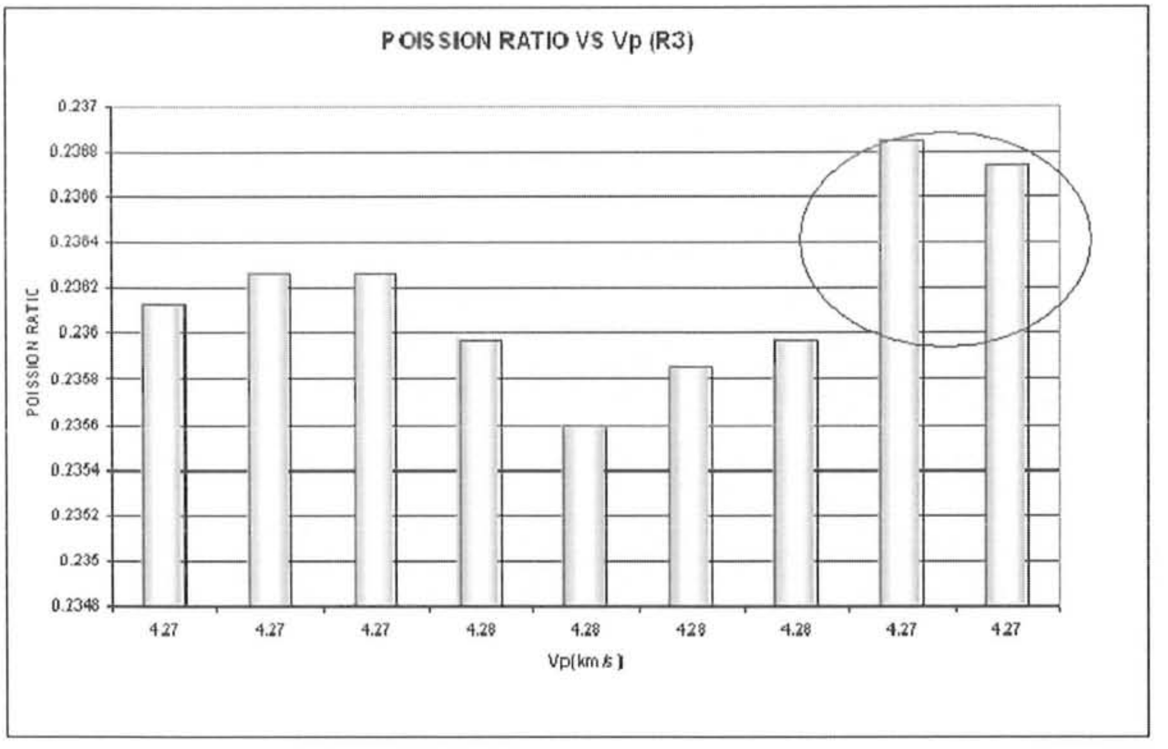


fig 4.8: Showing Poisson ratio vs Vp bar graph for reflector R3 in line :93-MN-09

Poisson ratio for hard rock is usually 0.5.it rarely exceeds this value. (OGDCL manuals by Zia ur Rehman)

In last targeted portion of fig:4.8 Poisson ratio has high value which can be an indication of hydrocarbon presence. But again it is not a huge change.

Fig no.5.7,5.8. 5.9 5.10 show Poisson ratio vs Vp bar graph for reflector 1,2,4,5 in line: 93-MN-09 respectively.

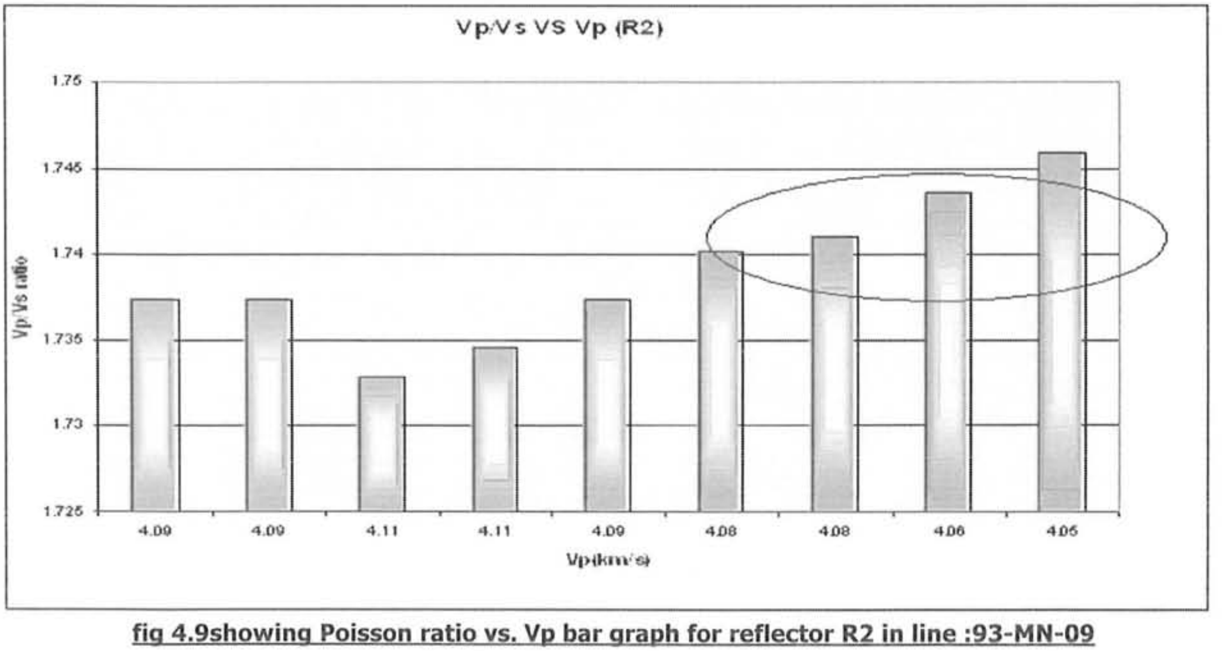


fig 4.9showing Poisson ratio vs. Vp bar graph for reflector R2 in line :93-MN-09

The above Fig 4.9: shows Poisson ratio vs. Vp and here is an important change in Poisson ratio indicates that hydrocarbons can be present or otherwise this lithology is compressible. Here trend of Poisson ratio value is from lower to higher suddenly while Vp (interval velocity) has nearly constant value.

The above Fig 4.10: shows Poisson ratio vs.Vp for R2. And here is an important change in Poisson ratio indicates that hydrocarbons can be present or otherwise this lithology is compressible. Here trend of Poisson ratio value is from lower to higher suddenly while Vp (interval velocity) has nearly constant value

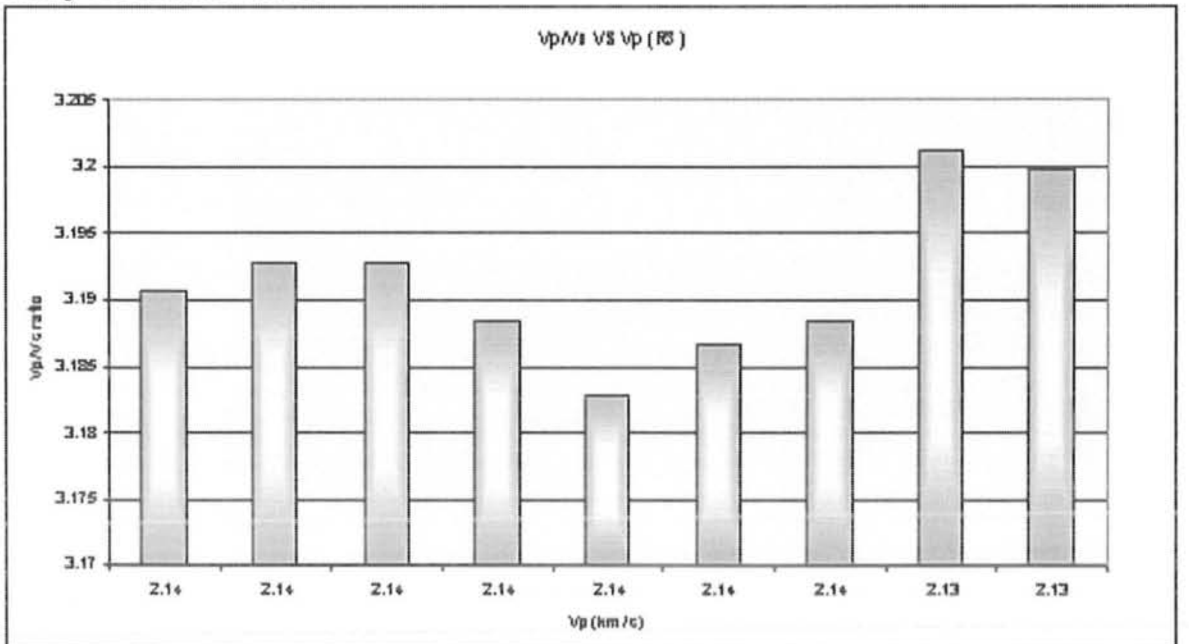


fig 4.12showing bar graph of Vp/Vs ratio plotted versus Vp (km/s) for R3 in line 93-MN-09.

