2D SEISMIC REFLECTION DATA

INTERPRETATION OF MIANWALI AREA IN PAKISTAN

By

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CERTIFICATE

This thesis of **Rashid Mehmood** is accepted in its present form by the Department of Earth sciences as satisfying the thesis requirement for the award of M.Sc. degree in Geophysics.

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DEDICATED TO MY PARENTS

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All thanks to Al-mighty Allah, Whose blessing empowered me to complete this dissertation successfully. I pay my tribute to the Holy Prophet Muhammad(PBUH), Whose life is perfect model for whole humanity.

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ABSTRACT

The department provided the migrated seismic section of Mianwali area of Pakistan. The aim of this dissertation is to interpret this seismic reflection data. This is a migrated processed 30 fold seismic section of line # 904-MWI-8A. The length of seismic line is 38.25 km and is oriented in direction SE-NW .The data acquisition as well as processing was done by OGDCL.

For the interpretation of this seismic data, three reflectors are marked on the basis of prominent reflection and change in lithology. The velocity information in the form of RMS and interval velocities at different CDPs is provided, from which the average velocities at these time are calculated with the help of Dix formula. Using respective time and velocity estimate the depth of each reflector was calculated.

The depth section is then plotted between depth of each reflector and shot points.The well log data of Kundian-01 and stratigraphical information of the area a reliable subsurface geological model has been formulated. This shows that reflectors have gentle slope and dipping with low angle towards NW.R2 is recognized an unconformity on the basis of well log data, Stratigraphy of the area and presence of pinch outs.The sequence present above unconformity is correlated to Siwalik Group comprising of Chingi and Nagri formations. While sequences below unconformity are Permian strata. Sedimentary column is thin towards south and there is uplifting towards south of the area due to Sargodha high, where formations are pinching out.Many faults are present which are mostly normal faults.

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Chapter#1

INTRODUCTION

1.1) The Project

The present study is based on interpretation of seismic reflection data collected and processed by Oil and Gas Development Company Limited (OGDCL) of Pakistan in Mianwali area. Seismic reflection gives the information about the subsurface lithology. In this method, physical measurements are made on the ground surface, and information is collected either by dynamite explosion within the earth (at few m depth) or by the movement of vibroseis on land, which sends a short, sharp pulse of sound into the ground. The pulse or elastic wave reflects at geological boundaries, across which acoustic impedance changes. If we measure the travel time of these waves accurately, then we need only the wave velocities of the formations through which they have traveled from the source to the receiver.

This dissertation is based on the "Interpretation of the Migrated Seismic Reflection Data" of Mianwali area provided by OGDCL. The area was surveyed in April/May 1990. The following latitudes and longitudes bound the area of prospect as shown in fig 1.3. Also see the tectonic map of Pakistan in fig 1.1 and Kohat-Potwar Foredeep in fig 1.2.

	Latitude	Longitude
Initial vibroseis point A	31° 25′ 00″ N	71° 30′ 00″ E
Final vibroseis point B	32° 40′ 00″ N	71° 35′ 00″ E

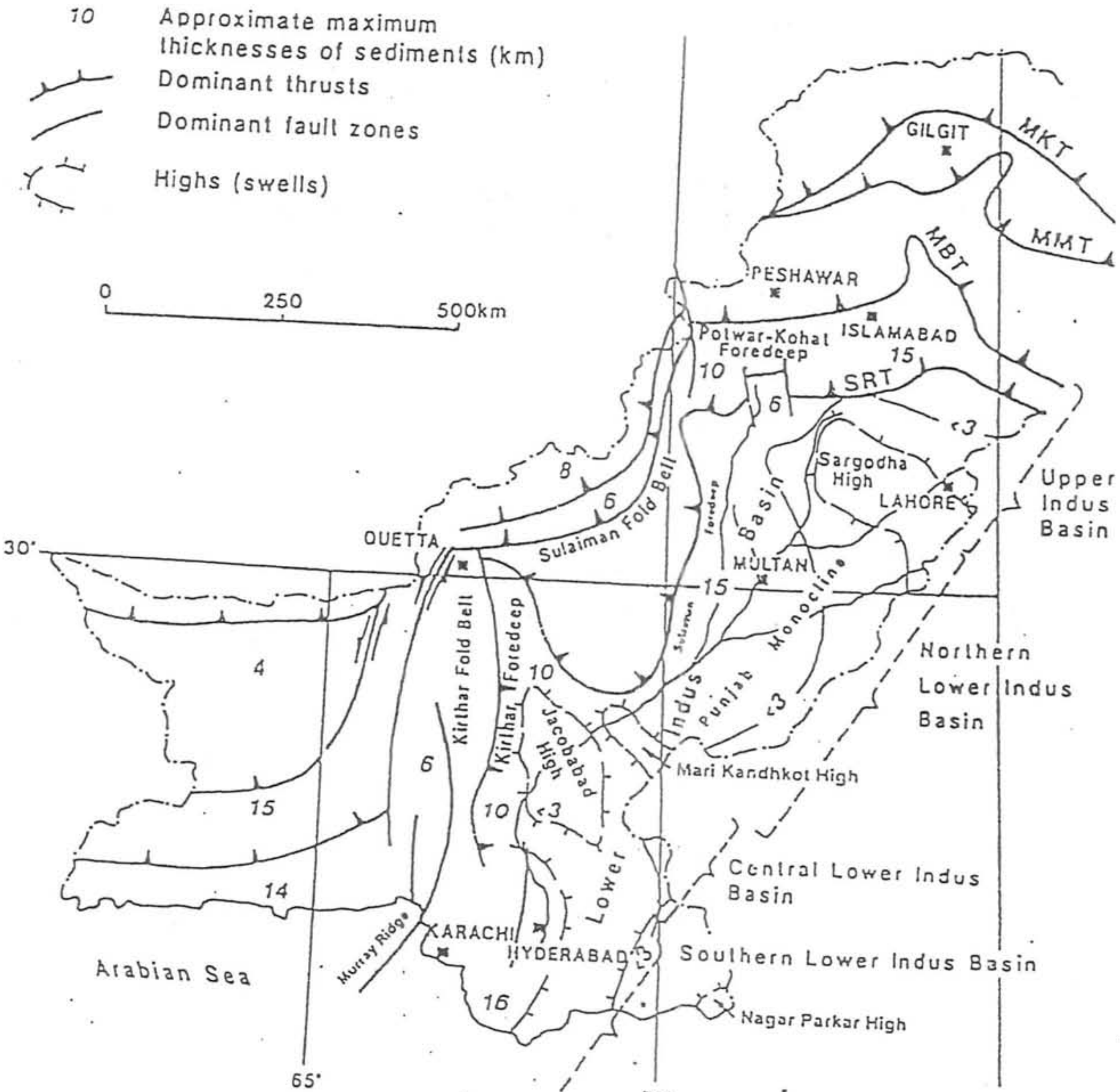


Fig 1.1. Tectonic zones of Pakistan (after "Facts and Figures", OGDCL, 1992).

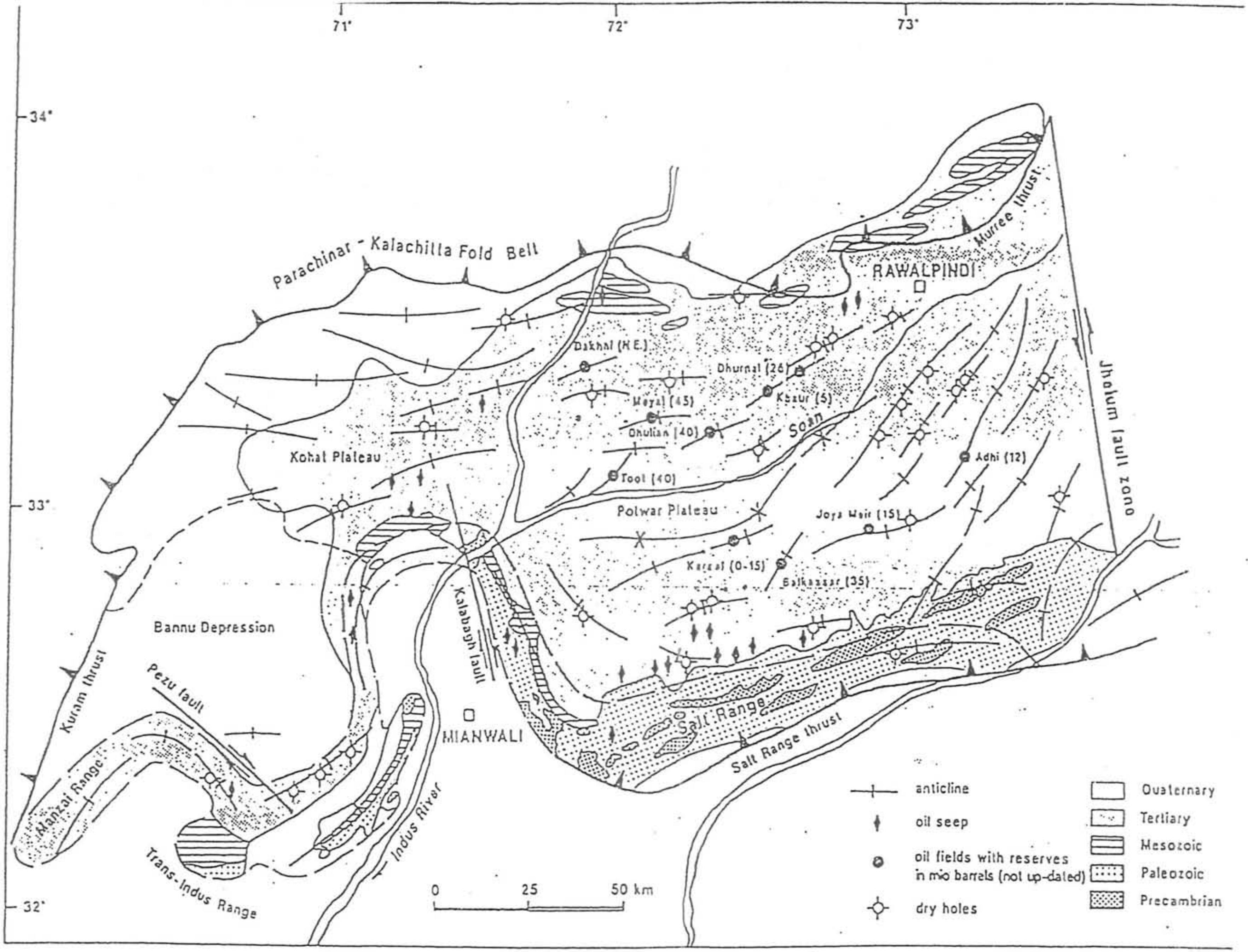


Fig 1.2. Simplified oil-geological map of the Potwar-Kohat Foredeep (after Khan et al. 1986, Hiller 1994)

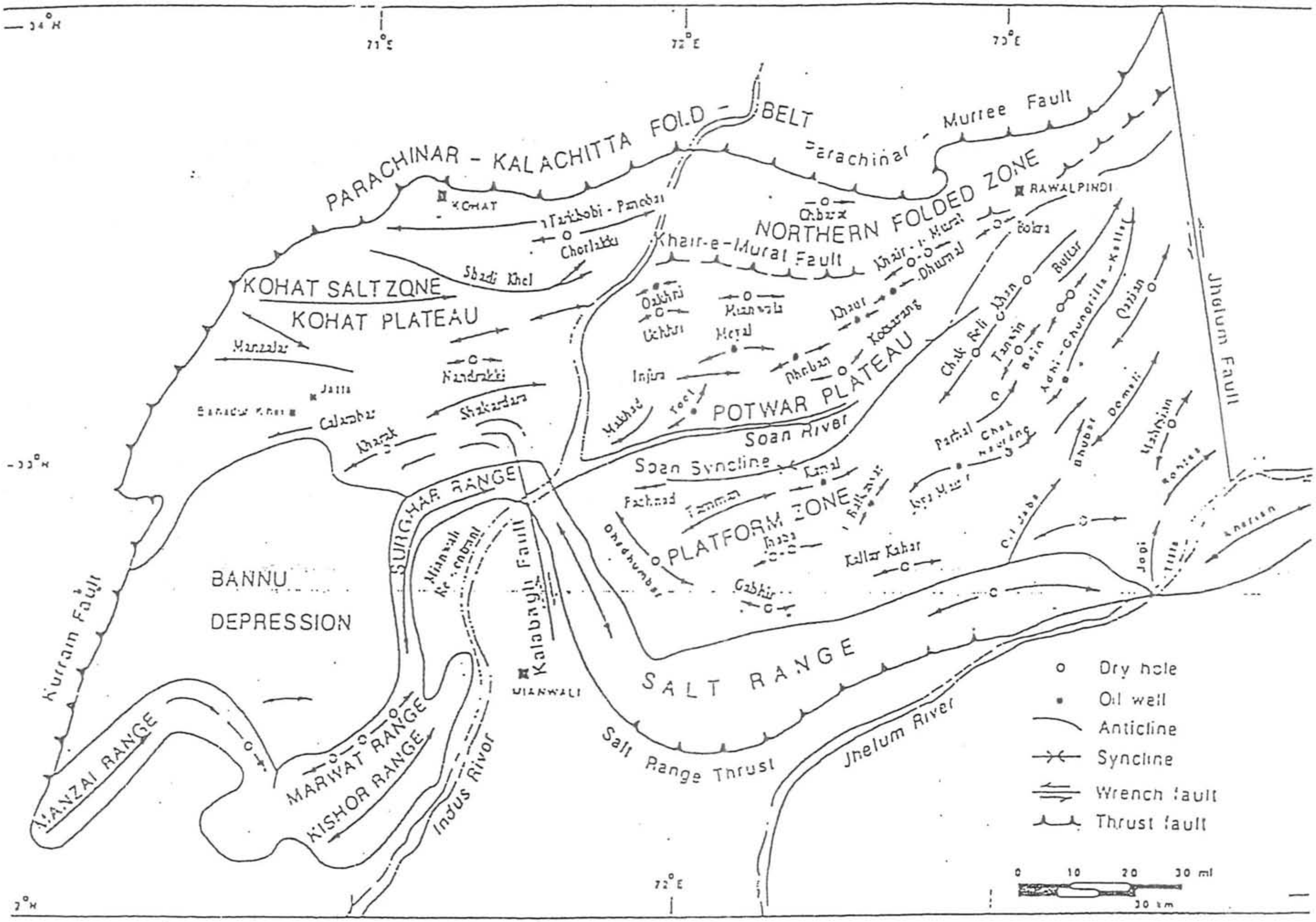


Fig 1.3 Structural map of the Kohat-Potwar Plateau (From Kazmi and Rana, 1982, Khan et al. 1986).

