2D SEISMIC INTERPRETATION OF LINE PC 9029-86 OF INDUS OFFSHORE

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CERTIFICATE

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DEDICATION

My whole Thesis work is especially dedicated to my beloved, dearest and loving respectable Parents, because I am nothing without them.

To my Friends who motivated, supported & encouraged me throughout my academic career to achieve the passion, & especially my beloved Uncle Mr. Liaqat Ali Butt.

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All appreciation and glory is for "Almighty God" the most gracious and the most merciful, who enabled me to think and to work.

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ABSTRACT

The aim of the dissertation is the 2D seismic interpretation of seismic line PC 9029-86 of INDUS OFFSHORE area, was provided by the Department of Earth Science, Q.A.U. Islamabad. The Shot Points Ranges of this line is from 3162-6733 and the part of this line which I interpret is from shot points (4161-5361). To investigate the lateral and vertical variation in the velocity, average velocity and Iso-velocity map was generated.

For the interpretation of seismic data Six reflectors are marked on the seismic section and named on the basis of their ages because there is a mixture of Formation and the specific stratigraphy of the area is not done, Which are Reflector 1 (Late Miocene), Reflector 2 (Early Miocene), Reflector 3 (Oligocene), Reflector 4 (Late Eocene), Reflector 5 (Early Eocene), Reflector 6 (Paleocene). Interpretation results indicated there is canyons, channels and valleys in the Indus Offshore area.

A time section is produced from the seismic section using the VP points and the two-way-times (TWT) of the reflectors and faults. These average velocities are then used to find the depths of the formations for the Geoseismic Section or Depth Section.

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CHAPTER # 1

INTRODUCTION

INTRODUCTION

1.1 Pakistan Offshore:

The Pakistan offshore extends for 700 km from Runn of Cutch to Iranian border, near Gwadar; it comprises two distinct structural and sedimentary basins, the Indus and Makran offshore basins, which are separated by Murray Ridge. This ridge is an extension of Owen Fracture Zone and forms the boundary between Indian and Arabian plates (Kazmi and Jan, 1997).

The Pakistan shoreline stretches east to west for nearly 700 km, east of Karachi 200 km of the crenulated deltaic coast is gullied by numerous tidal creeks. Fringing the sub aerial delta there is narrow 10-15 km wide sub aqueous delta. Near Karachi coast line bends sharply north ward and after a short distance forms a 60 km loop around the Sonmiani Bay, west of the Sonmiani Bay, the coast line is fairly regular, though it is slightly indented at Ras Malan followed by a hammer head shaped projection at Ormara (Ras Ormara).

Near Pasni it forms a small loop ending in the Ras Jaddi cape and encloses the Apsni Bay. Farther to the west there are more hammer head shaped projections of the coast near Gwadar, which encloses the Gwadar East Bay, the Gwadar west Bay and the Gwadar Bay. In this region of Makran there is a 15m to 65 m high rocky cliff standing above a very narrow beach; above cliff there is an elevated 16 to 32 km wide coastal plain, which is dotted with several hills and ridges (Kazmi and Jan, 1997).

1.2 Indus Offshore:

The area geographically lies between latitudes 23° 15' to 24° 30' N and longitudes 66° 30' to 67° 30' E, is the part of Indus offshore basin of Pakistan and forms the continental shelf that is about 120 Km south of Karachi city and is situated between the Gulf of Kutch and Murray Ridge spreading over 20,000 square Kms. It is comprised of two main structural zones, the Indus platform zone to the east and the Indus depression to the west. The Indus Offshore basin contains a thick sedimentary sequence ranging from Cretaceous to Recent. Seismic profiles of this region indicate gently dipping structures and abundant down to the basin type normal faults (Kazmi and Jan, 1997). The Indus basin was developed as a result of sedimentary deposition associated with

Himalayan's uplift. The sedimentation is continuing at present as the Indus River System drains the Himalayan sediments into the Indus Delta (Sattar, 2008).

Indus offshore basin falls in the Type IV (Intermediate Crustal type): an Extra-continental Down warp to Small Ocean Basin combined with Tertiary Delta Basins toward Oceanic Areas of Halbouty (1970) and Klemme (1980) and Extra-continental Trough Down warp of Riva (1983). The average shelf break to the west of the Indian continent occurs at about 200 m water depth whereas in the study area it is less than 150 m (Naini and Talwani, 1983).A satellite image showing the Indus Offshore area is highlighted in Fig 1.1.