The above figure 4.12 shows trend that Vp increases in farther portion for R3.

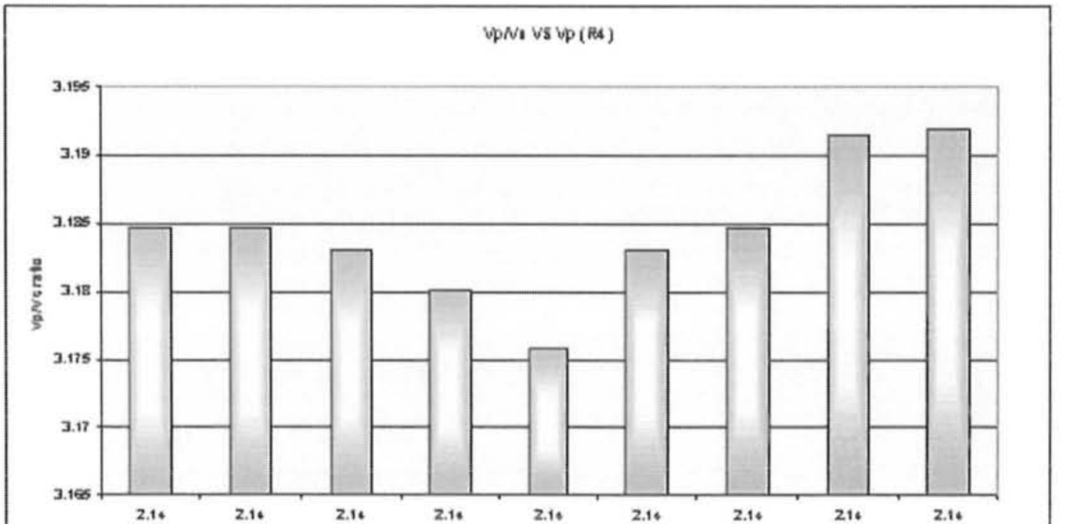


fig 4.13:showing bar graph of Vp/Vs ratio plotted versus Vp (km/s) for R4 in line 93-MN-09.

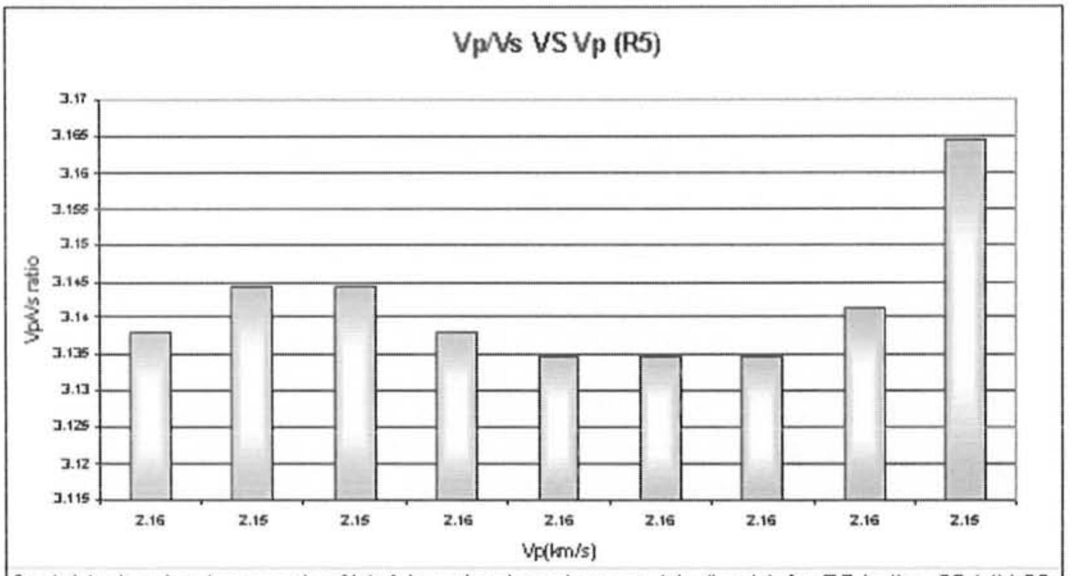


fig 4.14: showing bar graph of Vp/Vs ratio plotted versus Vp (km/s) for R5 in line 93-MN-09.

The above figure shows graph plotted Vp/Vs ratio vs Vp .it shows high value of Vp/Vs in last portion of the graph.

It means that value of Vs has dropped abnormally while Vp is same. And we know that shear waves cannot travel through fluids. So there may be some fluid present or may be some fault is present because velocity also decreases along the discontinuity.

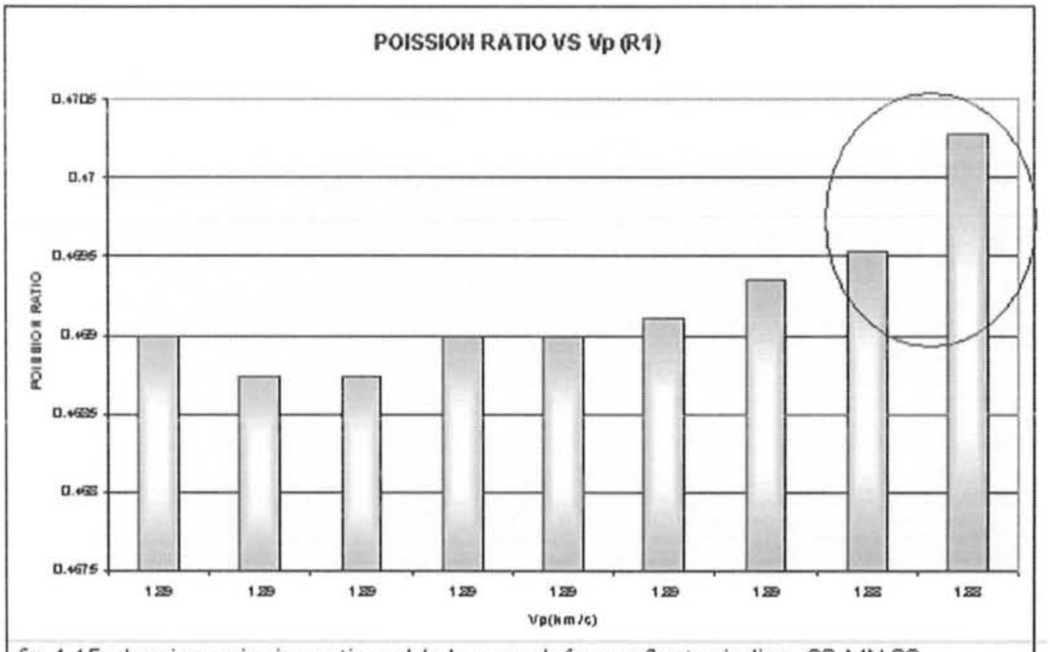


fig 4.15: showing poission ratio vs Vp bar graph for a reflector in line :93-MN-09

Poisson's ratio is the important parameter of Rock Physics.Poissons ratio has low values in the Basal sand Formation. Generally Poisson's Ratio has high values in the hydrocarbon zone. Also the values of Vp is high. So there is clear indication of absence of hydrocarbon as shown in the figure 4.15 But in last portion value of Poission ratio is abnormally high.