The Seismic profile number is **904-MWI-8A** and its orientation is SE to NW.The data is 30 fold which means each point in the subsurface is covered for a quality control and high resolution. The length of the profile is 38.25 km. The seismic data collected along this line was processed in OGDCL processing center, and migrated time section was made available for the purpose of this dissertation. RMS and Interval velocities computed during processing are also provided with the data.

These velocities are given at various CDP intervals and are used for the calculation of "Average Velocities" which is turn used to convert the given time section into a depth section.

The RMS velocities show that the data is recorded for 5 seconds, but it is displayed for 4 seconds. This line consists of a total 17 CDPs. Only 5 CDPs are allocated for interpretation.

1.2) Objectives

The objectives of the dissertation are given as under:

1. To calculate/determine the average velocities at CDPs with the help of RMS and Interval velocities information given at these CDPs.

2. To prepare depth section by marking the reflectors on the time section and reading their times and determine average velocities at these time.

1.3) Display Parameters

The acquisition parameters (recording parameters) and processing sequence will be discussed in their respective chapters, while display parameters are given below.

Horizontal Scale	:	20.0 (Trace per inch)
Vertical Scale	:	3.937 inches/sec
Polarity	:	Normal
Display	:	April, 1990
Processed at	:	OGDCL

1.4) Geology and Seismic Section

Geological knowledge enables us to conceive geological models and opinions that can be used predicatively and as a guide to the interpretation. Understanding the link between geology and seismic sections, we must establish the significance of the individual reflection and also establish the significance of the relationship of reflections to each other. Individual reflections have several measurable and descriptive properties that can be related to geology. The attributes most easily linked to lithology are reflection amplitude, polarity, continuity and frequency.

that can be related to geology. The attributes most easily linked to lithology are reflection amplitude, polarity, continuity and frequency.

The essential geology and geophysics required for interpretation objectives has been discussed in a regional frame work. An attempt has been made to deal with its actual approach so that this work could be clearly understood.

1.5) Geology and Tectonics of the Area

The line **(904-MWI-8A)**, lies in the eastern part of Mianwali (Upper Indus Basin) area. It is situated near the western Salt Range. In its north, Kalabagh Fault is present, whereas western boundary is marked by Khisore Range.

The geological history of Indus Basin goes back to Pre-Cambrian age. The main feature, which controls the sedimentation in the upper Indus Basin up to Jurassic, is "Pre-Cambrian Indian Shield", whose topographic high existing the form of Kirana Hills (Sarghoda High) and Nagar Parkar ridge. In the early Jurassic age, Indian Plate drifted away from the Gondwanaland due to geodynamic forces and move towards north side and collided with Eurasian Plate in cretaceous age. Due to this continental-continental collision, mountains (Himalayas and adjacent mountain ranges) formed, and sedimentation in the adjacent areas started. Sometimes, due to interruption in deposition, major unconformities created between Cambrian and Permian, Cretaceous and Paleocene and Eocene and Miocene times(Kazmi and Jan, 1997).

Kalabagh Fault forms the western margin of the Salt Range. It cuts folds and faults in the Eocambrian to Quaternary rocks. Tectonic slivers of Permian and older rocks occur along the fault zone (Gee, 1980). Southwards, Kalabagh fault apparently displaces the Salt Range Thrust, between jhelum and Indus River.

The sedimentary environment in the past and high tectonic activity at present indicates the variety of potential source, reservoir and trapping conditions in the study area, which are most valuable for petroleum exploration.

1.6) Stratigraphic Setting

The stratigraphic sequence of the area is somewhat similar to the "Western Salt Range" The sedimentary sequence ranging from Eocambrian to recent is exposed in the area . The exposed Eocambrian rocks are thinner while Permian sequence is thicker (700m) ion Western Salt Range . Tobra Formation Characterizes the angular unconformity at the base of Permian.

The exposed Mesozoic sequence is thickest (1000 m+) in the Western Salt Range . These are a number of minor unconformities indicating disruption in sedimentation and instability in the foreland sedimentary basin during the Mesozoic.

The Cenozoic sedimentary rocks consist of PALEOGENE sequence, deposite in widely varying paleoenvironments, ranging from shallow marine (Lockart , Nammal & Sakesar Formation), marine to continental (Hangu Formation), marine to lagoonal (Patala Formation), to continental molasse type (Rawalpindi & Siwalik Groups) , as shown in fig 1.4. A significant angular unconformity above the Cretaceous cuts down –

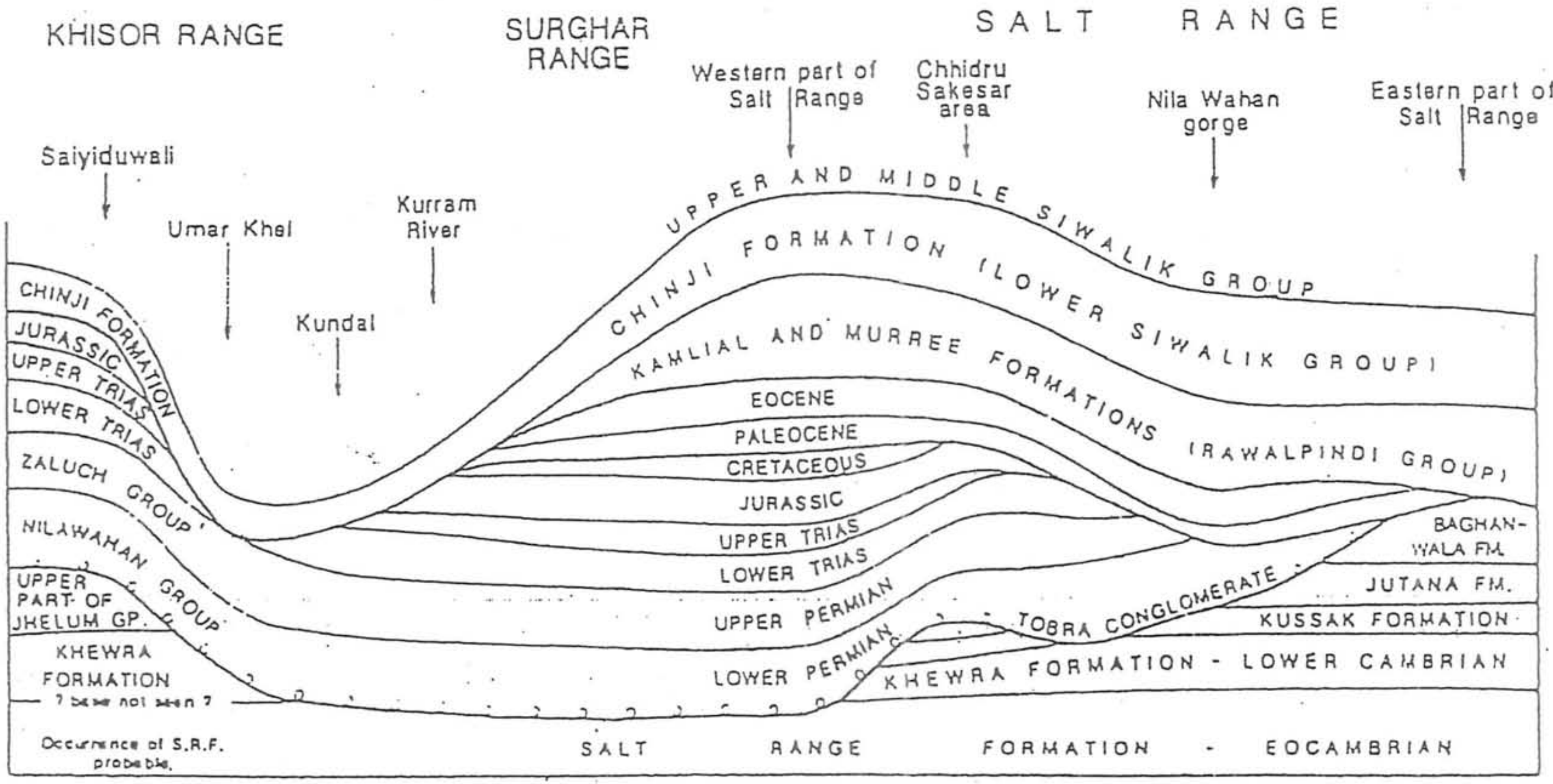


Fig 1.4 Section showing the stratigraphic sequence of the Salt Range and Trans-Indus Ranges (From Gee 1989).

section with progressive eastward overlap of paleogene sequence over successively older rocks until the paleogene(Lockart Formation) directly overlies the Permian (Sardhai Formation).

The Salt Range contains a perfect Permian section . It contains a wide range rich fauna. The Lower Permian contains a cold -water flora and fauna , whereas a warm-water flora characterizes the upper Permian . Similarly Eocene sequence and Siwalik rocks of this region are highly fossiliferous(Kazmi and Jan, 1997).

The stratigraphy of the area from younger to older is summarized below:

1.6.a) Siwalik Group

This group resets conforably on the Rawalpindi Group. The Siwalik Group Includes (in the ascending order) Chinji, Nagri, Dhok Pathan and Soan Formations.

	Age	Formation	Lithology
	Late Paleocene to early Pleistocene	Soan	Conglomerates, sandstone,siltstone &clay
Siwalik Group	Early to middle Pliocene	Dhok Pathan	Thick bedded sandstone , clay , Conglomerates
	Early Pliocene	Nagri	Thick bedded to massive salt , calcareous sandstone, sandy clay & Conglomerates
	Late Miocene	Chinji	Red clay , cross- bedded sandstone

1.6.b) Rawalpindi Group

The Rawalpindi Group resets disconforably on various Eocene formations. It includes the Murree & Kamlial Formation. The age of this group is Miocene.

	Age	Formation	Lithology
Rawalpindi Group	Early Miocene	Murree	Thick sequence of red & purple clay; interbedded grayish sanstone .
	Middle to Late Miocene	Kamlial	Grey to brick-red sand stone; purple shale and conglomerates.

1.6.c) Eocene to Cambrian Sequence

Age	Formation	Velocity	Lithology
Early Eocene	Chorgali	3500 m/ sec	Limestone with interbedded shale.
Early Eocene	Sakesar		Nodular and cherty Limestone.
Late Paleocene to Eocene	Nammal		Shale, marl and argillaceous Limestone

Late Paleocene	Patala		Shale, marl ,Limestone, sandstone
Paleocene	Lockhart		Grey and massive Limestone
Early Paleocene	Hangu		Sandstone , Shale, coal beds
Early cretaceous	Lumshiwal		Sandstone, silty or sandy shale
Late Jurassic to Early cretaceous	Chichali		Sandstone , Shale
Middle Jurassic	SamanaSuk		Dolomitic limestone,marl, Shale
Early Jurassic	Datta		Sandstone , Shale, siltstone
Late Triassic	Kingriali		Dolomite, limestone, shale
Middle Triassic	Tredian		Micaceous sanstone, shale
Early Triassic	Mianwali		Marl, limestone, Sandstone, siltstone and dolomite

1.6.d) Permian Sequence

It is well developed and perfectly exposed in the Salt Range. The Permian is subdivided into two groups:

The predominantly clastic Nilawahan group and the mainly calcareous Zaluch Group.

1.6.d1) Zaluch Group

It is subdivided into three formations distinguished from each other by differences in the proportion of lime stone . These are the Amb, Wargal and chhidru Formation.

