2D-Seismic Reflection Data Structural And Stratigraphic Interpretation Along With Lithology Identification Using Reflection Coefficient Of the northern part of the line HPK96-08- EXT:

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CERTIFICATE OF APPROVAL

This dissertation by **Mansoor Ahmed** is accepted in its present form by the Department of Earth Sciences, Quaid-i-Azam University Islamabad as satisfying the requirement for the award of degree of **M.Sc Geophysics.**

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ABSTRACT

The project area lies in Zamzama block of Dadu district (Sindh). In geological distribution of Pakistan, the Zamzama block situated in Kirthar fold belt that lies in southern Indus basin. This block was assigned to BHP for exploration and production. A seismic strike line HPK96-08 EXT of this area was provided to me by department of Earth Sciences (Q.A.U Islamabad) for its structural and Stratigraphic interpretation. It was a stacked migrated seismic section provided with RMS and Interval velocities. I was assigned half portion of the line ranging from shot point number 1840.75 to 2765.75

Iso-velocity map, average velocity and mean average velocity graphs were prepared for the investigation of subsurface tectonic effects. Using two way travel time, a time section was prepared. In the same way a depth section was prepared by using Dix equation. These two sections (time & depth) were prepared for the structural and Stratigraphic interpretation of the given section in time and depth domain. Generally thrusting is prominent in this area due to compressional regime but no structure was identified in my section as it lies along the strike of structure. However in Stratigraphic interpretation seven prominent reflectors were marked and names were given to those on the basis of well tops.

At the end. Reflection coefficient which is one of the most important parameter of Rock Physics was used for the identification of subsurface lithologies. The results of rock physics indicated the presence of limestone. sandstone and shale in the area

DEDICATION

This dissertation is dedicated to **father** and **mother** who build me so high with their wounded hands. This dissertation is also dedicated to all the family members who encourage me in every field of life.

Acknowledgement

All praises and admires to **ALLAH**, the creator of the universe and feeling of passion. Who blessed me with the knowledge and wisdom.

I am indebted to my dissertation supervisor **Madam Shazia Asim** and geology supervisor **Sir Matloob** for his inspiring guidance, dynamic supervision and constructive criticism that helped me to complete this task.

I also pay my humble regards to **Dr Zulfiqar,** chairman, department of **Earth Sciences, Quaid-i-azam University**, for his cooperation and guidance throughout the period of masters.

I pay my thanks to whole faculty of my department especially the teachers whose valuable knowledge, assistance, and guidance enabled me to take initiative, develop and furnish my academic carrier.

I acknowledge my seniors specially **Zaeem Bhai .** I also feel much pleasure in acknowledging nice company of my class fellows and friends specially, Ghulam Sarwar, Zaheer, Riaz, Farhan, Farrukh, Irfan, Zafar in university during my educational session and especially during dissertation. I will always remember my association and affinities with all of my class fellows.

Regards

Mansoor Ahmed

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CHAPTER # 1

Introduction To The Line

INTRODUCTION

1.1 Introduction to the Area

The given Project is to interpret the Seismic Section of seismic Line HPK96-08 EXT; of Dadu area, The Seismic Section is provided by the department of Earth science (Q.A.U). This section was prepared by Western Geophysical Melbourne Centre in July 1996. The project area lies in southern Indus basin, which has a number of oil and gas discoveries.

Location of the area of interest

The project area is located in Dadu block (Sindh) in lower Indus basin as shown in *Fig.1.1* maps showing the location of 2D seismic lines of Dadu area used for the purpose of contouring.

Longitudes: 67^0.40' 19".50E to 67040'05".62E

Latitudes: 26^{0}48'32".52N to 26030'55".53N

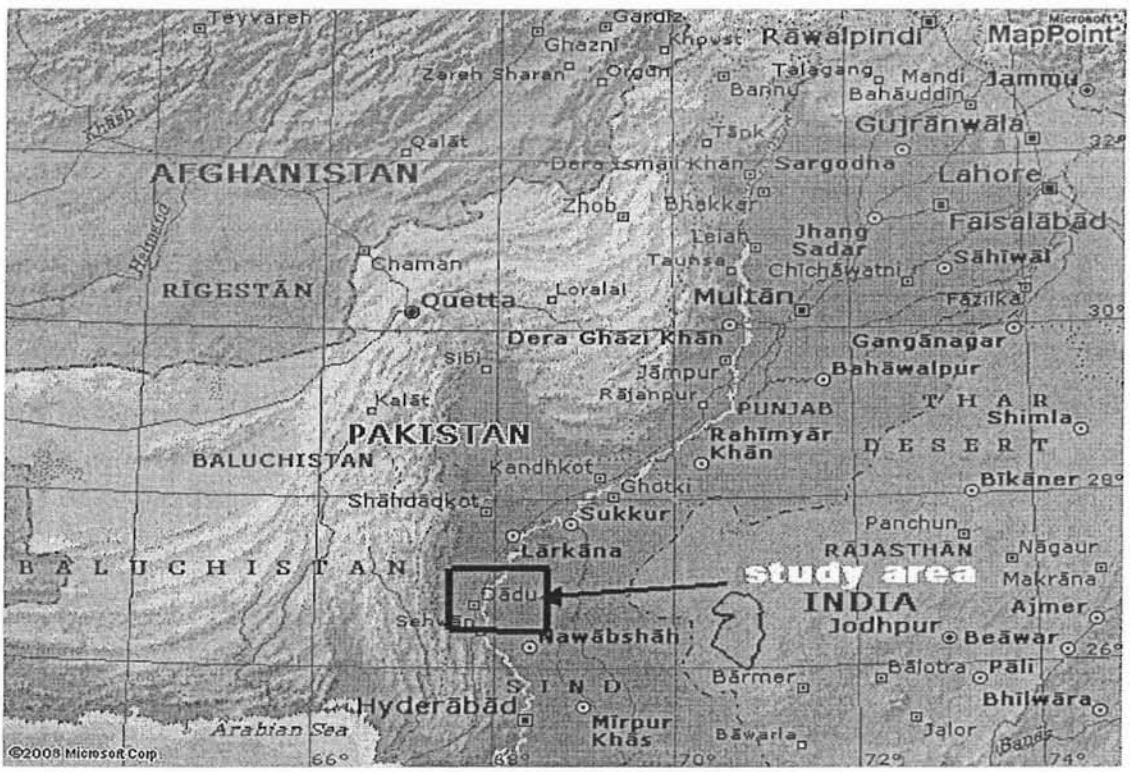


Fig.1.1 Map showing the location of area of interest

Base Map:

The project area is located in Dadu block (Sindh) in lower Indus basin as shown in Fig.1.2 map shows the location of Dadu

Area.

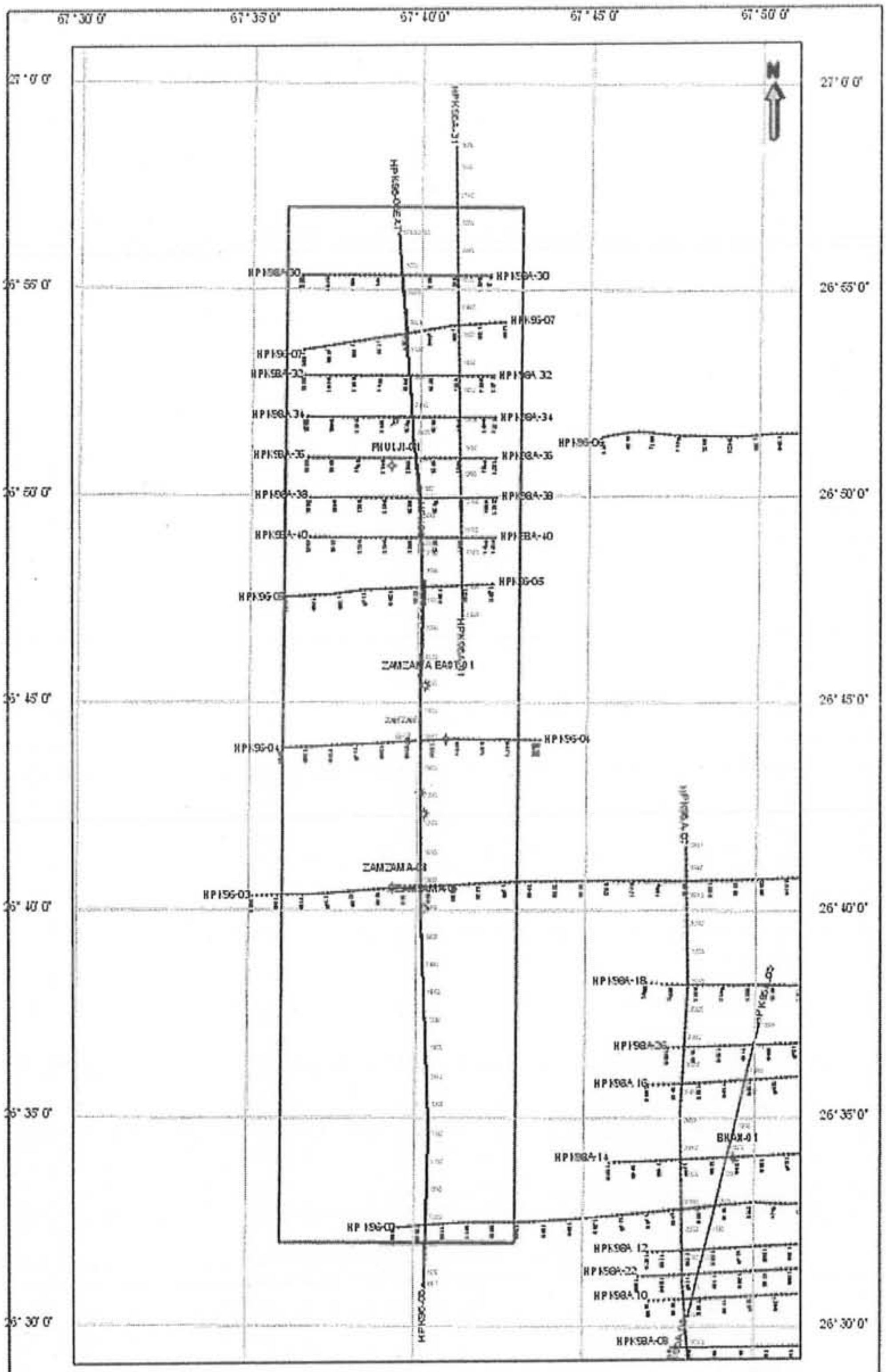


Figure 1.2 Base Map of Dadu Area

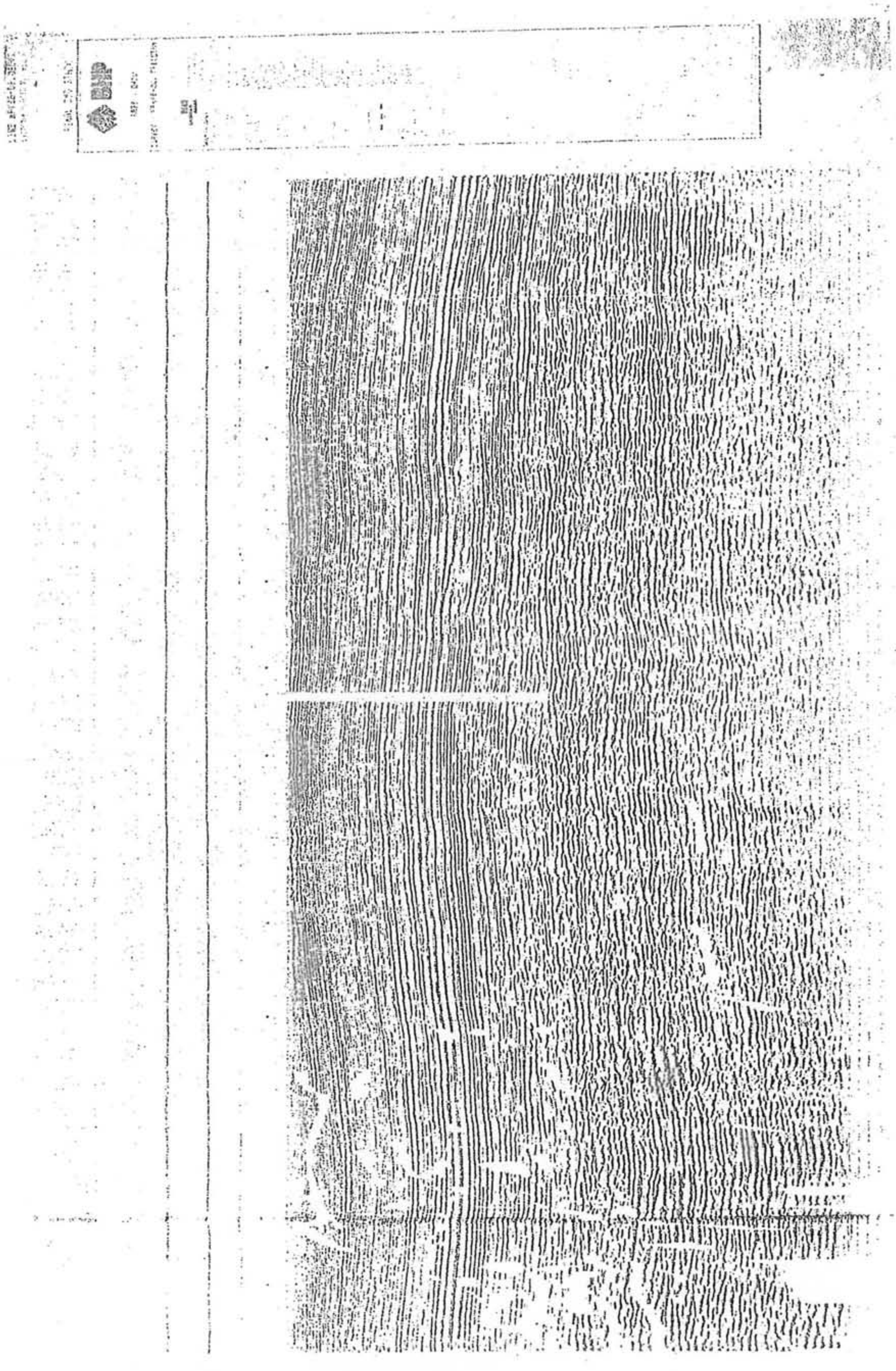


Figure 1.3 Seismic section of line no. HPK96-08 EXT

1.3 Seismic section

The seismic section of line HPK96-08 EXT begins with first shot point 884.25 to 2765.75 last shot point. The different and suitable field and processing parameters are given on seismic time section along the seismic velocities.

1.2 Objectives:

- To know the procedures /techniques involves in acquisition and under standing the processing phenomenon in order to assess the quality of data.
- Identification and Marking of Reflectors
- Velocity Analysis as a parameter.
- Preparation of time section.
- Preparation of depth section.
- Structural interpretation of the subsurface using seismic data
- To study the Stratigraphic setting of the area
- Identification of litholgy using reflection coefficients.

1.4 Survey parameters

The seismic line HPK96-08 EXT was recorded with the following parameters.

RECORDING DATA

Recorded by:	Western Geophysical
Party number:	372
Date:	March-April 1996

Instruments:

Instruments:	Sercel.368
Format:	SEG D 0015
Field Filter LO CUT:	8HZ/18DB
Alais:	178 HZ
Notch:	Out
Number of Data Traces:	240
Sample Interval:	2 MS
Recorded Length:	6.0 S
Norminal Fold:	60

Source Parameters:

Source type:	Dynamite TOVEX
Source patterns:	Single Hole
Source Depth:	12-20 meter
Charge size:	3 to 5 kg
S. P. interval:	50 M

Receiver Parameters

Geophone type:	LRS1011
Geophone Array:	12 phones per String, 2 string parallel array centre on station
Geophone spacing:	2 meter
Group interval:	25M

Spread Configuration:

Symmetrical Split Spread			
3087.5 - - 112.5 - SP – 112.5 - - 3087.5			
TR1	TR 120	TR121	TR 240

SCALES

Horizontal 20 traces/ cm

Vertical 10 cm/ sec

PROCESSING SEQUENCE

FORMAT CONVERSION

Input	SEGY
Output	WGC CODE 4 Format
Output data length	6000 MS
Resample	From 2 to 4 MS

GEOMETRY DEFINITION

Refraction static

1 layer model	
Datum	0 M
Weathering layer velocity	1250 M/S
Replacement Velocity	2000M/S

Amplitude Recovery

Geometric Spreading Compensation

A=1/ (Te(Vee2))
Where T= two way Time
V= RMS Velocity
Velocity Function Time (MS) Vel(M
4 1900 300 2000 1000 2500 2000 3200 3000 3800 4000 4200 6000 4600

Exponential gain:

6 DB/S, 0 – 4.0 S, Constant After 4.0 S

Zone Anomaly Processing:

Spike Removal

Trace Editing:

Bad Traces Edit

F-K Filter (Shot Domain):

Pass zone: + / - 3500 M/S (+ / - 7.14 MS/Trace)

NMO / Static Applied Before and Backed Out After

Designature

Wavelet length:	400 MS	
Instrument response parameter:	8/18	93/36 HZ
Target out put:	8/18	93/36 HZ
Reversible AGC:	500MS	
Receiver Domain Designature For Hydrophones		

First Pass Velocity Analysis:

2.0 Km interval

Surface Consistant Residual Statics:

Window	400 – 2800 MS
Maximum Shift	48 MS

Pre stack Scaling

Instantenous AGC 2000MS

DMO:

Kirchhoff DMO Common Offset Mode

Dip limit 60 degree

DMO Velocity Analysis

1.0 KM Interval

Normal Move Out Correction:

Correction To Datum

CMP Datum Static Application

Mute

Offset (M)	Time (MS)
450	4
500	3000
1200	700
2825	2000

Stack

Max: Fold: 60

Merge

Taper Merge Lines : HPK 96-08 and HPK96-08 ext

Over CMPs 2040 – 2090

Zero Phasing Filter	Zero Phase Conversion

Post Take TAU-P Filter	50% original data addback

Time Variant Filter

Time MS	Filter (HZ)
0	6-80
2000	6-75
4000	6-60
6000	6-50

Time Variant Scaling

AGC Expanding Windows

Start Time (MS)	Gate Length(MS)
0	500
250	500
500	1000
1000	1000
1500	1000
2000	1000
2500	1000
3000	3000

CHAPTER # 2

CHAPTER # 2

Geology Of The Area

Regional Geological Settings of Pakistan.

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

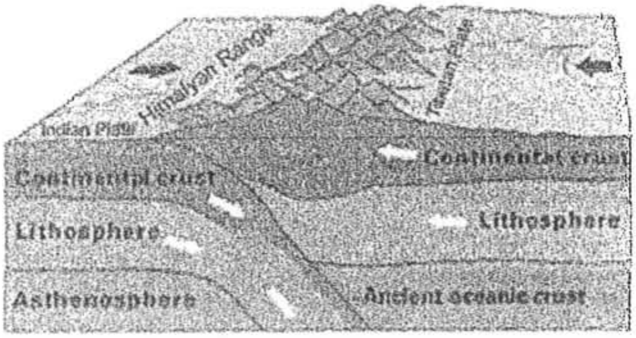


Fig. 2.1: Subduction of Indian plate beneath Eurasian plate

Pakistan has been divided into two broad geological zones, which are the;

i): Gondwanaland Domain

ii): Tethyan Domain

Pakistan is unique in as much as it is located at the junction of these two diverse domains. The southern part of Pakistan belongs to Gondwanian Domain and is sustained by the Indo-Pakistan Crustal Plate. The northern most and western region of Pakistan fall in Tethyan Domain and present a complicated geology.

Tectonic Zones:

Pakistan may be divided into the following broad tectonic zones.