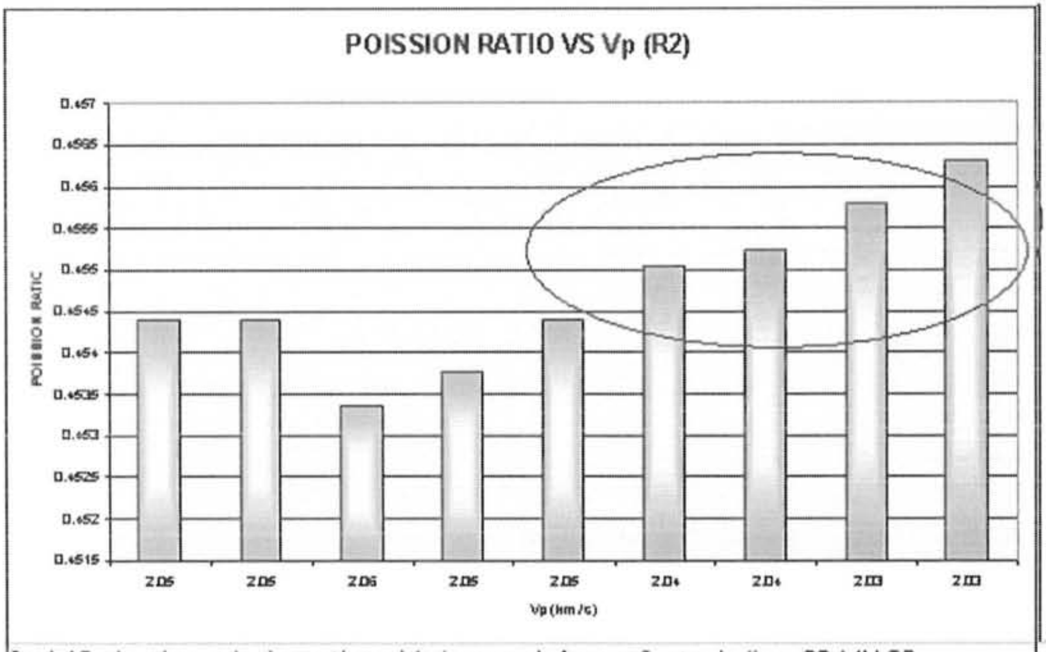


fig 4.16:showing poission ratio vs Vp bar graph for a reflector in line :93-MN-09

The above fig shows constantly increasing values of poission ratio from middle to last part .it may give some information about hydrocarbon presence.

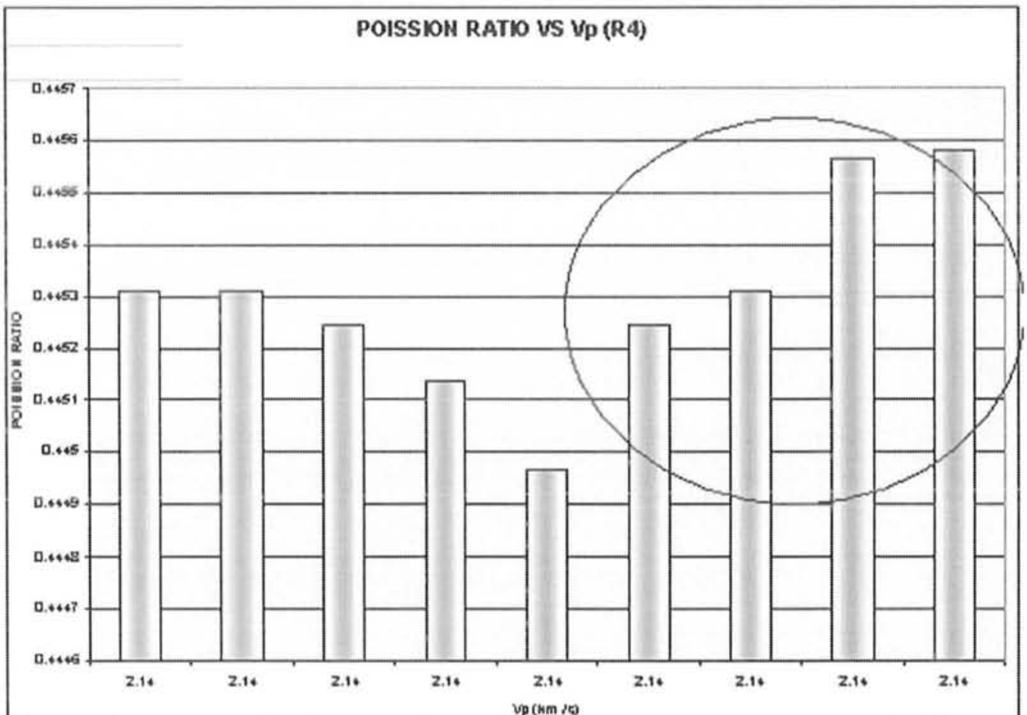


fig 4.17:showing poission ratio vs Vp bar graph for a reflector in line :93-MN-09

The last portion value of Poission ratio is abnormally high.this may give clue of the presence of hydrocarbons.

There are high chances of presence of H-C if such a situation is encountered when there is reliable data available but in our case data is not sufficient to draw valuable conclusions.

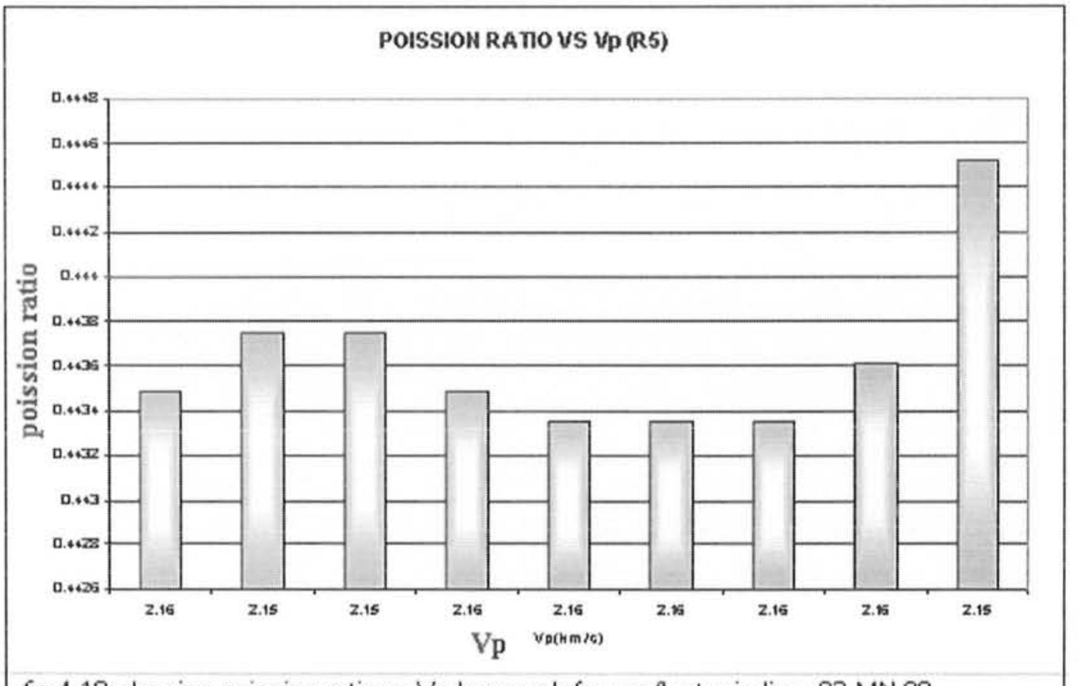


fig 4.18: showing poission ratio vs Vp bar graph for a reflector in line :93-MN-09

In above fig, no clear indication of hydrocarbon.

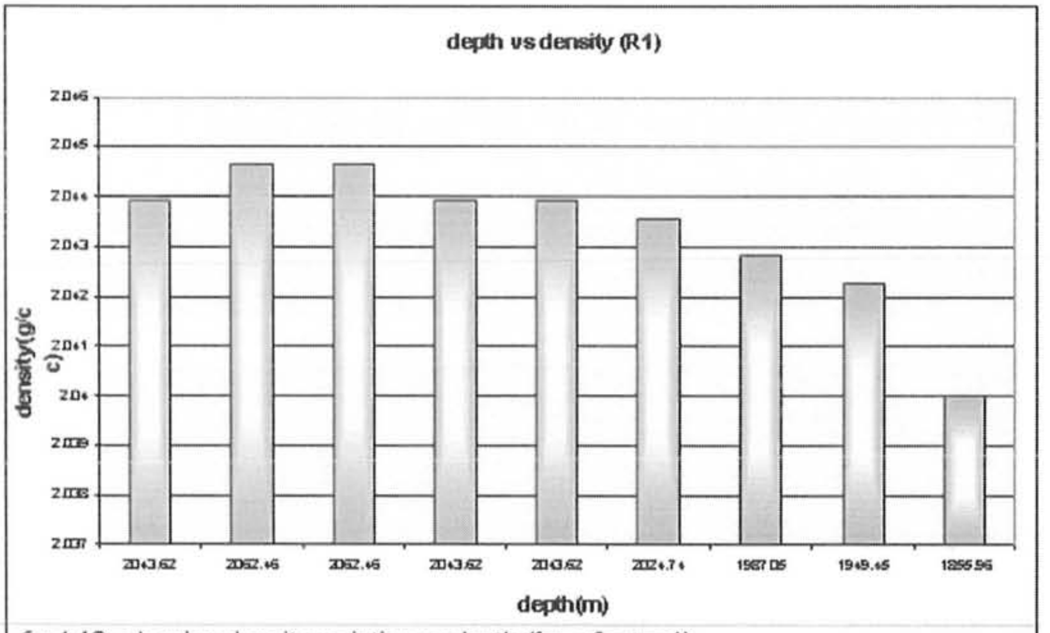


fig 4.19: showing density variation vs depth (for reflector 1)

The above graph plotted dnsity vs depth of R1 on each Vp. this graph doesn't give any evidence of presence of useful information.

