2D INTERPRETATION OF SEISMIC LINE PK87-1416
OF
BADIN BLOCK OF PAKISTAN

QUAID-I-AZAM UNIVERSITY
ISLAMABAD

BY
AAMIR NAWAZ
M.Sc (Geophysics)
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بسم الله الرحمن الرحيم

CERTIFICATE

This thesis of **Mr. AAMIR NAWAZ** is accepted in its present form by Department of Earth Sciences as satisfying the thesis requirements for M.Sc. degree in Geophysics.

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Quaid-I-Azam University,
Islamabad.

DEDICATED

TO

MY EVER LOVING

&

CARING

FAMILY

CONTENTS

ACKNOWLEDGEMENT

All worship is due to lord of creation, who himself invited the mankind in particular the believers, to think over the phenomena of the infinite cosmos and its countless dimensions and I offer my thanks to Holy Prophet (PBUH) who is forever a torch of knowledge and guidance to humanity and enable us to shape our lives according to the teaching of Isalm.

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Aamir Nawaz.

ABSTRACT

Interpretation of Line No. PK87-1416 of Badin Block, oriented in east west direction, has been conducted in the study. Five reflectors with eight faults have been delineated on the seismic section. Depths of the individual reflectors and faults have been calculated by using three methods namely Mean Line Method and Constant Velocity Method. Horsts and grabens are the prominent structures found in the subsurface. Lower Goru formation is the main reservoir in the study area.

Horsts are also seen in the depth section at two different locations. This shows that there may be a possibility of the hydrocarbons accumulation in these traps.

INTRODUCTION
&
GEOLOGY

INTRODUCTION AND GEOLOGY

1.1 Introduction:-

Seismic method provides the highest degree of accuracy if subsurface geological detail relative to other geophysical methods is available. Of all the physical methods used in geological exploration, this seismic reflection method is perhaps the most direct and when applied gives the least ambiguous results. This method is used to find discontinuities in the 'elastic' properties of the rocks, when the pulses or the energy (i.e. elastic waves) are released near surface of the ground. This energy is produced by dynamite explosion within the earth (at few meter depth) or by the movement of vibroseis on land, if the travel time of these waves are measured accurately, only the wave velocities of the formation are needed through which they have traveled from the source to the receiver.

In petroleum prospecting the length of the seismic record ranges from four or five seconds and the events, which appear on it, are usually measured to the nearest two or four milliseconds. The interpretations of these events consist in identifying their nature of reflections, in determining the depth and the cause of their origin. Since their signals are accurately timed, the key to their interpretation lies in determining the elastic wave velocity within the region, which they have traversed.

From our discussion it is cleared that data is acquired in the field then it is processed in the processing unit and the final step is interpretation of the processed data.

1.2 Available Data:-

The seismic line PK 87-1416 includes shot points numbered from 110 to 420. Root Mean Square (RMS) and interval velocities computed during processing also provided with the data.

These velocities are given in the CDPs and are use for the calculation of average velocities. Shot points contain seven CDPs that are CDP- 135, CDP-190, CDP-245, CDP-285, CDP-325, CDP-360, CDP-400.

1.3 Recording Parameters of the Seismic Profile:-

Recorder type	SERCEL SN 348
Tape format	SEG B
Sample rate	2MS
Record length	5Sec
Nominal fold	30

- Spread Diagram:

Asymmetric Split Spread

		Source		
TR_1 ________________	TR_{60}	*	TR_{61} ________________	TR_{200}
2015M	50M		50M	2015M

Display Parameters:

- Scales

Horizontal
1 : 19677

Vertical
10 cm/sec

Source Parameters:

Source	Dynamite
No. of holes	3 holes
Depth	60 feet
Source interval	56.6M
Charge size	2Kg/hole

Receivers Parameters:

No of Groups	120
Geophone type	SM4U
Geophone frequency	14Hz.
Pattern	9Geophones in series

4Strings/Station

No. of elements 36

1.4 Main Objective:-

The main aim of this dissertation is that to interpret this 2D-Seismic reflection section and to get some valuable information about the subsurface.

1.5 Regional Setting and Tectonics:-

It is considered that in the geological history, Indo-Pakistan shield was a part of Gondwanaland, which got separated from it as a Gondwanaland fragmentation. Indo-Pak plate started to move northward. Drift of the Indian plate was near the end around 55 Million ago (Eocene). The geological setting of Pakistan is divided into two regions.

- Gondwanian Domain.
- Tethyan Domain.

This southern part of Pakistan belongs to Gondwanian Domain and is sustained by Indo-Pak crustal plate. The northern most and western part of Pakistan fall in the Tethyan Domain and present complicated geology and complex crustal structure.

On the basis of plate tectonics, geological structures, organic history Pakistan is divided into following broad tectonic zones (Kazmi & Jan,1997) as shown in the figure 1.1

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 Acceretioney zone.
7. Chagai magmatic arc.
8. Pakistan offshore.

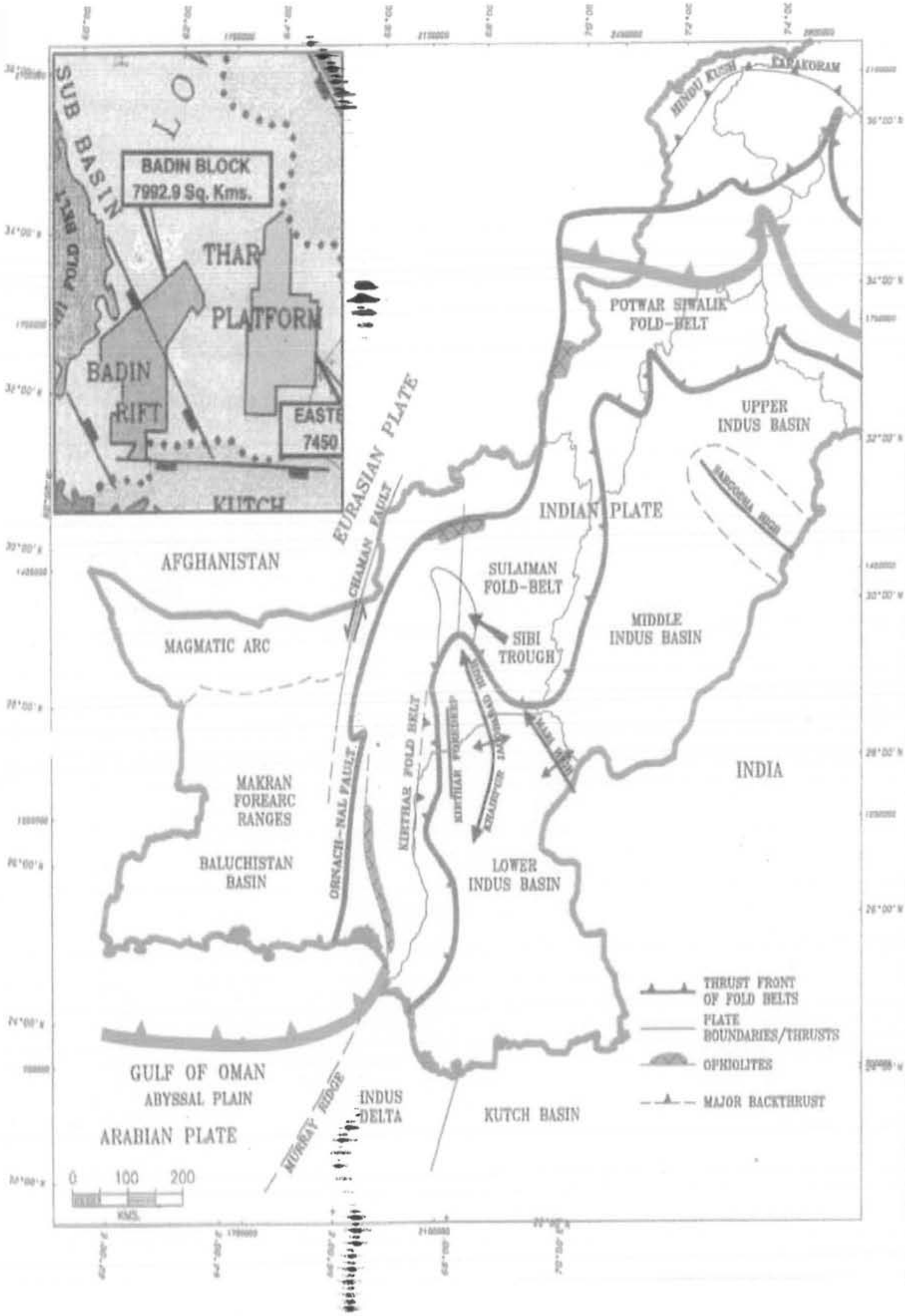
Within these broad tectonic zones there are several smaller zones. However, my area of study is part of Indus platform, "**The lower Indus Basin**", therefore brief discussion of this will be discussed here after.

1.6 Indus Basin:-

The Indus Basin, which covers an area of 535,580sq.km, is located on the northwest slope of the Indian shield and includes the fold belt. It is divided into Lower, Middle, and Upper Indus Basin based on structural highs. The Jacobabad-Kharpur and Mari-Khandkot highs and the Sargodha high are the basis of this division. The region between the Sargodha high and the MBT forms the upper part of the basin, which includes the Kohat-Potwar Plateau, the Bannu Basin, the Cis and Trans Indus Salt Ranges, and the northern Punjab monocline. The region between the Sukkur rift zone and Sargodha high, comprising the Sulaiman fold belt and foredeep and the southern Punjab monocline constitutes the middle part of the Basin. The lower part of the basin lies to the south o the Mari-Khandkot horst and comprises the Jacobabad high, Kirthar fold belt and its depression and the Sindh monocline. (Raza et al.1989a, Raza and Ahmed 1990, Kadri 1995).

1.7 Location of Area:-

Badin Block is located in the Lower Indus Basin approximately 160 km due east of Karachi city and in the south east of Pakistan. It would be appropriate to name Badin Block Area as Badin Rift Basin, which is characterized by a series of horst and graben structures present below the base Paleocene unconformity within the Cretaceous formation. These horst and graben structures were formed as a result of rifting between India and Seychelles during the Late Cretaceous.



HINDU KUSH
KARAKORAM
POTWAR SIWALIK
FOLD-BELT
UPPER
INDUS BASIN
SARGODHA HIGH
INDIAN PLATE
EURASIAN PLATE
CHAMAN FAULT
AFGHANISTAN
SULAIMAN
FOLD-BELT
SIBI
TROUGH
MIDDLE
INDUS BASIN
MAGMATIC ARC
KIRTHAR FOLD BELT
KIRTHAR FOREDEEP
MARI HIGH
INDIA
MAKRAN
FOREARC
RANGES
BALUCHISTAN
BASIN
ORNACH-NAL FAULT
LOWER
INDUS BASIN
THRUST FRONT
OF FOLD BELTS
PLATE
BOUNDARIES/THRUSTS
OPHIOLITES
MAJOR BACKTHRUST
GULF OF OMAN
ABYSSAL PLAIN
ARABIAN PLATE
MURRAY RIDGE
INDUS
DELTA
KUTCH BASIN
0 100 200
KMS.
SUB BASIN
BADIN BLOCK
7992.9 Sq. Kms.
THAR
PLATFORM
BADIN
RIFT
KUTCH

Fig 1.1

Stratigraphy of the Area

The stratigraphy of the Badin Block is given below:

PERIOD	EPOCH	FORMATION	LITHOLOGY
TARTIARY	Holocene	Gaj/Nari	Sandstone/Shales
		Laki	Laki Shales
	Paleocene	Ranikot	Ranikot Sand
		Khadro	Volcanic/ Basalt
			Khadro Sand
CRETACEOUS	Upper	Upper Goru	Upper Goru Shale
	Lower	Lower Goru	Upper Sands
			Upper Shales
			Middle Sands
			Lower Shale
			Basal Sands
		Sember	Sember Sands & Shales
JURASIC	Upper		
	Middle	Chiltan	Chiltan Limestone
	Lower	Shinwari/Datta	Sandstone, limestone, Marl, Shales/Sandstone

SEISMIC METHODS

SEISMIC METHODS

2.1 Introduction:-

Seismic surveying was first carried out in the early 1092s. Seismic methods are widely applied to exploration problems involving the mapping of sub surface boundaries of normally simple geometry.