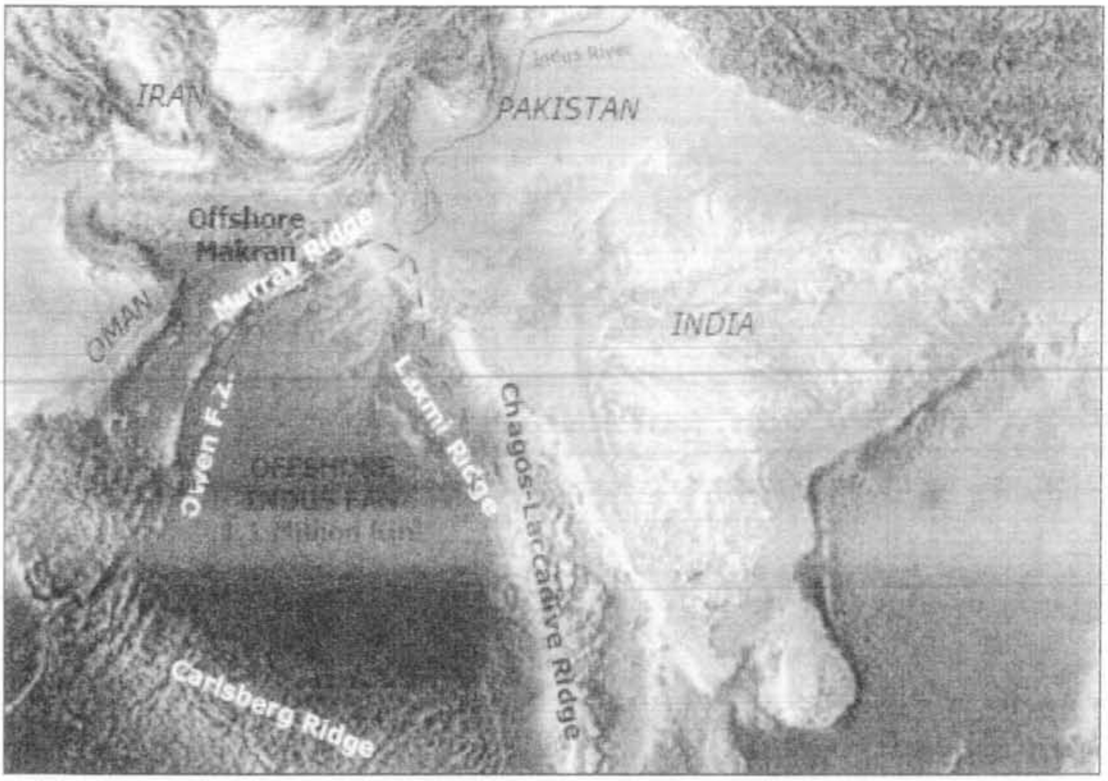

Figure.1.1. Location Map of Study Area (Moin Raza Khan, 2007)

1.3 Exploration Activity in Indus Offshore:

There is not any kind of discovery yet achieved in offshore. The reason for the exploration failure in the Indus offshore can be attributed to the only usage of the conventional methods to map and document the distribution and integrity of reservoir, seal, source and timing of gas generation and reservoir charge. Failure could be avoided by using advanced and modern interpretation techniques like seismic stratigraphy, rock physics parameters, inversion techniques, AVO techniques and 4D seismic methods etc.

1.4 Exploration Result in Indus Offshore:

There is not any kind of discovery yet achieved in offshore. The reason for the exploration failure in the Indus offshore can be attributed to the only usage of the conventional methods to map and document the distribution and integrity of reservoir, seal, source and timing of gas generation and reservoir charge. Failure could be avoided by using advanced and modern interpretation techniques like seismic stratigraphy, rock physics parameters, inversion techniques, AVO techniques and 4D seismic methods etc.

1.5 Earthquake Activity in Indus Offshore:

The data obtained for Indus offshore suggest that Indus offshore area is tectonically not very active. Only a few earthquake events have been found in Indus offshore and their magnitude are low as well.

1.6 Present Study:

Present study focuses on the structural and stratigraphic interpretation of the seismic lines of the area, in order to find structural and stratigraphic traps (if any present in the area). Earthquake study has been done to support structural interpretation and to see more structures present deeper than the penetration of conventional seismic method. In order to find the rock properties various rock physics parameters are calculated which are correlated with the parameters calculated from well logs. Also stress patterns have been calculated by using rheologic concepts in seismic methods to map the extensiona stresses in Indus Offshore.