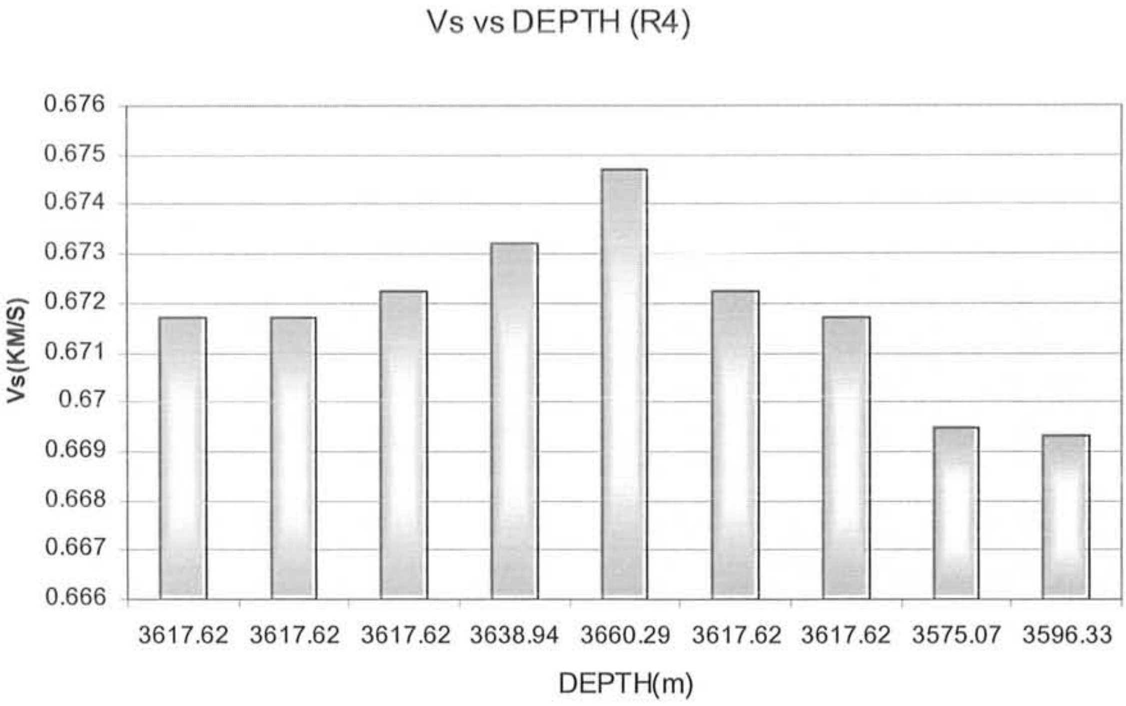


fig 4.20: showing Vs variation vs depth for reflector R4

The above graph b/w Vp vs. depth indicate no clear presence of hydrocarbon. Although Vp decreases in last portion but depth also decreases. So it couldn't be said that HC are present here.

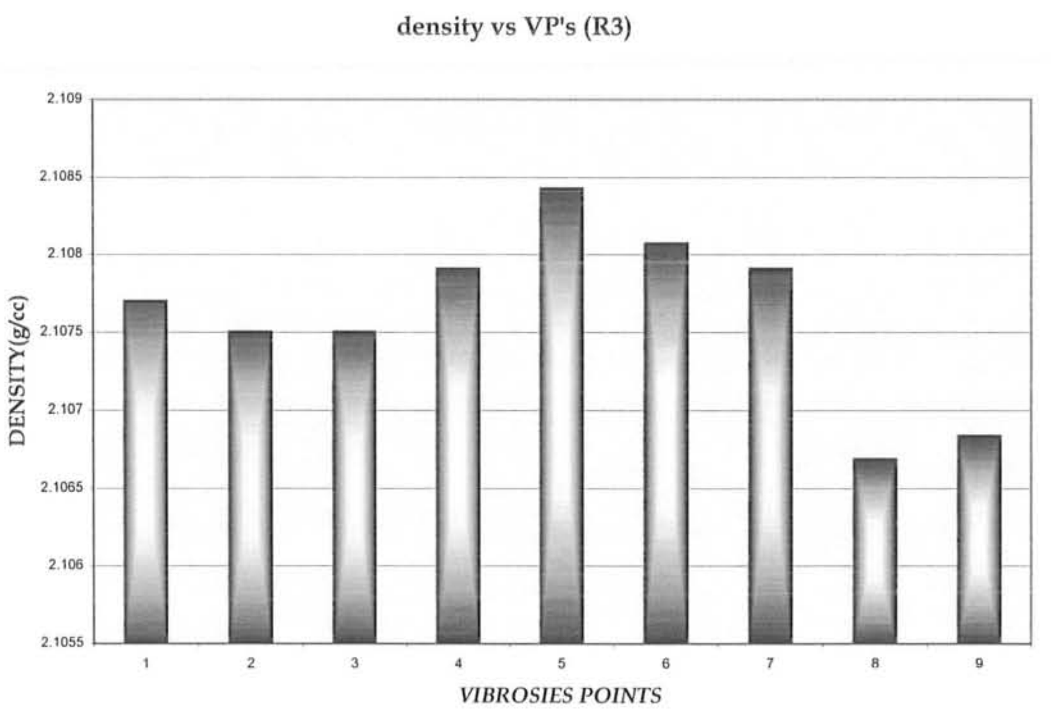


fig 4.21: showing density variations against each vibroseis point for reflector R3

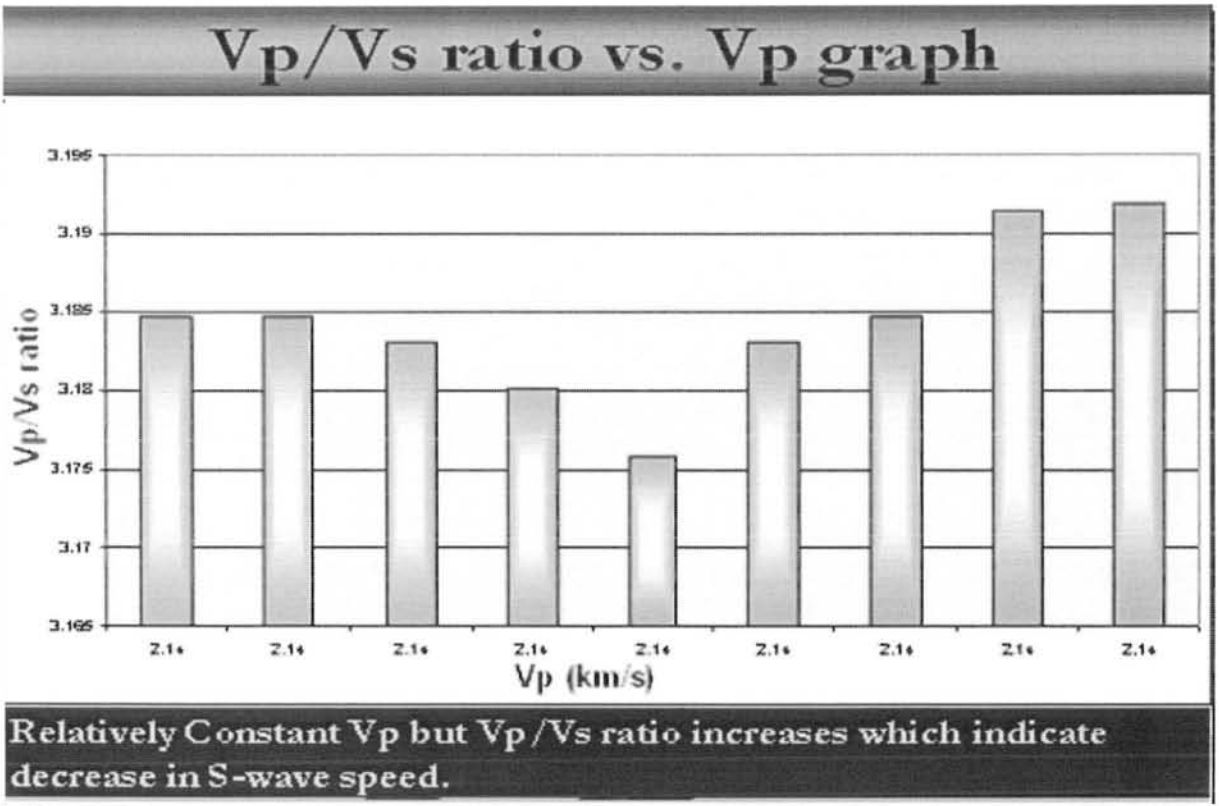


fig 4.21a: showing Vp/Vs ratio variations against Vp for reflector R3

The above figure graph that Vp is nearly constant but at the same time Vp/Vs ratio is increasing. This is indicator of drop in shear wave speed which indicates presence of liquid. But again we have no well data to confidently say that H-C are present but important thing is that analogy is same. and if we have sufficient data, remarkable conclusions can be drawn.