Seismic methods may be classified into two major divisions, depending on energy source of seismic waves, one in which the natural shock wave from earth quakes are suited to infer physical properties and structure of earth interior is called earth quake seismology. The other in which artificial explosions at selected sites to obtain information about regional or local structures generate the seismic waves is called explosion seismology (Sharma, 1976).

Large amount of energy released by earth quakes that probe the deep mantle and core of the earth. But there are other ways to produce seismic waves that can be focused on geologic features close to the earth surface. These waves can be generated by explosions and then recorded on seismometer (Robbinsion and Curoh, 1988).

2.2 Seismic Refraction:-

Seismic refraction is defined as the travel path of sound wave through an upper medium and along an interface (at a critical angle) and back to the surface. The acoustic wave, like light wave; follow the Snell's law of refraction.

Seismic refraction method is used to determine the thickness of unconsolidated material over lying bed rocks and depth to water table.

2.3 Seismic Reflection:-

Seismic reflection method records acoustic wave at the surface that is reflected off of subsurface stratigraphic interfaces where changes in the material density and conductive velocity of the acoustic waves are significant. The reflection pattern is described by Snell's law of reflection.

2.3.1 Application:-

Seismic reflection are used to determine,

1) Thickness of subsurface geology.
2) Structure of subsurface geology.
3) For hydrocarbon and mineral exploration.
4) They are used in earth quake and tectonic studies.
5) In the marine environment for resolving stratigraphic details (for example, the location and thickness of beach-sand deposits).

2.4 Influence of the Medium:-

As the medium of propagation of seismic waves is not the idealized homogeneous and isotropic in nature. So waves experience modification in there motion depending on the type of the medium.

2.4.1 Diffractions:-

When a seismic wave traversing a medium comes across an anomalous obstacle it bends, these phenomena of bending of waves is called diffractions.

2.4.2 Scattering:-

When diffraction occurs as a result of the small obstacles. It is called scattering.

2.4.3 Interference:-

When two or more waves trains superimpose one another they act to re-in force one another where there is agreement in phases and cancels out one another when they are out of phase, re-enforcement is called constructive interference and canceling out is called destructive interference.

2.4.4 Dispersion:-

Distortion of the wave from due to change of velocity with the frequency of the individual wave from is called dispersion.

2.4.3 Attenuation:-

Seismic wave traveling through a general type of the medium suffers reduction in the wave energy; this loss in energy is called attenuation. There main factors for wave attenuation are,

- Geometrical spreading.
- Absorption.
- Energy partition at interface.

2.5 Seismic Waves:-

Seismic waves are the waves of energy caused by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth and is recorded on seismographs. These waves travel radilly outwards.

2.6 Types of Seismic Waves:-

There are several different kinds of seismic waves, and they all move in different ways. The two main types of waves are

2.6.1 Body Waves.

2.6.2 Surface Waves.

2.6.1 Body Waves:-

These are the waves propagating inside the elastic material or we can say that these are the waves traveling with in the medium. There are two types of body waves.

a) Longitudinal Waves (Primary/Compressional):-

These are called as p-waves or primary waves because these are the waves, which arrive first. P-waves is the fastest of all seismic wave.

The wave path traversed by p-wave consists of a sequence of alternating zones of compressions and dilatations (rarefaction). That's why the waves are also called compressional waves. They are also called longitudinal waves because wave propagation and the

particle motion are in the same direction, as shown in fig 2.1.
The velocity (V_P) at which these primary waves travel through the material is determined by the elastic properties of the material.
It can be shown by the relationship.

$$V_p = \sqrt{k + 4/3u \big/ d}$$

Where,

k = Bulk Modulus

u = Shear Modulus

d = Density

b) Secondary Waves (Transverse/Shear):-

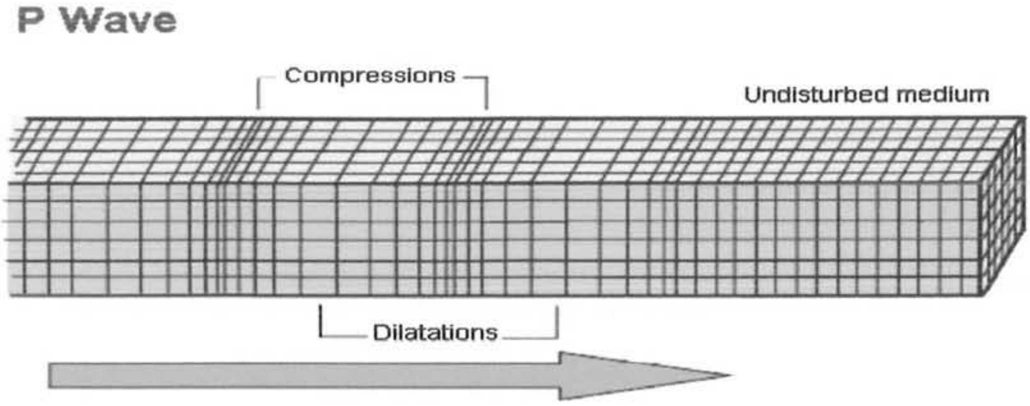
They are called secondary waves or S wave because they arrive second, following the P waves. These are also called transverse waves because particles motion is at right angle to the direction in which the waves are moving. These waves are sometime called Shear or Rotational wave because the wave travels in the form of crest and trough and they cause on angular deformation at constant volume, as shown in fig 2.2

2.6.2 Surface Waves:-

a) Love Waves:-

These waves are observed only when there is low velocity layer overlaying a medium in which elastic waves have a higher speed. The wave motion is horizontal and is perpendicular to the direction of propagation, as shown in fig 2.3.

The first kind of surface wave is called a **Love wave**, named after A.E.H. Love, a British mathematician who worked out the mathematical model for this kind of wave in 1911. It's the fastest surface wave and moves the ground from side-to-side.


P Wave
Compressions
Undisturbed medium
Dilatations

Fig(2.1)

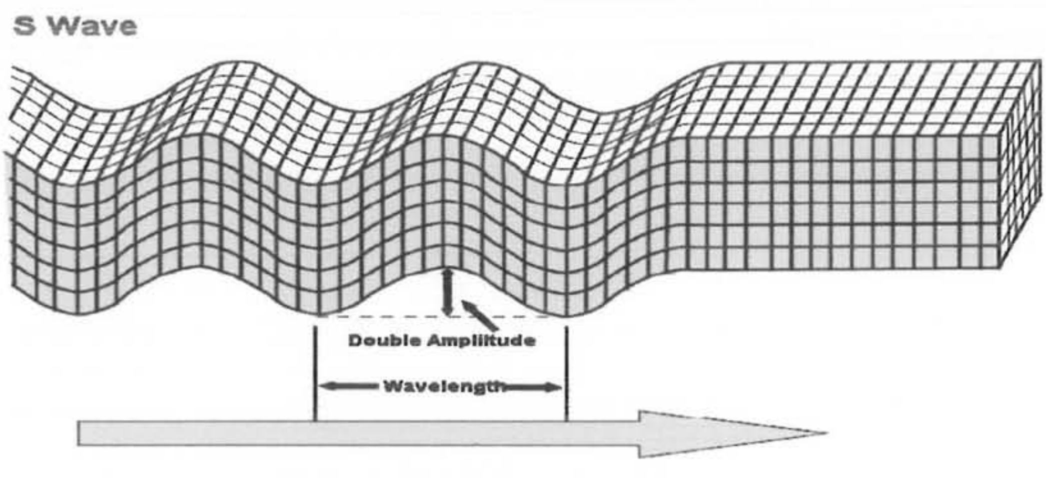

S Wave
Double Amplitude
Wavelength

Fig.(2.2)

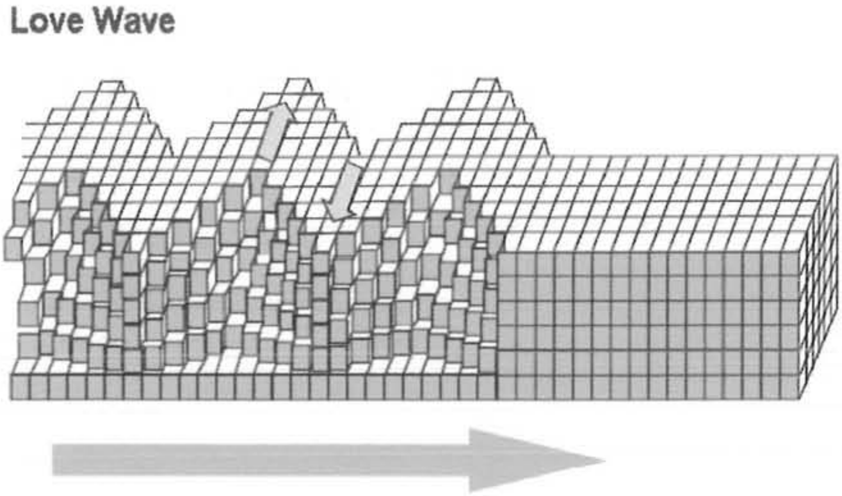


Fig.(2.3)

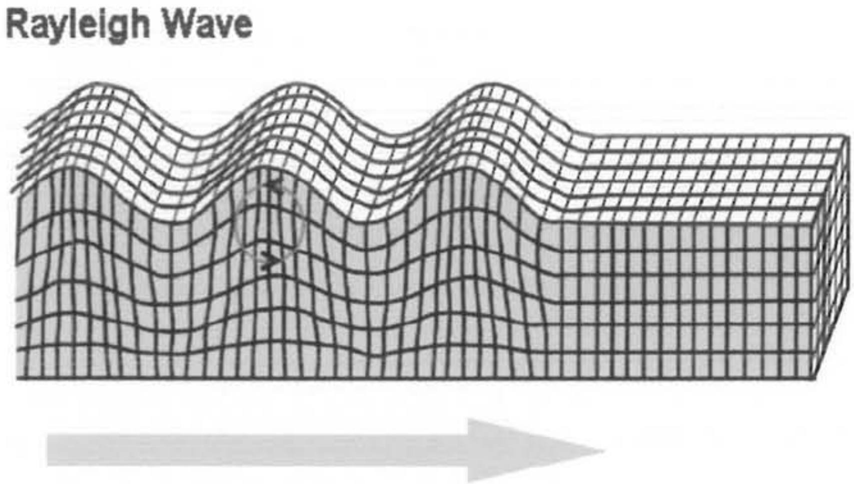


Fig.(2.4)

b) Rayleigh Waves:-

These waves travel long only the free surface of elastic solid. The particle motion is in a vertical plane and elliptical with respect to the direction of the propagation, amplitude of motion decreases exponentially with depth below the surface, as shown in fig 2.4

2.7 Seismic Wave Principle:-

2.7.1 Huygens's Principle:-

According to this principle, each point on a wave front may be considered as a recording source where the envelope of the wave fronts of the secondary wave defines the portion of the primary wave at the same later time (Al Sadi, 1980).

2.7.2 Fermat's Law:-

Applied to seismic rays, we may re-express the principle to the effect that a wave propagate along a ray oath for which the travel time is minimum (Al Sadi, 1980).

2.7.3 Superposition Principle:-

The result of adding a number of wave motions is equal to the sum of the effects of the individual component (Al Sadi, 1980).

2.7.4 Reciprocity Principle:-

The position of the source functions and the detector can be interchanged while the effects of the ray path are kept the same for the two cases.

SEISMIC VELOCITIES

SEISMIC VELOCITIES

3.1 Introduction:-

The information is defined as a vector quantity, which indicates the rate of change of displacement or the propagation rate of seismic waves without implying the direction (speed of the wave traveling inside the earth).

Velocity as a seismic parameter plays an important role in almost the whole range of activities involved in seismic processing. The accuracy of data reduction, processing and interpretation of seismic data depends mainly on the correctness of velocity measurement (Al Sadi, 1980).

Borehole velocity measurements offer more precision than surface based measurements. Wherever energy is produced by the source, it generates 'P' and 'S' waves, which enter into the earth. We use commonly the 'P'waves velocity.

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 behavior changes. An increase in grain size will result in the increase in velocity (Al Sadi, 1980).

The seismic velocity may be used to establish the following.

1. True depth.
2. Stacking of Seismic Data.
3. Migration of Seismic Data.
4. Possible Lithology determination.
5. Possible Porosity estimation.

3.2 Factors effecting Seismic Velocity:-

The seismic velocity in the rocks are affected by several factors are mentioned (Telford et al, 1976).