	Age	Formation	Lithology
Zaluch Group	Permian	Chhidru	Sandstone , Shale, limestone
		Wargal	Dolomite, limestone, shale
		Amb	Sandstone, limestone, shale

1.6.d2) Nilawahan Group

It consists of four formations: Tobra, Dandot , Warcha, and Sardhai formations.

	Age	Formation	Lithology
Nilawahan group	Permian	Sardhai	Dark violet to black siltstone
		Warchha	Sandy shale, Sandstone
		Dandot	Shale
		Tobra	Mudstone, Boulders

(1·7) Jhelum Group

AGE	FORMATION	LITHOLOGY
Cambrian	Baghanwala	Red Shale, Salt Pseudomorph
	Jutana	Light Green Sandy Dolomite
Cambrian	Kussak	Greenish Grey, Glauconitic, Micaceous Sandstone, Light Grey Dolomite
	Khewra	Purple Sandstone

(1·8) Salt Range Formation:

The basement rocks (Indian Shield) are overlain by the non-metamorphic sediments of the Salt Range Formation of Early Cambrian to Late Pre-Cambrian. It is also described as Saline Series by Gee (1945). It is composed of red, gypsiferous, salt marl with interbedded anhydrite, dolomite, oil shale, and thick seams of salts(Shah, 1977).

(1.9) Basement

The basement is of Indian shield of Pre-Cambrian age having exposures at Sargodha, Shah Kot & Sangla Hill etc.

Chapter#2

SEISMIC METHODS

2.1) Introduction

Seismic exploration is the use of seismic energy to probe beneath the surface of the earth, usually as an aid in searching economic deposits of oil, gas or minerals, but also for engineering, archeology and scientific studies. In exploration seismology, the seismic methods are applied at or near the earth's surface to measure the elastic properties of the subsurface and to detect variations in those properties.

In seismic surveying, the seismic waves are propagated through the earth's interior and the travel times of the waves are measured that return to the surface after reflection and refraction from the geological boundaries. These travel times are used to calculate the depth of subsurface geological interfaces.

2.2) Types of Methods

The subsurface information is mainly obtained by two methods.

- Refraction method
- Reflection Method

2.2.a) Refraction Method

Refraction is the change in direction of travel of wave front or bending of rays as it passes from one medium to another. Seismic refraction method is based on Snell's law.

2.2.b) Reflection Method

Reflection refers to the seismic energy that returns from an interface of contrasting acoustic impedance, known as reflector. This energy is recorded at the surface by sensitive detectors which respond to the ground motion produced by the reflected energy in time from place to place, which is indicative of the shape of structural features and their locations in subsurface. Therefore reflection techniques are mainly used in oil industry to produce structural maps of such deep-seated configurations such as anticlines, faults and salt domes (Dobrin & Savit, 1988).

2.3) Types of Seismic Waves

There are several kinds of seismic waves, and they all move in different directions. Two main types of waves are:

- Body Waves
- Surface Waves

2.3.a) Body Waves

Body waves can travel through the earth's inner layers. They are further divided into Longitudinal Waves and Transverse Waves. Longitudinal waves are those in which particles of medium move to and fro parallel to the direction of wave propagation. Longitudinal waves are also known as Primary Waves (P Waves). Transverse waves are those in which particles of medium move perpendicular to the direction of wave propagation. Transverse waves are also known as Shear Waves, Secondary Waves (S Waves).

2.3.b) Surface Waves

The waves, which propagate along the free surface of the earth, are called surface waves. Surface waves are of two types. Rayleigh waves have the particle motion in a vertical plane but elliptical and retrograde with respect to the direction of propagation. Love waves are observed only when there is a low velocity layer overlying a high velocity substratum.

2.4) Laws Governing the Propagation of Seismic Waves

The geometry of reflected or refracted ray path along which elastic waves are propagated in a medium is governed by certain simple rules, which are as follow:

2.4.a) Huygen's Principle

According to this principle, each point on wave front may be considered as a secondary source where the envelope to the wave front of these secondary waves define the position of the primary waves at some later time.

2.4.b) Fermat's Principle

Fermat's principle tells that the time required for light to travel from one point to the other along a given ray is less than the time taken to complete this journey by any other route.

2.4.c) Law of Reflection

This law states that the angle of incidence is equal to the angle of reflection. This law can be expressed mathematically as:

$$<i = <r$$

Where

i= Angle of incidence

r= Angle of reflection

2.4.d) Snell's Law

The direction of reflected and refracted waves traveling away from a boundary depends upon the direction of the incident waves and the speed of the waves. Mathematical form of the law is given below:

$$\text{Sin}i / \text{Sin}r = V_1 / V_2$$

Where

i = Angle of incidence

r = Angle of reflection

V_1 = Velocity of 1^{st} medium

V_2 = Velocity of 2^{nd} medium

The angle of incidence for which angle of refraction is 90°, is called the Critical Angle.

It is denoted by i_c. (Fig 2.1)

$$\text{Sin}i_c = V_1/V_2$$

2.5) Ray Path in Layer Media

At an interface between two rock layers, energy within an incident seismic pulse partition into transmitted and reflected rays must be equal to the energy of the incident ray.

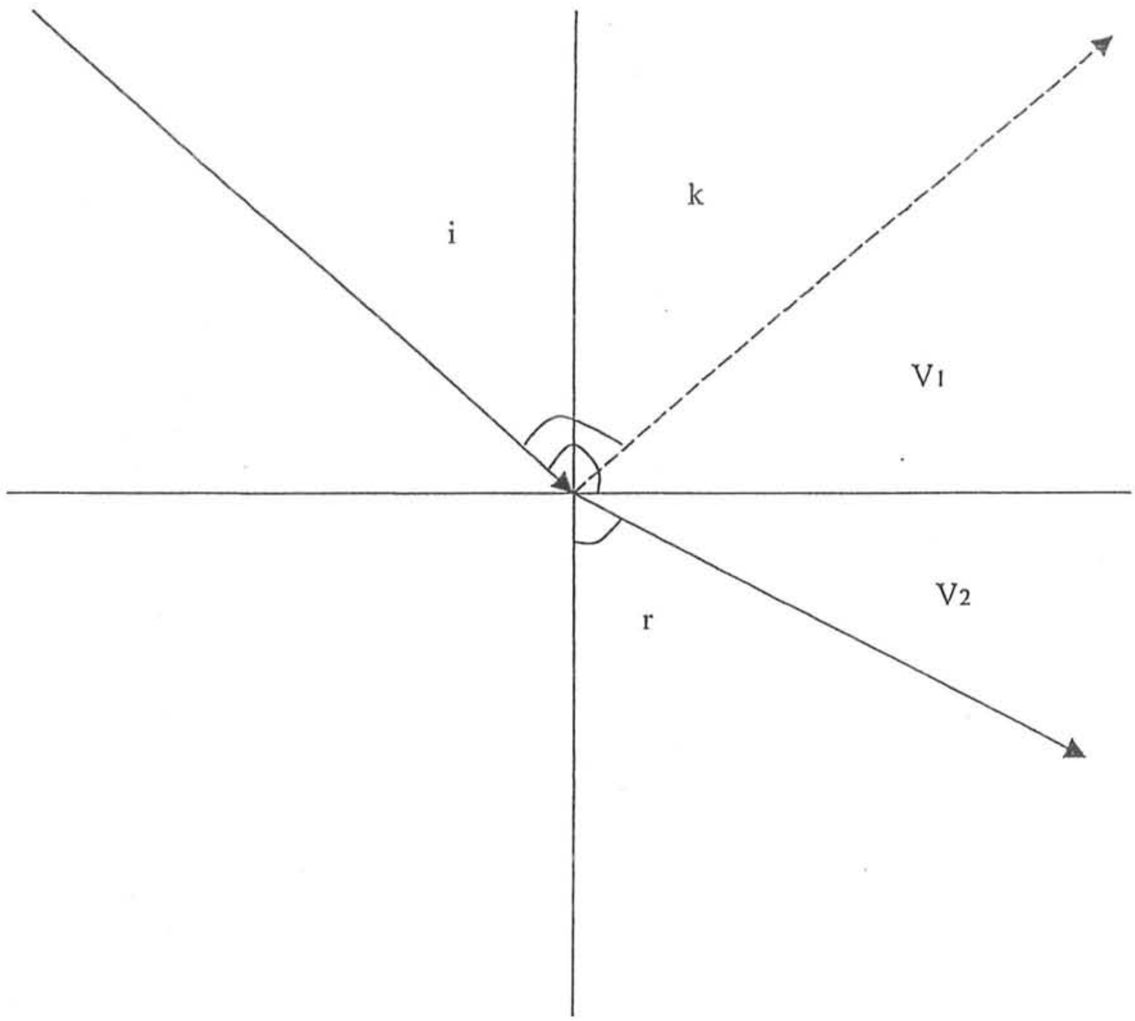


Fig 2.1 Snell ' s Law

The properties of energy transmitted and reflected rays are determined by the contrast in Acoustic Impedance (Z) across the interface.

2.6) Reflection Coefficient (R)

It is the ratio of amplitude of reflected ray (A_r) to the amplitude of incident ray (A_o).

Mathematically it can be expressed as:

$$R = A_r / A_o$$

2.7) Transmission Coefficient (T)

It is the ratio of amplitude of transmitted ray (A_t) to the amplitude of incident ray (A_0). Mathematical form of 'T' is given by:

$$T = A_t/A_o$$

2.8) Application of Seismic Reflection Method

Main applications of seismic reflection method are:

1) To find out structural traps (as anticlines, faults, salt domes and reefs) this may contain the hydrocarbons.

2) To investigate the stratigraphic features like discontinuous layers, wedge shaped layers, pinch outs or facies changes etc.

3) Reflection data can be used to determine the average velocities of seismic waves, which in turn, are used to 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 shallow subsurface features .

Chapter#3

SEISMIC VELOCITIES

3.1) Introduction

The rate at which a wave travels through a medium (a scalar) or the rate at which a body is displaced in a given direction (a vector) or the distance divided by travel time is called velocity and is denoted by "V".

The seismic velocities are generally needed for the determination of lithology and the physical nature of rocks and also for the calculation of dip and depth of interfaces. In short the 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. Generally, velocities increase with depth, but layer in which decrease in velocity may occur, indicates a physio-chemical change (Robinson & Coruh, 1988).

3.2) Objectives

Principle objective of seismic velocities is to convert time section into depth section to have structural as well as lithologic interpretation. Seismic velocities vary largely in sedimentary rocks as compared to igneous rocks and metamorphic rocks.

The change could be lateral or vertical depending on physical characteristics of medium. In terms of lithology whenever there is a change in grain size and mineralogical composition of the rock, velocity behaviour changes. An increase in grain size will result in the increase in velocity.

3.3) Types of seismic velocities:

3.3.a) Instantaneous Velocity

It is the velocity across a small particle of rock. It is the speed with which a wave front passes through a point, measured in the direction of travel. The velocity is measured by the sonic log.

$$V_{inst} = dz / dt$$

3.3.b) Average Velocity

Average velocity (V_{ave}) is simply the total distance traveled by a seismic wave from the source to some point within the earth divided by the recorded one-way travel time. We can express average velocity as,

$$V_{ave} = z / t$$

Where,

t = One way travel time

z = Total distance traveled

Average velocity increases with depth due to compaction. It is often used for time to depth conversion and for migration.

3.3.c) Root Mean Square (RMS) Velocity

When subsurface layers are horizontal with respective interval velocities of V_1, V_2, V_3, $V_4 \ldots V_n$ and one way interval times are t_1, t_2, t_3, $t_4 \ldots t_n$. Then V_{RMS} for n-layer model is obtained from relation.

$$V^2_{RMS} = 2\, \Sigma\, V_i\, Z \;\; / \Sigma\, T$$

$$V^2_{RMS} = \Sigma\, V_i\, Z \; / \Sigma\, t$$

Where

T = Two-way travel time

t = One-way travel time

i = 1,2,3,...

Z = Thickness of Layer

RMS is determined directly from borehole measurements.

3.3.d) Interval Velocity

Interval Velocity (V_i) is defined as the thickness of a particular layer divided by the time it takes to travel from the top of the layer to its base.

The equation of the interval velocity is

$$V_i = \Delta Z / \Delta t$$

Where,

ΔZ = Thickness of the layer

Δt = Travel time from the top of the layer to its base

3.3.e) Stacking Velocity Or Normal Move Out Velocity

Stacking velocity is obtained from the application of the normal move out (NMO) correction to CMP gather.

$$T_x^2 = T_o^2 + X^2 / V_{st}^2$$

Where

X = Offset distance from to receiver.

T_x = Two-way travel time of reflection at x.

T_o = Two-way travel time of reflection at zero offset.

V_{st} = Stacking Velocity.