1.7 Exploration Geophysics:

The branch of the geophysics which deals with the exploration is called **Exploration Geophysics**. Hydrocarbons are the main artificial source of energy today, but it is not easy to extract them by using the conventional sources, they are extracted by using exploration techniques such as seismic, receptivity, well logging etc. Hydrocarbons can also be extracted from the tar sands and oil shale or it could be synthesized from the coal but the technological, economic and environmental problems are so much fatal that we have to rely on the natural reserves of the hydrocarbons only.

1.8 Layout Of Exploration Geophysics:

Whenever an exploration project is started, it happens to be according to certain program, the steps for an exploration programe include the following steps:

- Objective of the survey
- Selection of the area to be surveyed
- Planning of the survey
- Information about the previous work
- Geographical information
- Longitude and latitude
- Land ownerships
- Topography
- Geological information.
- Structure and tectonics
- Stratigraphy
- Types of the rocks
- Structure and tectonics
- Stratigraphy
- Types of the rocks
- Depth of the investigation required.
- Type of the survey
- Base map
- Data acquisition.
- Data processing.
- Data interpretation

1.9 Introduction to seismic line:

The given Project is to interpret the Seismic Section along the seismic Line 9029-86 oriented in South East direction, the shot points ranging from 3162-6733 is provided for analysis and interpretation. And my contribution is from shot points number 4161-5361. The Seismic Section was provided by the department of Earth Sciences Quaid-i-Azam University Islamabad.

The survey was conducted by **Oil & Gas Development Corpoation Ltd. PAKISTAN** and **Petro-Canada** in the **Indus Offshore** area of Pakistan. The Acquisition and Processing of the data has been done carefully with the selection of appropriate field and Processing Parameters which are given below.

1.9.1 Acquisition Parameters:

The acquisition parameters are given below:

- Shot By — Sonic Exploration Ltd.
- Date — April 1986
- Vessel — M/V Bernler

Source:

- Source Type — Bolt PAR air guns 3772 cu. In. volume
- Gun pressure — 2000 psi
- Gun Depth — 7 m
- SP Interval — 25 m

Cable Information:

- Cable type — GECO GX-300
- Cable Depth — 11 m

Receiver Configuration:

- Receiver Type — Litton WM1-0045

- Groups 20 over 25 m
- Number of groups 120
- Group Interval 25 m

Recorder Information:

- Recorder Type DFS V
- Tape Formation SEG B
- Field Filter 8(18) – 128(72) Hz.
- Sample Rate 2 ms.
- Polarity Compressional wave is a negative number

Navigation

- Primary Navigation SYLEDIS
- Secondary Navigation ARGO

1.9.2 Data Processing Parameter:

After the data has been acquired, it passes through the whole processing sequence that includes different data processing techniques that are used to enhance the quality of the data. This data has passed through a desirable processing sequence and finally a "Time Section" was prepared. The time section gives the position of different reflectors in terms of two way reflection times; therefore first we have to convert it in to depth section to get the true picture of subsurface. Later on time section was converted in to depth section by estimation velocities so the processing parameters are given below.

- Processed By GEO-X
- Date Aug 1986
- Digital Conversion
- Resample 2 m to 4 m sample rate
- Amplitude Recovery (AT) exp (BT)
- Trace Edit
- F-K Filter DIps greater than +8 ms/trace and less than -4 ms/trace removed

Deconvolution:

Type	Multi-Channel Predictive
Channel Averaged	41 channels nearest to each trace
Prediction Distance	12 ms.
Activate Length	200 ms. both gates

Design Time

Gate # 1	300-3450 ms. at 0 meter offset
	2650-3750 ms. at 3190 meter offset
Gate # 2	2450-4550 ms. at 0 meter offset
	2750-5050 ms. at 3190 meter offset

Application And Time:

Gate # 1	2950 ms
Gate # 2	6000 ms

Shot And Cable Statics:

Mean Scaling	650-5450 ms. at 0 meter offset
	2550-5450 ms. at 3190 meter offset
CDP Trace Gather	Fold: 60
Velocity Analysis	
F-K multiple Attenuation	
NMO Correction	
Mute	325 ms. at 328 meter offset
	2400ms. at 3190 meter offset
Stack	Automatic Trace edits

Deconvolution:

Type	Simple-channel Predictive

- Prediction Distance 16 ms
- Active length
- Gate #1 120 ms
- Gate #2 200 ms

	Design Time	Application End Time
Gate #1	0 – 550 ms	450 ms
Gate # 2	450-5450 ms	6000 ms