1	Indus Plateform and foredeep
2	East Balochistan fold-and-thrust belt.
3	Northwest Himalayan fold-and-thrust belt
4	Kohistan-Ladakh magmatic arc
5	Karakoram bloack
6	Kakar Khoarasan flysch basin and Makran accretionary zone
7	Chagai magmatic arc.
8	Pakistan offshore

With in these broad tectonic zones there are subtle differences in tectonic and changes in structure style to merit further subdivision into smaller subdivision. Here we are not concern about those we are going to discuss the revelent that is the Indus Plateform and foredeep which is our area of interest as from all above mentioned tectonic zones our seismic line belongs to this area. (Kazmi A.H, et al. 1977)

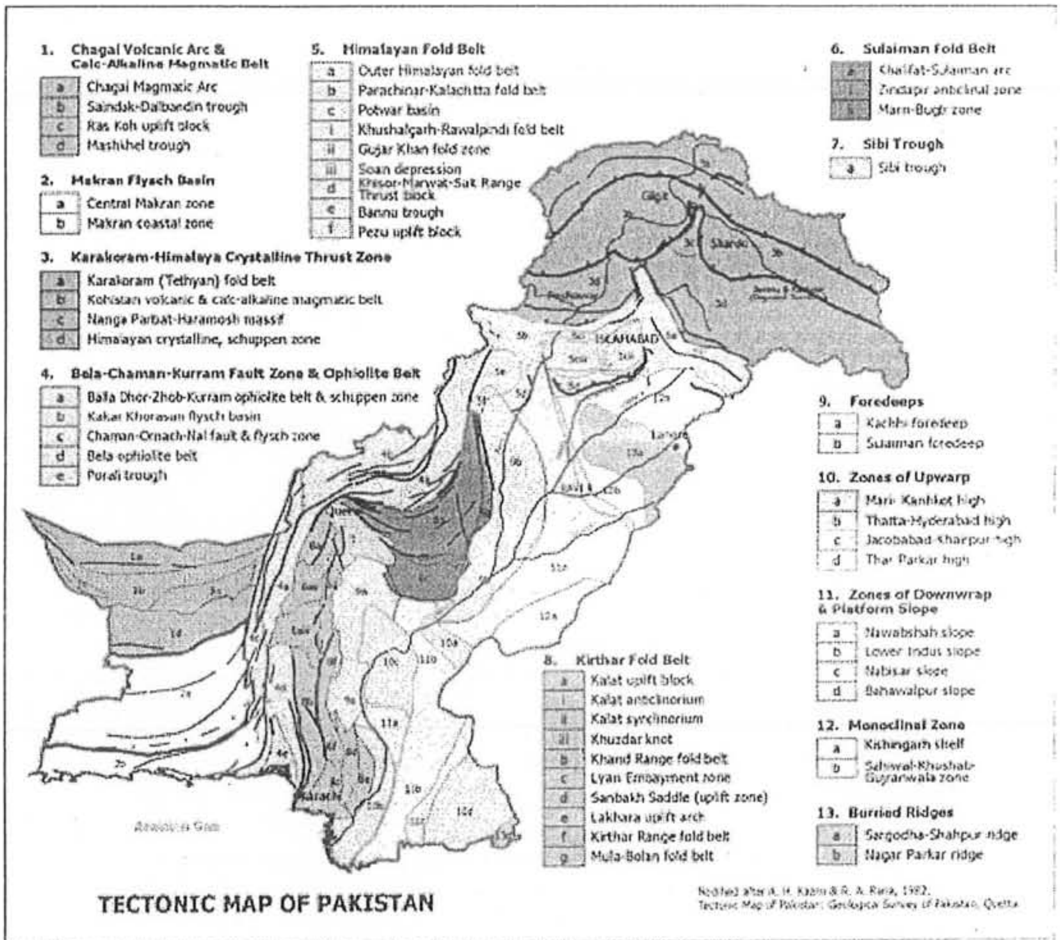


Figure2.2: Showing different Tectonic Zones of Pakistan (WWW..GSP.COM)

Structural Zones:

The Indus platform and foredeep comprise following main structural zones. (Kazmi A.H, et al. 1977)

- Buried Ridges
- Zones of Upwraps
- Zones of Down warps
- Foredeep

Basins of Pakistan:

Pakistan comprises two main sedimentary basins, Indus basin and Balochistan basin, which evolved through different geological episodes and was finally welded together during Cretaceous/Paleocene along Ornach Nal/ Chamman strike slip faults. The later on tectonic activities gave birth to a new basin that is called Kakar Khorasan basin

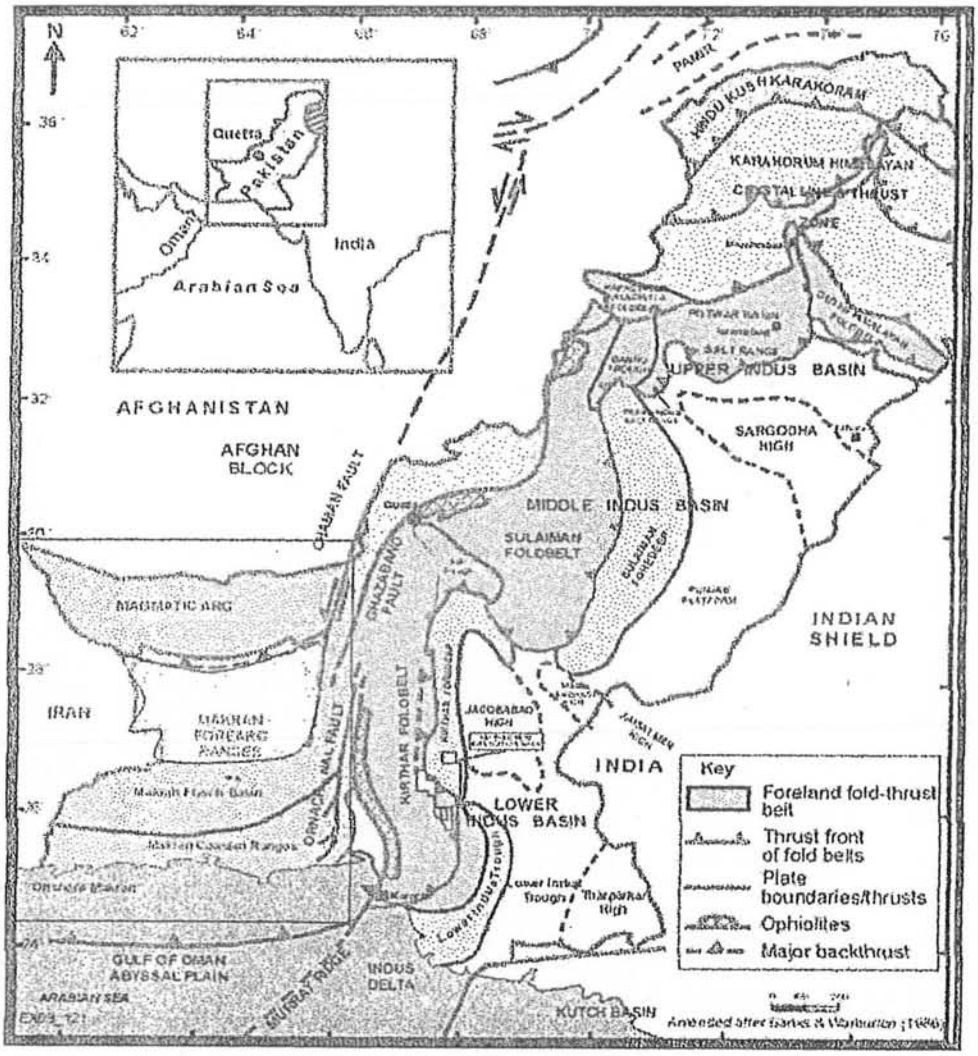


Figure 2.3: Showing different basins of Pakistan (WWW..GSP.COM)

. The Indus basin can conventionally be delineated into the following sub basins (Kadri, 1995):

- Upper Indus Basin
- Lower Indus

Following is the classification of Indus Basin.

- Upper Indus Basin: Kohat Sub-Basin.
  Potwar Sub-Basin.
- Lower Indus Basin: Central Indus Basin.

Southern Indus Basin (Kadri, 1995).

Boundaries of the Upper Indus Basin

Direction	*Structural Boundaries*
North	MBT
South	Sargodha High
West	Kurram Fault
East	MBT

The Upper Indus Basin is the northern extremity of the Indus basin. The main boundary thrust marks its northern limit and is scattered up to the Sarghodha High in the south. The Kohat-Potwar depression immediately lies southward of NW- Himalayas of Pakistan, is the northern potential zone of the upper Indus Basin. This area owes its origin to compressional tectonics and the northern margin of the Indian and Eurasian plates (Farah et al, 1984).

Boundaries of the Lower Indus Basin

Direction	*Structural Boundaries*
North	Sargodha High
South	Off Shore
West	Kirthar and Sulaiman Ranges
East	Indian Shield

The Lower Indus Basin is further divided into two classes,

(a) Central Indus Basin

(b) Southern Indus Basin

Boundaries of the Central Indus Basin

Direction	*Structural Boundaries*
North	Sargodha High, Pezu Uplift
South	Jacobabad KhairPur High, Mari Khandkot High
West	Marginal Zone Of The Indian Plate, Sulaiman Range
East	Indian Shield

Boundaries of the Southern Indus Basin

Direction	*Structural Boundaries*
North	Jacobabad KhairPur High, Mari Khandkot High
South	Off shore, Murray Ridge- Oven Fracture Plate Boundary
West	Marginal Zone of The Indian Plate, Kirthar Range
East	Indian Shield

Introduction to Study Area:

Dadu area lies in Zamzama Block (Sindh Province). The area is located in Southern Indus Basin, (Kirther foredeep). It is bounded by NE-Jacobabad High, east of Kirthar Fold Belt, south east of Nawabshah Slope and south by the Kirachi trough, and Lakhra anticline.

The Zamzama field is a major resource, covering an area of around 120 square kilometres, and ranking fourth in terms of Pakistan's discovered gas reserves. Zamzama is one of several gas fields discovered in the Sindh province. Others field include the Bhit gas field, which lies to the south west of Zamzama, and the Kadanwari, Sawan and Miano fields to the north east.

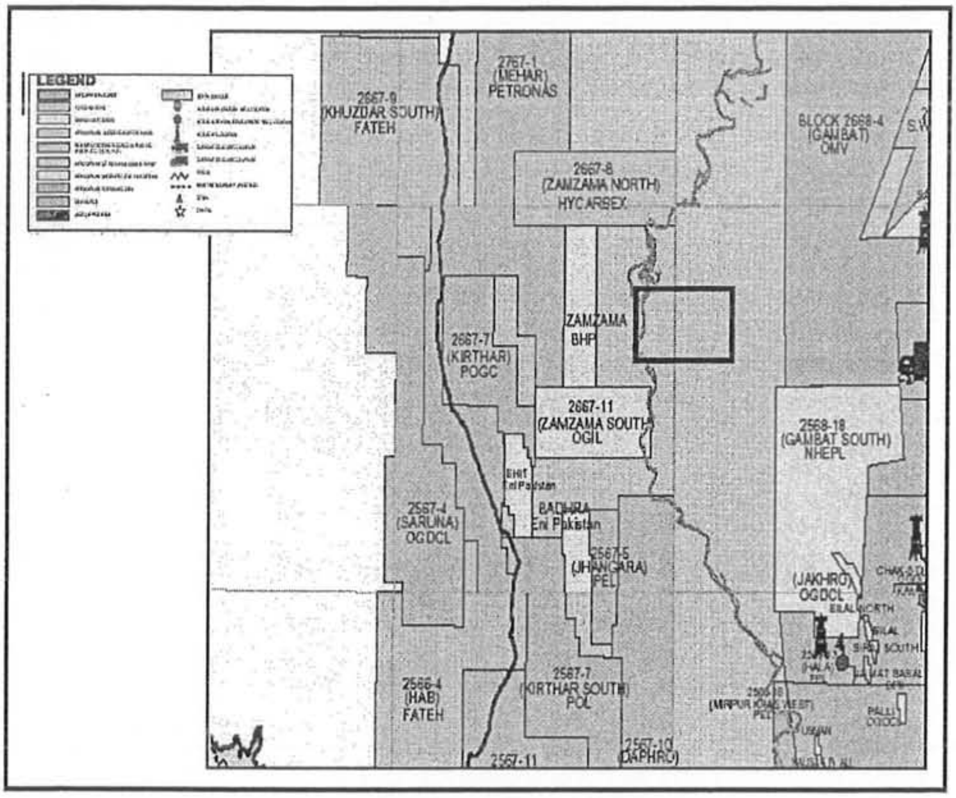


Fig 2.4: Map showing the area of Zamzama block.

Southern Indus Basin

This basin is located just south of the Sukkur Rift which is a divide between the Central and the Southern Indus basin. The oldest rocks encountered in the area are of Triassic age.

The Central and the Southern Indus basins were undivided until middle cretaceous when Khair Pur-Jacobabad High became a prominent feature, this is indicated by homogeneous lithologies of Chiltan Limestone which is of Jurassic age and Sembar Formation which is of lower cretaceous age and lie across the high. This part of the Indus Basin comprises the following four main units

(a) Thar Plateform
(b) Karachi Trough
(c) Kirthar Foredeep
(d) Kirthar Fold belt
(e) Offshore Indus

The platform and trough extend into the Offshore Indus. The Southern Indus Basin is bounded by the Indian shield to the east and the marginal zone of Indian plate to the west. Its southward is confined by Offshore Murray Ridge-Oven Fracture plate boundary. The oldest rocks encountered in the area are of Triassic age. Central and southern Indus Basins were undivided until Lower-Middle Cretaceous when Khairpur-Jacobabad high became a prominent positive Feature. This is indicated by homogenous lithologies of Chiltan Limestone (Jurassic) and Sembar Formation (Lower Crataceous) across the High. Sand facies of Goru Formation (Lower-Middle Cretaceous) are also extending up to Kandhkot and Giandari area. This is further substantiated by Khairpur and Jhat Pat Wells located on the High. In Khair pur –2 well, significant amounts of Lower Crataceous and Paleocene is missing while in Jhat Pat-01, the whole Cretaceous and Paleocene are absent with Eocene directly overlying Chiltan Limestone (Jurassic). Paleocene facies south of the High are quite different from those in North and are dominated by clasitic Sediments derived from the positive areas (Khairpur-Jacobabad High and Nabisar Arc).

a): Thar Platform

It is gently sloping Monocline analogous to Punjab Platform controlled by basement topography. The sedimentary wedge thins towards the Indian Shield whose surface expressions are present in the form of Nagar Pakar High. It differs from the Punjab Platform in that it depicts the buried structures formed due to extention tectonisim resulting from the latest counter-clockwise movement of the Indian Plate. It is bounded in the East by Indian Shield, merges into Kirthar and Karachi Trough in the West and is bounded in the north by Mari-Bugti Inner Folded Zone. A tratistructural cross section constructed through Thar Platform, Karachi Platform Trough and Offshore Indus. The Platform marks very good development of Early /Middle Crataceous Sand

(Goru) which are the reservoirs for all the oils/gas fields of Union Texas Pakistan and Oil Gas Development Corporation in this region.

b): Karachi Trough

It is an embayment opening up into the Arabian Sea. The Trough is characterized by thick Early Cretaceous sediments and also marks the last stages of marine sedimentation. It contains a large number of narrow chains like anticlines, some of which contains gas fields (Sari, Hundi and Kothar). The Early, Middle and Late Cretaceous rocks are well preserved in this area. It has been a trough throughout the geological history. The Upper Cretaceous is marked by westward progradation of a marine delta.

The most interesting feature of Karachi Trough is reportedly continued deposition across the Cretaceous/Tertiary (K/T) boundary wherein Korara Shales were deposited, the basal part of which represents the Danian sediments. This localized phenomenon probably represents a unique example where no Hiatus in sedimentation occurred at the end of Cretaceous era. Elsewhere, in Pakistan a break in deposition marked by laterites, Bauxites, Coal etc. is a common feature across the K/T boundary.

c): Kirthar Foredeep

Kirthar Foredeep trends North-South which have received the sediments aggregating a thickness of over 15000 meters. It has a faulted Eastern Boundary with Thar platform. It is inferred that the sedimentation had been continuous in this depression. However, from the correlation of Mari, Khairpur and Mazarani wells it appears that the Upper Cretaceous would be missing in the area. Paleocene seems to be very developed in the depression but is missing from Khairpur-Jacobabad High area. This depression, like Sulaiman Depression, is the area of great potential for the maturation of source rock.

d): Kirthar Fold Belt

This North-South trending tectonic feature id similar to Sulaman Fold that in structural style and stratigraphy equivalence. Rocks from Triassic to recent were deposited in this region. The configuration of the kirthar Fold Belt also marks the closing of Oligocene- Miocene seas.

The western part of Kirthar Fold Belt adjoining the Balochistan Basin, which marks the western edge of the Indus Basin, is severely disturbed. This Western margin is associated with the hydrothermal activities which resulted in the formation of economic minerals deposits of Barite, Flourite, Lead, Zinc, Manganese.

e): Offshore Indus

This area forms the part of passive continental margin and appears to have gone through two distinct phase of geological history (Cretaceous-Eocene and Oligocene-Recent). Sedimentation in the Offshore Indus started from Cratecous time. However, deltaic and submarine fans sedimentation has occurred since Middle Oligocene time with the inception of Proto-Indus System. Offshore Indus is divided into platform and depression along a Hinge Line in close proximity and parallel to 67°East longitude. Offshore platform is divided into Karachi Trough and the Thar Platform's deltaic area by a line which devudes Karachi trough from Thar Slope Onshore.

Structure of the Southern Indus basin

Southern Indus basin is characterized by passive roof complex-type structure and a passive back thrust along the Kirthar fold belt, a passive roof thrust forming a frontal culmination wall along the margin of the fold belt and the kirthar depression and out of syncline intra-molasses detachment in the kirthar depression sequence.

The kirthar and Karachi depression contain several large anticlines and domes and some of these contain small gas fields e.g. Sari, Hundi, Mazarani, and Kothar.But in the eastern part of it there are several faults and tilted blocks of Mesozoic rocks which form structural traps containing small oil and gas fields. On the northern side of it there is the Sukkur Rift zone bearing large anticlimax structures and contains the Khandkot and Mari gas fields.

Sandstones of Late Cretaceous (Campanian-Maastrichtian) age constitute much of the Pab and Mughal Kot Formations, which are well exposed in western Pakistan. In the south central part of the Kirthar fold belt, these units are dominated by quartzose sandstones with subordinate argillites and marls, all deposited on the western continental margin of the Indo-Pakistan Plate (Khan et al, 2002). The general stratigraphy of the study area in the study area is as under;

Mesozoic:

Wulgai Formation (Shale and sandstone) of Triassic age and Shirnab Formation (shale and sandstone with rare limestone) and Chiltan Formation (limestone) of Jurassic age are overlain in an upward direction.

Tertiary: Khadro Formation (sandstone), Bara Formation (sandstone and shale) and Lakhra Formation (limestone and shale) form the Paleocene succession. Eocene is limestone dominated sequence comprising Laki Formation (limestone and shale), Gazij Formation (shales), Kirthar Formation (limestone and subordinate shale). Oligocene – Moicene sequence comprises Nari (shale, limestone and sandstone) and Gaj (shale, sandstone and limestone) Formations. Post-Miocene section is mainly continental and contains fluviatile clastics overlain by alluviam.

Detailed Stratigraphy of the Area:

Alluvium

Age: Quaternary

Interval: Surface-654m

Thickness: +654m

Contact: The lower contact with Kirther Formation is unconformable

Environment: Continental (Alluvial deposits)

Lithology: Alluvium is the youngest deposit penetrated in this well.It is mainly composed of sandstone with subordinate beds of clay/ claystone and thin inerbeds of conglomerates.

Sandstone is multicoloured,white,brownish white,lithic,loose,friable,very fine to very coarse grained, sub angular to sub surrounded, poorly sorted, poorly cemented,micaceous, conglomeratic. Clay/Claystone is generally light earthy brown, yellow, chocoiate brown, reddish brown, soft, hydrophilic, sticky, pasty and calcareous.

Conglomerate is yellowish brown, light grey, yellow, medium hard and Calcareous.

Kirthar Formation

Age: Eocene

Interval : 654 m – 885 m

Thickness : 231 m

Contact : the lower contact with Laki Formation is confirmable

Environment: Shollow marine, reducing.

Lithology : Limestone with interbeds of shale and marl

Limestone is mudstone to wackstone, white, cream, light greenish grey, and soft to medium hard, inplaces hard, occasionally crystalline, and chalky.

Laki Formation

Age :Eocene

Interval :885 m – 1085 m

Thickness : 200 m

Contact :The lower contact with Sui Main Limestone is Conformable.

Environment :Shollw marine ,reducing.

Lithology :limestone with interbeds of shale.

Shale is greenish grey, light green brownish grey blocky, silty, slightly calcareous and fossiliferous.

Limestone is mudstone to wackstonelight brown, cream, in places white to light grey, medium hard to hard, cristlline, in places soft and chalky, argillaceous and highly fossiliferous.

Upper Ranikot Formation

Age :Paleocene

Interval : 1196 m to 1365 m

Thickness : 169 m

Contact : The lower contact with Upper Goru Formation is unconformable.

Environment : Mrine, Mixed Facies.

Lithology Upper Ranikot Formationconsists of shale with interbeds of limestone, subordinate marl and sandstone.

Shale is light to dark grey, brownish grey, dark brown, silty and pyretic, slightly too non calcareous.

Limestone is mudstone,white,light,cream,medium hard to hard in places chalky, occasionally pyretic and fossiliferous.

Marl is very light grey,dirty white,soft,soluble,pasty,and hydraulic.

Sandstone is white, loose friable, fine to medium grain.

Age :Paleocene

Interval : 1365m to 1810 m

Thickness : 445 m

Contact : The lower contact with Upper Goru Formation is unconformable.

Environment : Continental outwash/ sub-marine

Lithology Lower Ranikot Formation consists of sandstone with interbedded shale,clay claystone and thin beds of siltstone.

Sandstone is white to dirty white ,loose to friable,occasionally hard, medium to coarse grained.sub angular to rounded, occasionally angular ,surgary texture,moderately to poorly sorted,poorly to moderately cemented.

Shale is light to dark grey ,brownish grey,dark brown ,silty and pyretic,slightly calcareous.

Clay/Claystone is raddish brown to brick red,grey,soft,in places firm,medium hard,hydrophilic,pasty,sticky,soluble,silty,in places grading to siltstone,and noncalcreous.

Siltstone is reddish brown,rusty brown,medium hard,in places hard,compact and non calcarious.

The formation can be subdivided into three section on the basis of relative proportion of different lithologies:

Pab Sandstone

Age: Lower Cretaceous.

Lithology: White to brown colour sandstone with subordinate shale.

Contact: Upper contact with Ranikot Formation is disconformable and lower contact with Fort Munro Formation is conformable.

Parh Limestone

Age: Lower Cretaceous.

Lithology: Light grey micritic limestone and marl.

Contact: Upper contact with Fort Munro Formation is conformable and lower contact with Goru Formation is conformable

Upper Goru Formation

ge A :Cretaceous

Interval : 1810 m to 2083 m

Thickness : 273 m

Contact : The lower contact with Lower Goru Formation is conformable.

Environment : Mrine trasitional,occationlly sub littoral.

Lithology Upper Goru Formation consists of marl with thin beds of shale and limestone.

Marl is dirty white to grey,off white,soft to firm,sicky, soluble,lumpy in parts medium hard and grading into limestone.Occationally pyretic and silty.

Shale is grey to dark grey ,greenish grey,moderately indurated,chunky,sub laminated, in places blocky, in parts silty and pyretic.

Limestone is wackstone to packstone,light grey,off whute,medium hard and argillaceous.

Lower Goru Formation

Age :Cretaceous

Interval : 2083 m to 3002 m

Thickness : 919 m

Contact : The lower contact with Sember Formation was not Penetrated

Environment : Shallow mrine ,trasitional, sub littoral.

Lithology Lower Goru Formation consists of dominantly clay with subordinate shale ,sandstone,lesser siltstone and rare beds of limestone.