3.4) Factors affecting velocity

The seismic velocity in the rocks are affected by several factors

3.4.a) Effect of density and Elasticity

Square of Velocity is directly proportional to elasticity and inversely proportional to density. Mathematically, we can write it as,

$$(\text{Seismic Velocity})^2 = \text{Effective Elasticity}/\text{Density}$$

So it is expected that denser rocks would have low velocity, however, the reverse is true. It is because as the material becomes more compact its elasticity increases in such a way that it reduces the effect introduced by density increase.

3.4.b) Effect of porosity:

Lower the Porosity higher will be the velocity and higher the porosity lower will be the velocity.

Wyllie et al (1958) defined a relationship between porosity (Ø) and velocity (v) by the following relation.

$$1/V = \phi/V_f + (1-\phi)/V_m$$

Where

V_f == Velocity in the fluid

V_m == Velocity in the matrix material.

3.4.c) Effects of geological structure:

In an isotropic media, the recorded velocities are generally high, when measured along the strike of structure, than when measured perpendicular to the structure. This difference may be of the order of 5-15%.

3.4.d) Effects of Depth and geological age:

A quantitative relationship between velocity, depth and age of the rock particularly for the shale and sandstone section, (Robinson & Coruh, 1988), is given as

$$V = K\,(ZT)^{1/6}$$

Where

V = Velocity in feet per second.

Z = Depth in feet.

T = Age in years.

K = 125.3

3.4.e) Temperature

Seismic velocities decrease slightly with increase in temperature.

3.5) Methods for Velocity Determination

The analytical processed and measuring techniques of velocity are listed below,

3.5.a) Velocity Survey in Wells

Velocity surveys in well can be done in two ways:

- **Sonic Logging**

It is done by means of a source and receivers mounted on a probe, which is several feet long. The difference in arrival times at two receivers, usually one feet or three feet apart, indicates the P-wave velocity over a short area of rock along the side of well.

- **Well Geophone**

Well geophone, which is waterproof and can be clamped to the side of the well, is lowered to different positions where it is used to detect wave from small explosions on the land surface close to well.

The velocity "*V*" is found from the difference in arrival times $\Delta t = t_2 - t_1$ over an interval of two geophone positions.

$$\Delta z = z_1 - z_2$$

$$V = \Delta z / \Delta t$$

3.5.b) Dix Formula

For uniform horizontal layer and small offsets, the NMO velocities are equivalent to the root mean square velocities Vrms.

$$V_{n,\,avg} = [Vn,\, int\, (t_n - t_{n-1}) + V_{n-1,\,avg}\, (t_{n-1})] \,/\, t_n$$

Where

Vn,int= Interval velocity of nth layer

Vn,rms=RMS velocity of nth layer

tn,tn-1=Travel time of nth layer at zero off-set (Robinson & Coruh, 1988).

Dix's velocities are correct only for the horizontal strata and are larger than the true interval velocities for the dipping reflectors (Badley, 1985).

3.5.c) T2–X2 Method

This method is based on the equation,

$$T^2 = X2 / V^2_{rms} + T^2{}_o$$

Where

we plot T2 as a function of X2 we get a straight line whose slope is 1/V2rms. Whose intercept is $T^2{}_o$ from which we determine the corresponding depth.

3.6) Compressional and Shear Velocities in Rocks

Material & Source	Copmressional Velocity (m/sec)	Shear velocity (m/sec)
Granite	5520-5580	2870-3040
Granodiorite	4780	3100
Diorite	5780	3060
Gaggro	6450	3420
Basalt	6400	3200
Sandstone	1400-4300	
Limestone	1700-6060	2880-3030
Clay	1100-2500	
Loose sand	1800	500

(Badley, 1985).

3.7) Uses Of Seismic Velocities

- True Depth
- Stacking of seismic data
- Migration of seismic data
- Possible lithology determination
- Possible porosity estimation

Chapter#4

DATA ACQUISITION

4.1) Introduction

Seismic investigation starts in the field with the acquisition of data. Acquiring seismic data costs much more than processing it. The primary objectives of good seismic acquisition should include the maximization of signal to noise ratios by taking advantage of means and opportunities that will not be available at the processing stage.

The accuracy of seismic results depend upon the knowledge of geology of the area , the position of the seismic lines in relation to dip of layers, the rock structure, the spread geometry ,the interpretation procedures employed and the experience of the personnel involved in the work.

Seismic reflection data reveals adequate information of the subsurface geology, but that needs good S/N ratio. However, field reflection data often is associated with coherent and random noises, which cause a lot of difficulty in improving the desired signal.

A part from field parameters, appropriate field filters are used along with suitable gain settings during data acquisition for the suppression of noise and improving the desired signal.

In seismic data acquisition some receivers are placed at different location to detect vibrations produced by an energy source the receivers converts the mechanical vibrations in to electric current that is transmitted to a recorder, the recorder is design to preserve the information in a form that can be displayed and analyzed.

Acquisition systems essentially comprise a source pattern, a detection spread and digital recording instruments.

4.2) Seismic Surveying

In seismic surveying, we collect the seismogram, which may be defined as analog or as a digital time series that register the amplitude of ground motion as a function of time during the passage of seismic wave train. The basic requirement of a multi-channel reflection survey is to obtain recordings of reflected pulses at several offset distances from a shot point.

Seismic acquisition systems consists of three basic subsystems:

- Energy Sources
- Energy Receiving Unit
- Recording Systems

4.2.a) Seismic Energy Sources

One of the most important tools of seismic survey is "Energy sources ", used to produce seismic waves. Most seismic sources generate the compress ional wave energy. There are a very wide variety of seismic sources having a wide range of frequency components. We have either explosive or non explosive sources depending upon the requirement of the seismic survey.

Some important sources used on land are:

1) Dynamite
2) Vibroseis
3) Geograph (Dropping of weight)
4) Dinoseis(By exploding gas mixture)
5) Geoflex (Explosive cord buried in the ground at a shallow depth)

In Pakistan, we mostly use first two methods, because they give most accurate results than other methods. Vibroseis shooting collects the data of our dissertation.

4.2.a1) Explosive (Dynamite)

Explosive was formally the standard method used for the seismic emission on land. It is still employed to day in areas where its used is feasible. Dynamite charges from hundred gram to a few kg or buried in holes 3 to 5 meters deep, and 10 to 15 cm in diameter, at the base of the weathered zone. Several charges, horizontally spaced at intervals of a few meters, are blasted simultaneously.

➢ Advantage:

- It is a powerful energy source.
- It generates all the frequencies.

➢ Disadvantages:

Its major drawbacks are the storage and transport requirements, and the cost of drilling stations.

4.2.a2) Non-explosive (Vibroseis)

The vibroseis, developed by Continental Oil Company is the most popular surface source. Vibroseis does not use explosion, it uses a vibrator plate. The wave put into the earth by a vibroseis source is oscillatory. Rather than impulsive and persist for many seconds (about 12 sec), the frequency changing slowly over the duration of the signal (between 10 to 100 hz).

The return signals recorded in the field can not interpreted directly, the recorded data, therefore, must be processed by cross-correlations of the signal received by the geo-phones with the oscillatory source signal itself.

Vibroseis source is fast and safer and can be undertaken in populated areas (along roads tracks etc).

4.2.b) The Energy Receiving Unit

Seismic surveying consist of placing some receivers at different locations on the earth to detect ground vibrations produced by an energy source. Information is preserved in a form that can be displayed and analyzed.

Seismic detectors designed to transform seismic energy into electrical voltages are generally geo-phones on land in hydrophones at sea.

4.2.b1) Geo-phones

The basic principle of essentially all modern geo-phones used for production seismic work is that if a coil is moved through a magnetic field, a voltage is produced. Mostly land geo-phones are of the moving-coil type.

A coil is suspended by springs in a magnetic field of the magnet integrated with the case of instrument. A seismic wave moves the case and the magnet but the remains relatively stationary.

The movement of magnetic field with respect to the coil generates a voltage across the coil, which is proportional to the difference between the velocity of the coil and the magnet. The geo-phones " response" is expressed in volts per cm per.

4.2.b2) Seismic Cable

The geophone signal, which is the electric current produced by ground vibrations, is transmitted to the recording system by means of the seismic cable. Each geophone requires two wire conductors. Therefore, the number of conductors in the seismic cable depends on the number of geophones used in the survey. At regular intervals along the cable are "Takeout '' points where a geophone can be connected to its pair of conductors.

4.2.b3) Spread Configuration

➢ **Basic Spread**

By spread we mean the relative locations of source and point and center of the geophone groups used to record the energy from source. In 2D reflection surveys the source and the receivers will be on the same line while in 3D surveys the source and receivers are on different lines. Some of the basic spreads are:

➢ **Split Spread**

A seismic recording with live receiver positions extending along the seismic line in both directions from the source.

In a symmetrical split spread the live offset are the same in both directions, but different in an asymmetrical split spread.

➢ End Spread

End spread reach away from the source in one direction. This pattern can be modified in an inline offset spread by moving the source some distance away from the first geophone.

➢ Cross Spread

A cross spread consists of two split spreads centered about the same source.

➢ Broad-L & Broadside-T Spread

The source point maybe offset in the direction normal to the cable either at one end of the active part to produce a Broadside-L or opposite the center to give a Broadside-T spread.

4.2.b4) Common Depth Point (CDP) Profiling

In multi-channel seismic acquisition where beds do not dip, the common reflecting point at depth on a reflector, or the halfway point when a wave travels from a source to a reflector to a receiver. In the case of flat layers, the common depth point is vertically below the common midpoint. In the case of dipping beds, there is no common depth point shared by the multiple sources and receivers, so dip move out processing is necessary to reduce smearing, or inappropriate mixing, of the data. Common reflection point is a synonym for CDP.

The fold of CDP survey is given by equation:

$$N/2n$$

Where

N= Number of phone arrays along a spread.

n= Number of phone arrays spacing by which the spread is moved forward between shots

4.2c) Recording Systems

When the ground is vibrating, it is in continuous motion. A geophone responding to this motion produce a continuously varying electrical signal, which is, recorded either in analog or digital form. So there are two important recording systems:

1) Analog Recording System
2) Digital Recording System

An important feature of a seismic recording system is its dynamic range, which is the ratio of strongest and weakest signals that can be usefully recorded.

1) Analog Recording System

A seismogram is a graph that shows how amplitude of signal varies with time. An analog seismogram is a continuous record of ground motion as a function of time.

The analog recording system is made up of an assembly of electric units normally housed in the recording station.

Before the signal is recorded by analog system, it can be electrically amplified and filtered. The amplifier is used to increase the strength of the weak geophone signals. Some of these signals may be removed by means of electronic filtering before recording the signal.

An analog seismic recording system is equipped with a separate amplifier, filter circuit and a magnetic tape for each geophone. These components make up one channel of the recording system.

2) Digital Recording System

A digital recording system consist essentially of pre-amplifiers, and in analog filters, a multiplexer, a gain control amplifiers, an analog to digital converter, a formatter a tape unit and play back system.

➢ Preamplifiers and analog filters:

Preamplifiers and analog filters help to adjust the recorded pass band to the frequencies of the seismic signal, and to eliminate noise as much as possible. A low cut filter is generally applied at about 8 hz or so, to eliminate low frequency noise, and high-cut filter at 62.5 or 125 or 250 hz to prevent aliasing.

➢ Multiplexer:

The multiplexer switches the different channels in sequence at regular intervals, measure their amplitudes and feed them into a signal out-put channel.

Each channel is thus sampled at the sampling intervals, for example every 4 ms.

- **Gain control amplifier:**

It keeps the data transmitted to the analog to digital converter at an appropriate level, so that the recording remains sufficient accurate. It adjusts the amplitude of the seismic signal to the dynamic range of the recorder at all times.

- **Analog to digital converter:**

It converts the signals into a binary code number at the out-put of the gain control amplifier.

- **Formatter:**

This is a set of logic circuits designed to organize the digitized information before recording on the tape. Current industry accepted formats are 9 tracks SEG-B or C although 21 tracks format are also used.

- **Tape unit:**

The tape unit records the data on the magnetic tape. The tapes generally measure half an inch in width, have 9 tracks, and record at 1600 or 6250 bites per inch, at speed 40 to 120 inch per sec.

> **Play back:**

Play back of magnetic tapes serves to check the quality of the recording obtained, by giving an analog representation on camera.

The play back system comprises a " Deformattors", which reconstructs the binary data from the code recorded on the tape, a digital to analog converter which generates an analog voltage from the binary data, a demultiplexer which distributes the analog voltage to the different play back channels in a passed band filter system.

4.3) Common-Midpoint Method

A setup by which reflections are recorded from the same subsurface point with different source-to-geophone offset is known as common-midpoint (CMP) or common-depth point (CDP) shooting.

Each common-midpoint consists of two or more traces, the number of which determines the coverage or fold of the seismic record. For example, 2 traces for a common-depth point, produces 2-fold or 200% coverage, 24 traces, 24-fold coverage.

> **Advantages**

a) Quality data can be enhanced by increasing multiplicity (fold) of seismic data.

b) Seismic velocities can be determined during the phase of processing.