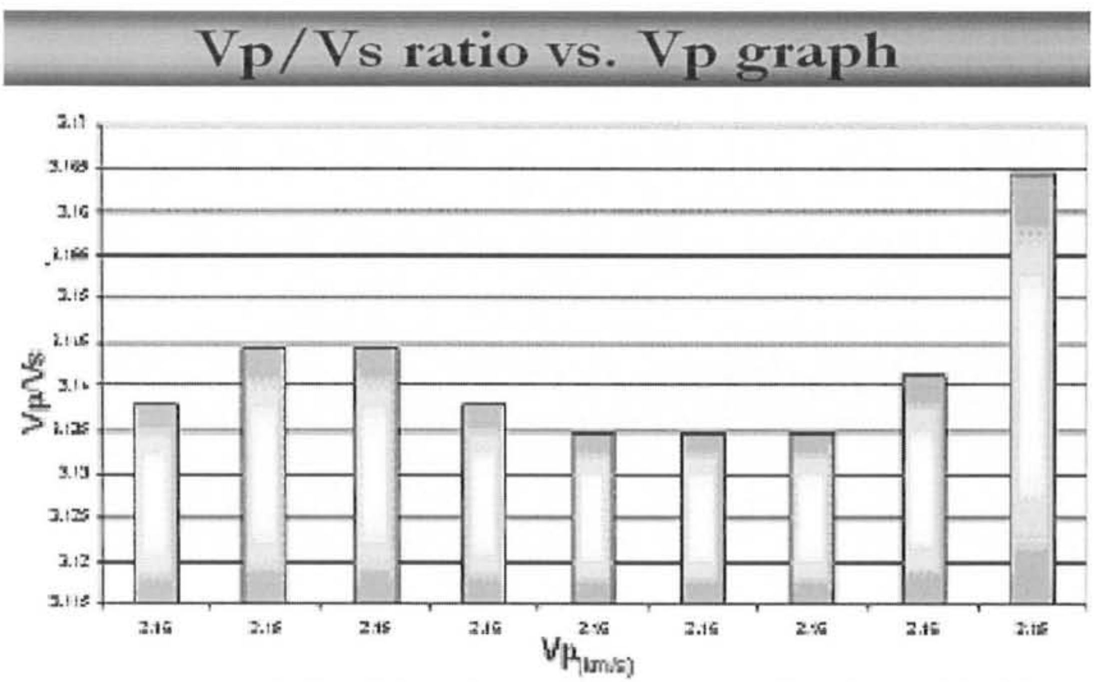


fig 4.21b: showing Vp/Vs ratio variations against Vp for reflector R3

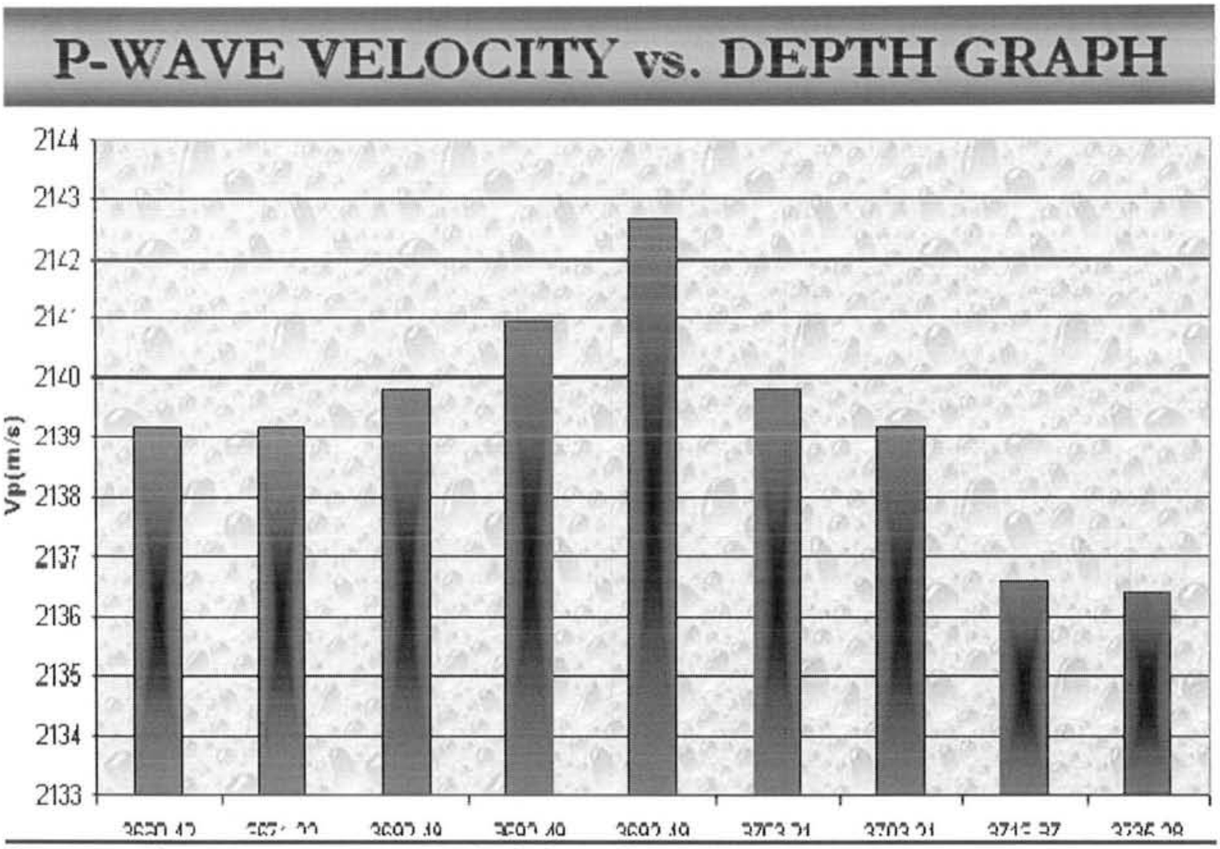


fig 4.21c: showing Vp variation vs depth for reflector R3

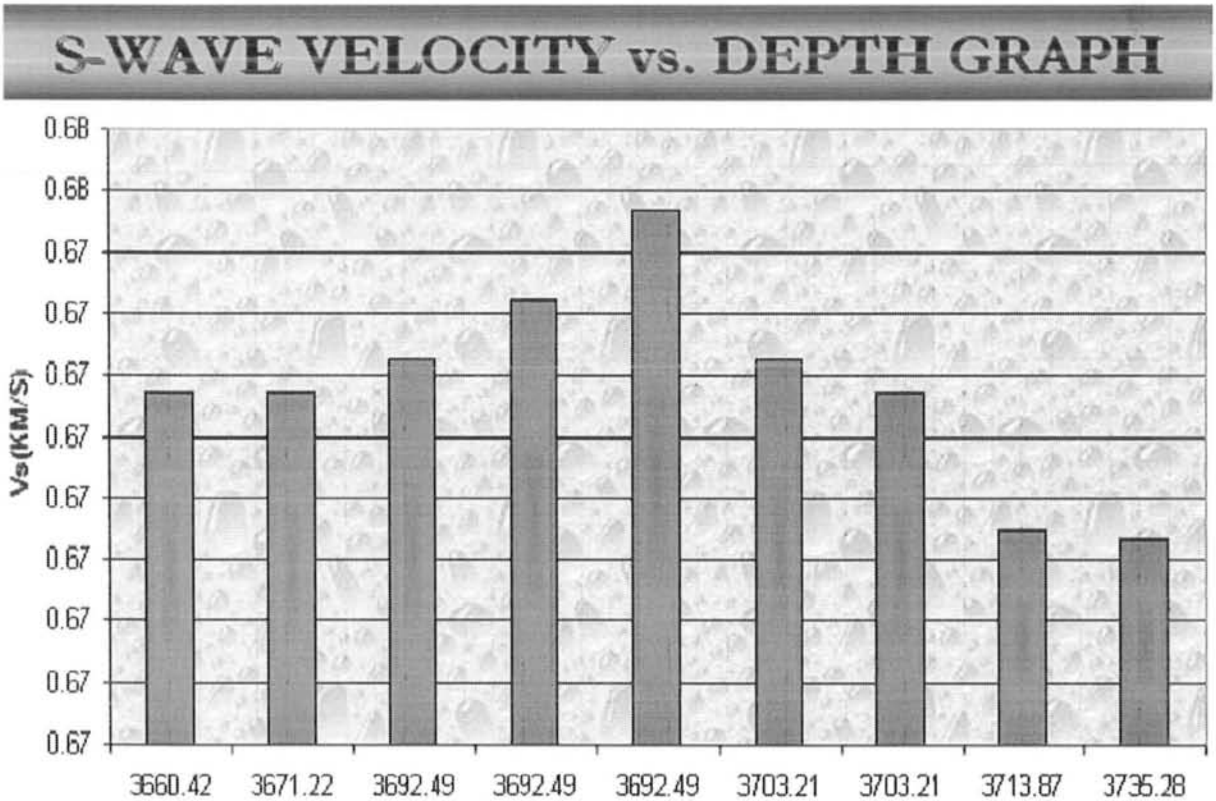


Fig 4.21d: showing Vs variation vs depth for reflector R3

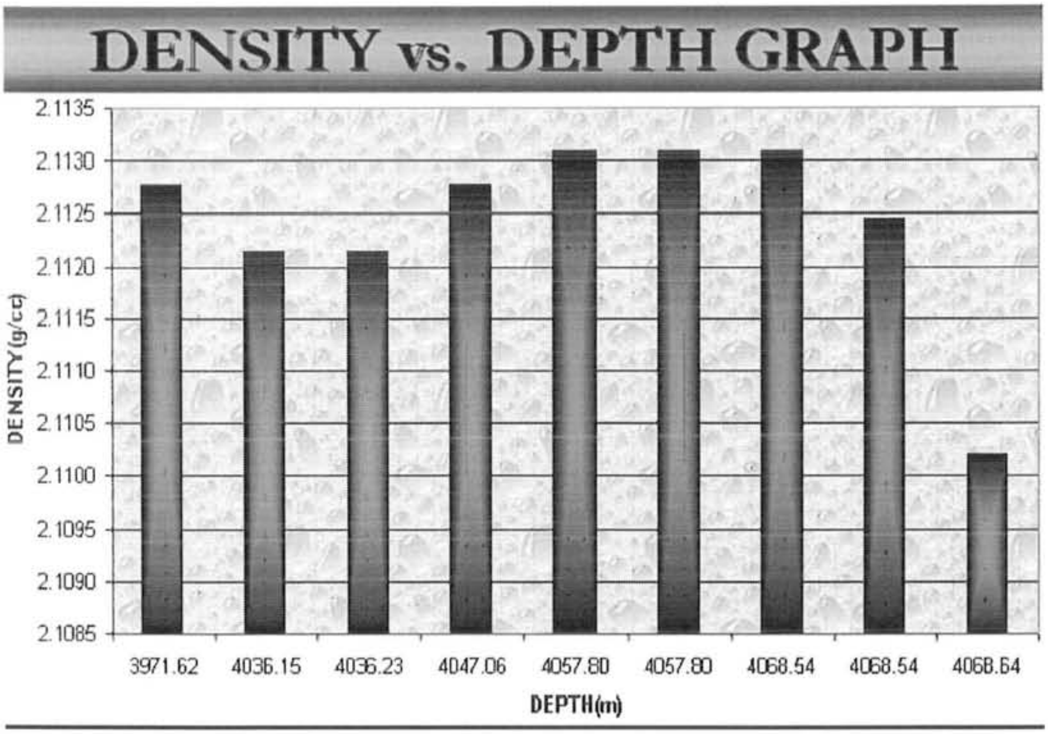


Fig 4.21e: showing density variation vs depth for reflector R3

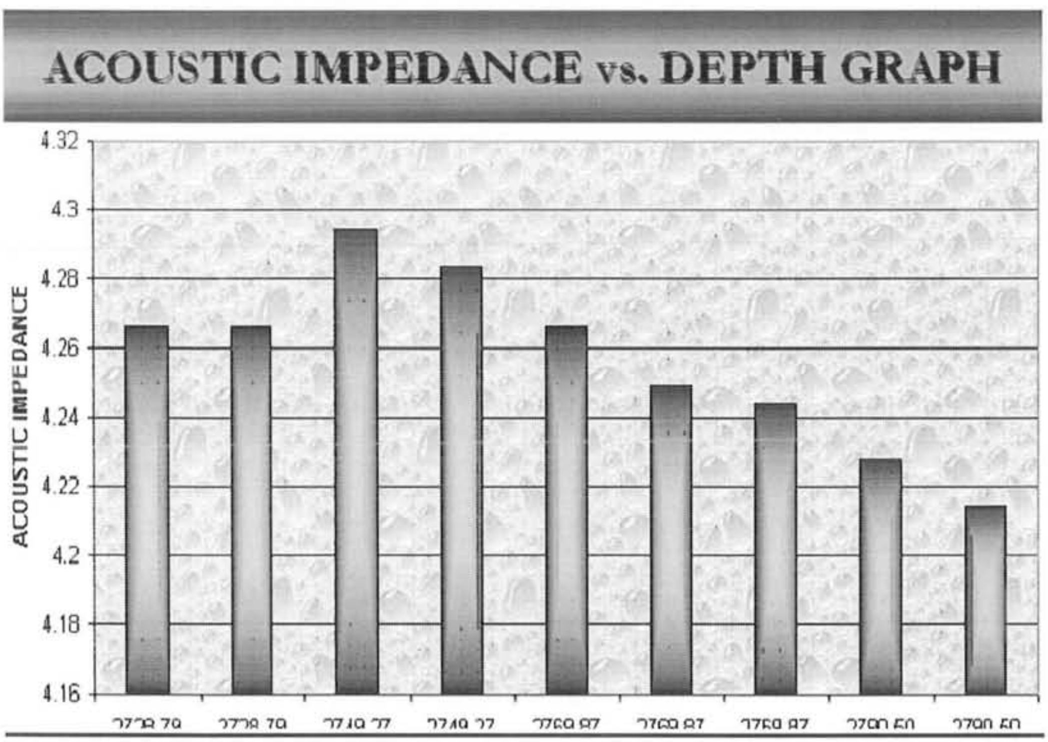


Fig 4.21f: showing acoustic impedance variation vs depth for reflector R3

REFLECTION COEFFICIENT

Reflection co-efficient (R-C):

The amplitude of seismic wave is changed by reflection and refraction.a wave incident on a boundary divides into reflected and refracted P and Sv waves. Because energy must be shared b/w these reflected and refracted waves.they will have smaller amplitude than the incident wave. Ratios that compare the amplitudes of reflected and refracted waves to the amplitude of incident wave can be calculated.suppose that an incident wave of amplitude Ho produces reflected P and Sv waves with amplitudes of H1p and H1s .the ratios