Clay is light to very light grey ,slightly brownish grey,soft ,rarely slightly firm,hydrophilic silty and pyretic.

Shale is light grey to dark grey,at places greenish grey,brownish greyto dark brownish grey,occationally dark brown,silty,pyretic and highly glauconitic,slightly calcareous.

Sandstone (in the upper part) is white to dirty white, brownish white light grey occationally *grading into siltstone,subangular to subrounded poorly to fairly sorted and cemented.*

Basal sand is white to dirty white ,medium hard very fine grained.

Massive sand is white brownish white ,hard,in places very hard, medium to coarse grained.

Marl is very light grey ,greenish grey,soft to firm lumpy silty

Siltstone is bronish white ,dirty white light grey to dark grey medium hard to hard.

Limestone is wackstone ,off white,light grey ,medium hard.

On the basis of relitive proportion of different lithologies,the formation can be sub divided into following section:

Chiltan Limestone

Age: Middle to Late Jurassic.

Lithology: Dark grey to black, oolitic to pisolitic limestone.

Contact: Upper contact with Sembar Formation is disconformable and lower contact with Shrinab Formation is conformable

3.6 Petroleum Prospect:

Source Rock:

Potential source rocks are Sembar shales, but also shales of Mughalkot are considered for their source potential.

Reservior Rocks:

Pab Sandstone is the main producer and Ranikot Formation in the north of the study area.

Seal Rocks:

Paleocene shales are act as a cap for Pab Sandstone.

CHAPTER # 3

CHAPTER # 3

Seismic Methods

Seismic Methods

3.1. `INTRODUCTION

Exploration seismic methods involve measuring seismic waves traveling through the Earth. Explosives and other energy sources are used to generate the seismic waves, and arrays of seismometers or geophones are used to detect the resulting motion of the Earth. The data are usually recorded in digital form on magnetic tape so that computer processing can be used to enhance the signals with respect to the noise, extract the significant information, and display the data in such a form that a geological interpretation can be carried out readily. (Kearey et al, 2002)

3.2. SEISMIC REFLECTION METHOD

The basic technique of seismic exploration consists of generating seismic waves

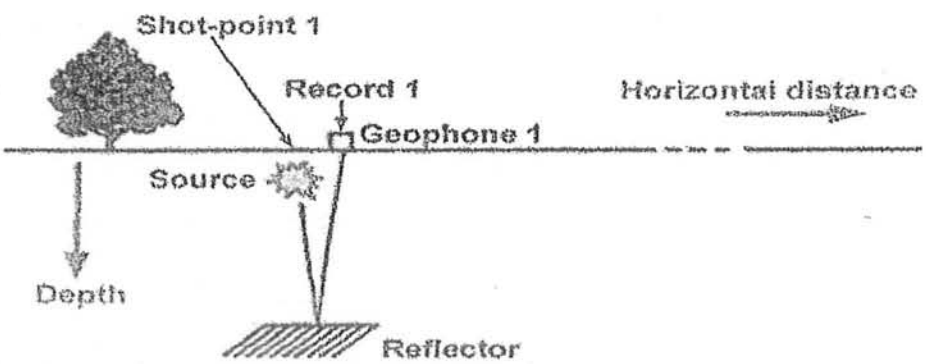


Fig. 3.1 (Basic layout of Seismic Reflection Acquisition)

and measuring the time required for the waves to travel from the source to a series of geophones, usually disposed along a straight line directed toward the source.

Structural information is derived principally from paths that fall into two main categories:

- Refracted paths
- Reflected paths

For both types of path, the travel times depend on the physical properties of the rocks and the attitudes of the beds.

Reflections of acoustic waves from the subsurface arrive at the geophones some measurable time after the source pulse. If we know the speed of sound in the earth and the geometry of the wave path, we can convert that seismic travel time to depth. By measuring the arrival time at successive surface locations we can produce a profile, or cross-section, of seismic travel times.

The objective of seismic exploration method is to deduce information about the rocks from the observed arrival times together with variations in amplitude, frequency and waveform. (Telford, et al. 1990)

Fundamental Law of Reflection

This law states that

"the angle of incident (between the ray and the normal to the interface) is equal to the angle of reflection (between the reflected ray and the interface)".

3.3. SEISMIC REFRACTION METHOD

Refraction method is based on the study of elastic waves refracted along geological layer. This method is generally used for determining low velocity zone (weathered layer). There is one type of refraction, which gives rise to a phase that can travel back to the surface. This corresponds to the case of critical incidence. Seismic refraction method is helpful in the interpretation of seismic data. (Al-Sadi, 1980)

The waves which return from the top of interface are refracted waves, and for geophones at a distance from the shot point, always represent the first arrival of seismic energy.(Telford, 2004)

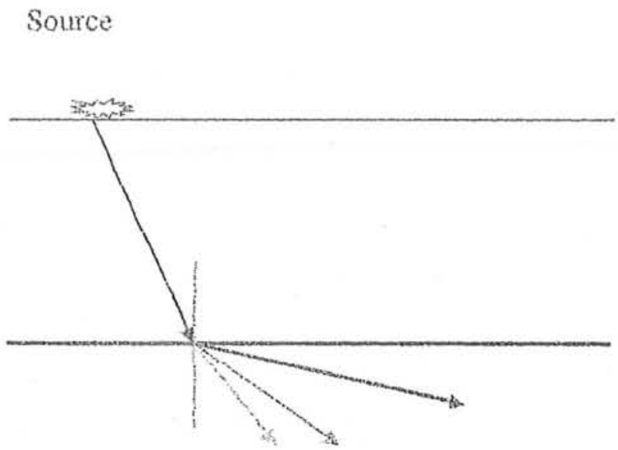


Fig. 3.2 *(Fundamental concept of refraction)*

The angle of the wave leaving the interface will be altered from the incident angle, depending on the relative velocities. Going from a low-velocity layer to a high-velocity layer, a wave at a particular incident angle (the "critical angle") will be refracted along the upper surface of the lower layer. As it travels, the refracted wave spawns up going waves in the upper layer, which impinge on the surface geophones.

Sound moves faster in the lower layer than the upper, so at some point, the wave refracted along that surface will overtake the direct wave. The point at which the refraction overtakes the direct arrival is known as the "crossover distance", and can be used to estimate the depth to the refracting surface.

Seismic refraction is generally applicable only where the seismic velocities of layers increase with depth. Therefore, where higher velocity (e.g. clay) layers may overlie lower velocity (e.g. sand or gravel) layers, seismic refraction may yield incorrect results. In addition, since seismic refraction requires geophone arrays with lengths of approximately 4 to 5 times the depth to the density contrast of interest , seismic refraction is commonly limited to mapping layers only where they occur at depths less than 100 feet. (Dobrin, 1988)

Fundamental Law of Refraction

A wave traversing a boundary between two media of velocity V1 and V2 is such that

$$\sin i/V1 = \sin r/V2$$

Where:

i = incident angle.

r = refraction angle.

Critical Refraction

Now a certain angle of incidence for which angle of refraction is 90° is called as critical angle and refraction at this stage is called as critical refraction as shown in fig.3.3

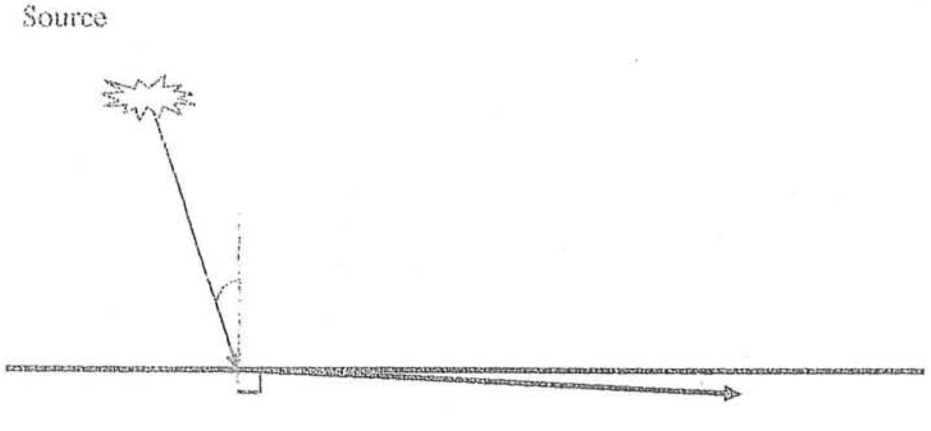


Fig. 3.3 *(Critical refraction between two Mediums)*

For critical refraction, Snell's Law attains the form as follow:

$$Sin\ i_c = V_1/V_2$$

Where i_c = Critical angle.

3.4. DIFFRACTION

Laws of reflection and refraction apply till that the interface is continuous and approximately planar. At abrupt discontinuities in interfaces, or structures whose radius of curvature is shorter than the wavelength of incident wave, the laws of reflection and refraction no longer apply. These discontinuities give rise to a radial scattering of incident seismic energy. This radial scattering is called as diffraction.

"Diffraction is the bending of a wave around objects or the spreading after passing through a gap. It is due to any wave's ability to spread in circles or spheres in 2D or 3D space"

OR

"A type of event produced by the radial scattering of a wave into new wave fronts after the wave meets a discontinuity such as a fault surface, an unconformity or an abrupt change in rock type".Diffracted phases are commonly observed in seismic recording and sometime are difficult to discriminate from reflected and refracted phases. (Kearey et al, 2002)

3.5. REFLECTION- AND TRANSMISSION-COEFFICIENTS

To derive the reflection and transmission coefficients for elastic waves, the boundary conditions at the interface are needed and are described by the Zoeppritz-Equations. These reflections coefficients depend on

- Difference in density
- Difference in velocity
- Angle of incident of the wave

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

Reflection coefficient

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

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

Transmission coefficient

Transmission coefficients are those which compare the amplitude of incident wave and refracted wave. Value of transmission coefficient varies from 0 to2. If Ai is the amplitude of incident wave and At is the amplitude of transmitted wave, then

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

transmission coefficient T is given as follow;

The product $Z = v\,\rho$ is known as the acoustic impedance. (Khan, 1988)

3.6. THEORY OF ELASTICITY

Elastic Properties of Solids

Stress

"Stress is the force (F) (applied) per unit area (A) of the body".

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

Mathematically;

Stress = F/A

Mainly there are two types of stress:

- Normal Stress
- Tangential Stress

(Heiland, 1968)

Strain

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

Strains can be divided into four types.

- Longitudinal Strain

- Transverse Strain
- *Shear Strain*
- Dilation

Hook's Law

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

Mathematically:

Stress ∞ Strain

Bulk Modulus (K)

"It is the ratio of stress to the volumetric strain"

Given by the relation as:

Mathematically:-

$$\text{Bulk modulus } K = \frac{\text{Volume Stress } P}{\text{Volume Strain } \Delta V/V}$$

Where 'k' is the compressibility coefficient.

Shear Modulus (μ)

The shear modulus is defined as "the ratio of shearing stress " τ " to the resulted shear strain "tan θ ". It is denoted by "μ".

Mathematically:

$$\text{Shear Modulus } \mu = \frac{\text{Shearing Stress } (\tau)}{\text{Shearing Strain } (\tan \theta)}$$

(Kearey et al, 2002)

It is also called as rigidity modulus.

For liquids and gases, shear modulus (μ) =0

Young's Modulus (E)

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

Mathematically:

$$\text{Young's Modulus } E = \frac{\text{Longitudinal Stress } F/A}{\text{Longitudinal Strain } \Delta L/L}$$

Poisson's Ratio (σ)

"The ratio of Transverse strain to longitudinal strain" is known as Poisson's Ratio. It is denoted by "σ".

Mathematically:

$$\text{Poisson's Ratio } \sigma = \frac{\text{Transverse Strain}}{\text{Longitudinal Strain}}$$

Relationship between Elastic Module

The all four module can be interrelated in the following way

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

$$\mu = E / 2(1+\sigma)$$ (Dobrin, 1988)

3.7. SEISMIC WAVES

Wave is a progressive disturbance propagated from point to point in a medium or space without progress or advance by the points themselves. Seismic waves are generally referred to as elastic waves because they propagated like that in an elastic band when it is stretched.

The theory of elasticity reveals that the energy propagated through the earth in the different form of seismic waves. Seismic waves are parcels of elastic strain energy that propagate outwards from a seismic source such as an earthquake or an explosion. (Kearey, 2002)

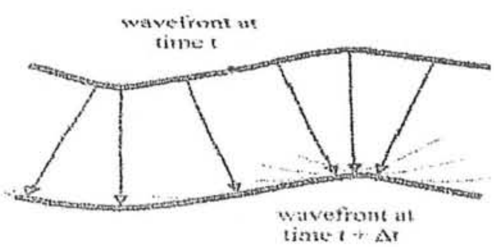
3.8. LAWS GOVERNING SEISMIC WAVES

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

- Huygen's principle
- Fermat's principle
- Snell's law

Huygens's Principle

"Every point on a wave front is a source of new wave that travels away from it in all directions" Figure 3.9 shows the generation of wave fronts by succeeding waves



Fermat's Principle

It states that

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

Snell's law

According to this law

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

Mathematically:

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

Where V_1 and V_2 are velocities in the upper and lower layers, α_1 is the angle of the incident ray-path with respect to the vertical, and α_2 is the angle of transmission of the refracted ray-path with respect to the vertical. Figure 3.11 shows the reflection of incident waves form a surface.

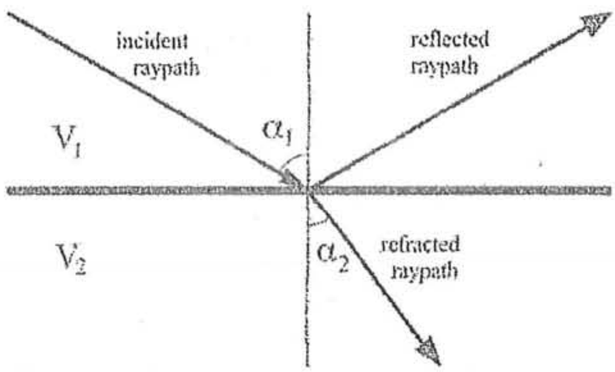


Figure 3.5 *(Refraction and reflection of an incident wave)*

(Robinson & Coruh, 1988)

3.9. TYPES OF SEISMIC WAVES

Seismic waves are messengers that convey information about the earth's interior. Basically these waves test the extent to which earth materials can be stretched or squeezed some what as we can squeeze a sponge. They cause the particles of materials to vibrate, which means that passing seismic waves temporarily deforms these particles can be described by its properties of elasticity. These physical properties can be used to distinguish different materials. They influence the speeds of seismic waves through hose materials. (Robinson & Coruh, 1988)

There are mainly two types of Seismic Waves:

- Body waves
- Surface waves

Body Waves

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

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

P- Waves (Primary Waves)

The particular kinds of waves of most interest to seismologists are the compressional or P-waves also called as compressional waves, longitudinal waves, primary waves, pressure waves, and dilatation waves (see Fig. 3.12). In this case the vibrating particles move back and forth in the same direction as the direction of propagation of waves. P-waves can pass through any kind of material - solid liquid or gas. The P-waves velocity depends upon density and elastic constants. (Dobrin, 1976)

The seismic velocity of a medium is a function of its elasticity and can be expressed in terms of its elastic constants.

For a homogeneous, isotropic medium, the seismic P-wave velocity Vp is given by;

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

Where:

μ is the shear modulus.

k is the bulk modulus.

ρ is the density of the medium.

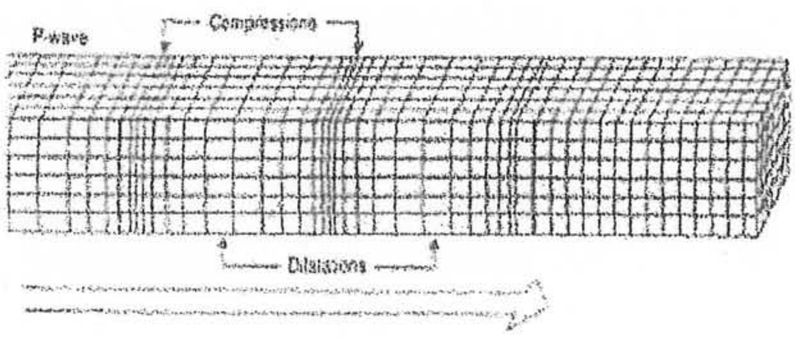


Fig. 3.6 *(The propagation of P-waves in an Elastic Medium)*

S- Waves (Secondary waves)

In shear waves, the particles vibrate in a direction perpendicular to the direction of propagation of waves (see Figure 3.7).

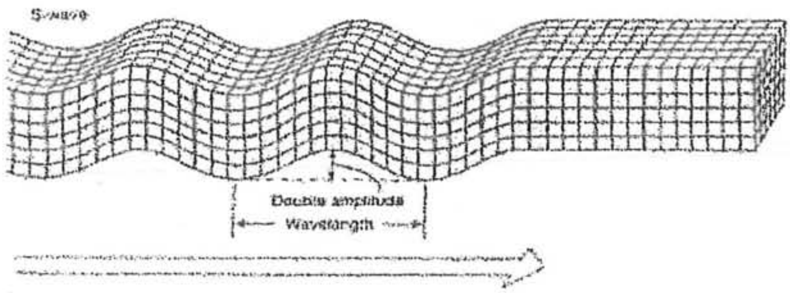


Fig. 3.7 *(The propagation of S-waves in an Elastic Medium)*

They are also called as Shear waves, transverse waves, and converted waves. For ideal gases and liquid μ=0. S-waves cannot pass through fluids. The velocity of S-waves is given by (using the same notation as of V_p); (Dobrin, 1976)

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

Characteristics of Body Waves

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

Frequency of body waves in exploration vary from 15Hz to 100Hz.

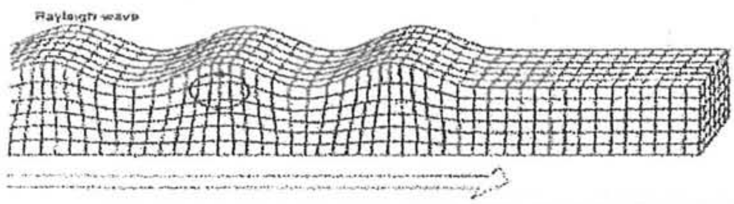
Surface Waves

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

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

- Raleigh waves
- Love waves

Raleigh Waves



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

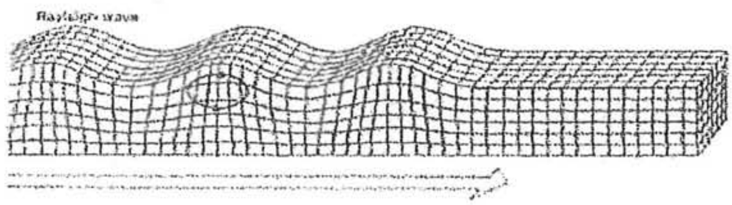


Fig. 3.8 *(Propagation of Raleigh waves*

Love Waves

A type of surface waves having a horizontal motion i.e. transverse to the direction of propagation. The velocity of these waves depends on
the density and modulus of rigidity and not depends upon the bulk modulus (k). The Figure 3.15 shows the propagation of Love-waves in
an elastic medium. (Kearey, 2002).

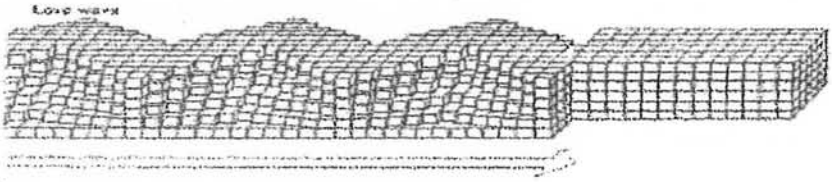


Figure 3.9 *(Propagation of Love waves in an Elastic Medium)*

3.10. ATTENUATION OF SEISMIC WAVES

Attenuation is simply the fall of energy of a wave with increase in distance from source. The energy of a wave in a given medium is directly proportional to the square of its amplitude. (Dobrin, 1976)

Fall of energy can be due to

- Spherical Divergence
- Absorption

Spherical Divergence

Spherical divergence is spread out of a wave from its source. As the source wavelet travels farther and farther from the source, its amplitude of vibration grows smaller. It is because of the fact that the continuously expanding spherical wave as expands, the same amount of energy, once received from source at time of onset of wave, has to be distributed over the larger area.

Change in amplitude of a wave with distance due to spherical divergence is given as:

$$H = \frac{H_0}{X}$$

Where: H: amplitude at distance x.

H_0: initial amplitude of the wave as it left the source.

X: distance from source.

Absorption

Absorption is simply the capture of energy of the wave by particles of the medium through which it propagates. It happens when particles of the medium start to vibrate, due to wave propagation, particles start to collide and so to rub each other. Due to this friction, some of the wave energy is converted into the heat energy. In this way, energy of wave propagating through the medium is decreased and amplitude decreases. Change in amplitude due to this absorption is given as:

$$H = H_0 e^{-\alpha x}$$

Where:

α: absorption coefficient.

x: distance from source. (Robinson & Coruh, 1998)

3.11. WAVE CONVERSION

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

3.12. SEISMIC VELOCITIES

Velocity is the bridge between time and depth, between milliseconds and feet, between timing lines and drill stem. Routinely velocities are used to stack seismic data, to migrate seismic data, and to convert time-recorded seismic sections to depth sections and time maps to depth maps. Velocities are also used more sophisticated ways, such as in attempts to predict porosity, geologic age, lithology, fracturing, fluid content, geopressure, and even drill-bit wear. Velocity data contain an enormous amount of information (Dobrin, 1988).

The Nature of Velocity Data

Seismic velocities vary largely in sedimentary rocks as compared to igneous and metamorphic rocks. Metamorphic and igneous rocks have little or no porosity and, the seismic wave velocity depend upon the elastic properties of the material making up the rock material itself. 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. In many areas, seismic velocity data can be used to identify lithology in discrete formations within the geologic section (Dobrin, 1988)

3.13. Effects of physical properties of rocks on seismic velocities

The Seismic velocities in rocks are affected by following physical properties of rock. These properties vary greatly in sedimentary rocks than in metamorphic rocks.