Fold of seismic data can be determined by the formula

$$\text{Fold} = N.\ \Delta G/_2\ \Delta\ S$$

N. Number of traces recorded

ΔG = group interval

ΔS = short point interval.

4.4) Channel/Group Interval

The group interval must not be more than double geological features and reflectors lateral extent.

Group interval ΔG can be determined from the following relationships,

Split spread

$$\Delta G = Xmax\text{-}Xmin/\ N/2\text{-}1$$

End-shooting

$$\Delta G = Xmax\text{-}Xmin/N\text{-}1$$

Where

X max: Maximum offset

X min: Minimum offset

N: number of channels

4.5) Short point/ vibrating point interval

The distance between Sps/ Vps is based on the following

- Fold of the seismic data being recorded.
- Channel interval (Δ G)

4.6) Seismic Noises

Seismic noise is the information contained on a record that we do not wish to use. Original seismic signal is very much changed by the unwanted signals. Noise includes the disturbances, which may interfere with desired signal. In seismic prospecting the reliability of seismic mapping indeed depends upon the reliability of record and reduces the presence of noise. There are two well-known kinds of seismic noises:

4.6.a) Coherent Noise

It is seismic energy, which aligns from trace to trace or record to record. This type of noise is often very similar in appearance to signal and usually is more difficult overcome. The sources of coherent noises are:

- Multiple Reflections
- Refracted Events
- Diffraction Events
- Ground roll
- Direct Arrivals

4.6.b) Random Noise

It includes seismic energy, which does not align from trace to trace or record to record.

Sources of random noise are:

- Wind Noise
- Water Noise
- Local Noise (People, traffic etc.)
- Bad geophone Noise
- System Noise

System noise includes:

- Thermal Noise
- Shot Noise
- Magnetic Fluctuations etc.

4.6.c) Noise Reduction

Following tools are used to control the noise in the field:

- Source Size
- Source Depth
- Electronic Filtering
- Source Arrays
- Receiver Arrays
- Electronic Mixing

Chapter#5

SEISMIC DATA PROCESSING

5.1) Introduction

Seismic data are recorded in the field on magnetic tape. About three to six weeks latter the information is transmitted to the interpreter as a seismic section. All of the intervening steps comprise the data processing phase of seismic exploration. The primary problem arises because different types of events can arrive at the geophone at the same time and so confuse each other. Surface waves, shallow refractions, multiples, converted waves from different horizons or other type of waves may all arrive at the same time as primary reflection and be supper imposed on the seismic record. The problem then is to separate the primary reflections, seismic, which have been refracted only once by bedding underneath the seismic line. To effect this separation, we need a discriminate that is, a respect in which the signal and noise amplitude, normal move out, or some other regards.

In data processing the data is analyzed to determine how the noise differs from the signal and the process is applied which utilizes this difference to attenuate the noise. Processing seismic data consists of applying a sequence of computer programs each designed to achieve one step along the path from field tape to record section.

As an input-output system, processing may be schematically represented in figure(5.1A) and figure(5.1B).

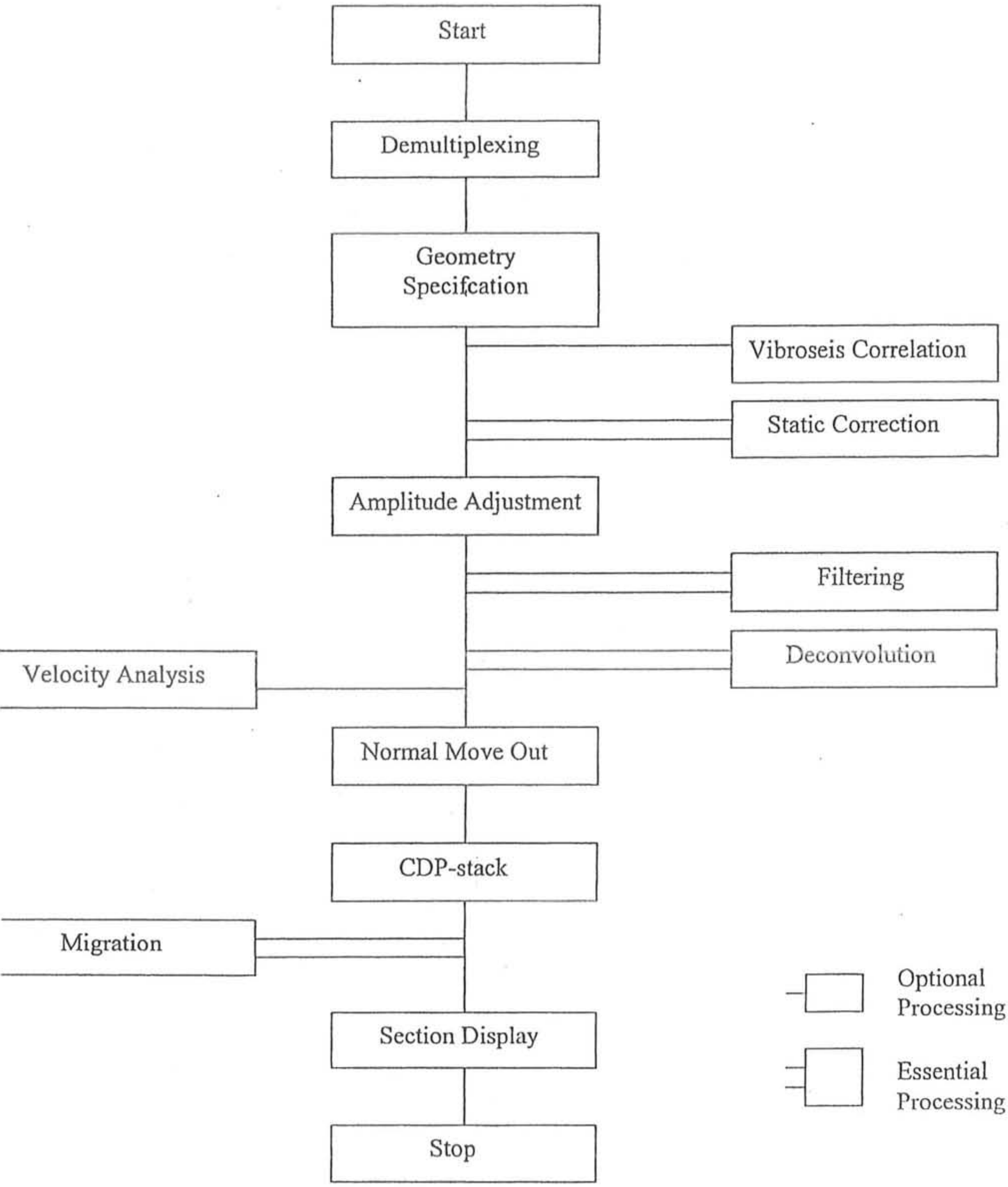


Fig (5.1B) illustrates Data Processing Scheme

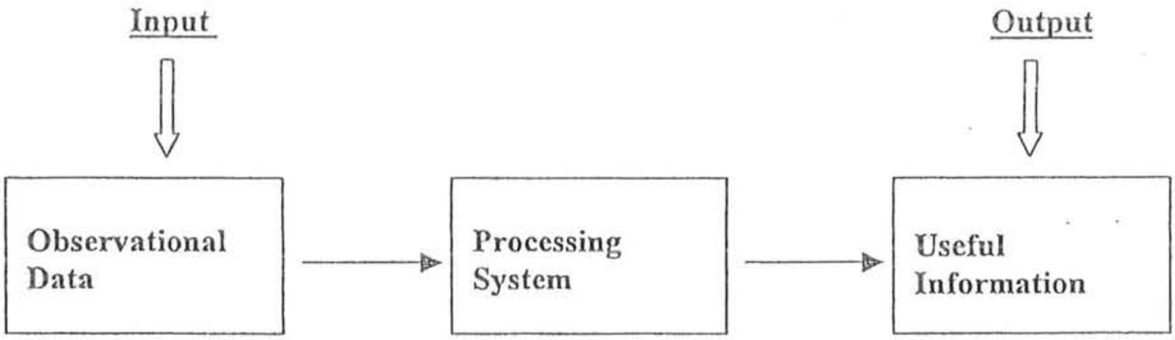


Fig: 5.1A

Modern data processing does not eliminate the need for judgments by seismologists. But it does not provide the means to assemble far more information in forms that can be examined more systematically and efficiently than would be possible without digital technology. This means that more informed judgments can be made (Robinson & Coruh 1988).

Naturally, the computer system forms the backbone of any modern processing center. The computer hardware and associated programs, known as software, make up the physical and practical bulk of the computer. The particular software mainly controls the type of processing.

In general, the selection of the processing sequence for a given set of field data depends upon the following factors:

- Intrinsic quality of the raw data
- Geological environment
- Processing philosophy
- Personal preference

- Cost

5.2) Processing techniques

The basic steps involved in processing are described below:

5.2.a) Demultiplexing

Field seismic data is recorded on the magnetic tape, using formats as SEGA,SEGB, and SEGC. Unlike analog seismograms, which are recorded in a form suitable for analysis, digital seismograms must be assembled from the digital tape by a sorting process. This sorting process is called Demultiplexing.

"The process of sorting data from the magnetic tape into individual is called Demultiplexing".

Demultiplexing, first step in seismic data processing according to Yilmaz (1978) is to transpose the matrix in such a manner that columns of the resulting matrix can be read as seismic traces representing different offsets related with a shot point. In a recording system of 'n' channels where each channel has been sampled 'm' times, values are put in the following manner:

$A_{11}, A_{12}, A_{13}, \ldots\ldots\ldots A_{12}, A_{22}, A_{23}, \ldots\ldots,$
$\ldots\ldots\ldots A_{1n}, A_{2n}, A_{3n}, \ldots\ldots\ldots A_{nm}$

A computer program used for the purpose of demultiplexing arranges the data in the following order to prepare a digital seismogram:

$A_{11}, A_{12}, A_{13}, \ldots\ldots, A_{1m}$

$A_{21}, A_{22}, A_{23}, \ldots\ldots, A_{2m}$

....

....

$A_{n1}, A_{n2}, A_{n3}, \ldots\ldots A_{nm}$

5.2.b) Vibroseis Correlation

On a vibroseis record, each reflection is as long as the input sweep. Each reflection is the near a duplicate of the sweep itself and so the refractions in the vibroseis record overlap and are generally indistinguishable. To make the vibroseis record useable, the reflections are compressed in to short wavelets. This is done by cross correlating, the data with the original input sweep. Thus correlated vibroseis data looks similar to impulsive source data.

5.2.c) Binary Gain Recovery

Modern digital recording systems use various gain ranging techniques to increase their dynamic range. Gain ranging instruments apply a gain to the signal before recording it and also keep a record of what gains were applied. The processing center "degain" the data, that is, remove the gain applied by the field instruments. The "degain" process is often called the "true amplitude gain recovery". After de-gaining the trace, the original signal is obtained.

Again there is problem of very rapid decay of amplitude due to spherical divergence effect and attenuation losses. To correct for the rapid decay of signal energy, a gain function may be applied. A gain function is a smoothly time varying gain applied to the data to being the overall amplitude up to the fairly constant level. This is referred to as gain recovery.

5.2.d) Amplitude Adjustment

A gain recovery function is applied on the data to correct for the amplitude effects of wave front divergence. This amounts to applying a geometric spreading function, which depends upon travel time, and an average primary velocity function, which is associated with primary reflections in a particular survey area. There are two broad types of amplitude gain programs: Automatic gain control and Relative true amplitude gain.

5.2.e) Trace Editing

Raw seismic data inevitably contains some unwanted noise and perhaps some dead traces. If obviously useless information is to be removed from the processing stream it must first be identified and then blanked or muted by assigning zero values to all samples in the affected time interval. Unwanted data are usually identified by visual examination of raw field traces although obvious cases (dead traces, strong noise bursts, etc) can be detected and edited automatically.

The raw field traces used in this editing procedure can be obtained from field monitor records.

5.2.f) CMP Sorting

Seismic data acquisition with multifold coverage is done in shot receiver coordinates (s,g). On the other hand, seismic data processing is done in midpoint-offset (y,h) coordinates.

The required coordinate transformation is achieved by sorting the data in to CMP gethers. Each individual trace is assigned to the mid point between the shot and receiver location associated with that trace. Those traces with the same mid point location are grouped together, making up a CMP gather.

CDP gather is equivalent to the CMP gather only when reflectors are horizontal and velocities do not vary horizontally. However, when there are dipping reflectors in the subsurface, these two gathers are not equivalent and only the term CMP gather should be used.

In common depth-point gather, the traces reflecting from the same point are collected. Traces are routinely gathered in to groups having same common element. The types of gathers usually made are

- Common Source Point
- Common Depth Point
- Common Receiver
- Common off-set

5.2.g) Convolution

The convolution the interaction of the signal and filter, such that the filter coefficient are time reversed with respect to the signal and then it cross cross correlated with the signal.