- Density of the rocks.
- Age of the rocks.
- Porosity.
- Effects of the geological structure:
- Temperature and pore fluid.
- Types of Industrial Fluid.

3.2.1 Density of rocks:-

Velocity is directly proportional to elasticity and inversely proportional to density.

$$(\text{Seismic Velocity})^2 = \frac{\text{effective Elasticity}}{\text{Density}}$$

So it is expected that denser rocks would have low velocity, however, the inverse is true. It is because as the materials become more compact its elasticity increase in such a way that it reduces the effect introduced by density increase (Al Sadi, 1980).

3.2.2 Age of rocks:-

A quantitative relationship between velocity, depth and age of the rock particularly for the shale and sandstone section, 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

3.2.3 Porosity:-

Lower the porosity higher will be the velocity and higher the porosity lower will be the velocity.
Relationship between porosity (ø) and velocity (v) is given below, (Telford et al, 1976).

$$\frac{1}{V} = \frac{\phi}{V_f} + \frac{(1-\phi)}{V_m}$$

Where,

V_f = Velocity of the pore fluid.
V_m = Velocity of the rocks matrix.

3.2.4 Effects of the geological structure:-

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

3.2.5 Temperature and pore fluid:-

Seismic velocity decreases slightly with temperature but freezing of pore fluid increases the velocity.

3.2.6 Types of industrials fluids:-

A sand containing water in pore spaces has higher seismic velocity then that containing oil and gas.

3.3 Types of seismic Velocity:-

There are number of velocities. Listed below are the most commonly used in interpretation.

3.3.1 Average Velocity:-

The average seismic velocity is the distance traveled by a seismic wave from the source location to some point on or with in the earth divided by recorded travel time.

$$V_{avg} = 2Z / T = Z / t$$

Where,

Z = Depth to reflector.
T = One-way travel time.
t = Two-way travel time.

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

3.3.2 Interval Velocity:-

It is defined as a thickness of a particular layer divided by the time it takes to travel from top of the layer to its base.

$$V_{int} = 2 \rho z / \rho T = \rho Z / \rho t$$

Where,

ρz = Thickness of stratigraphic layer.

ρT, ρt are two-way and one-way travel time with in a layer respectively. V_{avg} and V_{int} are same for low horizons.

3.3.3 Root Mean Square (RMS) Velocity:-

When subsurface 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

$$V_{rms} = 2\Sigma \, Vi \, \rho z / \Sigma \rho T$$

$$V_{rms} = \Sigma V^2 \rho t / \Sigma \rho t$$

Where,

ρT = Two-way travel time

ρt = One-way travel time.

RMS is determined directly from borehole measurements.

3.3.4 Stacking Velocity Or Normal Moveout:-

$$V_{nmo} = X / T^2_x - T^2_0$$

Where,

X = Offset distance from the receiver.
T_x = Two-way travel time of reflection at x.
T_0 = Two-way travel time of reflection at zero offset.

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

$$T^2_x = T^2_0 + X2 / V^2st$$

3.3.5 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 a sonic log.

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

3.3.6 Dix Average Formula:-

Grant (1965) showed that for uniform horizontal layer and small offset, the NMO velocities are equitant to the root mean square velocities Vrms.

$$V^2_n = V^2_{n,rms}\, t_n - V^2_{n-1,ms}\, t_{n-1} / T_n - t_{n-1}$$

Where the subscript n-1 and n indicate the upper and lower boundaries of the subject interval respectively.

3.4 Variation in Seismic Velocities:-

Variation in seismic velocities is of two types,

3.4.1 Lateral Variation:-

These variations are supposed as a result of slow changes in density, elastic properties and lithology, as depositional environment is not always the same throughout the formation. (Robinson, 1988).

3.4.2 Vertical Variation:-

These variations are due to lithological changes and increasing pressure due to increasing depth. Normally seismic velocities increase with increase in depth.

3.5 Velocity Measurement:-

In seismic prospecting two main approaches is available for the velocity measurement.

3.6 Velocity survey in well (Direct Method):-

- **Sonic Logging.**

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

- **Shooting in well.**

  Shooting in a well and recording the arrival time of the waves at different intervals, accomplish well shooting velocity determination.

3.7 Reflection travel time technique:-

- **T^2-X^2 Method.**

  This method is based on the equation:

  $$T = X / V^2_{rms} + T^2o$$

  When we plot T^2 as a function of X^2, we get a straight line whose slope is $1 / V^2_{rms}$, and intercept are T^2o, from which we determine the corresponding depth (Telford et al, 1986).

3.8 Compressional & Shear Velocity in Rocks:-

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

(Dobrin & Savit, 1988)

SEISMIC DATA ACQUISITION

SEISMIC DATA ACQUISITION

4.1 Introduction:-

The basic field activity in seismic surfing is the collection of seismogram which may be defined as analogue or digital time series that register the amplitude of the ground motion as function of time during the passage of a seismic wave train. The acquisition of seismogram involves conversion of the seismic ground motion in the electric signals, amplification and filtering of signals and their registration on a chart recorded or tape recorded.

The desired data recorded on a seismogram is signal and the undesired data, which disturb the signal, is called noise. The recording system and field layouts are designed such that to improve signal to noise ratio. The seismic reflection data is recorded in the field by using well defined field parameters that is source, receiver spread configuration. The seismic spread and detector arrays are arranged carefully to suppress noise and improve the quality of the signal. Apart from field parameters, appropriate field filter are used along with the suitable gain settings during data acquisition for the suppression of noise and improving the desired signal.

The components that are involved in collection of seismogram are:

- Input energy source.
- Profile arrays.
- Recording instruments.

4.2 Seismic Sources:-

Sources of seismic energy come in a variety of sizes and shapes. Virtually anything that impacts, or causes motion on, the surface of the earth will be a source of seismic energy. Unfortunately, most sources are uncontrollable, such as road traffic, wind (this causes noise by making bushes and trees move), aircraft, people walking, etc. For our experiments, we would like to control the source of the ground motion. In this discussion, we will restrict our example to that source which is used to acquire the data in our seismic section.

4.2.1 Explosive Energy Source:-

On land explosive are normally detonated in shallow shot holes to improve the coupling of the energy sources with the ground and to minimize the surface damage. Explosive offer reasonably cheap and highly efficient seismic source with a wide frequency spectrum but their use normally requires special permitting and present logistical difficulties of storage and transpiration.

a) Dynamite:-

This is most common energy source used in seismic prospecting. Normally it is explored inside a drilled hole at a depth ranging from few meters to several meters. The amount of charge depends upon whether it is a single hole or a pattern (multi hole) shooting. As a rough estimate, the charge weight is 10-50 kg of dynamite.

A well known variation of this method is what is called ***Air Shooting***. This involves simultaneous firing of number of charges placed at reasonable height above ground surface (al-Sadi, 1980).

b) Buried Primacord:-

The greatest enhancement of downward traveling energy can be obtained with a continuous source horizontally elongated. Such down ward directivity can be obtained with burying proper length of primacord, an explosive extracted rope like from detonating it at one end (or at its center) and letting the explosive disturbance propagate along it at a speed (22,000 ft/sec) much greater speed then the seismic propagation in the near surface material with in which it is buried. Burial is necessary to suppress noise and increase the efficiency of the energy transfer into the earth (Dobrin, 1988).

The principle **advantages** of explosive sources are

(a) Pound for pound, these types of sources impart the most amount of seismic energy into the ground of any of the sources described here,

(b) The energy tends to be very high frequency, and because the explosives are usually placed in a shallow borehole, it tends not to be contaminated by surface waves, and

(c) Explosive sources are very repeatable.

The principle **disadvantages** of explosive sources are

(a) Safety,

(b) Permitting. Landowners tend to be nervous about allowing the use of explosives on their property,

(c) Data acquisition using explosive sources is much slower than using impact or gun sources. This is primarily because boreholes must be drilled within which the explosives are to be placed, and explosives tend to be expensive to acquire and maintain.

4.3 Profile Array (Multichannel Reflection Profiling):-

The basic requirement of a reflection survey is to obtain the recording of reflected pulses at several offset from a shot point. An important reason for multichannel recording is the need to identify the reflection as such and separate them from the ground motion due to other source. Much of the undesired ground motion called **noise** are associated with shot or diffracted by surface or irregularities. (Dobrin & Sovit, 1988). Reflection survey is normally carried out along the profile. The shot point and associated spread of geophones are being moved progressively along the line to take lateral coverage of underlying geological section.

4.5 TYPES OF SPREAD:-

4.5.1 Split Spread:-

The detectors are distributed on either side of central shot point.

⟵————⟶ * ⟵————⟶

Where,

⟵——⟶ = Detectors.

* = Shot Point.

4.5.2 End Spread:-

The shot spread is located at one end of the detector spread.

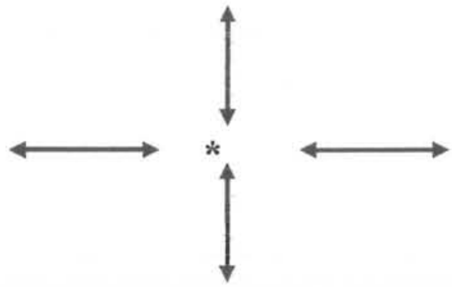
*⟵————⟶

4.5.3 In Line Offset Spread:-

To avoid ground roll (Noise) shot point is placed some distance along the line from nearest geophone group.

4.5.4 Cross Spread:-

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



4.5.5 L – Spread:-

L – Shaped spread consists of two lines which are extending in different direction from the same source (Robinson & Coruch, 1988).

4.6 Common Depth Point Profiling (CDP):-

If the shot detector spread configuration is moved forward in a Multichannel reflection profiling survey is such a way that no two reflected ray paths sample the same point on a reflector, the survey coverage is said to be single-fold. Each seismic trace then represents a unique sampling of some on the reflection. In CDP a set of traces recorded at different offset contains reflections from a common depth point on a reflector. The shot points and detectors location for such a set of traces known as CDP gather have a common mid point (CMP) below which the common depth point is assumed to lie.

4.6.1 Advantages of CDP:-

The CDP gather represent the best possible data set for computing velocity from the normal moveout (NMO) effect.

With accurate velocity information the moveout can be removed from each trace of a CDP gather to produce a set of traces that may be assumed algebraically to produce a CDP stack in which reflected arrivals are enhanced relative to the seismic noise.

The CDP principle breaks down in the presence of dip because the CDP then no longer directly underlies the shot detector mid point and reflection point differs for rays traveling to different offsets.

4.7 Fold:-

The number of repetition of one common reflected point is called fold. The fold is expressed as a percentage fold, single fold is of 100% coverage, 6 fold=600% coverage.
The relation as under can determine fold.

$$\text{Fold} = N\,(\Delta X / 2n)$$

Where,

N = No. of recording channels.

ΔX = Channel spacing or geophone interval.

n = Source interval.

4.8 Seismic Recording Instruments:-

4.8.1 Seismic Detectors:-

The detectors used in seismic surveying are electromechanical transducers that convert a mechanical input into electrical output. Devices used on land to detect seismic ground motions are known as seismometers or geophone.

4.8.2 Geophone:-

There are several types of geophone the most common is moving-coil geophone. In this instrument a cylindrical coil is suspended from a spring support in a field of a permanent magnet which is attached to the instrument casing. The magnet has cylindrical pole piece inside the coil and an angular pole piece surrounding the coil. The suspended coil represents as oscillatory system with a resonant frequency determined by the mass to the coil and the stiffness of its spring suspension. The geophone is fixed by a spike base into a soft ground or mounted firmly on hard ground. Due to ground vibrations the movement of the coil in the magnetic field generates a voltage cross the terminals of the coil. The shunt resistance across the coil terminals controls the amount of flowing current through the coil.

4.8.3 Seismic Cable:-

The geophone signal which is electric current produced by ground vibrations is transmitted to recording system by mean of seismic cable. A geophone is connected to cable on a point is called "Take Out".

4.9 Seismic Amplifies And Tap Recorders:-

Seismic amplifiers are required to amplify signals in the frequency range from a few hertz to a few hundred hertz. Most seismic amplifiers systems contain frequency filters for high-pass, low-pass, band-pass and band reject filtering. Filtering is commonly employed to produce a suitable visual record in the filed.