K-K Migration

Time-Variant Filter

- Cross over Length 500 ms
- Filter Values

16/20 – 65/75 Hz.	0 -450 ms
10/14 – 60/70 Hz.	450 – 950 ms
6/10 - 45/55 Hz.	950 – 3450 ms
4/8 – 35/45 Hz.	3450 – 4950 ms
4/8 – 30/40 Hz.	4950 – 6000 ms

Equalization:

- Neon Windows 0 – 400 ms 1000 ms windows from 400-6000 ms
  50% window overlap

Display:

- Horizontal Scale 20 traces/ cm. [1; 25,000]
- Vertical Scale 10 cm./ sec.
- Polarity Normal [compressional wave is a trough]

1.10 Base Map:

A base map is the map on which primary data and interpretations can be plotted. A base map typically includes locations of concession boundaries, wells, seismic survey points with a geographic reference such as latitude and longitude. Geophysicist typically use shot points maps, which show the orientation of seismic lines and the specific points at which seismic data were required , to display interpretation of seismic data. The line which is interpreted in this dissertation is also highlighted, and the map has been prepared using Precision Matrix an Integrated Geo Systems (Khan, 2000) application. . Base map of the study area is shown in Fig 1.2 and the line 9029A-86 is highlited on the basemap.

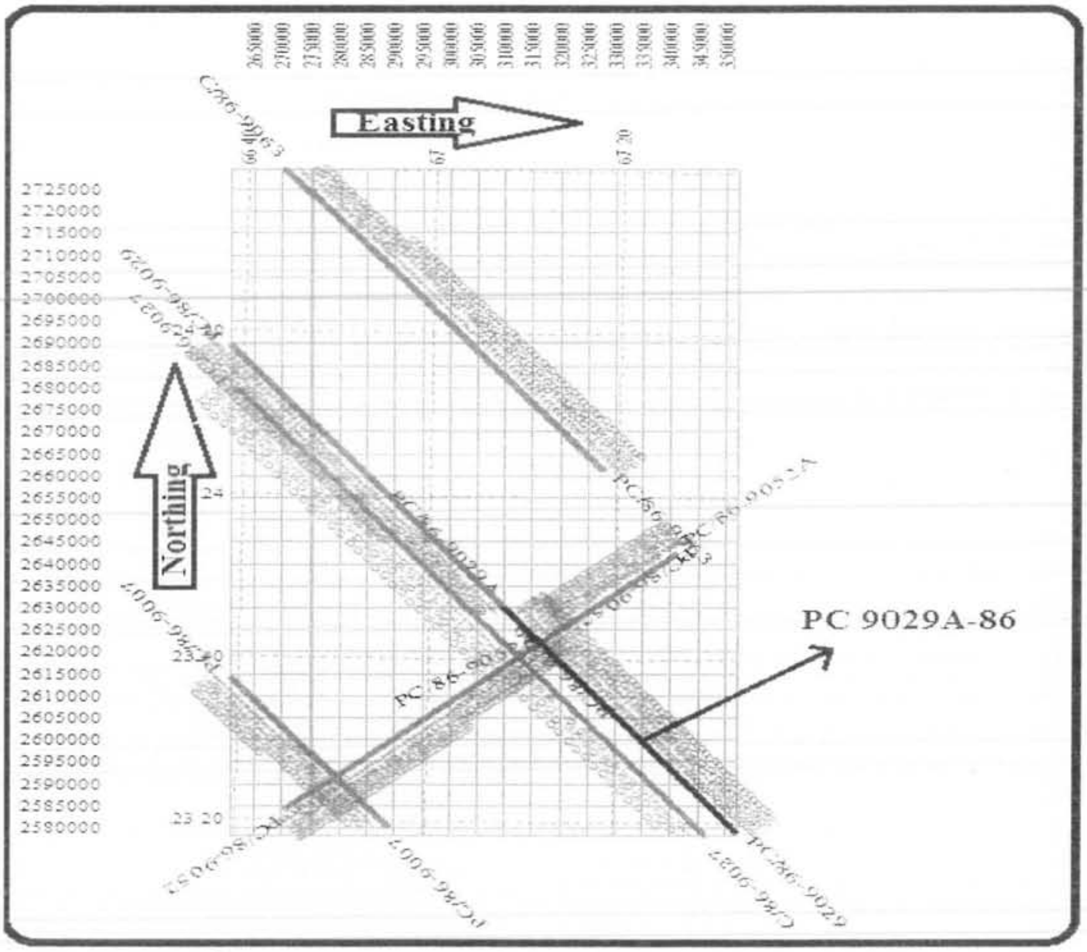

Figure: 1.2 Base map of the Indus Offshore area

1.11 Methodolgy:

This includes the following.