The convolution is a concept with wide practical applications in the time series analysis. Convolution of two functions f (t) and h (t) is defined by the operation

$$f(t) * h(t) = \int f(t)\ h(t-\tau)\, d\tau$$

.2.h) De convolution

De convolution may be defined as a certain process, which counteract a previous onvolution action. Consider the following convolution operation

$$Y(t) = f(t) * h(t)$$

Vhere,

f(t) are two convoled functions and Y(t) is the convolution output function. Now uppose Y(t)and f(t) are given then the processes of finding h(t)is called deconvolution nd the system which does that it is called inverse filter (Al-Sadi, 1980)

The earth itself acts as filter. It expends an impulsive in to a wavelet in to seneral avelets by reflection and refraction. Deconvolution has been developed as a mean off artially reversing the effect of the earth filter. Deconvolution has two objects

- It seeks to compress the wavelet in to a shorter impulse.
- It seeks to shift same wavelets produced by the incident wavelets that produced them.

In other words, deconvolution is designed to shape the pulse and attenuate multiples. he desired signal is obtained by convolving the record trace with another specially esigned trace (operator).

here are two types of deconvolution relatively common.

- Deterministic deconvolution
- Predictive deconvolution.

In predictive deconvolution the gape interval or prediction length is the length of trace unaffected by the deconvolution. For example, if the gape is 32 ms, then the deconvolution will not change the pulse shape over this interval. The operator length is the length of trace over which the deconvolution is effective as it is moved down each trace, and it should be long enough to cover the period of the longest multiple that is to be attenuate.

5.2.i) Static Corrections

Static corrections are constant for an entire trace. They consist of weathering corrections and elevation corrections.

The material near the surface of the earth is highly variable in velocity and thickness and reflection arrivals may vary because of near surface variations than because of the subsurface relief in which we are interested. This low velocity zone is called weather layer, see fig (5.2i).

The properties of this weather layer erect important effect on seismic data. The large velocity contrast at the base of the weathered layer bends ray path considerably.

This contrast is also a strong produce of multiples.

The effect of weathered layer is removed by applying a weathering correction.

$$WC=dw\ (1/Vw - 1/Vc)$$

Where

DW = thickness of weathered layer.

V_w = Velocity in weathered layer.

V_c = velocity in underline layer.

Since seismic sources and receivers are usually at or near the earth surface, raw reflection times are influenced by topographic effects. These effects are removed by elevation corrections.

$$E_{cs} = (Z - Z_o)/V_c$$

Where

Z_o = Datum surface elevation

Z = Source or receiver elevation

V_c = Velocity in below layer

Elevation correction is normally computed in two stages. First for all, source-points then for receivers.

5.2.j) Normal Move out

The distance from shot to geophone is gradually increasing for successive traces of a gather, so that the reflected energy takes a bit longer for successive traces. The delay time for reflections from a flat reflecting interface is called normal move out (NMO).

Multiple energy usually have more move out than the normal move out of the primary reflection.

5.2.k) Dynamic Correction

After the application of the static correction the reduced record time represents the two-way stint time where both the source and detector are effectively on the same datum. Now if we examine a reflection event on all the contributors of one CDP, We find these events falling on a hyperbola. This is due to dependence of travel time on the trace-offset, expressed by the NMO equation.

Tx=To + X2/V2 NMO

5.2.l) Muting

Trace muting is special type of data editing. The term is usually applied for the process of zeroing the undesired part of a trace. In order to avoid the stacking non-reflection events such as first arrivals with reflection, the first part of the trace is normally muted before carrying out the stacking process. This is occasionally reoffered to as first break suppression.

5.2.l1) Initial Muting

It removes the large energy bursts associated with first arrivals.

5.2.l2) Surgical Muting

It is applied to remove ground roll and airwaves present in the recorded data.

5.2.m) Automatic Residual Static

Due to un predicted variation of the velocity and thickness of the surface layer, a small but significant error may be committed in the computed remote sensing. These errors in the value of static correction of each seismic trace result in a deteriorating S/N ratio of the CDP stack section. Statistical processes called residual statistical analysis estimate these residuals.

The residuals are estimated by summing the number of statically and dynamically corrected traces, which belong to one CDP. The summation out put called the model trace is cross-correlated with each of the contributing traces in turn. The residual is then represented by the correlation log-time corresponding to the peak of the correlation function.

5.2.n) Velocity Analysis

It is the process of calculating seismic velocity, typically by using common mid point data, in order to better process the seismic data. Successful stacking, time migration and depth migration all require proper velocity inputs. Velocity or stacking velocity can be calculated from NMO. Before the traces can be stacked, normal moveout corrections have to be applied to shift reflection on all traces to a common arrival time.

5.2.O) CDP Stacking

Following static and NMO corrections the traces are ready for the next, and main, step in the processing sequence, in which all the values corresponding to a particular reflection time on each trace in a CDP are added together. This sum of the traces form one composite trace in which reflections are preserved at full strength, while all other energy is reduced. This procedure is known as staking, or compositing. Stacked data is also referred to as CDP or CRP data.

Stacking not only enhances the reflection from true reflectors but also attenuate multiple reflections.

5.2.p) Filtering

A filter is a system, which discriminates against some of its input. Seismic data always contains some signal information, which we want to preserve everything else is called noise, and we want to remove or reduce it. These systems, which are generally, called filters work either by covolution in the time domain or by spectral shaping in the frequency domain.

The most common types of filters are the following:

- Low pass frequency filters
- High pass frequency filters
- Band pass frequency filters
- Notch filters
- Inverse filters
- Velocity filters

Time Variant Filters

The frequency content of the initial source signal changes in a time-variant manner as it propagates through the earth. In particular high frequencies are more rapidly absorbed than low frequencies. This is because of the intrinsic attenuation in rocks. It is possible to estimate the maximum frequency to be expected at the particular depth.

Removal of unwanted frequencies above those maximum expected, one, is accomplished using a time variant filter whose pass band decreases in frequency with increasing reflection time. Use of a time-variant filter increases signal-to-noise ratio.

5.2.q) Migration

Migration moves dipping reflectors into their true subsurface positions and collapses diffractions, thereby delineating detailed subsurface features such as fault planes. So in this respect migration can be viewed as a form of spatial deconvolution that increased the spatial resolution. Migration does not displace the horizontal events, rather, it moves dipping events in the up dip direction and collapses diffractions, thus enabling us to delineate faults.

The goal of migration is to make the stacked section appear similar to the geologic cross section along the seismic line.

5.2.q1) Migration Techniques

Conventional migration techniques are based on Huygen's principle. There are two alternative methods, which are both based on this principle. These are:

- Wave front common-envelope method.
- Diffraction hyperbola method.

5.2.q2) Wave Front Common-Envelope Method

A dipping reflector is, according to reflection laws, perpendicular to the reflection rays in our model of source-receiver common position.

This means that the reflector is defined by the tangent surface (or common envelope) to all the wave fronts drawn for an incident seismic ray.

According to Huygen's principle, the superposed wave fronts will destructively interfere at all points except at the true reflection point.

5.2.q3) Diffraction Hyperbola Method

This method is based on the assumption that a reflector is made up of a packed series of diffraction points or scatters.

The diffraction hyperbola method is also known as the diffraction summation method, was the first compute implementation of migration.

Diffraction summation is a straightforward summation of amplitudes along the hyperbolic trajectory whose curvature is governed by the velocity function. It is also known as the Kirchhoff Migration.

5.2.r) Header Generation

After all of the samples 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 tape 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.

5.2.s) Display:

At the end of the processing sequence and some time at intermediate stages it is necessary to convert the digital data to analog format so that they can be displaced and then examined visually.

There are several methods for plotting digital data in analog form. The most common method is to pass the digital trace through a sample and hold device which produces an out put 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, which can then be smoothed into a continuous trace by passing through low pass filter. The analog signal is then displaced on paper or film by means of recording oscillograph (camera) or plotter.

5.2.t) Processing Objectives:

The improvement of the signal to noise ratio either by enhancing the signal or attenuating the noise. This is the object of most seismic data processing, which is generally designed to attenuate specific type of noise.

The repositioning of data elements (migrating). This data on unmigrated seismic sections are referenced to the locations of the source and receivers usually being plotted at the midpoint between them, migration repositions data to the locations of the reflecting points.

The measurement of the "attributes" of the data, including velocity, amplitude, frequency, polarity and other measurements.

The display of the data in a manner easily understandable by an interpreter, display parameters include the use of optimum scale for the particular interpretation objectives and displays that combine various types of measurements such as color displays.

Chapter#6

INTERPRETATION

6.1) Introduction

The interpretation of the reflection data involves its expressions in geological terms. When competently carried out, it requires the fitting together of all pertinent geological and geophysical information into an integrated picture that is more complete and more reliable than either source is likely to give alone. Ideally, this integration would be accomplished most efficiently if a single person highly competent both in geophysics and geology did it. In actual practice, individual with adequate training and experience in both fields are very few and it is usually necessary for a geophysicist and geologist to collaborate at this stage of the interpretation.

According to Dobrin and Savit (1988) interpretation is the transformation of the seismic reflection data into a structural picture by the application of correction, migration and time depth conversion. The seismic reflection interpretation usually consists of calculating the position of, and identifying geologically, concealed interfaces or sharp transition zones form seismic pulses return to the ground surface by reflection. The influence of varying geological condition is eliminated along the profiles to transform the irregular recorded travel times into acceptable subsurface models. This is very important for confident estimation of the depth and geometry of the bedrock or target horizons.

According to Badely, 1985, reflection seismic uses sound waves to investigate the subsurface. The acoustic impedance governs reflections, which is one of the rock properties.

Acoustic impedance= interval velocity *density

Reflections arise at boundaries across which acoustic impedance changes. No reflection occurs if the acoustic impedance does not change even if lithology changes. The greater the difference in the acoustic impedance is, the stronger the reflection. The size of change is defined by reflection coefficient (RC).

The major aim of seismic reflection surveying is to reveal as clearly as possible the structure of the subsurface. The geological meaning of seismic reflection is simply an indication of an acoustic impedance boundary where we want to know that whether this boundary marks a fault or a stratigraphic contact with any other boundary. We want to distinguish the feature that is not marked by the sharp boundaries.

A sequence of sedimentary rocks is grouped into unit called formations. These formations can be described in terms of age, thickness and lithology of the consistent layers. To distinguish different formations by means of seismic reflection is an important question in interpretation of data, which may be structural, lithological, or stratigraphic. For this purpose the data is correlated with well data and already known geology of the area. But in our case well data is available, suitable approx at a distance of 15km from the given line (904-MWI-8A) at VP-860.Thishas been correlated with the well data and the geology of the area.

6.2) Methods for Interpretation of Seismic Section

There are two main approaches for the interpretation of seismic section

- Stratigraphic analysis.
- Structural analysis.

6.3) Stratigraphic analysis

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

6. 4) Interpretation of the Given Data

So far we have discussed seismic section compiled from CDP stacked traces that have been migrated and deconvolved as necessary to remove false images that are artifacts of processing. This seismic section displays reflection arrival times. A variation along a profile is called time scanning.

6.4.a) General Description of Given Line 904-MWI-8A

Length of seismic line 904-MWI-8A is about 38.25 km, the first vibroseis point is 150 and the last vibroseis is 1000. It is 30 fold seismic data recorded using the vibroseis as source of energy. The line was recorded by OGDCL in 1990.The data was recorded for four milli-seconds. The present work include interpretation of VP 150 to VP 400.

- **Phase Type**

As energy source used is vibroseis, therefore its seismic signature is minimum phase wavelet.

6.5) Isovelocity Section

6.5.a) Method I (By using Dix average velocity)

Isovelocity section is prepared by using Dix average velocities. The velocity information provided along with the processed seismic reflection section include root mean square velocity and interval velocities, and we had been estimated it indirectly while processing 30 fold data. The values of average velocities on each CDP are determined by using Dix formula. The Dix average velocity formula given below.

Average Velocity = $\{V_{n,int}(T_n - T_{n-1}) + V_{n-1,avg}(T_{n-1})\} / (T_n)$

Where

T_n = Two-way travel time to deeper level.

T_{n-1} = Two-way travel time for shallower depth.

6.5.b) Preparation of Isovelocity Section.

In this method the velocity is used for determination of depth of every reflector is determined with the help of Dix average velocity contour section. The different average velocities under CDPs are calculated and then interpolate these values throughout the lines and are plotted along their respective times. Dix average velocity varies from 1500m/s-4700m/s for four seconds data and have been taken into account to construct a velocity control at an interval of 100m/s and the times of the reflector are also plotted on this section and velocity of the reflectors at each VP can be calculated with respect to above and underlying contours

6.5.c) Behavior of Isovelocity Section

Isovelocity section shows the vertical velocity variation but there is less lateral variation in the velocity. The average velocities on different CDP vary from 1500m/s-4700m/s for four seconds.

Subsurface velocity variation can be produced by the changes in the rock properties ıch as varying formation thickness and facies change. The velocity within the rock unit is ıainly influenced by their lithological characteristics and their age. The lateral variation caused y the faulting modifying the time structure of deeper reflectors.