- Porosity of rock
- Consolidation of rock
- Lithology of rock
- Pore fluid type
- The geologic age and depth of burial

3.14. Velocity estimation

Velocity as a seismic parameter plays an important role in almost the whole range of activities involved in seismic prospecting. The accuracy of data reduction, processing and interpretation of seismic data depends mainly on the correction of velocity *measurements.*

Since, in seismic prospecting, we require velocity values as a function of depth, all velocity determination methods aim at computing velocity depth- or time- function (Robinson & Coruh, 1988). Velocity estimation can be done by;

- By use of an exploration-well
- Velocity can be obtained by using well shooting
- The can be obtain from continuous velocity survey
- By the use of reflection travel times
- By the use of refraction travel times

3.15. Variations in seismic velocities

There are two types of variations in seismic velocities;

1. Lateral variation in seismic velocity
2. Vertical variation in seismic velocity

Lateral variations in seismic velocities

These variations are supposed because of slow changes in density and elastic properties due to changes in lithology or physical properties. Lateral variations make events appear to move up or down on time sections (Robinson & Coruh, 1988).

Vertical variations in seismic velocities

These variations are due to lithological changes of layering and increasing pressure due to increasing depth. Normally seismic velocities increase with the increase in depth (Robinson & Coruh, 1988). Vertical variation in velocity cause differences in the two way travel times of layers of equal thickness

3.16. Types of velocities used in seismic exploration:

The different types of velocities used in seismic exploration are;

- Average Velocity
- Interval Velocity
- Root-Mean-Square Velocity
- Normal-Move out Velocity
- Instantaneous velocity

Average Velocity

Average velocity is simply the total distance traveled divided by the total time traveled. The average seismic velocity is the distance traveled by a seismic wave from the source location to some point on or within the earth divided by the recorded travel time (Al. Sadi, 1980). The Figure 22 shows a two-layer case by which the average velocity is calculated.

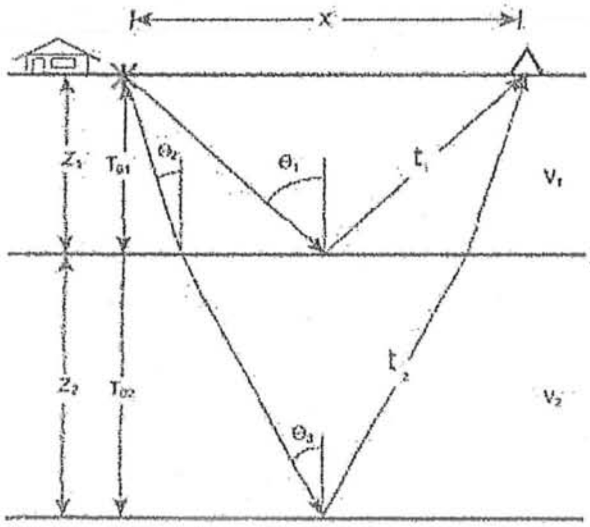


Figure3.10 (A two-layer case by which the average velocity is calculated)

If concerned with the distance and time from the surface of the earth to a point at depth, then the one-way distance and time is used (Dobrin, 1988). The average velocity in this case is simply;

$$V_a = \frac{\sum_{i=1}^{n} z_i}{\sum_{i=1}^{n} t_i} = \frac{\sum_{i=1}^{n} v_i t_i}{\sum_{i=1}^{n} t_i}$$

Nevertheless, if considering with the distance from the surface of the earth to a point at depth and back to the surface, then two-way distance and travel time is used, and average velocity equals 2Z/T (Dobrin, 1988). So, average velocity can be expressed as

$$V_a = \frac{z}{t} = \frac{2z}{2t} = \frac{2z}{T}$$

Where, t is one-way travel time, and T is the two-way travel time.

Interval Velocity

Interval velocity, V, 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 (Dobrin, 1988). The interval velocity is ΔZ (the thickness of a stratigraphic layer) divided by Δt (the time it takes to travel from the top of the layer to its base). The equation for interval velocity is:

$$V_i = \frac{Z_m - Z_n}{t_m - t_n} = \frac{Z_m - Z_n}{T}$$

The thickness $\Delta Z = Z_m - Z_n$ is also equal to the isopach value of the interval. A typical interval-velocity-versus-time curve compared to the average velocity is shown in Figure 23. The discrete boundaries in the interval-velocity curve indicate stratigraphic and velocity differences between two contiguous layers (Yilmaz, 2001). The average velocity can be determined by averaging the weighted summation of the interval velocities. If we sum the interval velocities for a series of rock layers, and weight them according to the two-way travel time within each layer, ΔT, the average value would be equal to the average velocity (Yilmaz, 2001). The equation for average velocity, V_A, in terms of interval velocity is:

$$V_a = \frac{\sum V_i \Delta T}{\sum \Delta T} = \frac{2\sum \Delta Z}{\sum \Delta T}$$

Where ΔZ is the interval thickness or isopach thickness.

Root-Mean-Square (RMS) Velocity

The root-mean-square (RMS) velocity is a weighted average. It is used as weighting process where the amount of weighting is determined by the value of the interval velocities. The weighting is accomplished by squaring the interval velocity values (Robinson & Coruh, 1988). So, in this approach, greater weight is given to the greater interval velocities. The equation for RMS velocity is given below

$$V_{rms}^2 = \frac{\sum_{i=1}^{n} v_i^2 t_i}{\sum_{i=1}^{n} t_i}$$

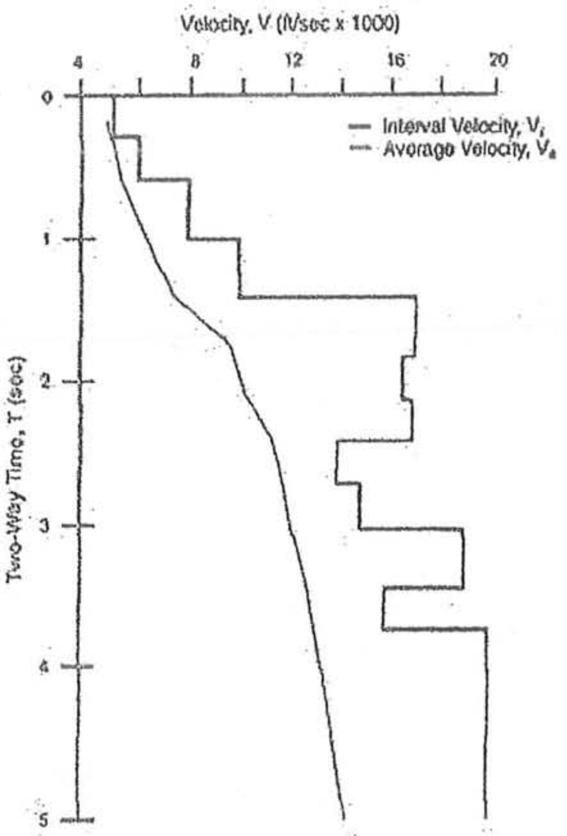


Figure3.11: (A typical interval-velocity-versus-time curve compared to the average velocity) (Yilmaz, 2001)

By comparing the equations it is clear that the RMS velocity is always greater than the average velocity. RMS velocity is strictly a mathematical weighted average and has no intrinsic meaning (Robinson & Coruh, 1988). Figure 24 shows a graphical comparison between the root mean square velocity and the average velocity.

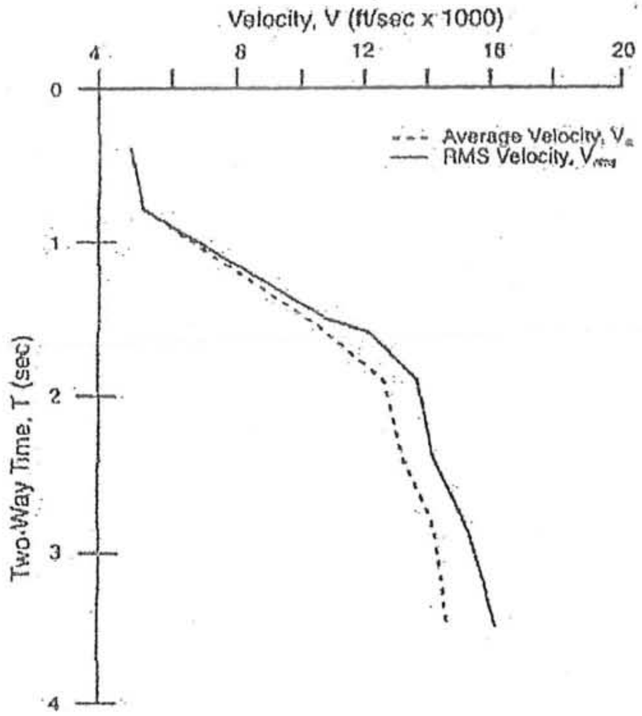


Figure3.12 : (A graphical comparison between the root mean square velocity and the average velocity) (Yilmaz, 2001)

Normal-Move out Velocity

The normal-move out (NMO) velocity, or stacking velocity, V_{nmo}, has a horizontal component (X). Therefore, it is dependent on the offset, depth, and spread length. Seismic records with source-to-receiver distances will yield different NMO velocity values. The NMO velocity increases as the value of X increases (Rehman, 1989). The equation for NMO velocity is:

$$V_{nmo} = \frac{X}{\sqrt{T_x^2 - T_x^2}} = \frac{X}{\sqrt{2T_0 \Delta T_{nmo}}}$$

Where, X = the offset distance from source to receiver, T_x = the two-way travel time of a seismic wave reflected off a particular interface and recorded at the receiver location, and T_0 = the two-way travel time of the seismic wave reflected off the particular interface at the zero-offset location.

We can calculate the NMO correction, ΔT_{nmo}, from the average velocity (by Figure). From the Pythagorean Theorem, we know that

$$d^2 = \Delta Z^2 + \left(\frac{X}{2}\right)^2$$

If we know the normal-movement velocity, it can be related to the average velocity using the equation $T = T_0 + \Delta T_{nmo}$ (Telford, 2004). Then approximate the NMO correction as a function of average velocity:

$$T_0 + \Delta T_{nmo} \approx \sqrt{T_0^2 + \frac{X^2}{V_a^2}}$$

$$\Delta T_{nmo} \approx \sqrt{T_0^2 + \frac{X^2}{V_a^2}} - T_0$$

The NMO correction can also be approximated from the RMS velocity. In this case,

$$\Delta T_{nmo} \approx \sqrt{T_0^2 + \frac{X^2}{V_{rms}^2}} - T_0$$

$$\Delta T_{nmo} \approx \frac{X^2}{2T_0 V_{rms}^2}$$

Instantaneous velocity

If the velocity varies continuously with depth, its value at a particular depth Z is obtained from interval velocity by contracting the interval ZI-Z2 to an infinitesimally thin layer having a thickness dZ (Telford, 2004). The interval velocity then becomes the derivative of Z with respect to "t", which is the instantaneous velocity, defined as follows:

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

Correlation between velocity types:

In seismic prospecting we are dealing with a medium which is made up of a sequence of layers of different velocities. In dealing with this kind of situation, it is necessary to specify the kind of velocity we are using. When velocity is measured for a defined depth interval, it is called as interval velocity and when it is determined for several layers it is called as average velocity (Al-Sadi, 1980).

Relationship between interval velocity, root mean square velocity and average velocity is given by "Dix Formula" (Al-Sadi, 1980). If root mean square velocities (V_{rms}) is given then interval velocities (V_{int}) can be determine by using the following form of Dix formula.

$$V_{int} = \sqrt{\left[\frac{(V_{RMS,n})^2 t_n - (V_{RMS,n-1})^2 t_{n-1}}{t_n - t_{n-1}}\right]}$$

If, on the other hand ,if given the average velocity (V_a), interval velocity(V_{int}) can be determined by another form of Dix- formula (Al-Sadi,1980).

$$V_{int} = \frac{V_{a,n} * t_n - V_{a,n-1} * t_{n-1}}{t_n - t_{n-1}}$$

Now, if we are given with interval velocities (V_{int}) and we have to determine average velocities (V_a), (Al-Sadi, 1980), then Dix formula attains the form as given below

$$V_{a,n} = \frac{(V_{int,n} * T_n - T_{n-1}) + (V_{a,n-1} * T_{n-1})}{T_n}$$

So if we are given with any of the interval, root mean square velocity or average velocity, the remaining two by using the corresponding form of Dix-formula.

Factors Affecting Velocity:

Different factors affect the seismic velocities, by which we infer the rock type or rock condition from an observed seismic velocity. The porosity, mineral composition, intergranular elastic behavior and fluid properties are the primary factors which affect seismic velocities and these factors are dependent upon overburden pressure, fluid pressure, micro cracks, age and depth of burial. The overburden pressure is usually defined as the vertical stress caused by all the material, both solid and fluid above the formation when a rock is buried, it is influenced by the overburden, which increases with time (Dobrin, 1988).

The increase of overburden causes the squeezing out of water from the rocks. But an impermeable layer is overlain by the compacting layer, in such case it will shut off the path for water to squeeze out. Therefore water is locked in the pores. Its stiffness then resists the deformation of rock grains into voids; therefore, it tends to maintain the porosity at great depth. Such rocks are said to be over pressure. The usual increase of velocity with depth can be reduced dramatically both by the maintenance of porosity and by the reduction of cementation by circulating water (Dobrin, 1988).

CHAPTER # 4

CHAPTER # 4

Seismic Data Acquisition

Seismic Data Acquisition

4.1 INTRODUCTION

Acquisition of seismic data, it is the very first step in the seismic exploration. It is the procedure through which seismic reflection data is acquired. With the help of modern electronics and computer industry, acquisition becomes very easy. Acquisition starts from shot and ends at recording the seismic events through various steps. Different energy sources are used to produce seismic waves and array of geophones are used to detect the resulting motion of earth. The data is recorded in digital as well as analogue form. (Kearey et al, 2002)

- First step in seismic data acquisition is to generate a seismic pulse with a suitable source.
- Second is to detect and record the seismic waves propagating through ground with a suitable receiver in digital or analogue form.
- Third is the registration of data on a tape recorder.

4.2 SOURCES OF ENERGY

Dynamite or Vibroseis is used as energy source. In case when Dynamite is used as energy source, we need Explosive detonators for every hole.

Sometimes you can have nice reflections at a depth more the 400 meters only with a small blank cartridge, other times you must use half a kilogram of explosive to record bedrock reflections below 100 meters of loose landslides. If the water level is near the ground surface, usually energy will propagates easily with high frequencies, in loose rocks, the loss of energy will be important and frequencies very low (30-50 Hz

Energy sources are categorized into two groups:

- Impulsive energy sources
- Non impulsive energy sources

Impulsive Energy Sources

Dynamite

It is commonly used to generate sources, used in seismic prospecting. Generally it is exploded inside a drilled hole at a depth ranging from few meters to several tens of meters (See fig. 4.1). The deeper the charge the less intensive the generated surface waves are. It is advisable to place this charge below the weathering layer as it absorbs the high frequency components. Charge is usually sealed with water or mud to increase coupling with surrounding. Amounts of charge per shot point depend upon pattern of shooting. (Telford, 2004)

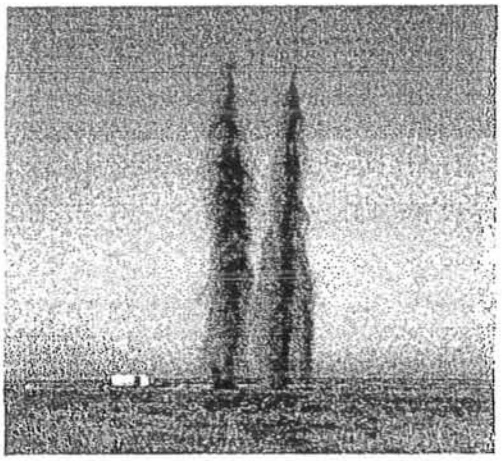


Fig.4.1 (Dynamite Shooting)

Non impulsive energy source

Vibratory Source

The most usual technique in "great seismic," vibroseismic becomes to the reach of the seismic high resolution thanks to the apparition of adapted recorders and of "small" vibrator. The seismograph records during several seconds (4-10 s) and then his software start the auto-correlation of the signal. After that, the observer can see on the recorder LCD display the correlated "shot". The vibrating source must have a elevated frequency vibration (several hundred of hertz) and of a variable length (sweep). An important advantage of the vibroseismic is its possible use in urban zone and in a "noisy" environment. OYO Center of Applied Geoscience in the Netherland has developed a "portable" 65 kg vibrator that generates a maximum peak force of 500 N with a frequency range between 25 and 1500 Hz.

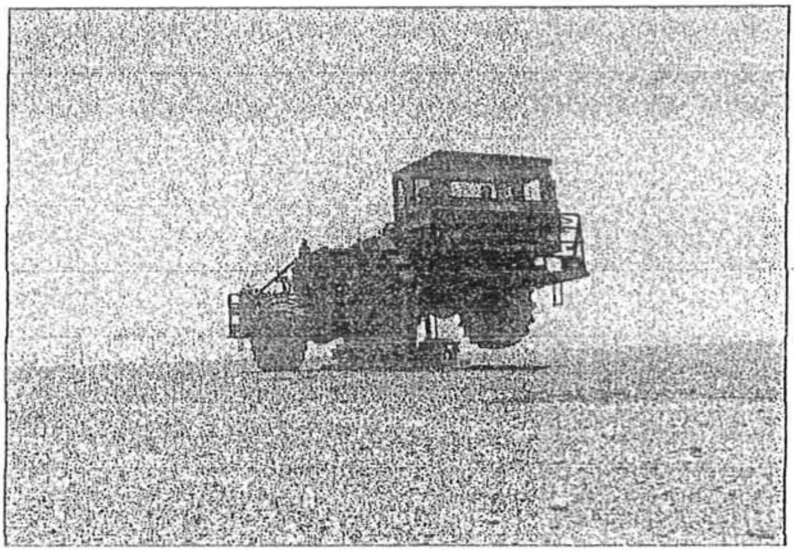


Fig.4.2 (LRS vibrator 309 of 22'000 ponds)

Other Sources of Energy

Hammer

A 5kg sledgehammer constitutes yet an effective and inexpensive seismic source. An accurate piezoelectric sensor trigger linked by cable to the recorder is set on the hammer; hits are generally made on an aluminum base plate. On soft ground, like some fields, the penetration of the waves is very weak (10 – 20 meters), striking directly on the asphalt of a road, produce often results astonishingly good (> 200 meters on some saturated soils).

Fig. 4.3 (Hammer)

Geograph

The Geograph method (also known as the Thumper) involves dropping a weight of about 3 tons from a height of about 3 m onto the ground. **(Telford, 2004)**

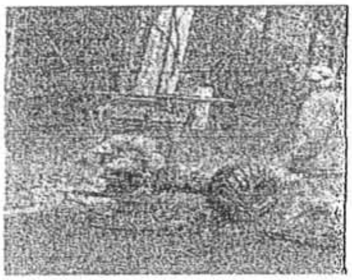


Fig.4.4 (fall of weight)

Dinoseis:

Instead of the freely falling weight used in the Geograph method, the weight in this method is power- driven against the ground surface **(Telford, 2004)**

Geoflex:

The seismic source consists of an explosive cord which is buried in the ground at a shallow depth. It is laid down by a hydraulically-operated plough which is especially designed for the purpose.

4.3 ACQUISITION SETUP

The seismic acquisition setup involves the following

1. The spread configuration
2. Shooting types
3. Selection of Shooting parameters
4. Selection of Recording parameters

The Spread Configuration

For acquisition of data and as well as to have quality of data high certain field operations are adopted. So the first step in this practice is the choice of spread type. The spread is defined as the lay out on the surface of, of the detectors which give recorded output for each source. Spread is made up of equal inter-receiver distance and a defined offset. There is certain number of spreads called as basic spreads, which are used in seismic acquisition (see Figure 4.5).

These spreads are:

- End on spread
- Inline offset spread
- Split Spread/Centre shooting
- Fan shooting

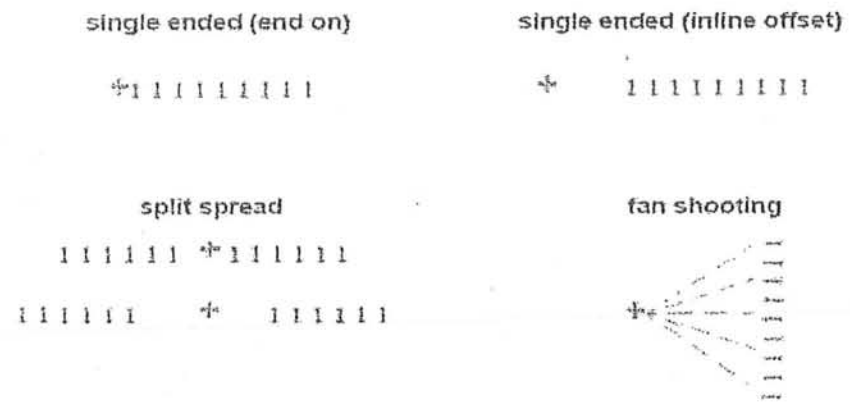


Fig. 4.5: (The basic spreads used in Seismic Acquisition)

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

Fan shooting is used in Transmission method. Transmission method differs from normal refraction method in the sense that it does not involve critical incidence of waves over the interface. In Transmission method, source and detector are on opposite sides of the investigated interface. Other techniques used in transmission method in velocity logging (well shooting, continuous velocity logging (CVL) and uphole survey. Fan shooting is used for determination of the dimensions of velocity anomalous structures. (Al-Sadi, 1980)

Shooting Types

There are different types of shootings used in the field. These types are:

- Symmetric shooting (In this type the number of channels on sides of source is same.)
- Asymmetric shooting (In this the number of channels on sides of source is not same)
- End shooting (The source is at one end of the spread)
- Roll along/Roll out shooting (In roll along method receivers are added in the spread while shooting in the source along the spread. Roll-out shooting is one in which the receivers are removed from the spread while shooting out along the spread.