Seismic Stratigraphy:

Seismic stratigraphy has been used as a tool to find the depositional patterns of the sediments in the study area. The tool has been used to delineate the presence of stratigraphic traps in the area. A depositional model has been generated for the study area on the basis of seismic stratigraphy.

Well log Analysis:

Well log analysis includes well logs processing, petrophysical interpretation, synthetic generation and correlation with seismic interpretation.

Rheology:

Three dimensional stresses have been calculated by using the rheological concepts in seismic methods.

Earthquake Seismology:

Earthquake studies have been done to find the structures below the penetration of conventional seismic method.

1.12 Objectives:

An attempt has been made to find structural and stratigraphic traps in the study area using various geophysical techniques.

Main objectives are as follows.

- Focus on the geology of the Indus offshore.
- A reliable picture of the subsurface can be obtain by understand the processing and interpretation procedure for structural intrepretation of the migrated seismic section.

- By using 2-D seismic reflection data we can interpret the structure of Pakistan Indus Offshore.
- Preparation of velocity, average velocity, Iso-velocity, R.M.S velocity graphs and Iso-time maps to investigate the lateral and vertical variation.
- Preparation of depth, time and velocity contour map on the basis of seismic data to confirm the presence of faults in our study area and also to confirm the vertical and lateral variation.
- Preparation of time section and its conversion into depth section to get the true picture of sub surface.
- Identification of the prominent reflectors on the seismic section.
- To find the three dimensional stresses in the area
- Identify the reservoir.

CHAPTER # 2

GEOLOGY & TECTONICS

GEOLOGY & TECTONICS

2.1 Introduction:

When we doing the seismic interpretation of the area then we know the geological and structural significance of the area.The information about geology of an area plays an important role for interpretation of seismic data, because some velocity effects can be generated from formations of different lithologies and also different velocity facts can be generated from some lithological horizons. To be prepared to deal with such complexities, an interpreter must have knowledge of the geology and its stratifications, unconformaties and major structures of the area such as fold, and fault etc.

2.2 Tectonic History of The Area:

It is believed that Indo Pakistan Subcontinent separated from Gondwana land about 130 million years ago. Its precise location within Gondwanaland in relation to Africa, Antarctica and Australia is uncertain because prior to the plate tectonics concepts all the study was based upon the land based data. India's pre drift location has always been remaining problematic with respect to Australia, Antarctica and Madagascar because these plates have rotated at varying rates and in different directions since India's separation. Furthermore the topography of the Indian Ocean and its seafloor spreading pattern are complex. Thus various assumptions are made to fix this problem concerning relative position of Madagascar, Chigos Trench, and the Mauritius Fracture Zone and rotation of various plates.

It is believed that Chigos Trench and Mauritius Fracture zones were linked and a transform fault extended along Ninety East Ridge. The ridge of Siri Lanka (precursor of Mid-Indian Ridge) was spreading in such a way as to propel India northward. The Chagos Mauritius and Ninety East transform faults on its either sides facilitated its northward movement. New crust was continuously generated along the spreading ridges. Australia and Antarctica remained connected at this time as a single continent while Madagascar, Africa and South America had already separated.

It has been estimated that between 130 and 80 million years, India moved northward at the rate of 3 to 5 cm/year. Thereafter its movement accelerated considerably. The vast distance of 5000 km was covered by India at the speed of about 16 cm/year relative to Australia and Antarctica. The movement was facilitated by transform faulting in the Proto-Owen fracture zone and extensive seafloor spreading.

The Neotethy had began to shrink. The Intra oceanic subduction generated a series of volcanic arcs (Kohistan, Laddakh, Nuristan, Kandhar) during cretaceous. About 102 million years ago, back arc basin was closed by magmatism and these arcs collided with Eurasia. About 50 million years ago, India's speed was reduced considerably due to collision between India and Eurasia and closure of Neo Tethy in Tibet.Since 55 million years India has steadily rotated counter clockwise coupled with Arabian separation from Africa about 20 million years ago, this separation caused convergence in Balouchistan.

Due to this collision between India and Eurasia, significant uplift took place on the active margin side of the Indian Plate due to which spectacular Himalayas along uplifted and deformed 2500 km long indo pak plate margin were originated. Due to this uplift, Indus River was generated which caused the Basin Floor Fan deposition on the passive margin side of the Indian plate, Tectonically.