6.6) Time and Depth Section

Time Section

Time section is actually the reproduction of seismic section, the time section actually consist of two scales one is horizontal scale representing VP's while the vertical scale shows time. The reflector in the given time section are marked on the basis of dominant reflection coefficient. The time for each reflector is read from the seismic section (for example the time of reflectors (R1, R2, R3). given and plotted against the vibroseis points.
The reflectors are dipping in the NW and pinch out to SE direction.

Depth Section

Generally the depth section gives the configuration of reflector in the same way as it is n the time section. To determine the depth the first step is to read time of each reflector from seismic section. Using the appropriate velocity values and time, the depth of each reflector is calculated by a formula.

Depth = V*T/2

Where

V = the velocity of respective reflectors

T = the two way travel time of each reflector and read from

Seismic section in seconds.

6.7) Depth Estimation

An accurate measurement of seismic velocities is an important step in seismic data interpretation and processing. Two different ways are used to determine the average velocity data in order to construct the depth section. These are

- Using Dix isovelocity contour graph.
- Using mean velocity curve..

6.7.a) Using Dix Isovelocity Contour Graph

In this method the velocity used for the determination of depth of every reflector is estimated with the help of average velocity contour map. The different average velocities under CDP's are calculated and then interpolate these values throughout the line and are plotted along their respective times. Dix average velocities vary from 1500m/s-4700m/s for four seconds data and have been taken into account to construct a velocity contour graph at an interval of 100m/s, and the time of reflector are plotted on this graph and the velocity of reflector at each VP can be calculated with respect to the above and underlying contours.

These velocities are used in the depth formula for estimation of depth of each reflector as shown in the depth section

Depth = Vavg* time (One way)

The complete depth model of line 904-MWI-8A based on the Dix iso-velocity section is shown in figure.

In this method, velocities of different zones is used for the conversion of time domain into depth domain. For this purpose, velocities for different reflectors are used. The depth of these reflectors is determined by using these velocities along with their respective time in the depth section. There are five prominent reflectors in the depth section which are R1, R2, R3. The trend of these reflectors exhibits the same trend as in the time section.
All the reflectors mentioned in the depth section, are dipping toward north. Now the detailed about each reflector are

➢ Reflector R1

This reflector having depth 786.4 m at VP-150 and 990.25m at VP-400.The time of the reflector R1 is 0.68 sec at VP- 150 and 0.85 sec at VP-400.

➢ Reflector R 2

This reflector having depth 893.1m at VP-150 and 1152 m at VP-400.The time of the reflector is 0.78 sec.at VP-150 and 0.96 sec at VP-400.

➢ Reflector R3

This reflector having depth 1218.9 m at VP-150 and 1518.5 5m at VP-400.The time of the reflector is 1.02 sec at VP-150 and 1.21 sec at VP-400.

6.8) Correlation of the Data with the stratigraphy of the area

Precise correlation of the reflectors in terms of their depths with the stratigraphy of the concerned area requires a lot of experience, knowledge and detailed information. For the interpretation of the given seismic section a well i.e. "KUNDIAN-01" was provided, which is at a distance of about 15km away from VP 860 on the given line. A number of prominent reflectors are visible, which are R1, R2, and R3 on the given line. In the allotted segment of the section reflectors R1, R2, R3 are present.

Reflections coming from approximately 0.68 sec can be considered as the top of Chingi formation. Above Chingi formation, lies the Nagri formation up to the surface. R2 can be considered as the top of Permian, therefore, indicating an unconformity due to the absence of some geological ages. Reflector R3 may be considered as the top of basement above which whole sedimentary sequence rests.

6.9) Structural analysis

According to Dobrin and Savit (1988) it is the study of reflector geometry on the basis of reflection time. The main application of structural analysis of seismic section is in the search for structural traps containing the hydrocarbons. Most structural interpretation used two ways reflection time rather depth and time structural maps are constructed to display the geometry of selected reflection event. Some seismic section contains images that can be interpretation without difficulty; discontinued reflections clearly indicate faults and undulating reflections reveals folded beds.

In our seismic section there are some faults through the seismic interfaces.In the present portion, four faults, F1, F2, F3 and F4, have been observed. Fault F1 and F2 are normal faults and cross the reflectors R1 and R2, while faults F3 and F4 displace only the reflector R2. This means that the reflector F1 and F2 show older tectonic disturbances.

Conclusions

Following conclusions were drawn from interpretation of the seismic line MWI-904-8A.

1. Reflectors have gentle slope and dipping with low angle towards NW.
2. R2 is recognized an unconformity on the basis of well log data, Stratigraphy of the area and presence of pinch outs.
3. The sequence present above unconformity is correlated to Siwalik Group comprising of Chinji and Nagri formations. While sequences below unconformity are Permian strata.
4. Sedimentary column is thin towards south and there is uplifting towards south of the area due to Sargodha high, where formations are pinching out.
5. Many faults are present which are mostly normal faults.
6. Basement is dipping towards North East at low angle of about 1 degree.

CDP 360				
TIME(sec)	VRMS(m/sec)	VINT(m/sec)	VAVE(m/sec)	Depth(m)
0	1500	0	1500	0
0.65	2278	2278	2278	740.35
0.85	2382	2692	2375.412	1009.55
1.35	2656	3066	2631.185	1776.05
1.7	2887	3643	2839.5	2413.575
1.9	2916	3152	2872.395	2728.775
2.6	3410	4484	3306.288	4298.175
4	4500	6022	4256.788	8513.575
5	5000	6633	4732.03	11830.08

Table 6.1

CDP 460				
TIME(sec)	VRMS(m/sec)	VINT(m/sec)	VAVE(m/sec)	Depth(m)
0	1500	0	1500	0
700	2229	2229	2229	780150
850	2306	2626	2299.059	977100
1450	2769	3316	2719.862	1971900
1850	3083	4021	3001.189	2776100
2400	3440	4435	3329.771	3995725
4000	4500	5734	4291.463	8582925
5000	5000	6633	4759.77	11899425

Table 6.2

CDP 560				
TIME(sec)	VRMS(m/sec)	VINT(m/sec)	VAVE(m/sec)	Depth(m)
0	1500	0	1500	0
750	2275	2275	2275	853125
900	2400	2947	2387	1074150
1650	2807	3228	2769.273	2284650
2300	3442	4682	3309.826	3806300
4000	4500	5623	4292.925	8585850
5000	5000	6633	4760.94	11902350

Table 6.3

CDP 660				
TIME(sec)	VRMS(m/sec)	VINT(m/sec)	VAVE(m/sec)	Depth(m)
0	1500	0	1500	0
900	2300	2300	2300	1035000
1150	2500	3115	2477.174	1424375
1700	2750	3210	2714.265	2307125
2200	3156	4256	3064.659	3371125
4000	4500	5729	4263.613	8527225
5000	5000	6633	4737.49	11843725

Table 6.4

CDP 760				
TIME(sec)	VRMS(m/sec)	VINT(m/sec)	VAVE(m/sec)	Depth(m)
0	1500	0	1500	0
0.7	2296	2296	2296	803.6
0.95	2455	2853	2442.579	1160.225
1.35	2675	3136	2648.037	1787.425
1.95	3000	3648	2955.718	2881.825
2.8	3436	4258	3351.054	4691.475
4	4500	6321	4242.038	8484.075
5	5000	6633	4720.23	11800.58

Table 6.5

Average Velocity (m/sec)	Time at CDP-360 (sec)	Time at CDP-460 (sec)	Time at CDP-560 (sec)	Time at CDP-660 (sec)	Time at CDP-760 (sec)
1600	0.083	0.096	0.091	0.112	0.088
1700	0.167	0.192	0.193	0.225	0.176
1800	0.25	0.288	0.29	0.338	0.264
1900	0.334	0.384	0.387	0.45	0.352
2000	0.418	0.48	0.484	0.562	0.44
2100	0.501	0.576	0.581	0.675	0.528
2200	0.585	0.672	0.677	0.787	0.615
2300	0.791	0.825	0.811	0.9	0.785
2400	1.166	0.977	1.007	1.041	0.955
2500	1.181	1.13	1.204	1.273	1.15
2600	1.377	1.283	1.4	1.505	1.345
2700	1.545	1.436	1.596	1.737	1.54
2800	1.713	1.578	1.716	1.88	1.735
2900	1.906	1.721	1.836	2.023	1.929
3000	2.098	1.836	1.956	2.166	2.144
3100	2.291	2.03	2.077	2.316	2.359
3200	2.484	2.197	2.197	2.466	2.575
3300	2.677	2.364	2.317	2.616	2.79
3400	2.824	2.53	2.49	2.766	2.925
3500	2.971	2.697	2.663	2.917	3.059
3600	3.119	2.863	2.836	3.067	3.194
3700	3.258	3.029	3.009	3.217	3.329
3800	3.413	3.196	3.187	3.367	3.463
3900	3.56	3.362	3.355	3.517	3.598
4000	3.707	3.528	3.528	3.667	3.733
4100	3.855	3.695	3.7	3.817	3.867
4200	4.002	3.861	3.873	3.967	4.002
4300	4.212	4.075	4.087	4.178	4.211
4400	4.423	4.288	4.3	4.389	4.42
4500	4.634	4.502	4.504	4.6	4.63
4600	4.844	4.716	4.728	4.811	4.839
4700	5.055	4.929	4.941	5.022	5.048

Table 6.6

R1			
VP's	Time(sec)	Velocity(m/sec)	Depth(m)
150	0.68	2260	768.4
160	0.69	2260	779.7
170	0.7	2260	791
180	0.71	2260	802.3
190	0.72	2255	811.8
200	0.71	2240	795.2
210	0.7	2230	780.5
220	0.71	2220	788.1
230	0.7	2215	775.25
240	0.7	2210	773.5
250	0.72	2210	795.6
255	0.72	2210	795.6
260	0.73	2210	806.65
261	0.73	2210	806.65
263	0.73	2215	808.475
264	0.72	2215	797.4
267	0.72	2215	797.4
270	0.72	2215	797.4
280	0.73	2220	810.3
290	0.75	2210	828.75
300	0.75	2215	830.625
302	0.76	2215	841.7
304	0.76	2215	841.7
306	0.77	2210	850.85
307	0.78	2210	861.9
310	0.79	2210	872.95
315	0.79	2215	874.925
320	0.79	2220	876.9
330	0.78	2200	858
340	0.79	2190	865.05
350	0.8	2230	892
352	0.8	2230	892
353	0.8	2230	892
356	0.81	2240	907.2
360	0.81	2260	915.3
370	0.82	2300	943
378	0.82	2310	947.1
380	0.83	2320	962.8
381	0.83	2330	966.95
382	0.84	2330	978.6
390	0.84	2330	978.6
400	0.85	2330	990.25

Table 6.7

R2			
VP's	Time(sec)	Velocity(m/sec)	Depth(m)
150	0.78	2290	893.1
160	0.79	2290	904.55
170	0.81	2300	931.5
180	0.82	3220	1320.2
190	0.83	2310	958.65
200	0.83	2300	954.5
210	0.81	2300	931.5
220	0.82	2300	943
230	0.82	2300	943
240	0.82	2300	943
250	0.84	2310	970.2
255	0.83	2320	962.8
260	0.83	2320	962.8
261	0.83	2320	962.8
263	0.84	2300	966
264	383	2300	440450
267	0.84	2300	966
270	0.83	2300	954.5
280	0.87	2300	1000.5
290	0.88	2300	1012
300	0.88	2300	1012
302	0.88	2290	1007.6
304	0.88	2290	1007.6
306	0.89	2320	1032.4
307	0.98	2320	1136.8
310	0.9	2310	1039.5
315	0.9	2310	1039.5
320	0.91	2310	1051.05
330	0.9	2300	1035
340	0.9	2330	1048.5
350	0.93	2340	1088.1
352	0.93	2350	1092.75
353	0.93	2350	1092.75
356	0.93	2335	1085.775
360	0.93	2335	1085.775
370	0.94	2360	1109.2
378	0.94	2380	1118.6
380	0.93	2390	1111.35
381	0.93	2400	1116
382	0.94	2400	1128
390	0.95	2400	1140
400	0.96	2400	1152

Table 6.8

R3			
VP's	Time(sec)	Velocity(m/sec)	Depth(m)
150	1.02	2390	1218.9
160	1.02	2390	1218.9
170	1.04	2395	1245.4
180	1.05	2395	1257.375
190	1.06	2400	1272
200	1.07	2400	1284
210	1.07	2405	1286.675
220	1.08	2410	1301.4
230	1.09	2420	1318.9
240	1.1	2440	1342
250	1.1	2440	1342
255	1.1	2450	1347.5
260	1.1	2450	1347.5
261	1	2450	1225
263	1.12	2450	1372
264	1.13	2450	1384.25
267	1.13	2450	1384.25
270	1.15	2470	1420.25
280	1.15	2480	1426
290	1.15	2480	1426
300	1.15	2480	1426
302	1.15	2480	1426
304	1.15	2450	1408.75
306	1.15	2460	1414.5
307	1.15	2440	1403
310	1.15	2440	1403
315	1.16	2450	1421
320	1.16	2450	1421
330	1.17	2470	1444.95
340	1.18	2480	1463.2
350	1.18	2490	1469.1
352	1.18	2490	1469.1
353	1.18	2490	1469.1
356	1.19	2490	1481.55
360	1.19	2490	1481.55
370	1.19	2500	1487.5
378	1.2	2500	1500
380	1.2	2500	1500
381	1.21	2510	1518.55
382	1.21	2510	1518.55
390	1.21	2510	1518.55
400	1.21	2510	1518.55