$$R1p = H_{1p} / H_o$$

And

$$R1s = H_{1s} / H_o$$

are called ***Reflection co-efficient***. (Robinson,E.S. & Coruh, C.(1988)

LITHOLOGICAL INTERPRETATION USING REFLECTION CO-EFFICIENT:

Interpretation of lithology can be made by using reflection co-efficient(R-C) method. I.e., certain values of R-C give information about the lithology type.
e.g.,
1) Negative values of R-C shows that formation consists of shale.
2) Values lying between 0.002-0.006 indicate presence of sandstone in the formation.
3) The values greater than 0.006 indicate that limestone is present in the formation.(reference)

METHOD TO CALCULATE REFLECTION CO-EFFICIENT:

To calculate REFLECTION CO-EFFICIENT between two different geologic horizons:we need acoustic impendence of both horizons.The formula of R-C is given below:

$$R\text{-}C = (\rho 2V2 - \rho 1V1) / (\rho 2V2 + \rho 1V1)$$

Where,
$\rho 1$= density of first medium
$\rho 2$= density of second medium
V1=velocity of p-wave in first medium
V2= velocity of p-wave in second medium

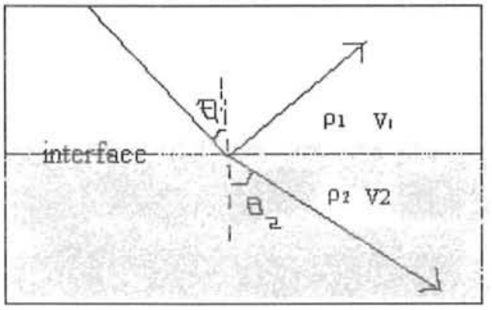


fig 4.22: showing velocities and density contrast across an interface.