4.4 SELECTION OF SHOOTING PARAMETERS

Selection of shooting parameters on the basis of experiments and their strict observation in the field is very important for good quality data acquisition.

The Source

There are different types of seismic energy sources are available in world. Among them, the use of vibrators now exceeds the shot hole. A major choice in designing field techniques is the energy source to be used. Many times, there is no choice. For example we would never use vibrators in swamp or drill shot in thickly settled areas. We do have a choice; we must balance the often conflicting the considerations of

a)-Cost

b)-Resolution

c)-S/N ratio

Basically there are three types of shooting parameters

1)-Size of charge

2)-Base of charge

3)-Depth of charge

Size of charge

Selection of size of charge plays very important role in good seismic data acquisition. Charge size is decided on the basis on comparison of shots carried with varying charge sizes. The thing should be born in the mind that whenever we go for comparison of charge, one should always start with using less quantity and then go on increasing it. Also use of more explosive does not necessary to enhance data quality, because when we increase charge size ground roll also increases. The choice of size is directed at four particulars:

1)-There must be sufficient out put from the source, at frequencies appropriate to good penetration, to make the signal at least as large as the noise at the time of deepest reflection of interest.

2)-There must be sufficient bandwidth to provide at least the desired resolution at the time of target reflection.

3)-The ratio of reflected signal to source generated noise, at all times of interest and after all the benefits provided by the geophones, arrays, instrumental filters and processing must be sufficient to protect the interpreter against mispicking.

4)-The first breaks, if required for reflection statics, must be sufficiently sharp to give statics of a precision appropriate to the reflection bandwidth, it must also persist to an offset to give the redundancy essential to reliable calculations.

Base of Charge

The distance over which holes/surface charges are spread is term as "Base of Charge"; this is also selected in the basis of results of experimental work.

Depth of charge

Shot is below the weathering, the effective source pulse usually becomes much crisper and richer in high frequencies. As the shot is moved deeper, the reflection or Ghost from the base of weathering interfaces the primary pulse. A shot that is too shallow generates the ground roll, does not give surface correction data, and does not radiate much energy downward; while a shot that is too deep wastes money and results is a weak signal.

Advantages of Deep Shot holes

1)-Attenuation of higher frequencies much lower, therefore high resolution can achieve.

2)-Uphole time can be directly recorded for good weathering control.

3)-Source pulse is much closer to minimum phase.

4)-Deep shots generate less surface noise.

5)-Ghost .if properly tackled may be advantageous.

6)-Ambient noise can be controlled easily by increasing the charge.

Disadvantages of Deep Shot holes

The greatest disadvantages of deep shot holes are that drilling is a slow, noisy process that must be carried out well clear of the recording spread.

Advantages of Shallow Shot holes

Shallow holes do not give near surface information, and they tend to generate high amplitude surface waves. The surface wave problem can be decreased by using very small, <0.1 kg, charge in each hole and using the array of shots as a measure of increasing total energy, instead of canceling surface waves. In this case, the holes in array may be very shallow, as little as1m, and spaced very close together.

Disadvantages of Shallow Shot holes

The Source for small charges, being rich in higher frequency, tends not to excite the frequencies usually dominant in surface waves. This approach is rarely practical for targets at reflection times greater than about 1.0 second.

4.5 SELECTION OF RECORDING PARAMETERS

Introduction

The quality of seismic data on the seismic section depended upon the earlier efforts in seismic data acquisition. Quality and suitability of the field data to large extent depend upon the correct selection of field parameters. First thing that challenge geophysicist is the geological problem, and then selection of geophysical parameters to address that geological problem. Before deciding the recording parameter following things should be kept in mind.

1)-Explain &define geological problem in the form of geophysical problem.

2)-Select suitable geophysical parameters

3)-Economic consideration on selected parameters.

Exploration Problem

1)-What is the depth of the target? Experimental working the field depend upon the dimension of geological problem.

2)-What should be the frequency? Resolution at target depth. Usually frequency is taken as 150/t

3)- What should be the reflection strength at target depth?

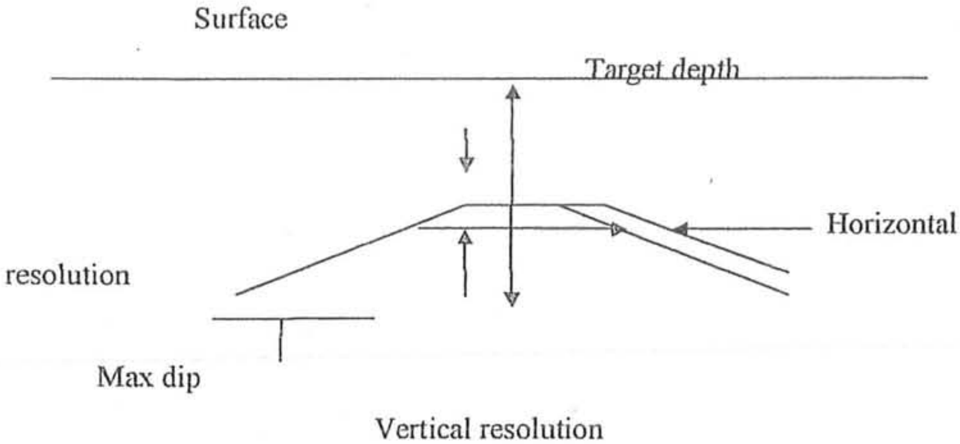


Fig.4.6

The depth of the target, maximum dip to be resolved, and vertical and horizontal resolution at that depth defines the exploration.

Many parameters depend upon dimension of structure, so they will not be changed by the field judgment .so these variables should be fixed the early stages. The parameters that entirely depend upon geological problem are

1)-Range of Source-Receiver Offset

2)-Group Interval

3)-Sample Interval

4)-Recording Filter

5)-Geophone Frequency

6)-Record Length

7)-Line Direction, Spacing, and Length

Some variables that are usually independent of the exploration problem and can changed based on field judgment are as follows.

1)-Charge size

2)-Charge depth

3)-Type of array

Spread geometry

a)-Far Offset

b)-Near Offset

c)-Group Interval

d)-Choosing of Geophone

e)-Geophone Array

f)-Fold

g)-Record Length

h)-Base length

a)-Far Offset

The depth of target directly determines the distance from the source to the farthest group. When we Design the field variables the field variable, a major task is to maximize the enhancement that occur in the stack.

Increasing the range of offsets has two effects.

1)-It increases the destructive interference between noise and multiple after dynamic correction

2)-For primary reflection it may decrease the accuracy of Nmo correction on hyperbolic approximation

In the field, therefore it is usual practice to produce a spread length at least as long as it is approximate at target depth. Standard starting point of seismic surveying is

Far group offset= target depth

b)-Near Offset

The earlier parts the near source traces valuable for computing the static, for computing velocities in the shallow section for slant stacking g and computing decon operator. We can summarize the requirements for the near offset in a two-part rule.

1)-We prefer the near group offset to no longer than one group interval.

2)-If a longer near –group offset must be used, it must be short enough that shortest offset included in any gather is less than the depth to the shallowest reflector of any interest.

c)-Group Interval

While selecting the group interval three things are most important.

1)-Horizontal resolution

2)-Dipping of beds

3)-Near surface velocity variation

General rule of thumb is that there should be 12traces for features of interest. General rule of thumb is that

Group interval = width of feature of interest / 6

d)-Choosing the Geophone

The geophone is of course, a low cut filter, whose characteristic is decided by natural frequency and damping. In field our main concern is to avoid introducing false signal. We usually use geophone-having frequency 10 to 20 Hz if the ground roll is not big problem.

If the area is noisy, we have to reduce the geophone sensitivity. Overall sensitivity of the array can be improved by increasing the no of geophone in the series. This overall sensitivity can reduce by increasing the no of parallel or it can be reduced by preamplifier gain.

Final note that the response of the geophone should include the response of the plant its frequency response and its distortion. Choosing geophone mean that it's dimension, the spike length, and position of wire connection should be appreciate to the type of the surface soil exposed in the area.

e)-Geophone Array

The source of seismic energy generates a lot of surface noise, which travel along the surface of the earth. This surface noise therefore, corrupts the reflected signal arriving at the same time. To kill surface noise we use proper receiver array.

"Layout of number of geophone over one wave length of the surface wave, the out put of the geophones in one half cycle of in line noise cancel the combined out put of those in other. The net result is that the total response of the array is zero for the in line surface wave".

There are different of array made in the Seismic data Acquisition Project depending upon their feasibility, some are as follows

- **a) Overlapping in line Array**
- **b) Linear array**
- **c) Nine arm star array**
- **d) Weighted Array**

The size of the array depend the upon base length.

Following Factors affect the Array dimension in the seismic survey.

1)-Practicality

2)-Averaging of plants

3)-Ambient noise

4)-Rough Terrain

5)-Normal move out

6)-Source generated Noise

7)-Airwave

8)-First Breaks

1)-Practicality

Practically term is related with efficiency of the crew and cost of survey .The complete pattern increase the survey cost, such as overlapping in line arrays, Weighted, Radial star array etc.

2)-Averaging of Plants

The array should such that labours can layout maximum geophone.

3)-Ambient Noise

Generally Longer Arrays and greater number of geophone are better for suppression of ambient Noise. The suppression of ambient Noise has to be performed by intelligent use of geophone and arrays.

4)-Rough Terrain

On a level ground terrain. The up coming reflection will hit all the geophone of the group simultaneously .The result would be a maximum response from geophone array, but if the terrain is rough ,the geophone will be inclined and the up coming energy would hit the successive geophone at slightly different time.

To reduce the problem, the array length should be with in the certain limits.

f)-Fold

The number of common depth point traces which sample essentially the same portion of reflector but different offsets. for example 50 fold mean recording the subsurface point 50 times, Once from each of 50 different offset distance. Fold for the seismic operation can determine by formula.

$$\text{No. of Fold} = N\Delta G/2.\Delta S$$

Where N= is No of Traces

ΔG= group Interval

ΔS=Shot point Interval

Multiplicity /fold of seismic data can be decided keeping in view the following things.

1)-Type of survey to be calculated. i.e. regional semi detail, or detailed

2)-Geological Objective

3)-Seismological condition of the survey

4)-Type of seismic equipment available with the crew, number of channels recorder.

5)-Cost factor of the seismic survey

the total base length can be of linear, parallgram, or star type. Geophone base length is selected on the bases of results of a noise profile.

1)-Areal arrays are really required to attenuate noise coming from the side of the line

2)-Airwave attenuation may require closer geophone spacing.

4.6 DETECTION AND RECORDING OF SEISMIC WAVES

After using energy sources, through which energy is supplied to earth, there comes the stage of detection and recording of seismic waves. In seismic detection it is necessary to detect vibration amplitude as small as 10-8 inches. Seismic equipment of adequate sensitivity, large dynamic range, and suitable frequency response is the aim of all development programs taking place in the field of seismic detection. Geophone is the most important detecting instrument used. (Al-Sadi, 1980)

Geophone

The receiver used for the detection of ground vibration is called a geophone or a seismometer. It is used for seismic surveying on land, and it can also be operated on the ocean floor if mounted in a suitable container. Mechanism is that the motion of a coil around a magnet induces electric current to flow in the coil (see Figure 4.6). The strength of that current depends on the speed of the motion. The response of geophones to vibration of different frequency can be tested with a device called a shake table. The frequency of vibration that stimulates the strongest geophone response is recognized as the natural frequency of the geophone. It is found from the highest point on the response curve. Geophones commonly have natural periods in the range of 5 to 40 Hz. The smaller, more compact ones ordinarily have higher natural frequencies. The geophone is in a class of instruments that we call harmonic oscillators. (Robinson & Coruh, 1988)

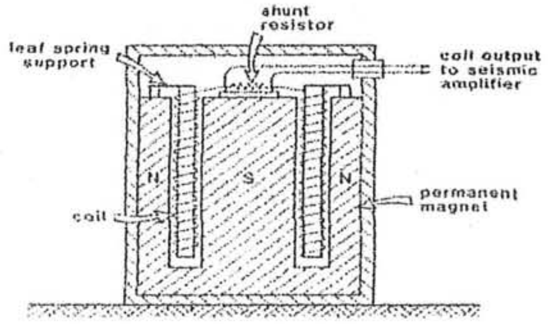


Fig 4.7: (Basic Nomenclature of Geophone)

Seismic Cable

Seismic cable is used to transmit geophone signal to recording system. Each geophone requires two wire conductors. Thus the number of conductors is double of geophones used in seismic cable. For small scale engineering surveys cable usually have 24 conductors which carry the signal of 12 geophones. The point where a geophone is connected to the pair of conductors is called the "takeout point". There are takeout points at regular intervals along the cable. (Robinson & Coruh, 1988)

4.7 SEISMIC DATA RECORDING:

The conventional seismic survey procedure is to monitor ground motions at a large number of surface locations, thus multi-channel recording systems are employed with up to several hundred separate recording channels. The signals are received with a large number of geophones (geophone groups) spread along a line extending from the shot point for a distance of thousands of feet. Each group transmits its data to the recording instruments on one information channel, by means of the seismic cable.

(Kearey & Brooks, 2002)

There are two types of recording systems generally used in seismic surveys.

- Analogue recording system
- Digital recording system

Analogue Recording:

Analog systems are systems for which the input and output are analog signals i.e. continuous amplitude signal. Analog magnetic tape recorders usually have heads for recording 26 to 50 channels in parallel. The analogue recording is constrained by its small dynamic range. In order to limitize the signal in the small available dynamic range of the analogue recording system, negative feed back amplification is employed which at one hand amplifies the weak signals and at other hand suppresses the strong signals.

(Telford, 2004)

There are two methods available for this purpose:

- Automatic Gain Control (AGC) measures the average output signal level over a short interval and adjusts the gain to keep the output level almost constant regardless of the input level.
- Time Variable Gain used to suppress the initial gain level and enhances the gain at later part of the recording when seismic signals have low amplitude.

Digital Recording:

One of the most significant developments in seismic technology has been introduction of the digital recording in the field first introduced into seismic work early in the 1960s. Digital recording represents the signal by a series of numbers which denote values of the output of the geophone measured at regular interval, usually 2 or 4 milliseconds.

Digital recording systems have following units:

- **Multiplexer**
- Amplifier
- A/D Converter
- Format Generator

Multiplexer:

It is a high-speed electronic switch that first picks the signal of channel-1 for a period of one micro second and charges its capacitor. Then it takes the signal of channel -2, then to channel-3 and so forth up to last channel. Then again it switches channel-1 and repeats the same procedure. Hence the data recorded, will be in multiplex form.

(Robinson & Coruh, 1988)

Amplifier:

The recording signal is then amplified by passing through the amplifier and then these signals are transmitted to the A/D converter.

(Robinson & Coruh, 1988)

A/D Converter

The amplified analog signal is converted into digital signals. In A/D converter different combinations of standard voltages are generated and tested to find the particular combination that exactly balances the signals. The voltages making up the combination are transmitted to the formatting unit.

(Robinson & Coruh, 1988)

Format Generator:

In format generator, the voltage pulses are converted to control signals that activate the recorder head to magnetize the appropriate bits on the magnetic tape. This entire sequence for channel-1 requires less than 30 microseconds.

(Robinson & Coruh, 1988)

Display of Seismic Data:

CDP profiling data from two-dimensional surveys are conventionally displayed as seismic sections, in which the individual stacked seismograms are plotted side by side, with their time axes arranged vertically.

(Rehman, 1989)

CHAPTER # 5

Seismic Data Processing

5.1 Introduction

Data Processing is sequence of operations which is carried out according to a pre-define program to extract useful information from a set of raw data. It can be said "as an approach by which the raw data recorded in the field is enhanced to the extent that it can be used for the geological interpretation" (see figure 5.1). Data processing is to convert the information recorded in the field into a form that mostly facilitates geological interpretation. (Al. Sadi, 1980)

Seismic data processing strategies and results are strongly affected by field acquisition parameters. Additionally, surface conditions have a significant impact on the quality of data collected in the field. Lack of seismic reflected events on seismic section is not the result of a subsurface void of reflectors. Rather it is caused by low signal-to-noise ratio (S/N) resulting from energy scattering and absorption in the medium of propagation. Surface conditions have an influence on how much energy from a source can penetrate into the subsurface. Besides surface conditions, environmental conditions and demographic restrictions can have significant impact on field data quality. Other factors that can influence the quality of data are weather condition and condition of recording equipment. In addition to field acquisition parameters, seismic data processing results also depend on the technique used in processing. Processing algorithms are designed for and applied to either single channel time series, individually, or multi-channel time series. (Dobrin, 1988)

5.2 Processing in General

Data Processing is a sequence of operation, which are carried out according to the pre-defined program to extract useful information from a set of raw data as an input-output system (Al. Sadi, 1980). Processing may be schematically shown as.

Observational Data ⇨ Processing System ⇨ Useful Information

5.3 Processing Sequence

The seismic data processing sequence can be broadly defined in five categories.

- Data Reduction

- Geometric Corrections
- Data Analysis and Parameter Optimization
- Data Refinement
- Data Presentation

5.3.1 Data Reduction

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

- *Demultiplexing*
- Geometry Definition
- Correlation
- Header Generation
- Display
- Editing and Muting
- Amplitude Adjustment

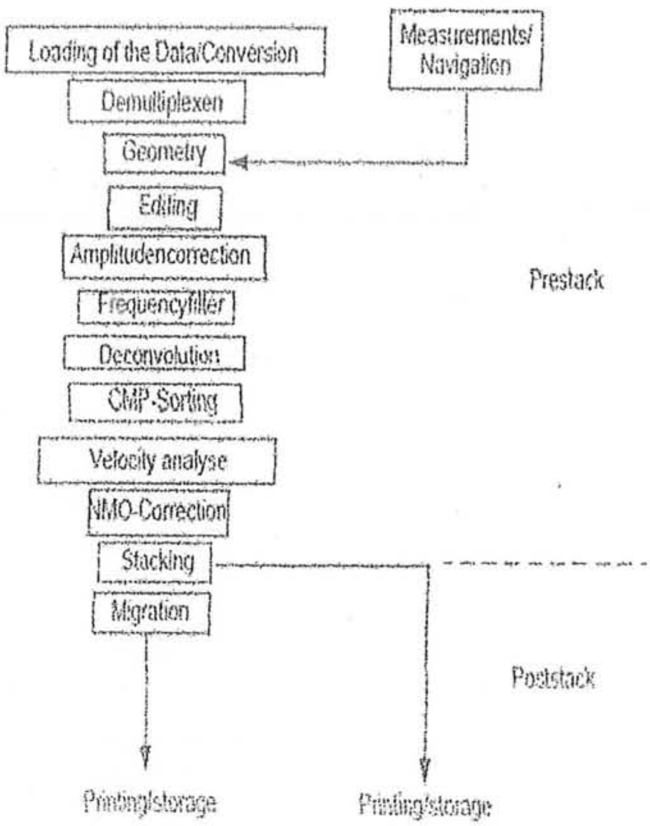


Figure 5.1 (Detailed Processing Sequence Flow Chart)

Demultiplexing

Data recorded on digital magnetic tape is not suitable for analysis therefore it is assembled from the digital tape by a sorting process. Thus "*the process of sorting data from the magnetic tape into individual channel sequence is called Demultiplexing*. Suppose there are four geophone arrays. Instantaneous voltage recorded by each geophone yields an array of samples. If each sample is identified by its geophone group source (A, B, C, D) and by its chronological sequence in that group (1, 2, 3, and 4). Then the output

$A_{11}A_{21}A_{31}$..........$A_{i1}A_{i+1,1}$.............A_{n1}
$A_{12}A_{22}A_{32}$.........$A_{i2}A_{i+1,2}$.............A_{n2}
$A_{13}A_{23}A_{33}$.........$A_{i3}A_{i+1,3}$.............A_{n3}
....
....
$A_{1m}A_{2m}A_{3m}$.........$A_{im}A_{i+1,m}$..........A_{nm}

This scrambled sequence is called Multiplexed data, and the unscrambling multiplexed array into Trace Sequential Array is called *Demultiplexing*. The digital seismic data is recorded on magnetic tape by the recorder in the following way (Robinson & Coruh, 1988).

After that data has been Demultiplexed, it is stored on tape in a convenient format in the following way, which is used in further processing.

A11, A12, A13,..........,A1m
A21, A22, A23,..........,A2m
....
....
....
....
An1, An2, An3,..........,Anm

Geometry Definition

The layout of receivers for each shot record the location of all shots along the line, and all such field information must be described in detail to the computer for the geometry-specification step. Most geometry programs can access the digitized base-map file.

Computer access is particularly necessary for processing crooked lines in which sources and receivers are not uniformly distributed along a straight traverse. The geometry program must calculate a source-receiver mid-point based on the two ground locations. All relevant geometric information is retained in the trace headers on the tape so that each trace is uniquely and accurately located. Later programs will time shift or filter as a function of ground location, offset, and/or other spatial coordinate(s) and time.

Correlation

Correlation is simply the measurement of similarity or time alignment of two traces. Since correlation is a convolution without reversing the moving array, a similar frequency domain operation also applies to correlation. (Yilmaz, 2001). There are two types of correlation;

1. Cross Correlation
2. Auto Correlation

1. Cross Correlation

Cross correlation measures how much two time series resemble each other. It is not commutative; output depends upon which array is fixed and which array is moved. As a measure of similarity, cross correlation is widely used at various stages of data processing (Yilmaz, 2001). For instance traces in a CMP gather are cross correlated with a pilot trace to compute residual static's shift. It is the fundamental basis for computing velocity spectra.