Table 6.9

Fig 6.2

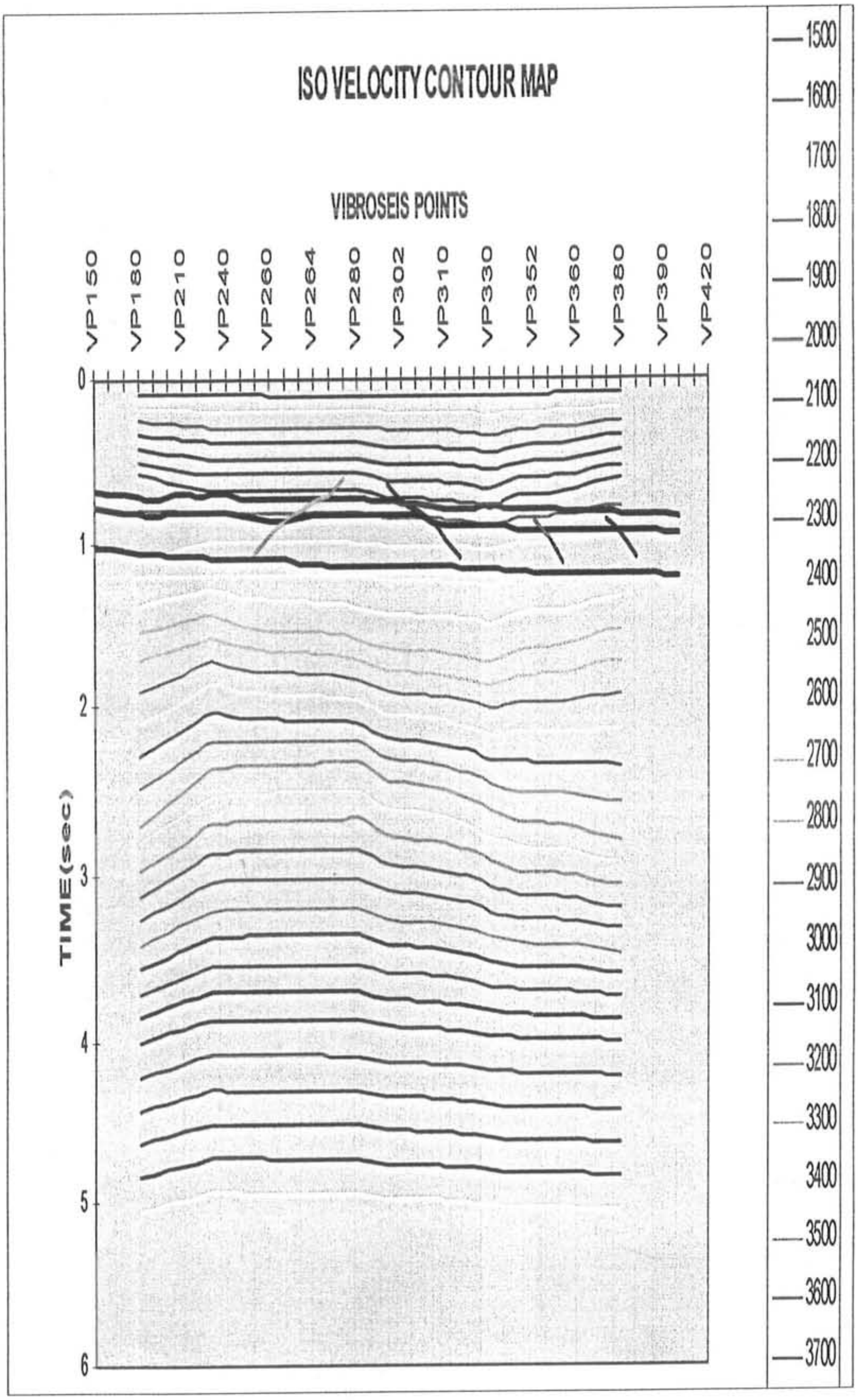
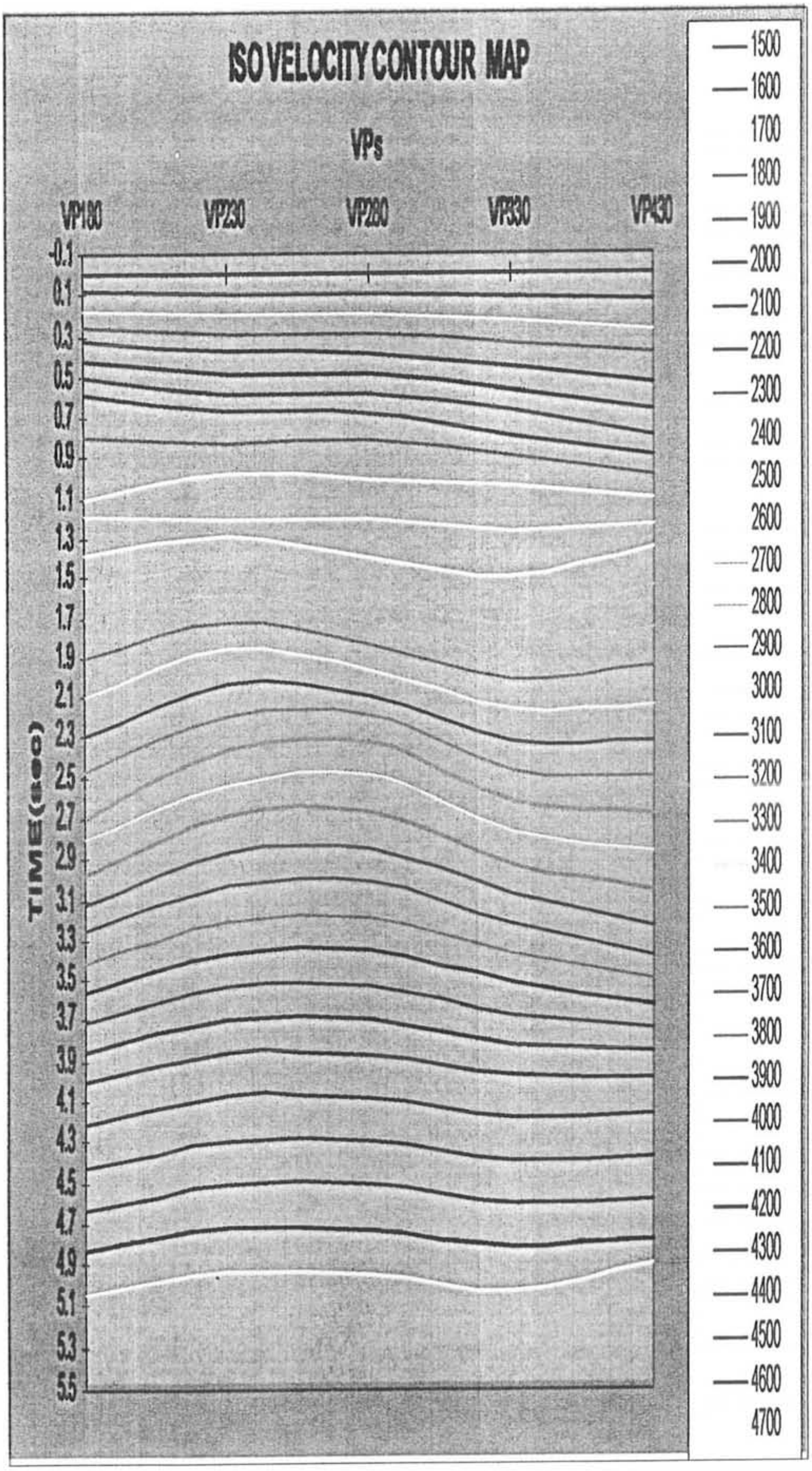
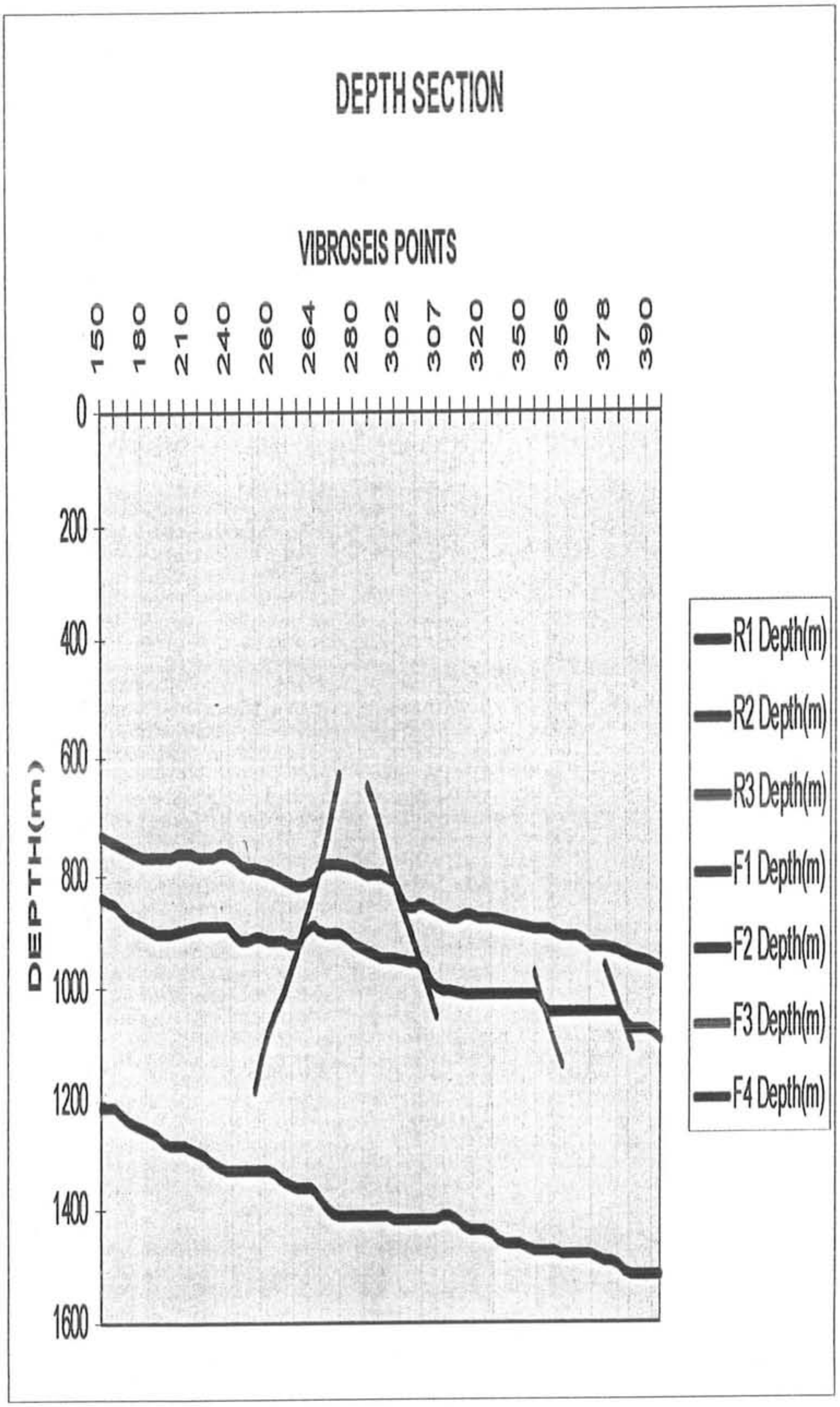

ISO VELOCITY CONTOUR MAP
VIBROSEIS POINTS
VP150
VP180
VP210
VP240
VP260
VP264
VP280
VP302
VP310
VP330
VP352
VP360
VP380
VP390
VP420
TIME(sec)
0
1
2
3
4
5
6
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700

Fig 6.1



ISO VELOCITY CONTOUR MAP
VPs
VP180
VP230
VP280
VP330
VP430
TIME(sec)
-0.1
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1
4.3
4.5
4.7
4.9
5.1
5.3
5.5
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
4100
4200
4300
4400
4500
4600
4700

Fig 6.3



DEPTH SECTION
VIBROSEIS POINTS
150
180
210
240
260
264
280
302
307
320
350
356
378
390
0
200
400
600
800
1000
1200
1400
1600
DEPTH(m)
R1 Depth(m)
R2 Depth(m)
R3 Depth(m)
F1 Depth(m)
F2 Depth(m)
F3 Depth(m)
F4 Depth(m)