4.9.1 Analogue Recording System:-

When the ground is vibrating it is in common motion. A geophone responding to this motion produces a continuously varying electrical signal. A seismogram is a graph that shows how the amplitude of the signal varies with time. Different technique may be used for obtaining seismogram.

On such technique is recording device that draws a continuous graph at the same time that it is receiving the geophone signal.

In another recording technique tape with a magnet sable coating is used. As the magnetic tape advance, the geophone signal continuously magnetizes the portion passing by the recorder head. These techniques which produce continuous graph were named analogue recoding techniques (Robinson &Coruh, 1988).

4.9.2 Digital Recording System:-

This recording technique is basically different from the above two. At discrete interval of time it measure the strength of geophone signal and record it as a number, so rather then a continuous graph it represent us a series of numbers. Later these numbers can be plotted and a seismogram prepared by connecting the points. The technique of recording the geophone output at discrete moments is called digital recording. Seismic survey for petroleum now utilizes digital recording system (Robinson & Courch, 1988).

4.10 Dynamic Range:-

An important feature of seismic recording system is dynamic range, which is the ratio of the strongest and weakest signal.

Mathematically Dynamic Range = A / a

Where, A is the maximum signal amplitude and "a" is the weakest signal.

4.11 Seismic Noises:-

The undesired data, which overlap our signal, called noise. There are two type of noise.

4.11.1 Coherent Noise:-

Which displays some regular pattern on a seismogram, it consists of recognizable waves such as surface waves, reflected waves and multiples produced by source.

4.12.2 Incoherent Noise:-

Display no systematic pattern, it may arrive simultaneously from many sources such as wind blowing on trees and passing traffics.

4.13 Basic Tools For Controlling Noise In The Field:-

- Source size.
- Source depth.
- Source arrays.
- Receiver arrays.
- Electronic mixing.
- Electronic filtering.

SEISMIC DATA PROCESSING

Seismic Data Processing

4.1 Introduction:-

Data processing is a sequence of operation that is carried out according to the predefined program to extract useful information from a set of raw data (Dobrin & Savit, 1988; Al Sadi, 1980).

Processing seismic data consists of applying a sequence of computer programs each designed to achieve one step along with the path from field tape to record section. From ten to twenty programs are usually used in a processing sequence, and these are selected from a library of several hundred programs. For example one program may operate in time domain while other works in the frequency domain, yet they may yield similar result (OGTI Manual, 1989).

According to Dobrin & Savit 1988 Seismic data processing is composed of basically-phase content, data compressing (stacking), and data positioning (migration). These adjustments increase that signal to noise ratio, connect the data for various physical processes that obscure the desired (geologic) information of the seismic data, and reduce the volume of data that the geophysicist must analyze.

According to Yilmaz 1987 there are three primary stages in processing seismic data. In there usual order of application, they are

i. Deconvolution
ii. Stacking
iii. Migration

4.2 Basic Steps Involved In Seismic Data Processing:-

Generally there are five basic steps in seismic data processing shown below in table.

- Data Reduction.
- Geometric Corrections.
- Data Analysis and Parameter Optimization.
- Data Refinement.

4.3 Data Reduction:-

In this step the following jobs are performed:

- Demultiplexing
- Vibroseis Correlation
- Header Generation
- Display
- Edit
- Amplitude Adjustment

4.3.1 Demultiplexing:-

Data from the field arrive at the processing centre in tapes written in multiplexed format because that is the way the sampling is usually done in the field--- successive samples on the tape represent the succession of channels at the same instant in time.

Multiplexed data thus use time, not channel, as the primary index (Dobrin & Savit, 1988).

If we identify each sample by its geophone group source (A, B, C, D) and by its chronological sequence in that group (1, 2, 3....) then we see that output will be

$A_1, B_1, C_1, D_1, A_2, B_2, C_2, D_2, A_3, B_3, C_3, D_3$....

This scrambled sequence is referred as "multiplexed" array. However, it is more convenient to process seismic data in trace sequential array:

A_1, A_2, A_3..... B_1, B_2, B_3...... C_1, C_2, C_3.......

This unscrambling of multiplexing array into a trace sequential array is called demultiplexing. So demultiplexing is accomplished by a simple compute sorting program and it is the first step in any data processing sequence (OGTI Manual, 1989).

4.3.2 Vibroseis Correlation:-

In most seismic method an energy source is used that generates a very short pulse. But the signal generated in the vibroseis method is not a short pulse, rather a "sweep" lasting some seen seconds or longer. The sweep is transmitted through the earth and reflected as is any seismic signal but on a vibroseis record, each reflection is as long as the input sweeps rather being a pulse. So each reflection is a near reflection in the vibroseis record overlap and is generally indistinguishable. To make the vibroseis record useable, we must "compress" the reflections into short wavelets. This is done by cross correlating the data with the original signal generated by the vibroseis.

4.3.3 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.

4.3.4 Display:-

At the end of the processing sequence, and something at the intermediate stages, it is necessary to reconvert the digitized data to analog format so that they can be
displayed and 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 produces 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 smoothed into a continuous trace by passage through a low pass filter.

4.3.5 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 values to all samples in the effected time interval. Several forms of editing are used through out data processing, which are

- Editing during demultiplexing
- Muting

4.3.5.1 Editing during Demultiplexing:-

Now during the demultiplexing process there are two types of editing available:

1. Automatic Editing
2. User Selected Editing

Automatic editing will reject traces which contains any sync error or rare too short. The user selected editing is the one where the user must specify which traces or records will be omitted.

4.3.5.2 Muting:-

If obviously useless inform is to be removed from the processing stream, it must first be identified and then blanked, which is called muting.

It is two main types:

a. Initial Muting
b. Surgical Muting

Initial muting removes the large energy bursts associated with first arrivals, while the surgical muting removes the "Ground Roll", "Raleigh waves" which propagates along the earth's surface, and "Air Waves".

4.3.6. Amplitude Adjustments:-

A gain recovery function is applied on the data to correct for the amplitude effects of wave front (spherical) divergence. This amounts to applying geometric spreading functions, which depend upon travel times, and an average primary velocity function, which is associated with primary reflections in a particular survey area. Gain is applied to seismic data for spherical spreading correction (Yilmaz, 1987). Often AGC (automatic gain control) is applied to raise the level of the weak signals. AGC Attempts to make amplitudes similar for all off sets, for all times and for all mid points. A typical method of calculating the gain to be applied is to calculate the median or overage amplitude within sliding windows the trace, then to calculate the multiples needed to equalize the median values in all the windows (Dobrin & Savit, 1988).

4.4 Geometric Corrections:-

A seismic trace on a field monitor shows reflected energy bursts from subsurface rock layer interfaces. We later measures the travel times from source down to reflect and back to geophones and use them together with average velocity information to compute depths to various reflectors. However, before we use these reflected energy bursts we must apply several corrections to compensate for geometric corrections include static corrections and NMO corrections applied on the trace gathered data.

4.4.1 Trace Gathering:-

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

- Common Source Point gathers
- Common Depth Point gathers
- Common Receiver Point gathers
- Common Offset gather

4.4.2 Static Corrections:-

Reflections are recorded at the earth's surface, which may vary in elevation, after they have passed through the weathered layer. The weathered layer may very in both thickness and velocity. Removing near surface effects is desirable so that:

- Changes in reflection time across a stacked records section can be attributed wholly to subsurface effects.
- Individual traces in CDP gather are properly aligned to preserve reflected signals when they are stacked.

Removing near surface effects requires two corrections.

- Weathering Correction
- Elevation Correction

❖ Weathering Corrections:-

A weathering correction replaces the actual travel time through the weathered layer by a computed travel time world result if the weathered layer (the low velocity layer) were replaced by and equal thickness of the underlying higher velocity rock.

Although the weathered layer does vary in thickness, its approximate thickness is usually known from previous experiences in the prospect area.

- **Elevation Corrections:-**

The effects of topography on a trace's reflection times are removed by applying this correction, which in effect, move both source and receiver vertically to a preselected datum surface. This surface is usually (but not always) a flat datum plane (OGTI Manual, 1989).

The elevation datum surface is chosen before the first data from a new area are processed. In areas of gentle relief it is usually a flat plane about 100ft below the average surface elevation in the area.

4.4.3 Dynamic Corrections:-

One of the steps of processing the data is to rearranges the traces to make CDP gathers. Fig. The traces from different records, which correspond to the same depth point location, are collected together into a single record. The traces are normally arranged within this gather record in order of increasing offset distance. Then the reflected signals from a single horizontal interface align along a hyperbola. The term normal move out or NMO means the variation in reflection travel time with offset distance from source to receiver.

The NMO equation is

$$T_x^2 = T_0^2 + x^2 / V^2_{NMO}$$

Where,

$$T_0 = 2h / V_{NMO}$$

$$\Delta T = T_x - T_0$$

Therefore, NMO equation becomes

$$\Delta T = (T_0^2 + X^2 / V^2)^{1/2} - T_0$$

4.5 Data Analysis And Parameter Optimization:-

There are five steps involved in this

- Filtering
- Deconvolution
- Velocity Analysis

4.5.1 Filtering:-

A filter is a system, which discriminates against some of its input. Seismic data always contain 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 convolution 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

4.5.2 Deconvolution:-

Deconvolution is a filtering process designed to improve resolution and suppress multiple reflections. 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, will convert each wavelet into a single spike.

4.5.2.1 Types Of Deconvolution:-

- **Spiking Deconvolution:-**

It assumes the input is minimum phase and all frequencies are to be leveled in the spectrum. The effect of this type of filter is to concentrate the energy of the pulse as near as possible to the front of the wavelet, i.e., to turn the wavelet into as near a spike as possible (Dobrin & Savit, 1988).

❖ **Predictive Deconvolution:-**

Predictive deconvolution uses the autocorrelation of a trace to ascertain the periodicities within the data. The geophysicist determines from the autocorrelation (s) the necessary operator length, usually a few hundred milliseconds that will span significant reverberation caused energy on the autocorrelation, and a gap, or time delay after the zero lag value. The filter designed from the autocorrelation, when convolved with the data trace, predicts reverberations and multiples. The predicted trace is subtracted from the observed trace to give the prediction error, which should be the trace with the predicted reverberations and multiples.

4.5.3 Velocity Analysis:-

Because of the different source-receiver offsets of the traces in a CDP gather, the arrival time of the arrival time of the reflection from a common depth point will be different on each trace. Before the traces can be stacked, normal move out correction have to be applied to shift reflection on al traces to a common arrival time.

4.6 Data Refinement:-

The processes described thus far are used to reformat, correct and diagnose data characteristics. In this step for data refinement the following procedures are carried out.

- Stacking
- Migration

4.6.1 Stacking:-

Once the necessary corrections have been applied, the data may be stacked. In the "corrected gather" the traces have been gathered into depth point order, both static and dynamics applied, and the traces muted. All that remains to stack the data is to sum all the traces in each depth point, resulting in a single stacked trace being out put for each depth point (OGTI Manual, 1989). One or the other of two considerations is the basis for selecting the seismogram traces that will be stacked. Common offset stacking is done with traces that have the same source-receiver offsets, all of which are centered on the same point (Robinson & Coruh, 1988).

Stacking is data compression of one to two orders of magnitude. After stack, the data are displayed at the surface location of the midpoint between source and receiver. When all adjustments to the data have transformed the offset data into time and phase coincidence with the zero offset trace, a stack trace is used as the approximation to the zero offset trace, a stack trace is used as the approximation to the zero offset trace. With flat reflectors, the common midpoint CMP and CDP are both widely used often interchangeably. With dipping reflectors, the CMP after conventional processing is not the CDP. The correct positioning of reflecting points will be by migration (Dobrin & Savit, 1988).

4.6.2 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 (Yilmaz, 1987).

4.6.2.1 Migration Techniques:-

- **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. (Al-Sadi, 1980)

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

❖ Diffraction Hyperbola Method:-

This method is based on the assumption that reflector is made up of a packed series of diffraction points or scatters (Al-Sadi, 1980). 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 know as the Kirchhoff Migration.

INTERPERTATION

SEISMIC INTERPRETATION

6.1 Introduction:-

Interpretation is a transformation of seismic reflection data into a structural picture by the application of several techniques. Interpretation is transformation of seismic data into structural and stratigraphic picture through the series of different steps.