2. Auto Correlation

Cross correlation of a time series with itself is known as auto correlation. It is a symmetric function. Therefore only one side of the auto correlation needs to be computed. (Yilmaz, 2001)

Vibroseis Correlation

The signal generated by a vibroseis is not a short pulse but rather a sweep lasting some seven to ten seconds. The sweep is transmitted through earth and reflected signal. Each reflection is a near duplicate of a sweep itself, so the reflections in vibroseis record overlap act are indistinguishable. To make it useable reflections are compressed into wavelets through cross-correlation of data with original input sweep. After correlation each reflection on record looks similar to impulsive source data. This involves cross correlation of a sweep signal (input) with the recorded vibroseis trace. The sweep is a frequency-modulated vibroseis source signal input to the ground (Yilmaz, 2001). There are two types of sweep;

1. Up Sweep (When frequency of the vibroseis source signal increases with time)
2. Down Sweep (When frequency of the vibroseis source signal decreases with time)

Importance of Vibroseis Correlation

For Vibroseis source, we have a sweep (a train of waves) rather than a short pulse/source wavelet whereas most seismic impulsive sources generate a very short pulse which can be used directly to examine subsurface structure Vibroseis sweep lasts for several seconds depending upon the sweep time. So in case of vibroseis source all reflected and refracted signals on a vibroseis seismogram overlap one another extensively. Even after demultiplexing of the vibroseis seismogram it is impossible to recognize the reflections. So vibroseis correlation procedure is applied.

(Robinson. & Coruh, 1988)

Vibroseis correlation enables us to extract from each of the long overlapping sweep signals on vibroseis seismogram, a short wavelet much like those obtained with seismic impulsive source

Editing and Muting

Raw seismic data contains unwanted noise and sometime dead traces due to instrumental reasons. Thus the quality of data recorded is first observed by visual examination of raw field traces. Data may be affected by following reasons

- Polarity reversals in data
- Poor traces as well as poor bits

To remove polarity reversal, trace with reverse polarity is multiplied with it that becomes a trace with the polarity. Therefore editing is a process of removing or correcting traces, which in their original recorded taken, may cause stack deterioration (Rehman, 1989).After doing this all the contributing traces per each CDP are gathered together. Each trace in one CDP is identified by it s shot point and receiver numbers .The CDP-gathers may be displayed as such for direct inspection and checking of edited data.

- **Muting**

Trace- muting is a special type of data editing. This term is applied for process of zeroing the undesired part of a trace. In order to avoid stacking non-reflection events (such as first arrivals and refraction arrivals) with reflection, the first part of the trace is normally muted before carrying out the stacking process .This is occasionally referred to as first break suppression. (Al-Sadi,1980)

Muting is useful to remove useless information from the processing stream in a way that first identifies the information to be removed and then blanked. Muting is categorized as *Initial Muting*, to remove first arrivals; usually done later in processing, and *Surgical Muting,* to remove air waves or ground roll energies.

- **Amplitude Adjustment**

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

a. Trace Normalization

b. Trace Balancing

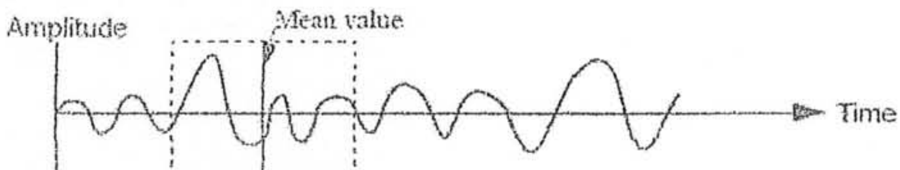
a. Trace Normalization:

Trace Normalization is an amplitude adjustment applied to the entire trace. It is directly applicable to the case of a weak shot or a poor geophone plant. All absolute values of a trace are summed and compared with a reference value. A scaling factor is determined from the difference between the summation and the reference value, which is used to multiply all data with. Other possibilities of trace normalization could be *Average value* (Arithmetic or RMS), *Median*, *Maximum Value* to compensate the difference in amplitude which occurs due to the increasing distance between the source and receiver and the lateral differences in amplitudes. But the loss of amplitude with increasing depth is not taken into account.

b. Trace Balancing-AGC:

The AGC function does not employ a gain to the whole trace, but employs a gain to a certain time sample within a time gate. First, the mean absolute value of trace amplitudes is computed within a specified time gate. Second, the ratio of the desired 'RMS' level to this mean value is assigned as the value of the gain function. This gain function is then applied to any desired time sample within the time gate; say the n^{th} sample of the trace. The next step is to move the time gate one sample down the trace and compute the value of the gain function for the $(n+1)^{th}$ time sample and so on (fig. 5.2). The time gate is very important. Very small time gates can cause a significant loss of signal character by boosting zones that contain small amplitudes. In the other extreme, if a large time gate is selected, then the effectiveness of the AGC process is lessened. 256- to 1024-ms AGC time gates are commonly chosen.

A disadvantage is that when the AGC gain is applied, it is not possible to reconstruct the original signal again. Therefore, the AGC is only used for display and printing purposes.



Principle of AGC

Figure 5.2 (AGC window showing how it works)

Display

The data so processed is generally displayed in various modes (fig. 5.3) to summarize the information gathered. At any point of processing sequence the seismic analyst can display the data in wiggle trace or other modes. The choice of display is a matter of the client taste, but is not affected by company dictum. Currently, the data provided by OGDCL is the variable area with wiggles plot.

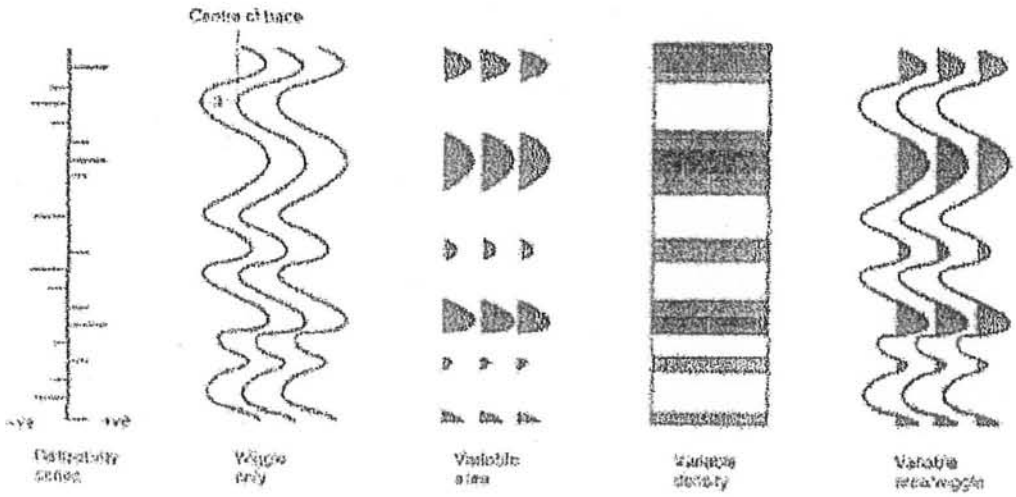


Figure 5.3 (Common Display types for Seismic Trace)

Automatic Gain Control

A grain recovery function is applied on the data to correct for the amplitude effects of wave front (spherical) divergence (Yilmaz, 2001). This amounts to applying a geometric spreading function, which depend upon travel time, 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.

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 time and for all mid points (Dobrin, 1988). A typical method of calculating the median or average amplitude with in sliding windows down the trace , then to calculate the multiples needed to equalize the median value in all the window.

In interpretation of seismic section, variations in amplitudes of reflections can be the important factors .Lateral amplitude variations, from trace to trace, within a reflection event (bright spots) may be the direct indications of the presence of hydrocarbons. Vertical amplitude variations, from event to event, may be helpful in identifying and correlating reflecting horizons.

5.3.2 Geometric Corrections

In order to compensate for the geometric effects, we have to apply certain corrections on the recorded data .These corrections are called as geometric corrections (Dobrin, 1988). These corrections are applied on the traces gathered during trace editing and muting .The geometric corrections are

1. Static correction
2. Dynamic correction

1. Static Correction

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

- Elevation correction
- Weathering correction

For land data, elevation corrections are applied at the stage of development of field geometry to reduce the travel times to a common datum level (Yilmaz, 2001).This level may be flat or floating along the line.

2. Dynamic Correction

Dynamic correction compensates the effect of offset of receiver from the source .It is also related to the shape of the subsurface interfaces .It is also of two types.

- Normal move out correction (NMO).
- Dip move out correction.

Normal move out correction is related more to the non-dipping interfaces. On the other hand dip move out correction is related to the dipping reflectors. It accounts for the effect of dip of the subsurface interface along with the effect of offset distance of receivers (Robinson & Coruh, 1988).

Dip-move out correction is applied to data following the normal-move out correction using flat-event velocities (Yilmaz, 2001). Figure 5.4 is the diagrammatical representation of the concept of static and dynamic corrections .

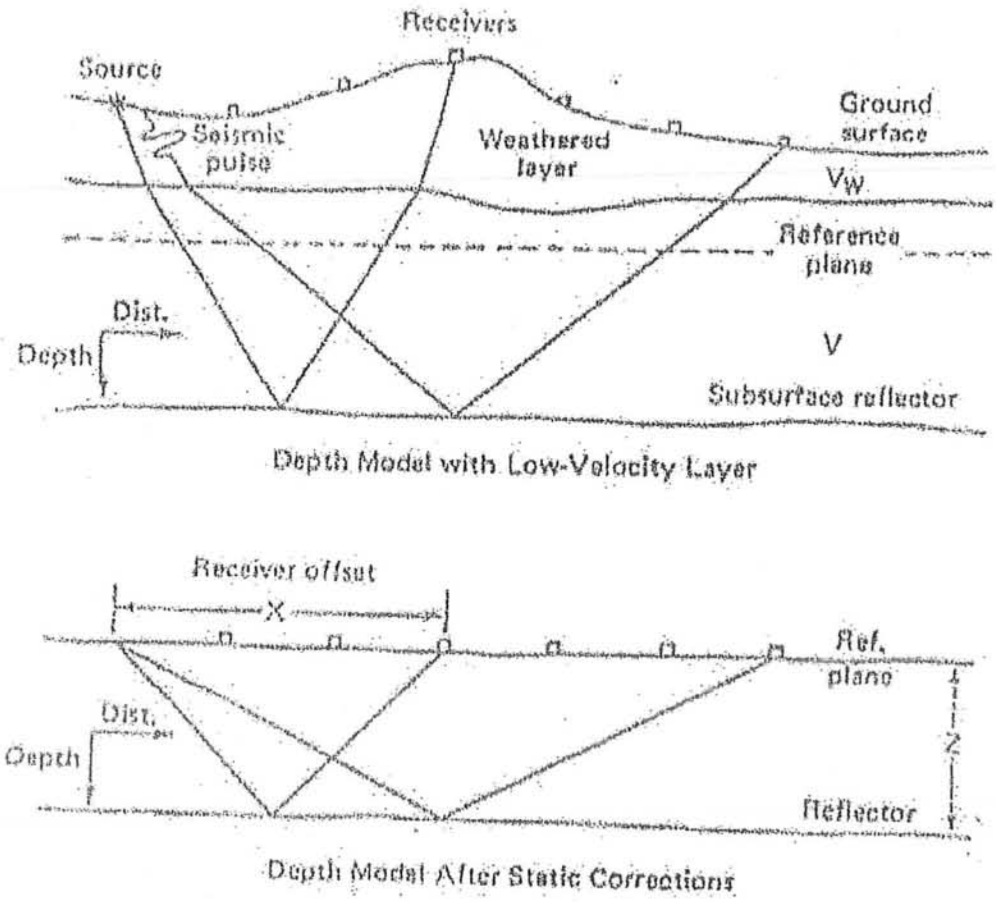


Fig. 5.4: Diagrammatic representation of static and dynamic corrections.

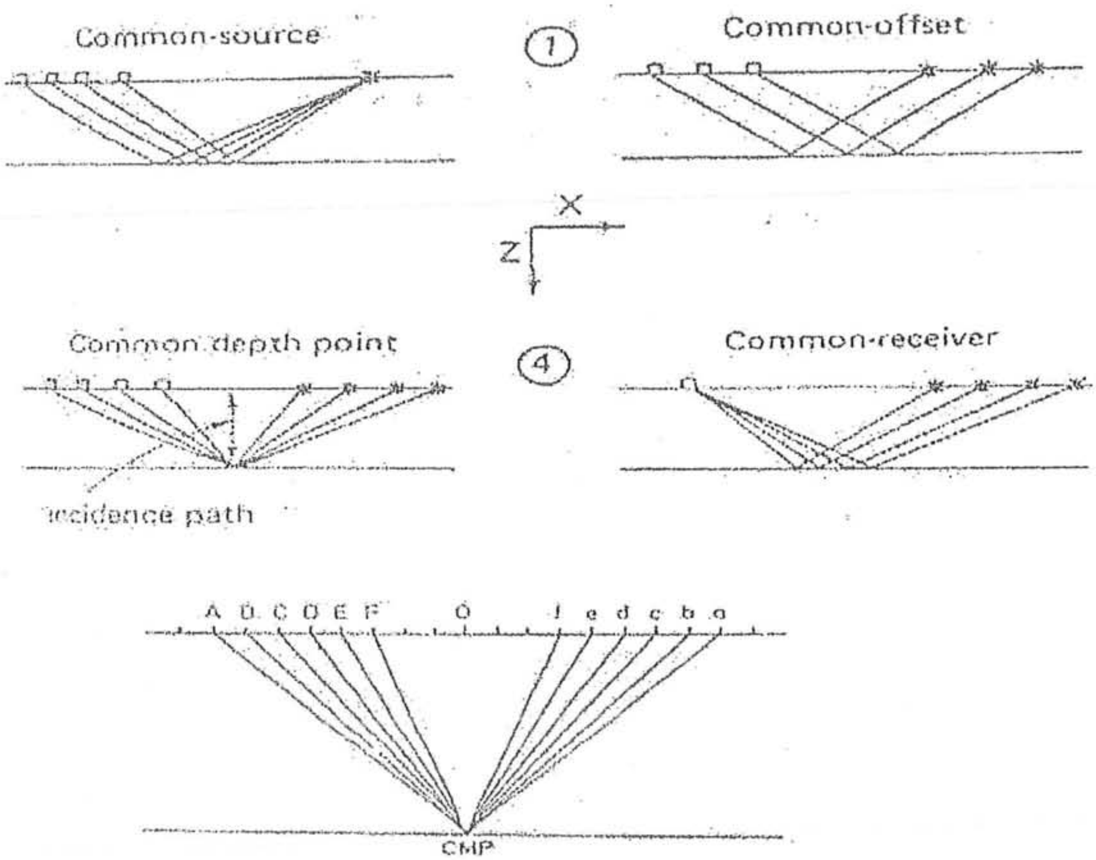
- **Trace Gathering**

Traces are routinely gathered into groups having some common elements.

- Common Source Point Gather.
- Common Depth Point Gather.
- Common Receiver Point Gather.
- Common Offset Gather.

- Common Mid Point Gather.

The concept of various types of Trace Gathers is shown in the Figure 5.5 as fallow:



CMP Gathers

Fig5.5: Diagrammatic representation of different trace gathers

The classical shooting pattern involves the procedure of a fixed shape spread, which moves along a linear profile at a regular move up rate. Such a spread is made up of equal inter-trace distances and a defined offset (Yilmaz, 2001). This technique ensures CDP coverage of a fold, which increases as the move up rate decreases. Multifold coverage can be calculated in terms of number of recording channels N, the geophone interval (X) and (S), and source interval as;

$$\text{Fold number} = N\,X/2\,S$$

The ability to combine seismogram traces to obtain multifold reflection vastly improve signal to noise ratio. CDP technique is most common for data acquisition now days.

5.3.3 Data Analysis and Parameter Optimization

Three steps involved in this procedure. These three are:

1. Filtering
2. Deconvolution
3. Velocity Analysis

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 it. Different trace configuration and increase in number of geophones at a point may decrease the noise but all the noise is not cut, so filters are used for further enhancement of signal. Thus filtering

"Is a process of spectrum modification which involves suppression of certain frequencies" (Robinson & Coruh, 1988)

- **Digital Filters**

It is numeric operator, which is convolved with a given digital function to filter out certain frequency components. It is also called time domain filter. Frequency filtering is avoided because weak reflection in the same frequency range that may be filtered out (Al-Sadi, 1980).The systems, which are generally called filters work either by convolution in the time domain or by spectral shaping in the frequency domain to remove the undesired information (Yilmaz,2001). The most common types of filters used are as follows

1. Low pass frequency filter
2. High pass frequency filter
3. Band Pass frequency filter
4. Notch filter
5. Velocity filter
6. F-K filter

- **F-K Filters**

Events that dip in the (t,x) plane can be separated in the (f, k) plane by their dips. This allows the elimination of certain types of unwanted energy from the data. In particular, coherent linear noise (in the form of ground roll), guided waves, and side-scattered energy commonly obscure the genuine reflections that may be present in recorded data. These types of noise usually are isolated from the reflection energy in the (f, k) space.

➢ Deconvolution

It is the process by which the wavelet associated with the significant reflections is compressed and reverberatory energy that trails behind each reflection is largely attenuated .It is a filtering process designed to improve resolution and suppress multiple 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, with convert each wavelet into a single spike (Dobrin, 1988)

It is a class of operations developed as a mean of partially reversing the effect of earth filter. When dynamite is blasted, spike is produced that is visible in the seismogram. Spike has very high frequency and short wavelength. When it travels through earth its amplitude decreases and it becomes a waveform, with lower frequency and greater wavelength. Thus earth is absorbing higher frequencies with time and depth. This behavior of earth is termed as hi-cut filter.

Thus Deconvolution with a reverse process by which these higher frequencies are reproduced, called reverse filtering. Sometime- there are fake reflectors produced due to multiples which can cut by Deconvolution and deeper reflections become identifiable. (Yilmaz, 2001)

➢ Velocity Analysis

Velocity in seismic processing is an important parameter, which controls the stacking quality. Thus the proper velocity value gives the optimum dynamic correction which leads to efficient stacking process. The seismic traces of a common depth point gather are basis for each velocity analysis. Before velocity Analysis suitable static correction and data enhancement procedures are applied to the data (Yilmaz, 2001).

A series of normal moveout corrections, each based on arbitrary constant velocity are then applied to each trace of data set. Then NMO corrected traces are stacked to produce a single output trace. This calculation is repeated for each constant velocity until the range of velocities applied extends from the minimum to maximum to be encountered in the area. The velocity increments may not be uniform but may be rather small for application of slower velocities, which yield large normal moveout and large for higher velocities. A plot of velocities against record time for each analysis location represents the velocity function for that location.

Velocity analysis is performed on selected CMP or CDP gathers. The out put from one type of velocity analysis is a table of numbers as a function of velocity vs. Two-way zero off set time also called as velocity spectrum. Numbers present in the table represent some measure of signal coherency along the hyperbolic trajectories governed by velocity, off set, and travel time.

The curve in each spectrum represents the velocity function based on picked maximum coherency values associated with the primary reflections. The pairs of numbers along each curve denote the time_ velocity values for each pick. These velocity time pairs are picked from these spectra based on maximum coherency peaks to form velocity functions at analysis locations.

n areas with complex structures, velocity spectra (defined above) often fail to provide sufficient accuracy in velocity picks. In that case, the data on staked with a range of constant velocities (called as constant velocity analysis), and the constant velocity stacks themselves are used in picking velocities. (Yilmaz, 2001)

5.3.4 Data Refinement

The processes described till now are used to make data free of the factors that decreases its quality. Also these processes are used to reformat the data and to diagnose its characteristics (Rehman, 1989). Data refinement consists of the following two main stages.

1. Stacking
2. Migration

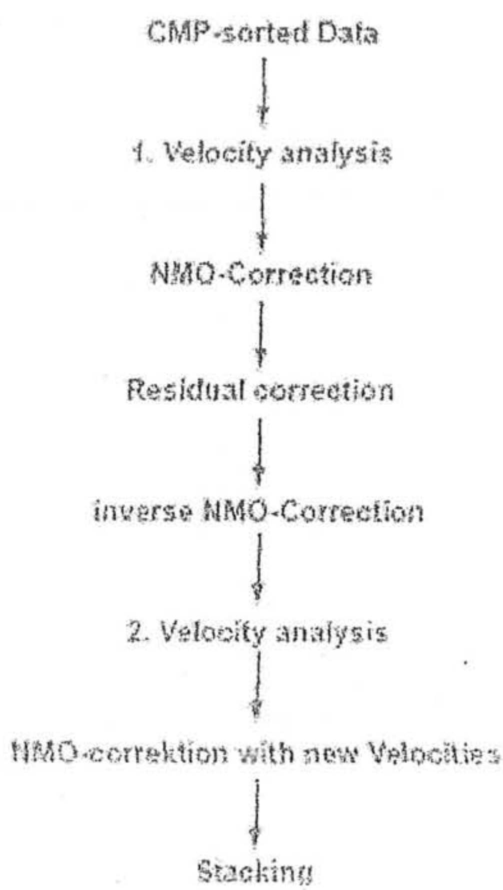
Along with these two processes, there is another procedure occasionally used in data refinement and is called as Residual Statics.

1. Stacking

Stacking is simply the process of adding up together the traces present in certain gathers, obtained during the seismic data acquisition .It is applied only when the all necessary corrections have been applied. The result of stacking is the corrected gather. In the "corrected gather" the traces have been gathered into the depth order. Both the static and dynamics corrections have been applied to it and the traces have been muted (Dobrin, 1988). All that remains is to stack the data. Stacking result in a single stacked trace as an out put for each depth point present in gathers.

One or 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. (Dobrin, 1988)

Scheme of Residual Static Corrections



Stacking is a data compression of one to two orders of magnitude. The signal-to-random noise ratio is increased through an N fold stack by N. After stacking, 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 traces, the common midpoint CMP and CDP are both widely often interchangeably. With dipping reflectors, the CMP after conventional processing is not the CDP. The correct positioning of reflection point will be by migration. (Dobrin, 1988)

➢ Migration

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

If the reflector is flat, the reflection point will be located directly beneath the shot/receiver station, and the record section displays the event in its true position, plotted in time rather than depth (Robinson & Coruh, 1988).