The Indus offshore Basin can be divided into three main units like:

- An Offshore depression on the west between Murray ridge and hinge-line.
- The Offshore Karachi trough platform in the middle between the hinge line and the Karachi shore line.
- The Offshore Thar slope platform or Indus River deltaic area on the east.

2.3 Regional Geological Setting:

The Indian Ocean and the Himalayas are the two most pronounced global features surrounded the Indo-Pak subcontinent. Both have the same origin and are the product of the geodynamic processes of

- sea-floor spreading,

- continental drift and
- collision tectonics.

A plate of the earth's crust carrying the Indo-Pakistan landmass rifted away from the super continent Gondwana land followed by the extensive sea-floor spreading and the opening up of the Indian Ocean. The Indian plate traveled 5000 Km northward due to the geodynamic forces and eventually collided with Eurasia. The subduction of the northern margin of the Indian plate finally closed the Neo-tythes and the Indian Ocean assumed its present widespread expanse. This collision formed the Himalayas and the adjacent mountain ranges. Pakistan has been divided into two broad geological zones, which are the:

- Gondwanaland Domain
- Tethyan Domai

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 and complex crustal structure.

2.3.1 Northward Drift of The India And Opening of The Indian Ocean:

The Indo-Pakistan subcontinent separated from the Gondwana motherland about 130 million years ago. It has been estimated that between 130 million years and 80 million years India moved northward at a rate of 3 to 5 cm/year. From 80 million years ago India moved at an average rate of about 16 cm/year relative to Australia and Antarctica figure 2.1.

2.3.2 Formation of Kohistan-Ladakh Island Arc And Its Collision With Eurasia:

The Neotethys had begun to shrink by the time Indian began its northward drift around 130 m.y.

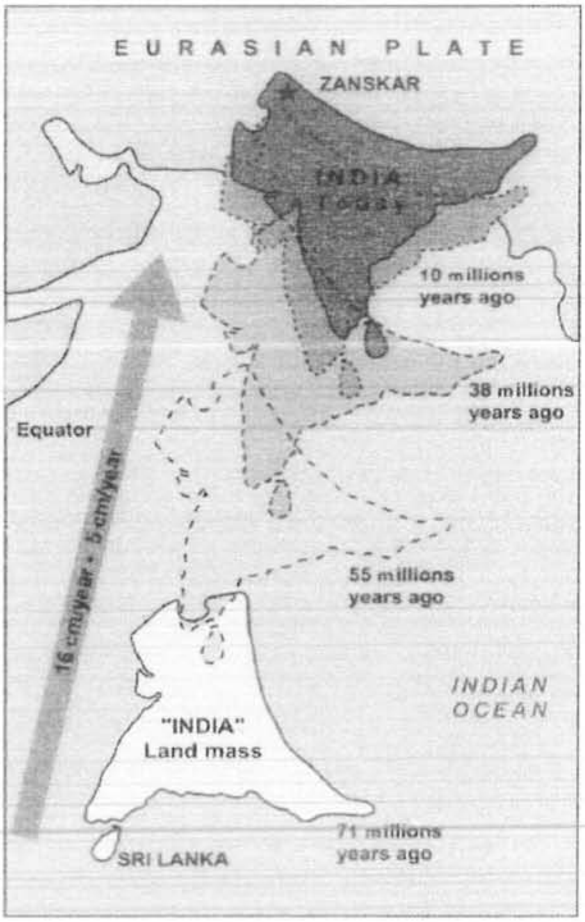

Figure 2.1. Shows the northward drift of Indian plate.(www.gsp.com.pk)

ago. Intra-oceanic subduction generated a series of volcanic arcs (Kohistan-Ladakh, Nuristan, Kandhar) during the Cretaceous. This arc was intruded by 102 Ma precollision granitoids followed by the intra-arc rifting and magnetisms. Arc magmatism covered a life-span of about 40 Ma after which the back-arc basin closed and Kohistan-Ladakh arc collided with Eurasia along the southern margin of the Karakoram plate.

2.3.3 India-Eurasia Collision And Himalayan Upheaval:

The abrupt slowing down of Indian's northward movement between 55 and 50 m.y. ago is attributed to this collision (Powell 1979). The abrupt slowing down of Indian from 18-19.5 cm/year to 4.5 cm/year occurred at 55+Ma. A combined India-Australia plate started moving away from Antarctica. Motion ceased along the former plate boundary (the Ninety East Ridge), and the Proto-Owen fracture no longer remained at transform fault, though it was reactivated later, about 20 Ma ago.