Extracting non-structural information from the seismic data is called seismic facies analysis such as separating out time depositional units, based on detecting unconformities, determining depositional environments, examing the lateral variation of the individual series of reflection events. Where as extracting from seismic data the geologic structure such as folding and faulting is referred as structural interpretation (Dobrin & Savit, 1988)
Kearey & Brooks (1984) have described two main approaches used in interpretation of seismic sections.

1) Structural Analysis. 2) Stratigraphic Analysis.

6.1.1 Structural Analysis:-

In the structural analysis the main objective is to search out the structural traps containing hydrocarbons. In such analysis interpretation usually take place against a background of continuing exploration activity and an associated increase in amount of information referred to subsurface geology. The most common structural feature associated with oil is anticlines and faults.

6.1.2 Stratigraphic Analysis:-

Stratigraphic analysis involves the subdivision of seismic sections into sequences of reflections that are interpreted as the seismic expression of genetically related sedimentary sequence. Unconformity can be mapped from the divergent pattern of reflections on a seismic section. The presence of unconformable contacts on a seismic section provides important information about the depositional and erosional history of the area and on the environment existing during the time when the movements took place.

6.2 Isovelocity Map:-

In the given section V_{rms} , V_{int} are given , then V_{avg} are calculated at the SP-135, 190, 245, 285, 325, 360, 400 directly from interval velocities with the help of Dix formula. Dix average velocities are contoured at an interval of 100 m/sec.

A considerable variation in the average velocity contour map with time exists vertically as well as laterally.

6.3 Time Section:-

The seismic section display arrival time variations along a profile. This are called time section. The time section shows five major reflectors R1, R2, R3, R4, R5 and eight faults F1, F2, F3, F4, F5, F6, F7, F8.

The time of each horizon is read from seismic section and plotted against the shot points as shown in the fig.

6.4 Depth Section:-

Depth section provides a good control to observe the reflectors by using average velocities and one-way time of reflected wave. Mathematically

$$\text{Depth (m)} = V_{avg} * T \text{ (m/sec)} / 2000$$

Where,

D = Depth
T = Two way travel time in milliseconds
V = Dix average velocity in milliseconds

It is prepared by plotting SP versus depth of different reflectors and faults.

6.5 Method Used For the Preparation of Depth Section:-

Preparation of depth section is the most important step for the interpretation of seismic data. This method is described below.

6.5.1 Mean Average Velocity Line Method:-

This method employs the plotting of mean average velocity line by averaging velocity line by averaging the entire average velocity Vs time plot CDP window.

That average line was then used for the estimation of velocities under each shot points at their respective time corresponding to each particular reflector. Those velocities are then used in the depth formula for the calculation of depth each reflector. The depth section prepared by this method is shown in the fig.

6.5.2 Constant Velocity Method:-

In this method we used a constant velocity for individual reflector, that velocity is obtained by taking average of the velocity obtained by mean line and then multiplying that velocity with the reflector time and then plotting that depth against shotpoints.

6.6 Description of the Reflectors:-

- **Reflector #1:**

The reflector varies between S.P-110 to S.P-420 at time range of 0.680 to 0.730 and at depth of 731m to 803m in the depth section. The data is given in the table # 6.9

- **Reflector # 2:**

The reflector varies between S.P-110 to S.P-420 at time range of 1.400 to 1.205 and at depth of 1995m to 1608.68m in the depth section. The data is given in the table # 6.10

- **Reflector # 3:**

The reflector varies between S.P-110 to S.P-420 at time range of 1.800 to 1.535 and at depth of 2826m to 2275.64m in the depth section. The data is given in the table # 6.11

❖ **Reflector # 4:**

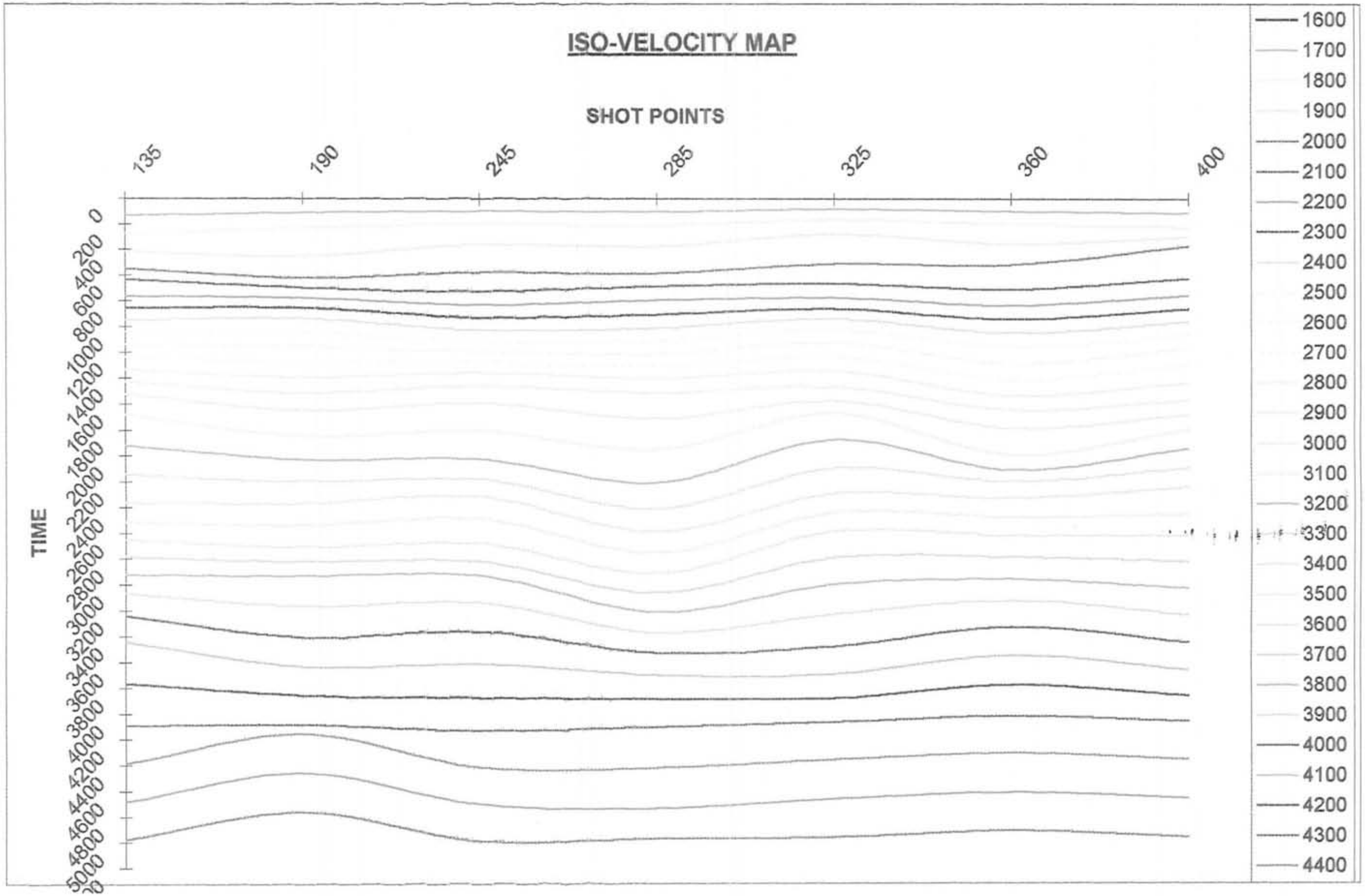
The reflector varies between S.P-110 to S.P-420 at time range of 2.440 to 2.290 and at depth of 4270m to 3904.45m in the depth section. The data is given in the table # 6.12

❖ **Reflector # 5:**

The reflector varies between S.P-110 to S.P-420 at time range of 2.800 to 2.600 and at depth of 5208m to 4680m in the depth section. The data is given in the table # 6.13

CONCOLUSIONS

- Five reflectors are being marked on the basis of continuity and their depths are calculated
- Iso-velocity map shows the lateral and vertical changes due to lithology and structural variation.
- The seismic line seems to lie along the dip.
- Normal faulting is observed in the subsurface.
- Horst and graben are the prominent structures found in the subsurface.
- No stratigraphic trap (Unconformity, pinchouts) seems to exist in the area. A horst structure as mentioned above is found in the subsurface, which can be a good structural trap