However, if the reflector is not flat, the reflection point will not lie directly beneath the shot/receiver position, and the true position of the reflector will differ from its apparent position (Yilmaz, 2001). Figure 5.6 shows the subsurface dipping reflector's response.

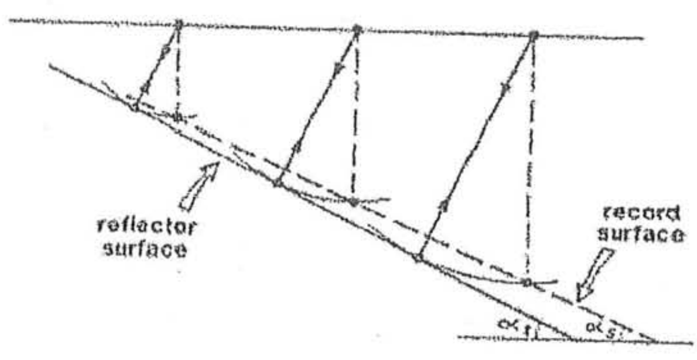


Figure 5.6: (Seismic response form a dipping reflector, the recorded surface gives the apparent dip of the reflector surface)

Therefore, migration is a tool used in seismic processing to get an accurate picture of the subsurface layer. It involves geometric repositioning of recorded signals to show a boundary or other structure, where it is being hit by the seismic wave rather than where it is picked up Now, not only the position but the dip angle can incorrectly imaged by vertically plotting (Rehman, 1989).

- **Important features of Migration**

Following are the important features of migration (Rehman, 1989);

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

- **Types of Migration**

With respect to the stage when migration is applied on the seismic data during processing, there are two important types of migration.

a): Pre-Stack Migration.

b): Post-Stack Migration

a) Pre-Stack Migration:

Pre-stack migration is essentially when seismic data is adjusted before the stacking sequence occurs. The popular form of pre-stack migration is depth migration (PDM). PDM requires the user to know more about velocities of the layers. Once the user inputs these into the data with velocity analysis methods, there will be some error in the image. This error is caused by dipping reflectors or diffractions. The PDM will adjust the picture according to the velocities given.

When It Is Applied?

Pre-stack migration is often applied only when the layers being observed have complicated velocity profiles, or when the structures are just too complex to see with post-stack migration.

Advantages And Disadvantages:

Pre-stack is an important tool in modeling salt diapirs because of their complexity and this has immediate benefits if the resolution can pick up any hydrocarbons trapped by the diapir. Overall, pre-stack migration, depth and time, is a valuable tool in better imaging seismic data, but it is limited by the amount of time and money required to conduct a pre-stack migration.

Most of the pre-stack migration will be run when post-stacking has failed to resolve the layers or structures. However, with advances in computers, pre-stack migration will eventually become more economical.

b) Post-Stack Migration:

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

Basic Idea:

As in pre-stack migration, post stack migration is based on the idea that all data elements represent either primary reflections or diffractions. This is done by using an operation involving the rearrangement of seismic information so that reflections and diffractions are plotted at their true locations. The reason that migration is needed is due to the fact that variable velocities and dipping horizons cause the data to record surface positions different from their sub-surface positions. The stacking is accomplished by making a composite record by combining traces from different records. Filtering is involved with stacking because of timing errors or wave-shape difference among the data being stacked.

Advantages And Disadvantages:

A disadvantage of using post stack migration compared to pre-stack migration is that it does not give as clear results as pre-stack. Post stack usually gives good results though, when the dip is small and where events with different dips do not interfere on the migrated section. Its cost is less than the pre-stack migration section.Pre-stack migration is essentially when seismic data is adjusted before the stacking sequence occurs. The popular form of pre-stack migration is depth migration (PDM).

Time And Depth Migration:

Now on the basis of the form of data on which migration is applied, there are two types of migration. A process which collapses diffractions and moves dipping events toward the true position but leaves the migrated image with a *time axis* which must be depth converted at a later stage. Time migration assumes that the diffraction shape is hyperbolic and ignores ray bending at velocity boundaries. The true Earth coordinates are of course in depth, not time. Even so, interpreters often need data in time coordinates, because the standard interpretation systems, log synthetics, and seismic-attribute techniques work with time and frequency, not depth and wavelength.

A time-migration can also be easily compared to the input stack section since they have the same vertical axis. Time migration is very fast and is robust to errors (sometimes up to 10%) in the velocity model. Further, errors in the shallow velocity model do not affect imaging of deeper structures. Judging the "correctness" of a time migration is a rather arbitrary process but lateral velocity variations will cause positioning errors as indicated by *image rays*. An image ray, as shown in the adjacent figure for a single diffraction point, is normal to the recording surface and will show the lateral positioning error due to time migration. Unlike rays which indicate the direction of propagation, the image ray has no physical meaning. If an interpreter is at all worried about the positioning of data prior to drilling a well then a depth migration should always be performed. Surprises may result - particularly in 3D where structures can change dramatically in depth. Time migration, following the tradition of NMO and stack, uses an *imaging* velocity field, i.e., one that best focuses the migrated image at each output location. This velocity field is free to change from point to point, so that time migration, in essence, performs a constant-velocity migration at each image point, where the constant changes from point to point.. "*The goal of time migration is to produce an image, not a geologically valid velocity field!*" Depth migration, in contrast, uses an *interval* velocity field, i.e., a model of the Earth's subsurface. The interval velocities used are averages of the actual Earth velocities, where the average is taken over some characteristic distance such as a wavelength. This allows depth migration to model seismic wave behavior within the Earth much more accurately than time migration can. In particular, it allows us to use depth migration, especially depth migration before stack, as a velocity estimation tool.

Time migration will tolerate a certain amount of error in the velocity model. The commonest way to build a velocity model for time migration is to take the picked stacking velocities (assuming they are equal to *Vrms*) and smooth them sufficiently that the interval velocity model (from *DIX* conversion) is smooth and approximately resembles the geological structure. Almost always in modern processing DMO or pre-stack time migration will have been applied to attempt to remove the dip-dependence of stacking velocities. For time migration to be worthwhile the velocity model can vary smoothly in depth and very slowly laterally.

Hazards In Migration Process:

1. Conventional migration is performed in the plane of the record section. The record section displays a two dimensional slice of the three dimensional earth. If the seismic line is not aligned perpendicular to strike, the reflections cannot be properly migrated in the record section plane.
2. All migration methods are based on simplified models of the real earth. They involve assumptions about ray paths which cannot be verified. If the assumptions are poor the results will be poor. All of the routine migration methods in general use involve one very important assumption that over burden velocity layer are horizontal. If the real earth departs from this model, standard migration methods fail.

CHAPTER # 6

CHAPTER # 6

Seismic Data Interpretation

6.1 Introduction

Interpretation is the transformation of seismic data into structural and Stratigraphic picture through a series of different steps. Thus threading together all the available geological and geophysical information including the seismic and then integrating them all in a single picture can only give a picture closer to the reality.

The main purpose of seismic reflection survey is to reveal as clearly as possible, the structures and stratigraphy of the subsurface. The geological meanings of seismic reflection are simply indications of different boundaries where there is a change in acoustic impedance. These observed contrasts are associated with different geological structures are stratigraphic contacts.

To distinguish different formations by means of seismic reflection is an important question in interpreting seismic reflection data. For this purpose the data is correlated with the well data and geology of the area under observation, which is already known (previous literature). The well data provides links between lithology and seismic reflections. The reflector identification is the next stage by which the actual interpretation starts and it establishes a stratigraphic frame block for the main interpretation.

Extracting from seismic data the geological structures, such as folding and faulting are referred to as structural interpretation. On the other hand, extracting non-structural information from seismic data is called, "Seismic Facies Analysis".

There are two main approaches for the interpretation of seismic section:

- Stratigraphic Analysis
- Structural Analysis

6.2 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 sequences.

Basic principle in the seismic stratigraphic analysis is that reflections are taken to define chronostratigraphic units because interfaces that produce them are the stratal surfaces. Unconformities can be mapped from the divergence 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. The success of seismic reflection method in finding stratigraphic traps varies with the type of trap involved. Most such entrapment features are reefs, unconformities, disconformities, facies changes, pinch-outs and other erosional truncations. Some of the parameters used in seismic stratigraphic interpretation are:

1. Reflection Configuration
2. Reflection Continuity
3. Reflection Amplitude
4. Reflection Frequency
5. Interval Velocity
6. External Form

The purpose of the reflection method in locating hydrocarbons in Stratigraphic traps has been much less favorable than in finding structurally entrapped oil and gas.

6.3 Structural Analysis

Structural information is based on the interpretation of seismic sections. Usually it is difficult to make a certain structural interpretation on the basis of only one seismic section. Grids of seismic data are required to determine the 3-D geometry. In structural analysis the main objective is to search out structural traps containing hydrocarbons. In such analysis interpretation usually takes place against a background of continuing exploration activity and associated increase in amount of information referred to surface geology.

Interpreting the faults during structural interpretation is very important. Faults are often critical to accumulation of oil either in a positive or a negative way. A fault may form a seal by cutting of a structural and stratigraphic feature so the oil is trapped against the fault or faults may act as a migration path.

This type of analysis is very suitable in case of Pakistan, as most of the hydrocarbons are being extracted from the structural traps. It is study of reflector geometry on the basis of reflection time. The main application of the structural analysis of seismic section is in the search for structural traps containing hydrocarbons. Most structural interpretation used two-way reflection times rather depth and time structural maps are constructed to display the geometry of selected reflections events. Some seismic sections contain images that can be interpreted without difficulty. Discontinuous reflections clearly indicate faults and undulating reflections reveal folded beds.

6.4 Interpretation of the given Data

6.4.1 Marking of Horizons:

First step is the identification of the seismic horizon (as a formation), from which the seismic waves are reflected. The identification was based upon some characteristics like are wavelet and whether the wavelet is a minimum or a zero phase wavelet. The center of the strong bend of energy was picked that represented the top of the reflector. The continuous traces of wavelets running across the section marks horizons. It is difficult to mark the continuity because the wavelets or the traces tend to mix up or the sequence might break due to subsurface structural changes or abrupt lithological changes or the most common problem faced is the presence of different types of noises. Such noises cause the distortion of the signal.

The time for each reflector was marked from the seismic section on the basis of dominant reflection. Seven horizons *(Gaj, Kirthar, Ghazij, Laki, Danghan, Pab and Fort Munro)* were picked up on the line **HPK96-08 EXT**. The reflectors were strong enough to be picked due to variation in acoustic impedance that is eventually caused by change in lithology. However no fault was found in this seismic line.

6.4.2 Construction of Iso-Velocity Contour Map:

With the help of velocity information, the velocity contours were drawn which show the vertical as well as lateral variation in velocities. The vertical variation is mainly due to the formational changes over burden pressure and age factor etc; however lateral variation in velocities may be due to the folding and dipping of strata .The graph, which shows(Fig: *6.1*) the velocity counter is called Iso-velocity map rhR was prepared by using ***Dix Average Velocity***.

Iso-velocity map shows the vertical velocity variation but there is less lateral variation in the velocity. The velocity variation trends are almost smooth indicating the constant change in velocity with time but there are some wavy undulations observed and they are smoothly curved representative of subsurface structure.

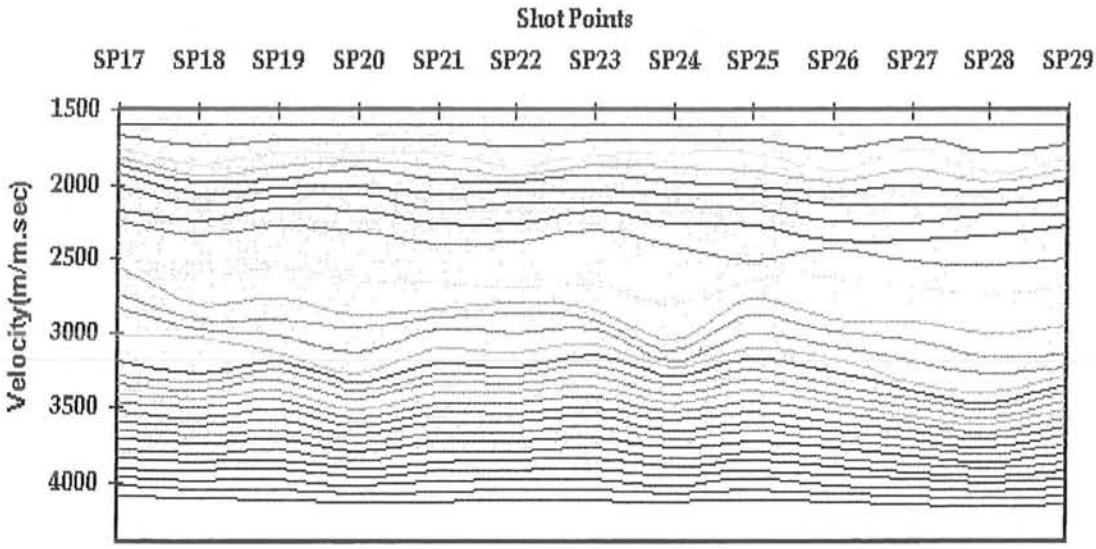


Figure 6.1: Iso-Velocity map

6.4.3 Preparation of Average Velocity Graph:

Twenty four velocity windows were used that were given on the top of section at different SPs having Root Mean Square Velocity, Interval Velocity of different subsurface layers at different times. From these windows the average velocity graph (Fig: 6.2) was prepared by plotting the average velocity versus time. The velocity was plotted along vertical axis and time along the horizontal axis.

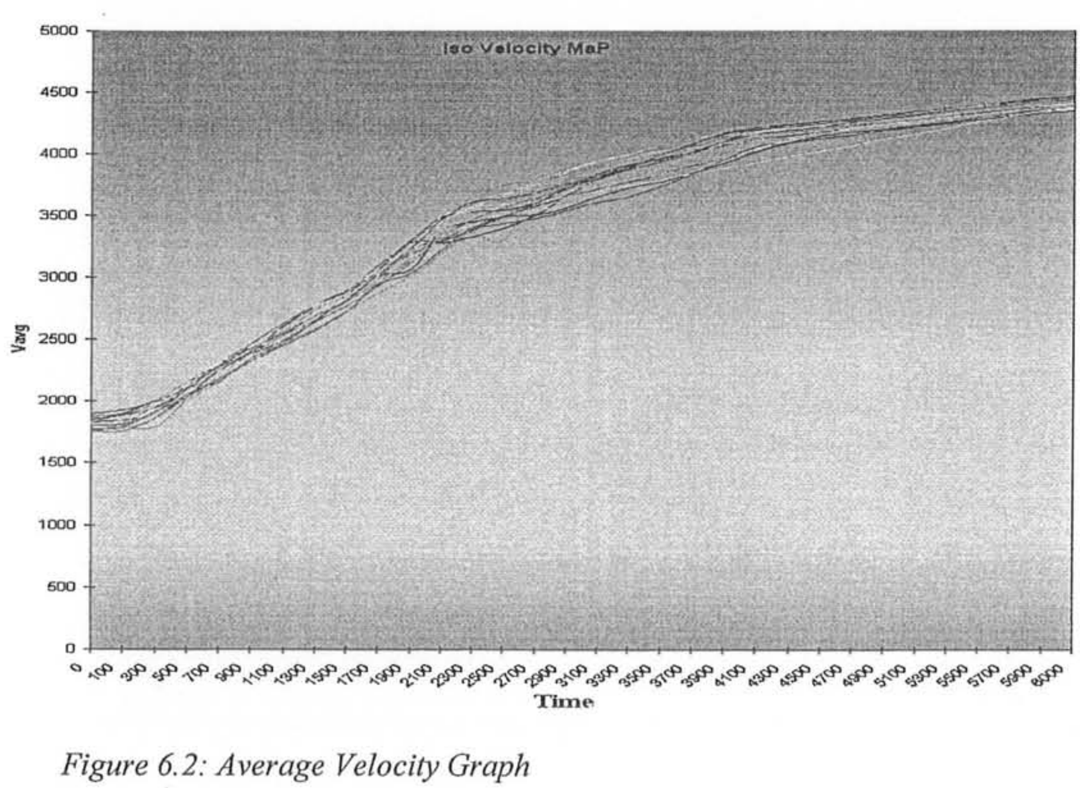


Figure 6.2: Average Velocity Graph

6.4.4 Mean Average Velocity Graph:

The mean velocity was found by taking the sum of the average velocities divided by total number of observed averaged velocity values. This mean average velocity was then plotted against time to construct mean average velocity graph (Fig: 6.3)

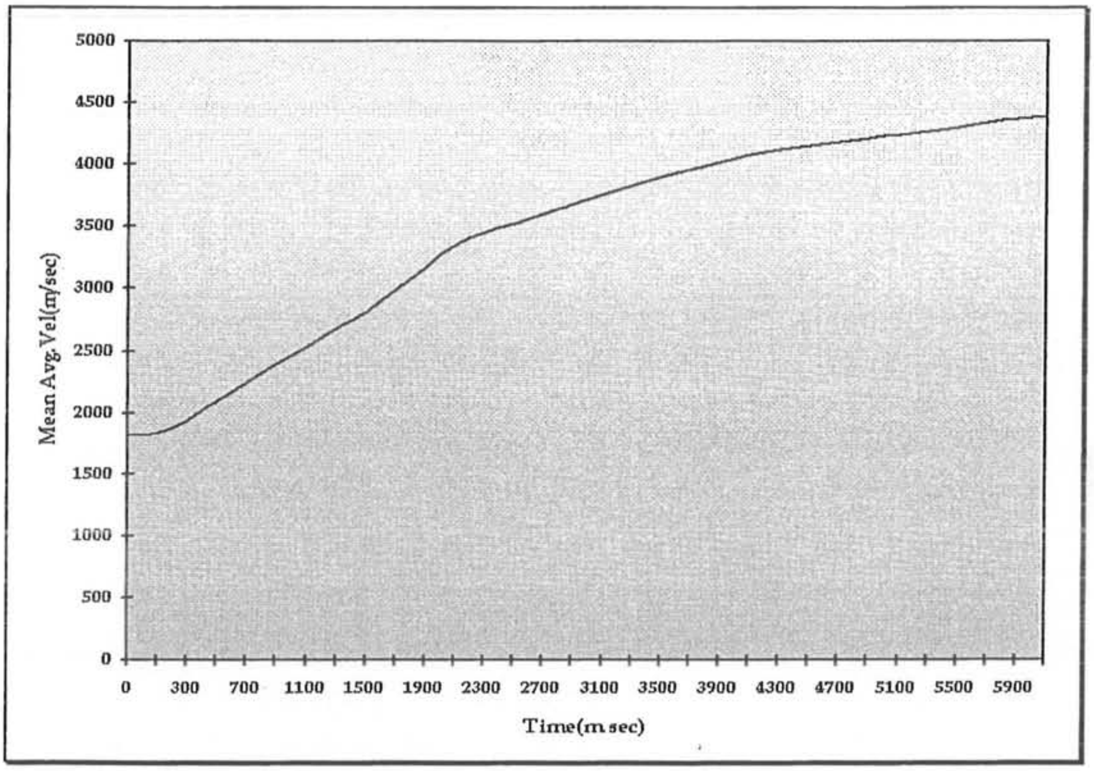


Figure 6.3:Mean Average Velocity Graph

6.4.5 Seismic Time Section:

Time section was prepared for stratigraphic and structural interpretation of seismic section in time domain. It consists of two scales; horizontal scale consists of SPs while the vertical scale consists of two-way time in seconds. The time for each reflector is marked from the seismic section and plotted against the short points. The time section shown in figure 6.4 shows the tectonically less disturbed horizons with no faults.

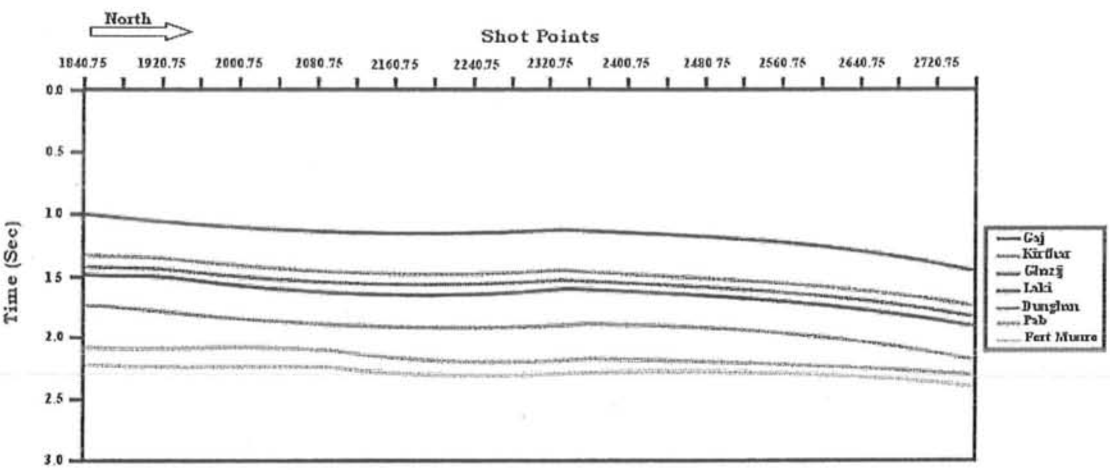


Figure 6.4: Time section of the given line

6.4.6 Depth Section:

A map of seismic time is intended to show the structure of a horizon in the subsurface. To make a map that is more truly related to the subsurface, depths must be calculated from the times (One way travel time). For this truly velocities (Average velocity) are needed. Generally the depth section gives the configuration of reflectors in the same way as the time section, the difference is that it shows the subsurface structure in depth domain. To determine the depth of the marked reflectors on the seismic section, the formula employed is:

$$S = (VxT)/2$$

Where S=Depth of the reflector, T=Two-way time of the reflector

But the velocity determined from the seismic data is not true and deeper the horizon is, the poorer it will be. So problems will arise when the maps of the depth are tied with the wells. This is why most of the maps are made in seismic reflection time. But the velocity pull up and pull down makes the time structure in correct below the feature that is why it is some times essential to make the depth section along with the time maps.