Since 55 Ma ago India has steadily rotated counterclockwise. Coupled with Arabian's separation from Africa about 20 Ma ago, this rotation caused convergence in Balauchistan, closure of some the some smaller basins (Scistan, Katawaz), collision various crustal blocks in Iran-Afghanistan region and formation of the Balauchistan fold-and-thurst belt.The India Eurasia collision produced the spectacular along uplifted and deformed 2,500 Km long Indo-Pakistan plate margin.

2.4 The Indus River:

The Indus River is 2900 km long and drains in an area of 970000 km^2, average suspended load are 450 MT/Year, with an average discharge of 67000 m^3/sec. The Indus is the eleventh largest river in the world. The Indus Delta Covers 8000 km^2 with its apex 185 km from the coast. Much of the Delta is marshy, flooded at high tide and covered with mangroves along the coast.

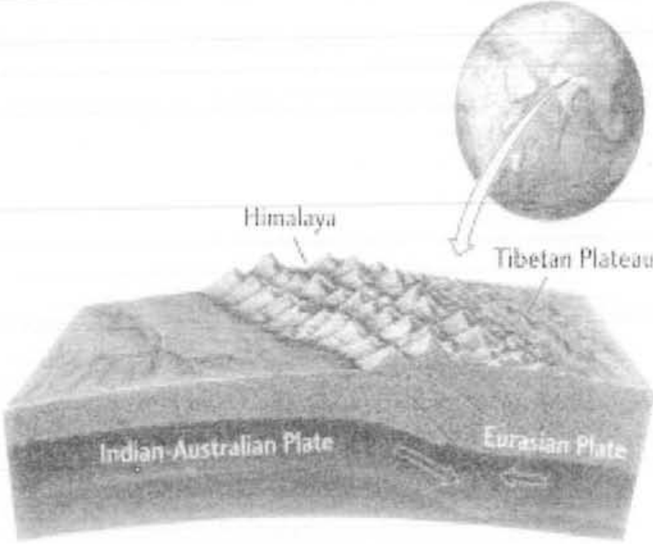

Figure 2.2 (subduction of Indian plate beneath Eurasian plate and formation of Himalaya)

.(www.gsp.com.pk)

2.5 *Hydrocarbon Potential of Indus Offshore:*

11 wells have been drilled from 1961 to 2007, 9 of these wells gone dry with gas shows and one resulted in non commercial gas discovery.Four different plays were targeted by these wells

- Karachi Plate Form Play (5 wells)
- Murray Ridge Play (1 well)
- Indus Delta Play (4 wells)
- Eocene Carbonate Buildup Play (Deep Water, 1 well)

All of these wells targeted the clastic reservoir except Pak G21, which was drilled in 2005 to test the deep water Eocene Carbonate Build Up. No oil or gas deposit was discovered, but gas shows and traces were recorded. However, considering the large area (7,700 mi2; 20,000 km2) the number of wells drilled represents an insufficient effort of exploration and drilling (Shuaib, 1982). The drilling status uptil 2007 has been shown in Figure 2.3. Exploration history in the late 50's when Sun acquired a gravity survey followed by a near shore seismic campaign in 1961-62. Three dry wells were drilled near shore between 1961 and 1964; they targeted the Karachi Platform play which is the extension of the Lower Indus Play (Badin Area).

- Dabbo Creek-1 (1963)
- Paitani Creek-1 (1964)
- Koranggi Creek-1 (1964)

In the Offshore Indus Delta Play, exploration efforts commenced in late 60's with an extensive seismic campaign carried out by Wintershall. Three wells were then drilled in the Tertiary Indus Offshore shelfal area between 1972 and 1975, one of them, the Indus Marine C1 was aimed to test Oligocene-Eocene reservoirs on the Murray ridge, possibly analogues to Karachi Platform, all of these wells were dry with significant gas shows. In 1978, Huskey drilled Karachi South A1 in order to verify the presence of Paleocene and Cretaceous clastic objects, it was again on the offshore extension of the Karachi Platform, again, it was a failure.

- Indus Marine A-1 (1972)
- Indus Marine B-1 (1972)

- Indus Marine C-1 (1975)

In 1985, the well Pak can-1 drilled by OGDC made the first gas discovery in the Indus Delta Play, it was a noncommercial discovery, it tested 3.7 mmscfd flow from 2.5m thick Miocene shelf sand , the flow was non stable and gas was reported to be dry with 2.7% CO_2 and no Hydrogen Sulfide and of thermo genic origin. In 1989-90, after the acquisition of good quality seismic data, Occidental frilled Sadaf1; it was a dry well with gas shows.