V1 and V2 used are the interval velocities usually denoted by Vp.

CALCULATION OF R-C for line 93-MN-09 (from VP 190-VP270):

To calculate R-C FOR THE GIVEN LINE ;following procedure is adopted.
Calculated upper and lower times of each and every reflector marked on seismic section and named them as T2 and T3 respectively.
The time of prominent reflection above each reflector was also calculated denoted as T1.
From solved velocity windows,average velocity Vave for each time is listed opposite to the time.

- Depth d1 is calculated by formula **d1=(V*T1)/2**
- Depth d2 is calculated by formula **d2=(V*T2)/2**
- Depth d3 is calculated by formula **d1=(V*T3)/2**
- Interval velocity Vp1 is then calculated using relation **Vp1=2*(d2-d1)/(T2-T1)**
- Interval velocity Vp2 is then calculated using relation **Vp2=2*(d3-d2)/(T3-T2)**
- Density ρ1 is calculated by **ρ1=.31*(Vp1)^0.25**
- Density ρ2 is calculated by **ρ2=.31*(Vp2)^0.25**
- Then R-C is calculated as **R-C= (ρ2Vp2- ρ1Vp1)/ (ρ2Vp2+ ρ1Vp1)**

Data table of R-C for all reflectors R1-R5 is given in table 5.1

Lithological Interpretation of reflectors of line 93-MN-09 (VP190-VP270):

Lithologies are interpreted on basis of R-C as follows:

For reflector R1:

R1 varies in time from 1.18sec to 1.25sec from VP190 to VP270. The value of reflection coefficient for R1 is 0.04 which indicate that may be lithology of R1 is sandstone. (www.freespace.virgin.net)

For reflector R2:

R3 varies in time from 1.86 sec to 1.9 sec from VP190 to VP270. The value of reflection coefficient for R3 is -0.02 which indicate that lithology of R3 may be is sandstone. (www.freespace.virgin.net)

For reflector R3:

R4 varies in time from 2.01 sec to 2.05 sec from VP190 to VP270. The value of reflection coefficient for R4 is 0.04 which probably indicate that lithology of R4 is sandstone.(www.freespace.virgin.net)

For reflector R4:

R5 varies in time from 2.15 sec to 2.21 sec from VP190 to VP270. The value of reflection coefficient for R5 is –4.84E-16 which indicate that lithology of R5 is shale. (www.freespace.virgin.net)

Thus on basis of reflection co-efficient, lithologies can be interpreted

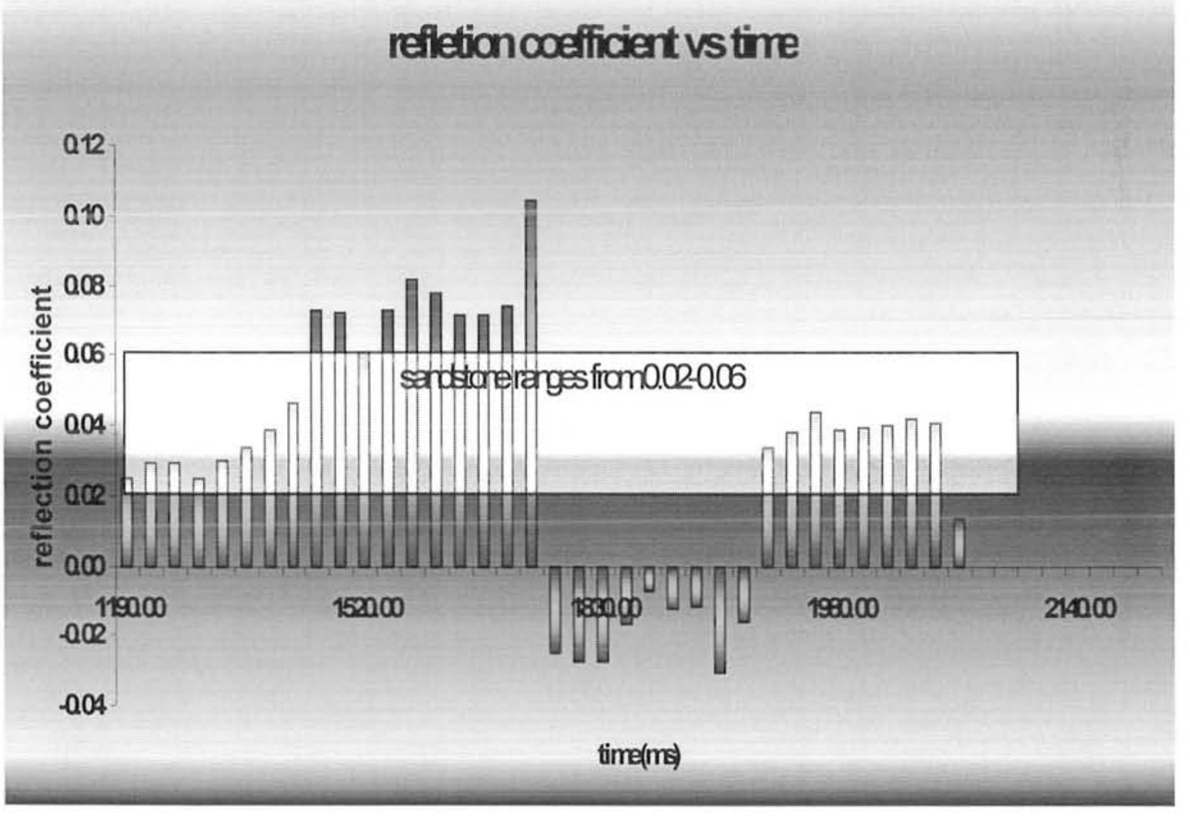


Fig 4.23:This graph b/w time and R-C shows that at certain times .R-C has changed.

The semi transparent portion shows range of sandstone.Negative values are for shale whereas limestone has value greater than 0.06 .

CONCLUSIONS:

- Total five reflectors (R1, R2, R3, R4, R5) & two faults (F1 and F2) were marked.

  On basis of Stratigraphy of the area :

  Reflector R1 is SIWALIKS of Pleistocene.
  Reflector R2 is MURREE Fm of Miocene
  Reflector R3 is CHORGALI Fm of Eocene
  Reflector R4 is LOCKHART Fm of Paleocene
  Reflector R5 is Basement.

- Lithological interpretation has been made on basis of reflection co-efficient.

- Other parameters relating Rock physics Vs--, bulk modulus, shear modulus, Vp/Vs ratio Poisson ratio and lame's parameter were calculated.

- As the study area lies in compressional regime, regional scale reverse faults are observed, making pop-up geometries favorable for the accumulation of hydrocarbons.

- Lithologic characterization for a particular Interval Velocity have been done.

- The area has thick deposition as basement is encountered approximately at depth of 5000m.
- On the basis of velocity, density, Impedance and reflection coefficient It can be suggested that the lithology of

- R1 is mainly mixture of sand and shale.
- R2 is majorly SANDSTONE.
- R3 is majorly limestone and shale.
- R4 is mainly limestone.

- The given data is not sufficient to draw most accurate conclusions.

REFRENCES:

- Dobrin, M.B. (1976) "Introduction to Geophysical Prospecting" (third edition). Mc Graw Hill, London.
- Kadri, I.B. (1995) "Petroleum Geology of Pakistan" PPL Pakistan.
- Kazmi, A.H. & Abbas, S.G "Metallogeny and Mineral Deposits of Pakistan", Orient Petroleum Inc.
- Kazmi, A.H. & Jan, M.Q. (1997) "Geology and Tectonic of Pakistan" Graphic publishers, Karachi, Pakistan.
- Khan Z.R (1989) "Practical Seismic Data Processing", Oil and Gas Training Institute, Islamabad.
- Khan, M.A (2004) "Introduction to Seismic Data Acquisition", Oil and Gas Training Institute, Islamabad.
- Khan, Z.R (1988) "Fundamental Of Seismic Data Processing", Oil and Gas Training Institute, Islamabad.
- LISA M. et.al.2004
- Robinson,E.S. & Coruh, C.(1988)"Basic Exploration Geophysics", John Wiley & Sons, Inc New York
- Tarbuck, E.D & Lutgens, F. K "Earth Science" (Eight edition) 1997, Prentice Hall, New Jersey.
- Telford, W.M, Geldort, L.P, Sheriff, R.E. "Applied Geophysics" (second edition), Cambridge University Press.
- Yilmaz, O. (2001) "Seismic Data Analysis: Processing, Inversion and Analysis of Seismic Data" Society of Exploration Geophysics, Tulsa.
- www.freespace.virgin.net
- www.earth.google.com
- www.thefreedictionary.com