ISO-VELOCITY MAP
SHOT POINTS
135
190
245
285
325
360
400
TIME
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
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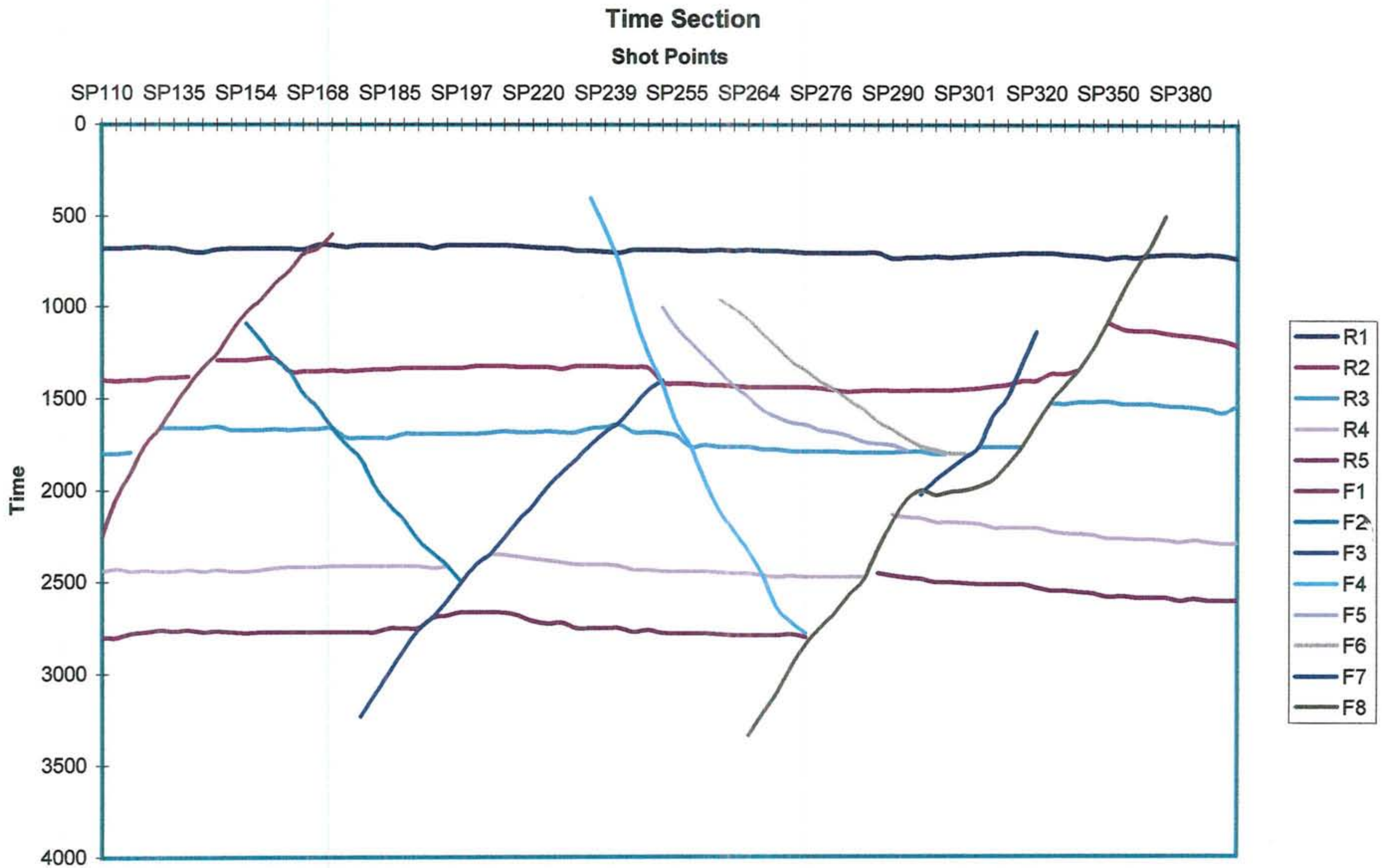
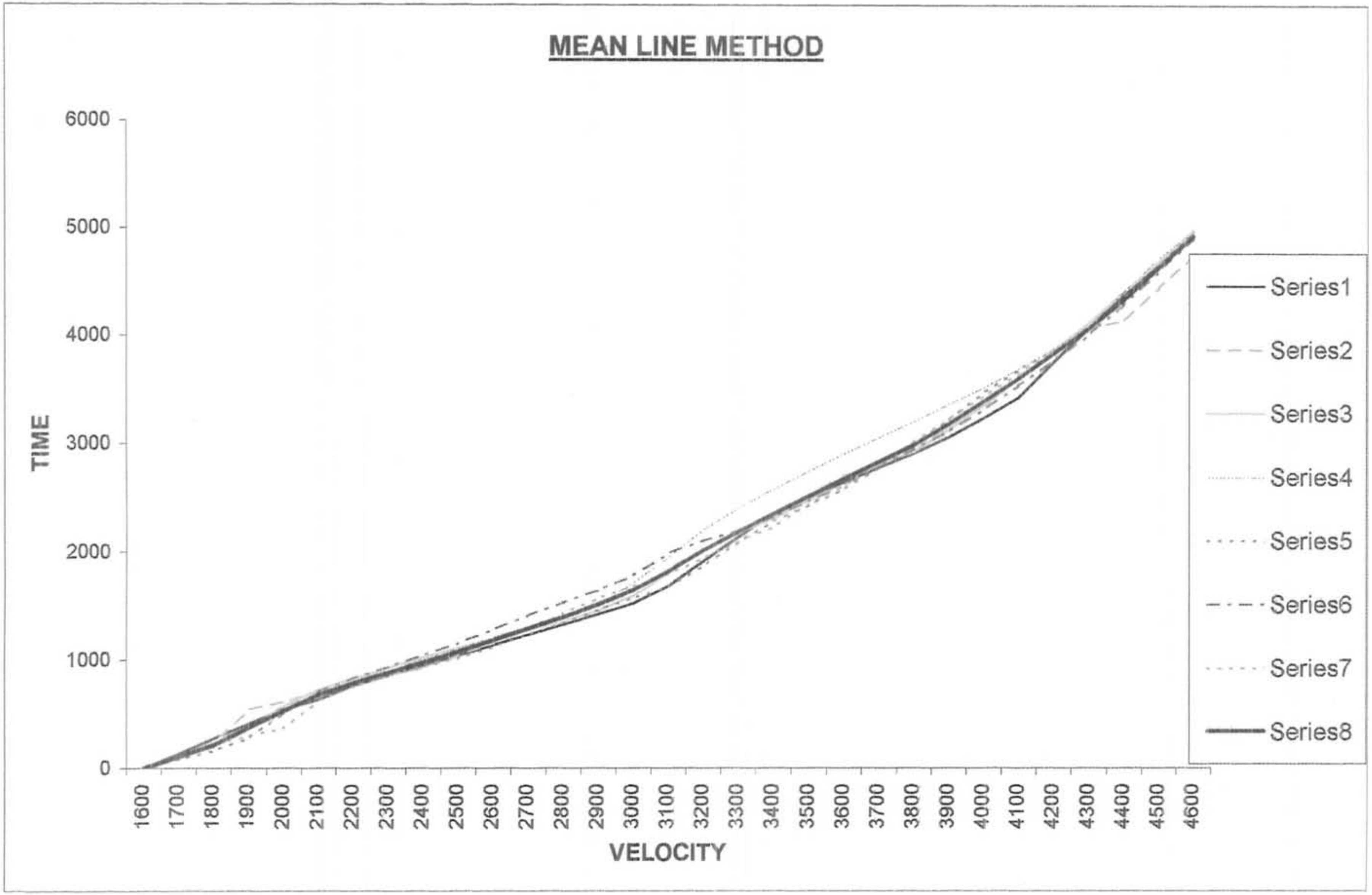
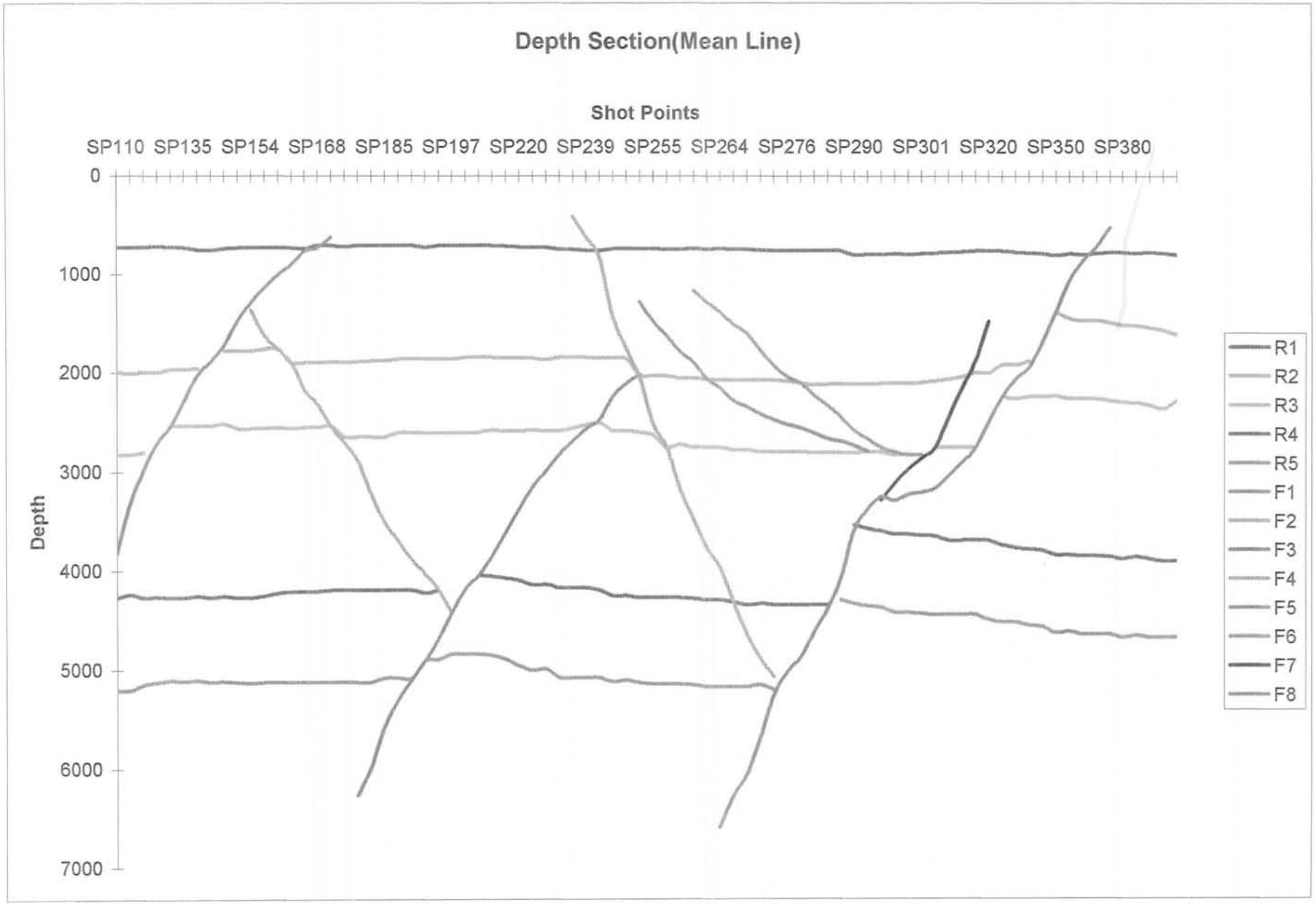
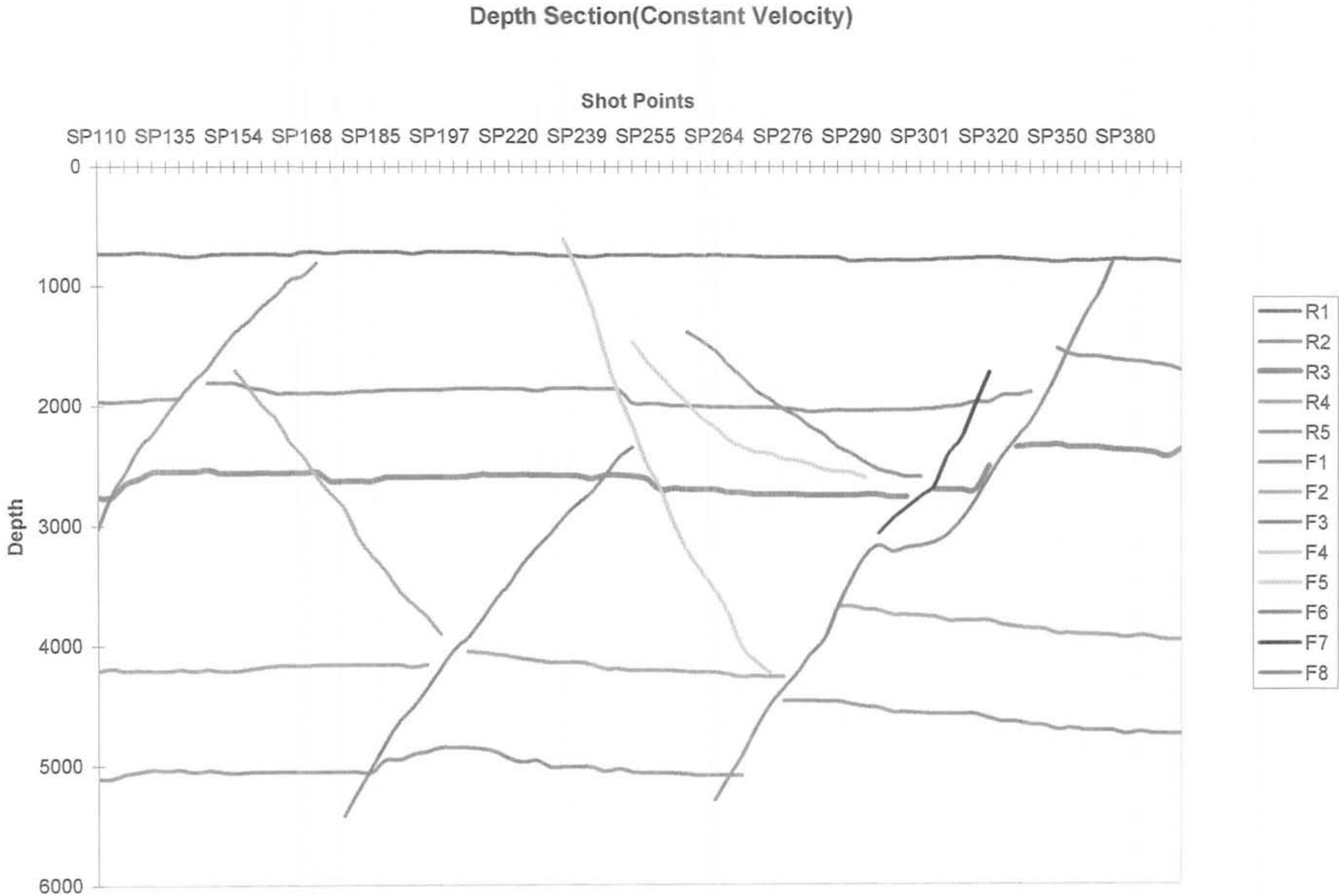
4100
4200
4300
4400



Time Section
Shot Points
SP110 SP135 SP154 SP168 SP185 SP197 SP220 SP239 SP255 SP264 SP276 SP290 SP301 SP320 SP350 SP380
0
500
1000
1500
2000
2500
3000
3500
4000
Time
R1
R2
R3
R4
R5
F1
F2
F3
F4
F5
F6
F7
F8


MEAN LINE METHOD
TIME
6000
5000
4000
3000
2000
1000
0
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
VELOCITY
Series1
Series2
Series3
Series4
Series5
Series6
Series7
Series8


Depth Section(Mean Line)
Shot Points
SP110 SP135 SP154 SP168 SP185 SP197 SP220 SP239 SP255 SP264 SP276 SP290 SP301 SP320 SP350 SP380
0
1000
2000
3000
4000
5000
6000
7000
Depth
R1
R2
R3
R4
R5
F1
F2
F3
F4
F5
F6
F7
F8


Depth Section(Constant Velocity)
Shot Points
SP110 SP135 SP154 SP168 SP185 SP197 SP220 SP239 SP255 SP264 SP276 SP290 SP301 SP320 SP350 SP380
0
1000
2000
3000
4000
5000
6000
Depth
R1
R2
R3
R4
R5
F1
F2
F3
F4
F5
F6
F7
F8