Horizon Depth Estimation:

An accurate measurement of seismic velocities is an important step in the seismic interpretation and processing. Different methods are adopted in order to construct the depth section. These methods include:

- Depth section by Dix constant Average Velocity
- Depth section by taking mean of all average velocities

Depth Section By Taking Mean Of All Average Velocities:

The depth of each horizon was calculated by putting the velocities and their respective time in the depth formula. Then depth was plotted against their corresponding shot points to get depth section (Fig: 6.5)

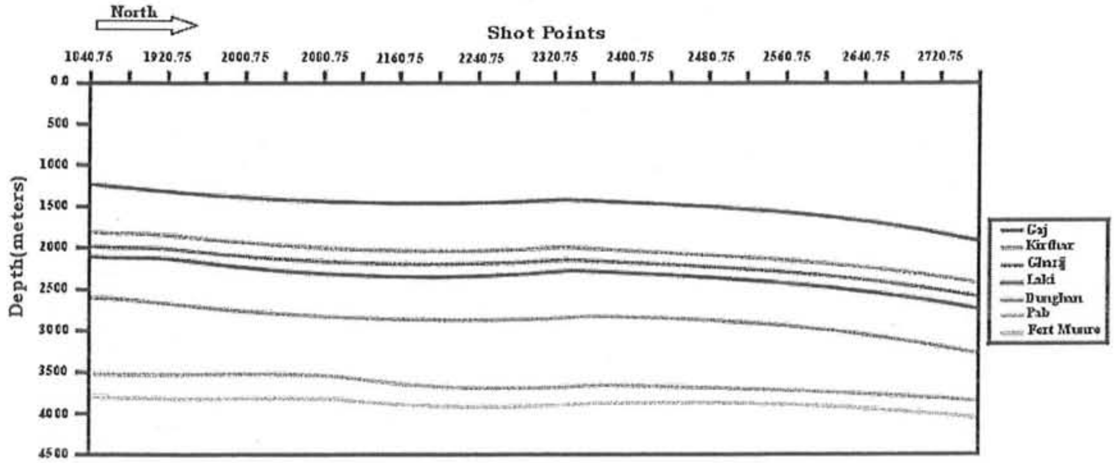


Figure 6.5: Depth section of the given line

6.5. Reflection Coefficient

Reflection coefficient is simply defined as "The ration of incident amplitude to the reflected amplitude".

Mathematically it is expressed as

$$R= (d2xV2)-(d1xV1)/ (d2xV2)+(d1xV1)$$

Where d1 and V1 are density and velocity of layer 1 and d2,V2 are density and Velocity of layer 2.

In different reflectors different lithology was marked on the basis of reflection coefficient's range as follows.

Reflection Coefficient's Range	*Lithology*
Higher than 0.06	Limestone
Less than 0.06 & greater than 0.02	Sandstone
Less than 0.02	Shale

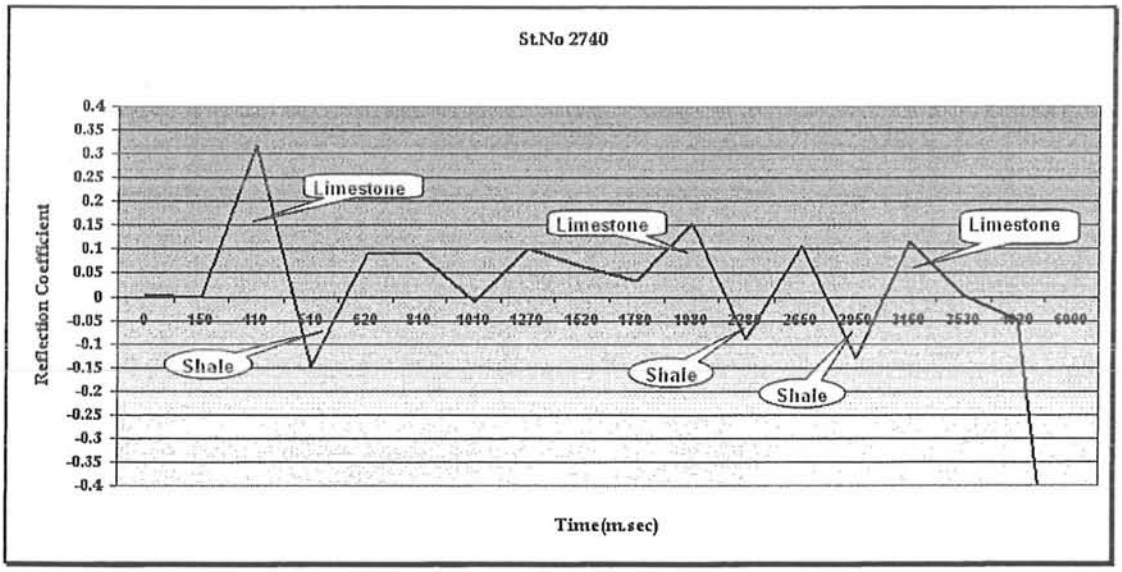


Figure 6.6: Graph between Reflection Coefficient & Time on St.No:2740

Figure 6.6 shows the presence of limestone and shale in the subsurface. Limestone lies in the area that has reflection coefficient higher than 0.06. While shale lies in the area where reflection coefficient is less than 0.02.

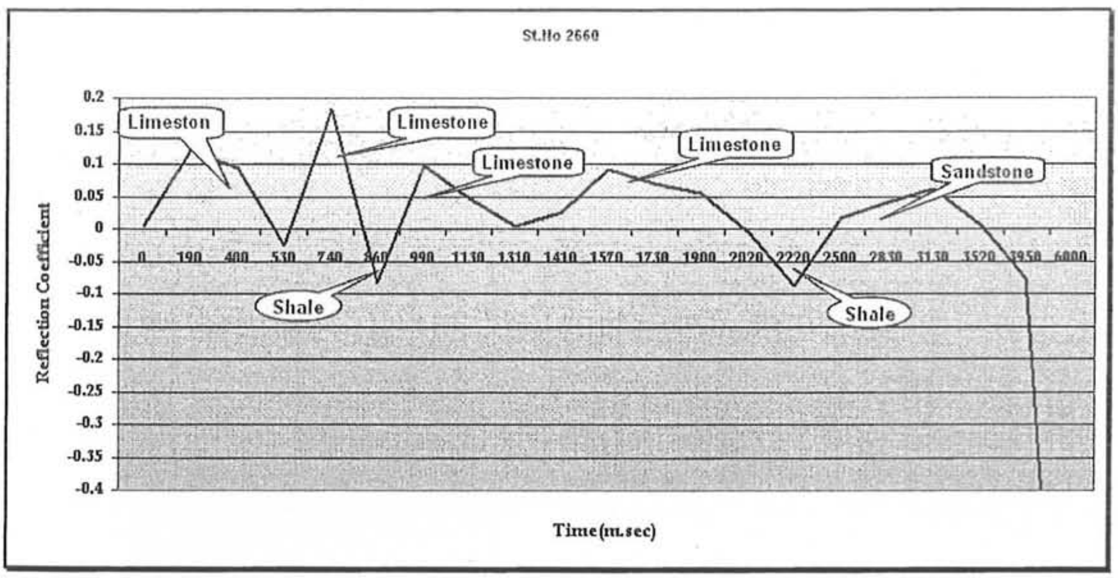


Figure 6.7: Graph between Reflection Coefficient & Time on St.No:2660

Figure 6.7 shows the presence of limestone, sandstone and shale in the subsurface. Limestone lies in the area that has reflection coefficient higher than 0.06. Sandstone lies in the area where reflection coefficient is higher than 0.02 but less than 0.06. While shale lies in the area where reflection coefficient is less than 0.02.

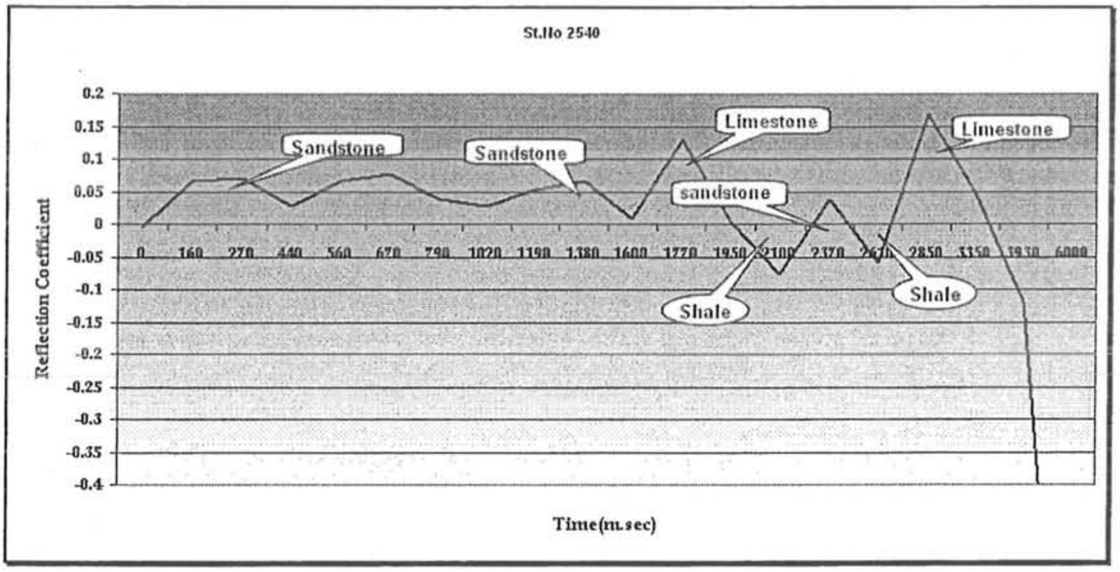


Figure 6.8: Graph between Reflection Coefficient & Time on St.No:2540

Figure 6.8 shows the presence of limestone, sandstone and shale in the subsurface. Limestone lies in the area that has reflection coefficient higher than 0.06. Sandstone lies in the area where reflection coefficient is higher than 0.02 but less than 0.06. While shale lies in the area where reflection coefficient is less than 0.02.

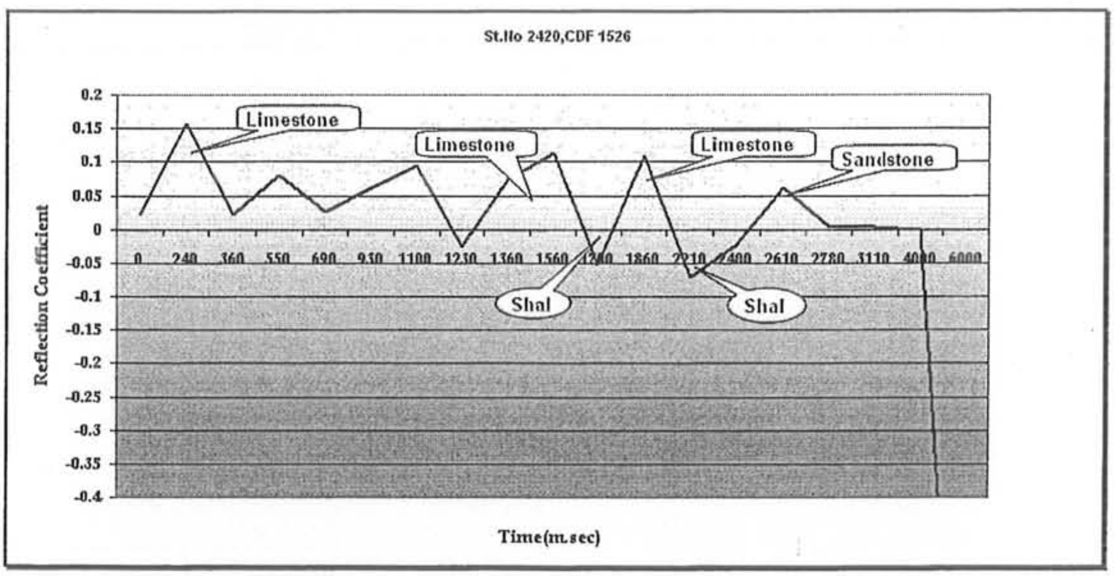


Figure 6. 9: Graph between Reflection Coefficient & Time on St.No:2420

Figure 6.9 shows the presence of limestone, sandstone and shale in the subsurface. Limestone lies in the area that has reflection coefficient higher than 0.06. Sandstone lies in the area where reflection coefficient is higher than

0.02 but less than 0.06. While shale lies in the area where reflection coefficient is less than 0.02.

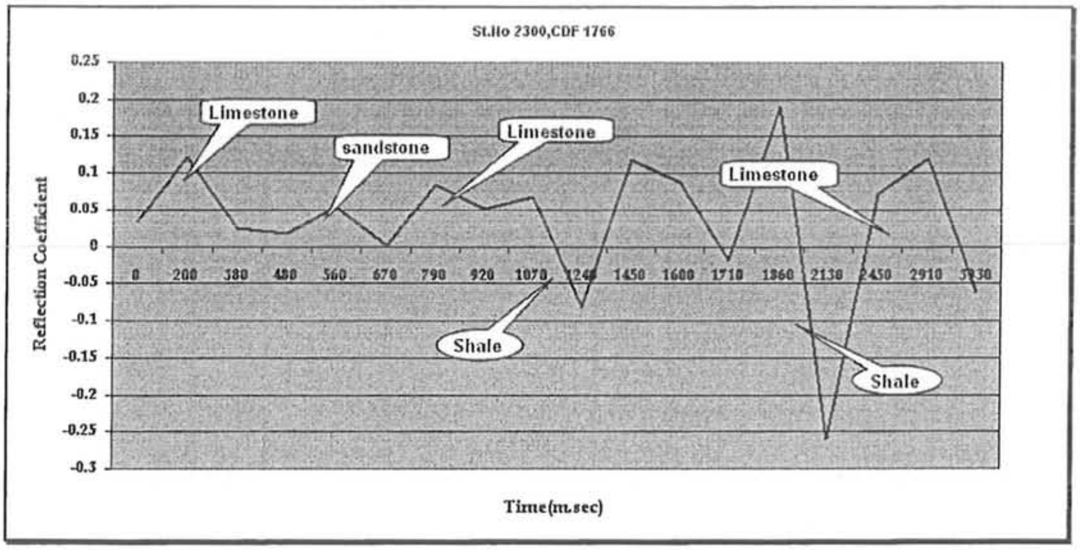


Figure 6. 10: Graph between Reflection Coefficient & Time on St.No:2300

Figure 6.10 shows the presence of limestone, sandstone and shale in the subsurface. Limestone lies in the area that has reflection coefficient higher than 0.06. Sandstone lies in the area where reflection coefficient is higher than 0.02 but less than 0.06.While shale lies in the area where reflection coefficient is less than 0.02.

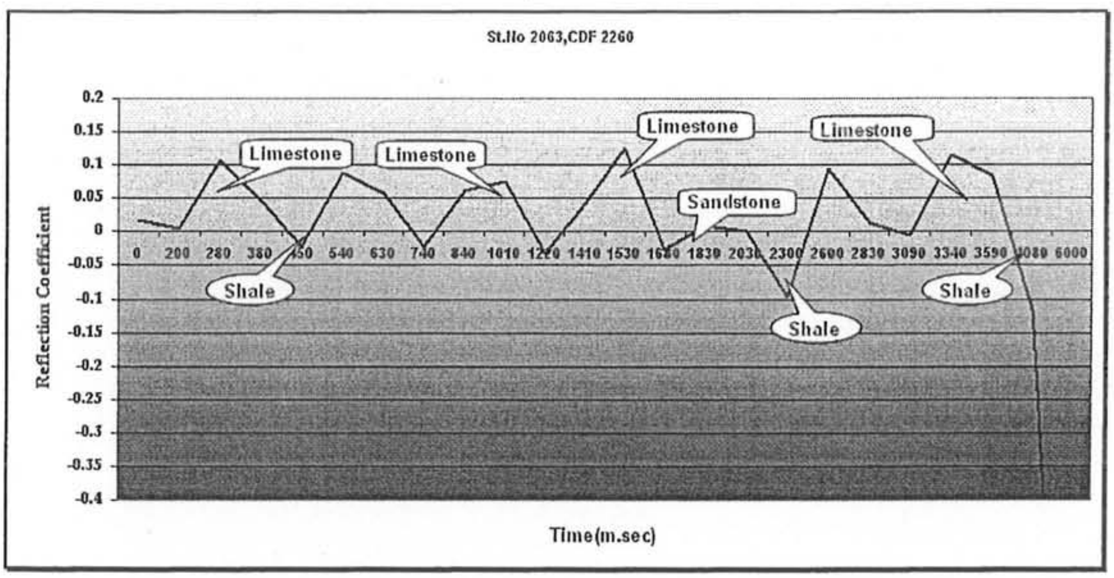


Figure 6. 11: Graph between Reflection Coefficient & Time on St.No:2063

Figure 6.11 shows the presence of limestone, sandstone and shale in the subsurface. Limestone lies in the area that has reflection coefficient higher than 0.06. Sandstone lies in the area where reflection coefficient is higher than 0.02 but less than 0.06. While shale lies in the area where reflection coefficient is less than 0.02.

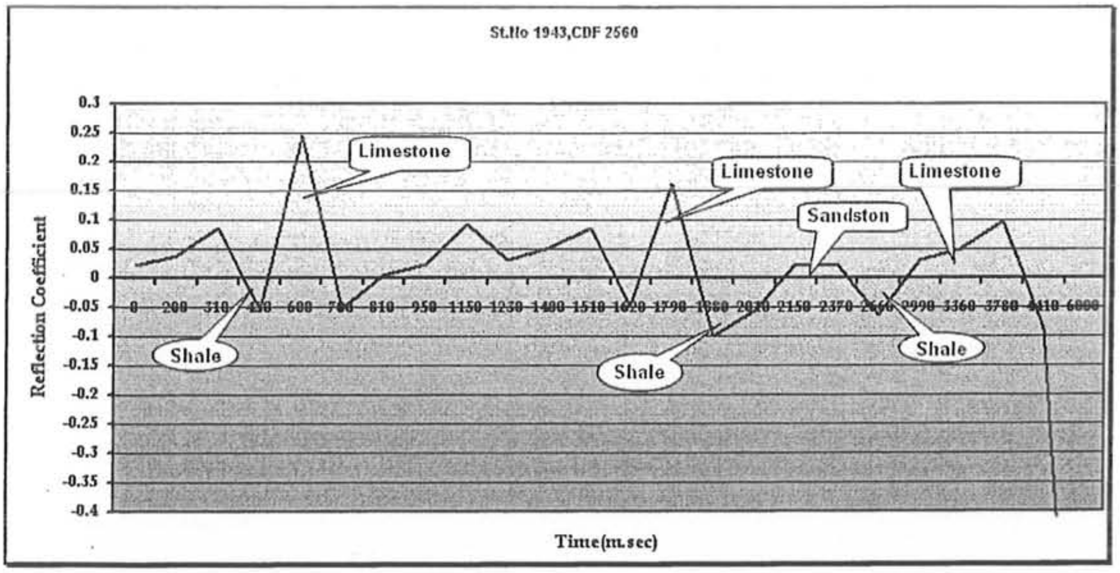


Figure 6. 12: Graph between Reflection Coefficient & Time on St.No:1943

Figure 6.12 shows the presence of limestone, sandstone and shale in the subsurface. Limestone lies in the area that has reflection coefficient higher than 0.06. Sandstone lies in the area where reflection coefficient is higher than 0.02 but less than 0.06.While shale lies in the area where reflection coefficient is less than 0.02.

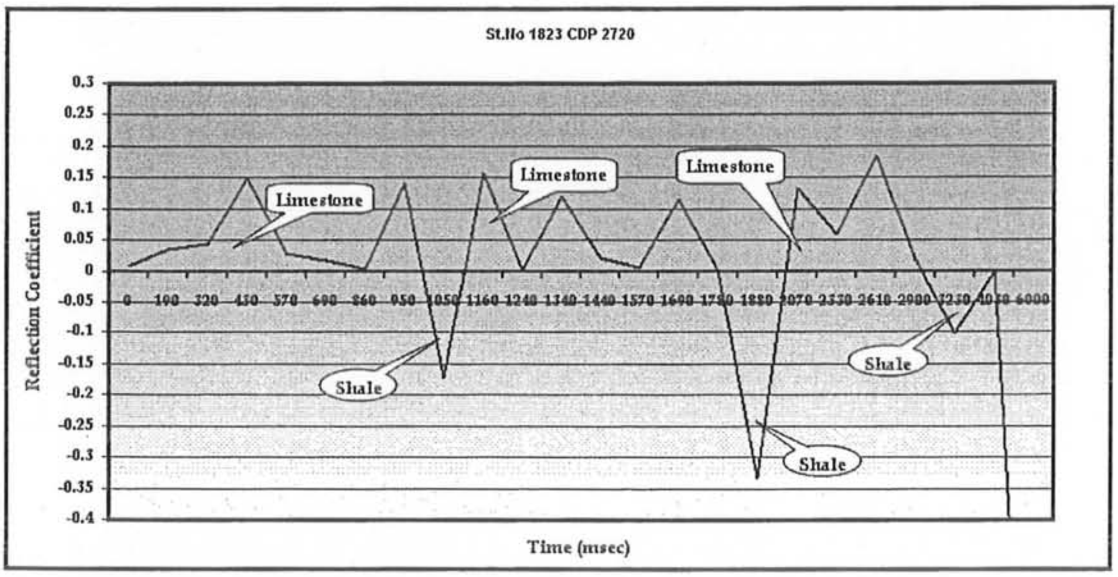


Figure 6. 13: Graph between Reflection Coefficient & Time on St.No:1823