TABLES
&
FIGURES

TABLE 5.1:ROCK PHYSICS PARAMETERS FOR R1, R2, R3, R4,R5

R1	Vint(m/s)	Density (g/cc)	ac imp	Vs(km/s)	s wave impedance	shear modulus	bulk modulus	Vp/Vs	poisson ratio (s)	Lame's parameter
VP 190	1889.77	2.04	3.86	0.46	0.93	0.43	6.73	4.14	0.47	4.25
VP 200	1892.55	2.04	3.87	0.46	0.94	0.43	6.75	4.12	0.47	4.24
VP 210	1892.55	2.04	3.87	0.46	0.94	0.43	6.75	4.12	0.47	4.24
VP 220	1889.77	2.04	3.86	0.46	0.93	0.43	6.73	4.14	0.47	4.25
VP 230	1889.77	2.04	3.86	0.46	0.93	0.43	6.73	4.14	0.47	4.25
VP 240	1888.35	2.04	3.86	0.46	0.93	0.42	6.72	4.15	0.47	4.26
VP 250	1885.74	2.04	3.85	0.45	0.93	0.42	6.70	4.16	0.47	4.28
VP 260	1883.61	2.04	3.85	0.45	0.92	0.42	6.69	4.17	0.47	4.29
VP 270	1875.32	2.04	3.83	0.44	0.91	0.40	6.64	4.22	0.47	4.34

R2	Vint(m/s)	Density (g/cc)	ac imp	Vs(km/s)	s wave impdnce	shear modulus	bulk modulus	Vp/Vs	poisson ratio (s)	Lame's parameter
VP 190	2046.19	2.08	4.27	0.59	1.23	0.73	7.76	3.46	0.45	2.62
VP 200	2046.19	2.08	4.27	0.59	1.23	0.73	7.76	3.46	0.45	2.62
VP 210	2057.02	2.09	4.29	0.60	1.25	0.75	7.83	3.42	0.45	2.45
VP 220	2052.85	2.09	4.28	0.60	1.25	0.74	7.80	3.44	0.45	2.52
VP 230	2046.19	2.08	4.27	0.59	1.23	0.73	7.76	3.46	0.45	2.62
VP 240	2039.58	2.08	4.25	0.59	1.22	0.72	7.71	3.48	0.46	2.72
VP 250	2037.62	2.08	4.24	0.58	1.22	0.71	7.70	3.49	0.46	2.75
VP 260	2031.55	2.08	4.23	0.58	1.20	0.70	7.66	3.51	0.46	2.83
VP 270	2026.28	2.08	4.21	0.57	1.19	0.69	7.62	3.53	0.46	2.90

R3	Vint(m/s)	Density (g/cc)	ac imp	Vs(km/s)	s wave impdnce	shear modulus	bulk modulus	Vp/Vs	poisson ratio (s)	Lame's parameter
VP 190	2136.92	2.11	4.50	0.67	1.41	0.95	8.36	3.19	0.45	0.99
VP 200	2136.12	2.11	4.50	0.67	1.41	0.94	8.36	3.19	0.45	1.01
VP 210	2136.12	2.11	4.50	0.67	1.41	0.94	8.36	3.19	0.45	1.01
VP 220	2137.76	2.11	4.51	0.67	1.41	0.95	8.37	3.19	0.45	0.97

VP 230	2139.87	2.11	4.51	0.67	1.42	0.95	8.38	3.18	0.45	0.93
VP 240	2138.42	2.11	4.51	0.67	1.41	0.95	8.37	3.19	0.45	0.96
VP 250	2137.76	2.11	4.51	0.67	1.41	0.95	8.37	3.19	0.45	0.97
VP 260	2132.83	2.11	4.49	0.67	1.40	0.94	8.34	3.20	0.45	1.08
VP 270	2133.43	2.11	4.49	0.67	1.40	0.94	8.34	3.20	0.45	1.06

R4	Vint(m/s)	Density (g/cc)	ac imp	Vs(km/s)	s wave impedance	shear modulus	bulk modulus	Vp/Vs (s)	poisson ratio	Lame's parameter
VP 190	2139.18	2.11	4.51	0.67	1.42	0.95	8.38	3.18	0.45	0.94
VP 200	2139.18	2.11	4.51	0.67	1.42	0.95	8.38	3.18	0.45	0.94
VP 210	2139.81	2.11	4.51	0.67	1.42	0.95	8.38	3.18	0.45	0.93
VP 220	2140.92	2.11	4.51	0.67	1.42	0.96	8.39	3.18	0.45	0.90
VP 230	2142.65	2.11	4.52	0.67	1.42	0.96	8.40	3.18	0.44	0.87
VP 240	2139.81	2.11	4.51	0.67	1.42	0.95	8.38	3.18	0.45	0.93
VP 250	2139.18	2.11	4.51	0.67	1.42	0.95	8.38	3.18	0.45	0.94
VP 260	2136.59	2.11	4.50	0.67	1.41	0.94	8.36	3.19	0.45	1.00
VP 270	2136.43	2.11	4.50	0.67	1.41	0.94	8.36	3.19	0.45	1.00

R5	Vint(m/s)	Density (g/cc)	ac imp	Vs(km/s)	s wave impdnce	shear modulus	bulk modulus	Vp/Vs (s)	poisson ratio	Lame's parameter
VP 190	2157.57	2.11	4.56	0.69	1.45	1.00	8.50	3.14	0.44	0.54
VP 200	2154.96	2.11	4.55	0.69	1.45	0.99	8.49	3.14	0.44	0.60
VP 210	2154.96	2.11	4.55	0.69	1.45	0.99	8.49	3.14	0.44	0.60
VP 220	2157.57	2.11	4.56	0.69	1.45	1.00	8.50	3.14	0.44	0.54
VP 230	2158.88	2.11	4.56	0.69	1.46	1.00	8.51	3.13	0.44	0.51
VP 240	2158.88	2.11	4.56	0.69	1.46	1.00	8.51	3.13	0.44	0.51
VP 250	2158.88	2.11	4.56	0.69	1.46	1.00	8.51	3.13	0.44	0.51
VP 260	2156.27	2.11	4.56	0.69	1.45	1.00	8.49	3.14	0.44	0.57
VP 270	2147.10	2.11	4.53	0.68	1.43	0.97	8.43	3.16	0.44	0.77

TABLE 5.2:REFLECTION COEFFICIENT DATA FOR REFLECTORS R1,R2, R3, R4

R1	mean velocity(m/s)	Vp 1(m/s)	Vp 2(m/s)	density 1	density 2	R C	lithology
VP 190	3417.15	3764.34	3779.54	2.43	2.43	0.015	shale
VP 200	3420.08	3767.22	3785.11	2.43	2.43	0.018	shale
VP 210	3420.08	3767.22	3785.11	2.43	2.43	0.018	shale
VP 220	3417.15	3764.34	3779.54	2.43	2.43	0.015	shale
VP 230	3414.22	3761.62	3779.54	2.43	2.43	0.018	shale
VP 240	3411.29	3756.34	3776.69	2.43	2.43	0.020	sandstone
VP 250	3408.36	3748.23	3771.48	2.43	2.43	0.023	sandstone
VP 260	3405.43	3739.44	3767.22	2.42	2.43	0.028	sandstone
VP 270	3387.85	3707.22	3750.63	2.42	2.43	0.044	sandstone
R2	**mean velocity(m/s)**	**Vp 1(m/s)**	**Vp 2(m/s)**	**density 1**	**density 2**	**R C**	**lithology**
VP 190	3512.31	4045.55	4092.38	2.47	2.48	0.043	sandstone
VP 200	3519.32	4052.57	4092.38	2.47	2.48	0.037	sandstone
VP 210	3526.34	4066.60	4114.04	2.48	2.48	0.043	sandstone
VP 220	3515.82	4052.57	4105.69	2.47	2.48	0.049	sandstone
VP 230	3508.81	4041.84	4092.38	2.47	2.48	0.047	sandstone
VP 240	3505.42	4032.78	4079.15	2.47	2.48	0.043	sandstone
VP 250	3505.42	4028.95	4075.24	2.47	2.48	0.043	sandstone
VP 260	3502.02	4015.32	4063.09	2.47	2.48	0.044	sandstone
VP 270	3495.41	3985.34	4052.57	2.46	2.47	0.063	limestone
R3	**mean velocity(m/s)**	**Vp 1(m/s)**	**Vp 2(m/s)**	**density 1**	**density 2**	**R C**	**lithology**
VP 190	3621.42	4290.93	4273.84	2.51	2.51	0.082	limestone