TABLES

ISO-VELOCITY CONTOUR MAP DATA Table 6.1

Velocity (m/sec)	Time(m/s) SP135	Time(m/s) SP190	Time(m/s) SP245	Time(m/s) SP285	Time(m/s) SP325	Time(m/s) SP360	Time(m/s) SP400
1600	0	0	0	0	0	0	0
1700	133	108.76	98.37	104.01	80.5	98.5	113.02
1800	271.49	230.39	196.75	208.03	161.5	201.93	223
1900	411.79	541.73	362.09	375.59	275.97	358.03	298
2000	548.48	620.93	576.32	583.2	508.16	514.12	373
2100	633.24	699.5	729.39	685.06	663.44	708.54	624.1
2200	762.87	776.9	828.88	792.55	772.67	832.44	753
2300	856.19	854.31	928.38	902.51	855.51	939.51	856.92
2400	949.61	931.72	1027.87	1008.7	938.36	1047.42	960.85
2500	1044.59	1041.89	1115.76	1109.36	1021.2	1158.33	1064.77
2600	1039.58	1158.25	1196.45	1210.01	1123.64	1284.25	1168.69
2700	1234.56	1274.61	1277.14	1310.66	1232.64	1410.16	1298.53
2800	1329.55	1391.4	1357.85	1401.92	1341.1	1535.19	1435.86
2900	1425.8	1512.05	1460.28	1514.3	1466.92	1647.29	1573.2
3000	1525.69	1649.2	1596.64	1715.18	1576.72	1785.34	1682.63
3100	1685.23	1841.7	1804.92	1951.12	1674.06	1990.05	1798.33
3200	1918.81	2030.13	2025.11	2209.13	1875.18	2109.04	1946.07
3300	2141.63	2198.27	2180.66	2408.01	2092.23	2199.63	2093.41
3400	2361.64	2366.27	2316.77	2588.44	2289.9	2330.45	2240.75
3500	2514.91	2536.49	2486.75	2754.44	2438.3	2476.15	2452.83
3600	2649.38	2706.71	2682.05	2914.6	2586.71	2621.75	2620.98
3700	2784	2823.43	2823.63	3063.03	2791.38	2788.46	2824.75
3800	2919.4	2931.85	2931.02	3213.38	2998.54	2956.78	3029.51
3900	3069.83	3167.89	3141.94	3371.84	3231.54	3125.09	3238.72
4000	3243.79	3404.11	3364.43	3530.31	3481.98	3328.44	3451.67
4100	3438.64	3632.11	3616.17	3703.24	3965.1	3549.22	3663.27
4200	3765.87	3858.68	3874.67	3887.26	3882.99	3782.78	3865.4
4300	4093.07	4085.25	4133.17	4107.89	4070.88	4024.94	4067.53
4400	4389.91	4156.81	4418.35	4423.38	4362.28	4312.04	4360.85
4500	4685.9	4459.68	4704.05	4738.87	4664.04	4614.64	4662.27
4600	4981.89	4762.55	4989.74	4970.55	4965.81	4917.24	4963.68

SHOT PONIT # 245

TIME	TIME DIFF	V_{RMS}	V_{INT}	DIX AVG	DEPTH
0	0	1600	1600	1600	0
242	242	1846	1846	1846	223.366
556	314	1991	2096	1987.19	552.439
720	164	2102	2441	2090.56	752.602
1066	346	2496	3162	2438.32	1299.62
1407	341	2993	4182	2860.92	2012.66
1616	209	3149	4046	3014.19	2435.47
2076	460	3345	3957	3223.1	3345.58
2375	299	3590	4968	3442.78	4088.3
2758	383	3791	4855	3638.89	5018.03
2977	219	4042	6411	3842.81	5720.02
3503	526	4248	5264	4056.22	7104.47
4138	635	4493	5657	4301.86	8900.55
5000	862	4798	6052	4603.59	11509

Table6.4

SHOT POINT # 285

TIME	TIME DIFF	V_{RMS}	V_{INT}	DIX AVG	DEPTH
0	0	1600	1600	1600	0
259	259	1849	1849	1849	239.446
570	311	1991	2102	1987.04	566.306
716	146	2152	2690	2130.38	762.676
968	252	2398	2988	2354.65	1139.65
1321	353	2796	3672	2706.67	1787.76
1474	153	2990	4316	2873.72	2117.93
1798	324	3146	3775	3036.13	2729.48
2201	403	3294	3886	3191.74	3512.51
2494	293	3450	4450	3339.56	4164.43
2859	365	3695	5061	3559.33	5088.06
3183	324	3947	5707	3777.94	6012.59
3599	416	5244	6052	4040.8	7271.42
4020	421	4493	5228	4165.13	8371.91
5000	980	4791	5857	4496.74	11241.9

Table 6.5

SHOT PONIT # 135

TIME	TIME DIFF	V_{RMS}	V_{INT}	DIX AVG	DEPTH
0	0	1600	1600	1600	0
190	190	1742	1742	1742	165.49
532	342	1994	2121	1985.64	528.18
697	165	2151	2593	2129.41	742.099
944	247	2449	3141	2394.09	1130.01
1400	456	2986	3868	2874.16	2011.91
1581	181	3189	4457	3055.37	2415.27
1967	386	3347	3928	3226.61	3173.37
2410	443	3545	4316	3426.86	4129.37
2762	352	3845	5474	3687.76	5092.8
3302	540	4048	5901	4049.70	6686.05
3394	92	4289	5812	4097.75	6953.88
4102	708	4488	5340	4311.93	8843.77
5000	898	4793	5992	4613.67	11534.2

Table6.2

SHOT POINT # 190

TIME	TIME DIFF	V_{RMS}	V_{INT}	DIX AVG	DEPTH
0	0	1600	1600	1600	0
211	211	1794	1794	1794	189.267
535	324	1894	1996	1916.33	512.618
672	137	2093	2740	2084.25	700.308
944	272	2495	3284	2429.94	1146.93
1379	435	2890	3601	2799.34	1930.14
1605	226	3093	4120	2985.31	2395.71
2002	397	3297	4017	3189.9	3193.09
2303	301	3487	4553	3368.05	3878.31
2719	416	3746	4940	3608.56	4905.84
2932	213	3988	6308	3804.66	5577.63
3439	507	4199	5256	4018.62	6910.02
4072	633	4488	5812	4297.41	8749.53
5000	928	4792	5945	4603.21	11508

Table 6.3

SHOT POINT # 325

TIME	TIME DIFF	V_{RMS}	V_{INT}	DIX AVG	DEPTH
0	0	1600	1600	1600	0
161	161	1800	1800	1800	144.9
270	109	1898	2034	1894.47	255.753
504	234	2002	2116	1997.32	503.325
720	216	2150	2461	2136.43	769.115
1041	321	2599	3397	2525.13	1314.33
1339	298	2897	3757	2799.29	1874.12
1522	183	3052	4008	2944.62	2240.86
1687	165	3247	4677	3114.06	2626.71
2248	561	3494	4149	3372.33	3790.5
2593	345	3751	5119	3604.73	4673.53
3082	489	3994	5092	3840.71	5918.53
3583	501	4196	5271	4040.7	7238.91
4088	505	4495	6216	4309.42	8808.45
5000	912	4797	5966	4611.58	11529

Table 6.6

SHOT POINT # 360

TIME	TIME DIFF	V_{RMS}	V_{INT}	DIX AVG	DEPTH
0	0	1600	1600	1600	0
191	191	1793	1793	1793	171.232
501	310	2040	2178	2031.22	508.821
738	237	2151	2360	2136.81	788.483
1135	397	2553	3168	2497.5	1417.33
1528	393	2890	3695	2805.49	2143.39
1728	200	3092	4335	2982.52	2576.9
2041	313	3242	3969	3133.81	3198.05
2224	183	3494	5580	3335.09	3708.62
2632	408	3795	5134	3613.95	4755.96
3131	499	4051	5197	3866.25	6052.61
3838	707	4297	5581	4182.12	8025.49
4087	249	4491	5829	4272.22	8730.28
5000	913	4797	5978	4583.7	11459.3

Table 6.7

SHOT POINT # 400

TIME	TIME DIFF	V_{RMS}	V_{INT}	DIX AVG	DEPTH
0	0	1600	1600	1600	0
217	217	1792	1792	1792	194.432
514	297	2030	2188	2020.82	519.351
727	213	2194	2547	2174.98	790.605
1192	465	2691	3322	2622.43	1562.97
1576	384	2990	3770	2902.04	2286.81
1771	195	3196	4520	3080.19	2727.51
2254	483	3547	4611	3408.22	3841.06
2836	582	3751	4781	3689.95	5232.35
3123	287	3998	5133	3822.56	5968.93
3638	515	4253	5554	4067.66	7399.07
4084	446	4493	6108	4290.48	8761.16
5000	916	4797	5967	4597.62	11494.1

Table 6.8

Depth of Reflector 1

Shot Points	2-Way Time(sec)	Velocity (m/sec)	Depth (m)
SP110	0.680	2150	731
SP120	0.680	2150	731
SP127	0.675	2150	725.63
SP130	0.670	2150	720.25
SP132	0.675	2150	725.63
SP135	0.680	2150	731
SP139	0.695	2165	752.34
SP140	0.700	2170	759.5
SP144	0.685	2155	738.09
SP150	0.680	2150	731
SP154	0.680	2150	731
SP160	0.680	2150	731
SP162	0.600	2150	731
SP164	0.680	2150	731
SP167	0.685	2155	738.09
SP168	0.660	2140	706.2
SP170	0.660	2140	706.2
SP171	0.670	2150	720.25
SP175	0.660	2140	706.2
SP180	0.660	2140	706.2
SP185	0.660	2140	706.2
SP187	0.660	2140	706.2
SP188	0.660	2140	706.2
SP190	0.675	2150	725.63
SP192	0.660	2140	706.2
SP197	0.660	2140	706.2
SP200	0.660	2140	706.2
SP203	0.660	2140	706.2
SP205	0.660	2140	706.2
SP210	0.665	2145	713.22
SP220	0.670	2150	720.25
SP225	0.675	2150	725.63
SP230	0.675	2150	725.625
SP236	0.690	2160	745.2
SP237	0.690	2160	745.2
SP239	0.695	2165	752.34
SP240	0.700	2170	759.5
SP250	0.685	2155	738.09
SP251	0.685	2155	738.09
SP252	0.685	2155	738.09
SP255	0.685	2155	738.09
SP256	0.690	2160	745.2
SP260	0.690	2160	745.2

Shot Points	2-Way Time(sec)	Velocity (m/sec)	Depth (m)
SP261	0.685	2155	738.09
SP263	0.690	2160	745.2
SP264	0.685	2155	738.09
SP267	0.690	2160	745.2
SP268	0.690	2160	745.2
SP270	0.695	2165	752.39
SP275	0.700	2170	759.5
SP276	0.700	2170	759.5
SP277	0.700	2170	759.5
SP280	0.700	2170	759.5
SP283	0.700	2170	759.5
SP285	0.700	2170	759.5
SP290	0.730	2200	803
SP292	0.725	2195	795.69
SP296	0.725	2195	795.69
SP298	0.720	2190	788.4
SP300	0.725	2195	795.69
SP301	0.720	2190	788.4
SP303	0.715	2185	781.14
SP310	0.710	2180	773.9
SP311	0.705	2175	766.69
SP312	0.700	2170	759.5
SP320	0.700	2170	759.5
SP326	0.700	2170	759.5
SP330	0.710	2180	773.9
SP335	0.715	2185	781.14
SP340	0.720	2190	788.4
SP350	0.730	2200	803
SP360	0.720	2190	788.4
SP362	0.725	2195	795.69
SP363	0.715	2185	781.14
SP370	0.710	2180	773.9
SP380	0.710	2180	773.9
SP390	0.715	2185	781.14
SP400	0.710	2180	773.9
SP410	0.715	2185	781.14
SP420	0.730	2200	803

Table 6.9

Depth of Reflector 2

Shot Points	2-Way Time(sec)	Velocity (m/sec)	Depth (m)
SP110	1.400	2850	1995
SP120	1.405	2855	2005.64
SP127	1.400	2850	1995
SP130	1.400	2850	1995
SP132	1.385	2840	1966.7
SP135	1.385	2840	1966.7
SP139	1.380	2835	1956.15
SP144	1.290	2750	1773.75
SP150	1.290	2750	1773.75
SP154	1.290	2750	1773.75
SP160	1.280	2740	1753.6
SP162	1.280	2740	1753.6
SP164	1.350	2805	1893.38
SP167	1.350	2805	1893.38
SP168	1.350	2805	1893.38
SP170	1.345	2800	1883
SP171	1.350	2805	1893.38
SP175	1.345	2800	1883
SP180	1.340	2795	1872.65
SP185	1.340	2795	1872.65
SP187	1.330	2790	1855.35
SP188	1.330	2790	1855.35
SP190	1.330	2790	1855.35
SP192	1.330	2790	1855.35
SP197	1.330	2790	1855.35
SP200	1.320	2780	1834.8
SP203	1.320	2780	1834.8
SP205	1.320	2780	1834.8
SP210	1.325	2785	1845.06
SP220	1.325	2785	1845.06
SP225	1.325	2785	1845.06
SP230	1.335	2790	1862.33
SP236	1.320	2780	1834.8
SP237	1.320	2780	1834.8
SP239	1.320	2780	1834.8
SP240	1.325	2785	1845.06
SP250	1.325	2785	1845.06
SP251	1.330	2790	1855.35
SP252	1.410	2860	2016.3
SP255	1.415	2865	2026.99
SP256	1.415	2865	2026.99
SP260	1.425	2875	2048.44
SP261	1.425	2875	2048.44

Shot Points	2-Way Time(sec)	Velocity (m/sec)	Depth (m)
SP263	1.430	2880	2059.2
SP264	1.435	2885	2069.99
SP267	1.435	2885	2069.99
SP268	1.435	2885	2069.99
SP270	1.435	2885	2069.99
SP275	1.435	2885	2069.99
SP276	1.440	2890	2080.8
SP277	1.450	2900	2102.5
SP280	1.460	2900	2117
SP283	1.455	2900	2109.75
SP285	1.450	2900	2102.5
SP290	1.455	2900	2109.75
SP292	1.455	2900	2109.75
SP296	1.450	2900	2102.5
SP298	1.450	2900	2102.5
SP300	1.450	2900	2102.5
SP301	1.445	2895	2091.64
SP303	1.440	2890	2080.8
SP310	1.430	2880	2059.2
SP311	1.420	2870	2037.7
SP312	1.400	2850	1995
SP320	1.400	2850	1995
SP326	1.360	2810	1910.8
SP330	1.360	2810	1910.8
SP335	1.340	2795	1872.65
SP350	1.080	2550	1377
SP360	1.115	2585	1441.14
SP362	1.125	2597	1460.81
SP363	1.125	2597	1460.81
SP370	1.140	2605	1484.85
SP380	1.150	2625	1509.38
SP390	1.155	2620	1513.05
SP400	1.170	2630	1538.55
SP410	1.180	2650	1563.5
SP420	1.205	2670	1608.68

Table 6.10

Depth of Reflector R3

Shot Points	2-Way Time(sec)	Velocity (m/sec)	Depth (m)
SP110	1.800	3140	2826
SP120	1.800	3140	2826
SP127	1.790	3130	2801.35
SP132	1.660	3055	2535.65
SP135	1.660	3055	2535.65
SP139	1.660	3055	2535.65
SP140	1.660	3055	2535.65
SP144	1.650	3050	2516.25
SP150	1.670	3065	2559.275
SP154	1.670	3065	2559.275
SP160	1.670	3065	2559.275
SP162	1.665	3060	2547.45
SP164	1.670	3065	2559.275
SP167	1.665	3060	2547.45
SP168	1.665	3060	2547.45
SP170	1.660	3055	2535.65
SP171	1.710	3090	2641.95
SP175	1.710	3090	2641.95
SP180	1.710	3090	2641.95
SP185	1.710	3090	2641.95
SP187	1.690	3080	2602.6
SP188	1.690	3080	2602.6
SP190	1.690	3080	2602.6
SP192	1.690	3080	2602.6
SP197	1.690	3080	2602.6
SP200	1.690	3080	2602.6
SP203	1.685	3080	2594.9
SP205	1.675	3070	2571.125
SP210	1.680	3075	2583
SP220	1.680	3075	2583
SP225	1.675	3070	2571.125
SP230	1.680	3075	2583
SP236	1.680	3075	2583
SP237	1.660	3075	2552.25
SP239	1.655	3050	2523.875
SP240	1.640	3048	2499.36
SP250	1.680	3075	2583
SP251	1.680	3075	2583
SP252	1.685	3080	2594.9
SP255	1.700	3085	2622.25
SP256	1.760	3120	2745.6
SP260	1.750	3110	2721.25
SP261	1.760	3120	2745.6

Shot Points	2-Way Time(sec)	Velocity (m/sec)	Depth (m)
SP263	1.760	3120	2745.6
SP264	1.760	3120	2745.6
SP267	1.775	3125	2773.44
SP268	1.775	3125	2773.44
SP270	1.785	3130	2793.53
SP275	1.785	3130	2793.53
SP276	1.785	3130	2793.53
SP277	1.785	3130	2793.53
SP280	1.790	3130	2801.35
SP283	1.790	3130	2801.35
SP285	1.790	3130	2801.35
SP290	1.790	3130	2801.35
SP292	1.785	3130	2793.53
SP296	1.785	3130	2793.53
SP298	1.800	3140	2826
SP300	1.795	3135	2813.67
SP303	1.760	3120	2745.6
SP310	1.760	3120	2745.6
SP311	1.760	3120	2745.6
SP312	1.760	3120	2745.6
SP326	1.520	2950	2242
SP330	1.525	2955	2253.19
SP335	1.515	2950	2234.63
SP340	1.515	2950	2234.63
SP350	1.510	2950	2227.25
SP360	1.525	2955	2253.19
SP362	1.525	2955	2253.19
SP363	1.525	2955	2253.19
SP370	1.535	2965	2275.64
SP380	1.540	2970	2286.9
SP390	1.545	2975	2298.19
SP400	1.555	2985	2320.84
SP410	1.575	2995	2358.56
SP420	1.535	2965	2275.64

Table6.11

[illegible] of Reflector 4

Shot Points	2-Way Time(sec)	Velocity (m/sec)	Depth (m)
SP110	2.440	3500	4270
SP120	2.425	3495	4237.69
SP127	2.440	3500	4270
SP130	2.435	3500	4261.25
SP132	2.440	3500	4270
SP135	2.440	3500	4270
SP139	2.430	3500	4252.5
SP140	2.440	3500	4270
SP144	2.430	3500	4252.5
SP150	2.440	3500	4270
SP154	2.440	3500	4270
SP160	2.430	3500	4252.5
SP162	2.420	3490	4222.9
SP164	2.415	3485	4208.14
SP167	2.415	3485	4208.14
SP168	2.415	3485	4208.14
SP170	2.410	3480	4193.4
SP171	2.410	3480	4193.4
SP175	2.410	3480	4193.4
SP180	2.410	3480	4193.4
SP185	2.410	3480	4193.4
SP187	2.410	3480	4193.4
SP188	2.410	3480	4193.4
SP190	2.420	3490	4222.9
SP192	2.410	3480	4193.4
SP203	2.345	3448	4042.78
SP205	2.350	3448	4051.4
SP210	2.360	3450	4071
SP220	2.370	3455	4094.16
SP225	2.380	3480	4141.2
SP230	2.390	3465	4140.68
SP236	2.400	3475	4170
SP237	2.400	3475	4170
SP239	2.400	3475	4170
SP240	2.410	3480	4193.4
SP250	2.430	3500	4252.5
SP251	2430	3500	4252.5
SP252	2.440	3500	4270
SP255	2.440	3500	4270
SP256	2.440	3500	4270
SP260	2.440	3500	4270
SP261	2.445	3502	4281.20
SP263	2.450	3505	4293.63

Shot Points	2-Way Time(sec)	Velocity (m/sec)	Depth (m)
SP264	2.450	3505	4293.63
SP267	2.460	3510	4317.3
SP268	2.470	3520	4347.2
SP270	2.465	3515	4332.24
SP275	2.470	3520	4347.2
SP276	2.470	3520	4347.2
SP277	2.470	3520	4347.2
SP280	2.470	3520	4347.2
SP283	2.470	3520	4347.2
SP290	2.130	3320	3535.8
SP292	2.145	3330	3571.44
SP296	2.150	3345	3595.88
SP298	2.170	3347	3631.50
SP300	2.170	3347	3631.50
SP301	2.175	3350	3643.13
SP303	2.180	3350	3651.5
SP310	2.200	3355	3690.5
SP311	2.200	3355	3690.5
SP312	2.200	3355	3690.5
SP320	2.200	3355	3690.5
SP326	2.220	3370	3740.7
SP330	2.230	3380	3768.7
SP335	2.235	3385	3782.74
SP340	2.40	3390	3796.8
SP350	2.260	3398	3839.74
SP360	2.260	3398	3839.74
SP362	2.265	3400	3850.5
SP363	2.265	3400	3850.5
SP370	2.270	3400	3859
SP380	2.280	3405	3881.7
SP390	2.270	3400	3859
SP400	2.280	3405	3881.7
SP410	2.290	3410	3904.45
SP420	2.290	0.3410	3904.45

Table 6.12

Depth of Reflector 5

Shot Points	2-Way Time(sec)	Velocity (m/sec)	Depth (m)
SP110	2.800	3720	5208
SP120	2.800	3720	5208
SP127	2.780	3705	5149.95
SP130	2.770	3700	5124.5
SP132	2.760	3700	5106
SP135	2.765	3700	5115.25
SP139	2.760	3700	5106
SP140	2.770	3700	5124.5
SP144	2.765	3700	5115.25
SP150	2.770	3700	5124.5
SP154	2.775	3702	5136.53
SP160	2.770	3700	5124.5
SP162	2.770	3700	5124.5
SP164	2.770	3700	5124.5
SP167	2.770	3700	5124.5
SP168	2.770	3700	5124.5
SP170	2.770	3700	5124.5
SP171	2.770	3700	5124.5
SP175	2.770	3700	5124.5
SP180	2.770	3700	5124.5
SP185	2.750	3695	5080.63
SP187	2.750	3695	5080.63
SP188	2.750	3695	5080.63
SP190	2.690	3650	4909.25
SP192	2.680	3650	4891
SP197	2.660	3640	4841.2
SP200	2.660	3640	4841.2
SP203	2.660	3640	4841.2
SP205	2.665	3645	4856.96
SP210	2.680	3650	4891
SP220	2.710	3660	4959.3
SP225	2.725	3675	5007.19
SP230	2.720	3670	4991.2
SP236	2.750	3695	5080.63
SP237	2.750	3695	5080.63
SP239	2.750	3695	5080.63
SP240	2.750	3695	5080.63
SP250	2.770	3700	5124.5
SP251	2.760	3700	5106
SP252	2.775	3702	5136.53
SP255	2.780	3705	5149.95
SP256	2.780	3705	5149.95

Shot Points	2-Way Time(sec)	Velocity (m/sec)	Depth (m)
SP260	2.780	3705	5149.95
SP261	2.785	3705	5159.21
SP263	2.790	3710	5175.45
SP264	2.790	3710	5175.45
SP267	2.790	3710	5175.45
SP268	2.790	3710	5175.45
SP270	2.785	3705	5159.23
SP275	2.800	3720	5208
SP285	2.450	3505	4293.63
SP290	2.465	3515	4332.24
SP292	2.475	3520	4356
SP296	2.480	3525	4371
SP298	2.500	3540	4425
SP300	2.500	3540	4425
SP301	2.505	3540	4433.85
SP303	2.510	3545	4448.98
SP310	2.510	3545	4448.98
SP311	2.510	3545	4448.98
SP312	2.510	3545	4448.98
SP320	2.530	3552	4493.28
SP326	2.545	3555	4523.74
SP330	2.545	3555	4523.74
SP335	2.555	3565	4554.29
SP340	2.560	3570	4569.6
SP350	2.580	3590	4631.1
SP360	2.575	3585	4615.69
SP362	2.585	3595	4646.54
SP363	2.585	3595	4646.54
SP370	2.585	3595	4646.54
SP380	2.600	3600	4680
SP390	2.590	3595	4655.53
SP400	2.600	3600	4680
SP410	2.600	3600	4680
SP420	2.600	3600	4680

Table6.13

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