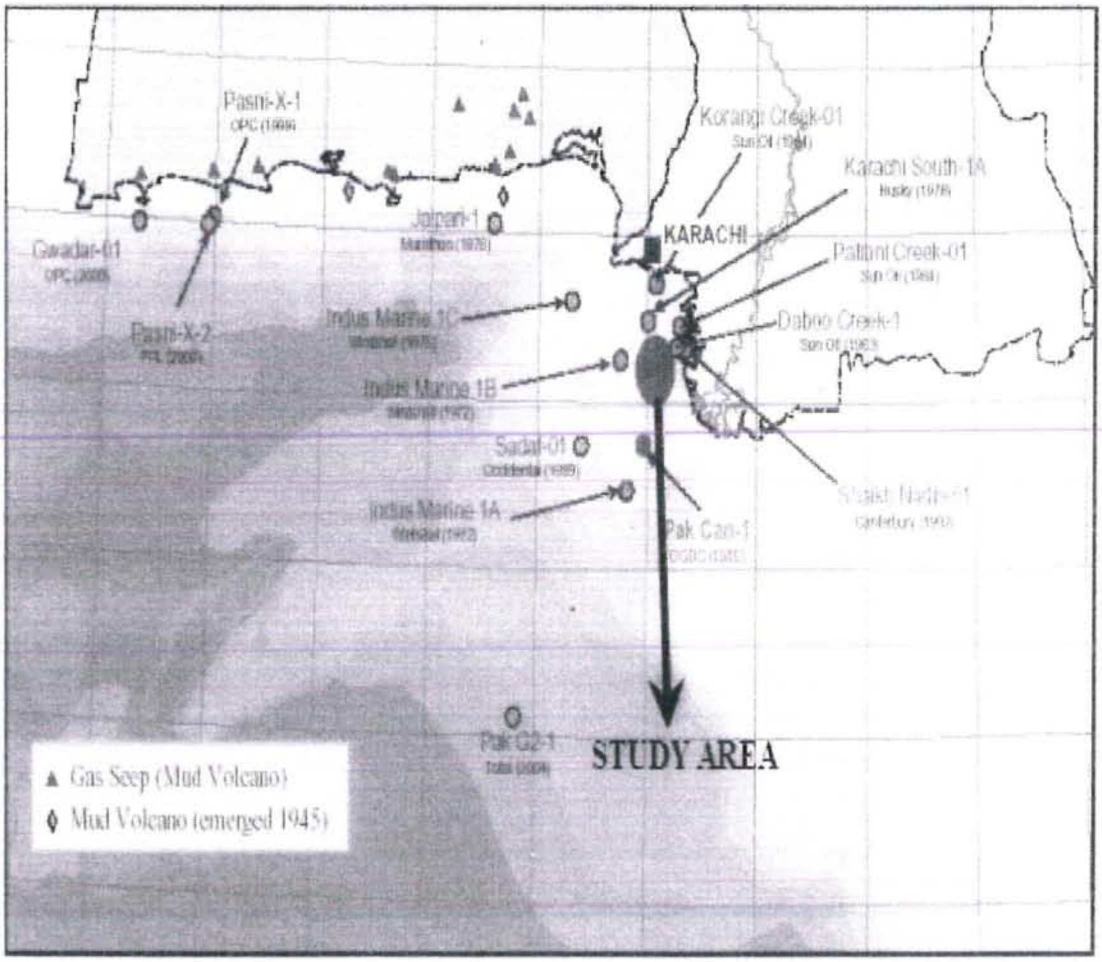

Figure 2.3: The Exploration History Of Pakistan Offshore (www.gsp.com.pk)

In 1992, Sheikh Nadin1 was drilled by Centerburg Resources, it was technically an onshore well bur was very close to the shoreline, it was drilled to retest the structure target of the first exploratory well, the Dabbo Creek, it was also abandoned as a dry well for non commercial hydrocarbon accumulation. Regarding the wells drilled on the Offshore Platform, overall low reservoir quality of the pab main target may have badly impacted the exploration efforts. All of the wells drilled in the offshore, encountered gas shows through out the entire Tertiary succession. The wells located outside the offshore platform also experienced the overpressure in the Miocene section and four were abandoned with out reaching the programmed TD, however no or very limited overpressure can be inferred in Plateform domain.

In 2005, total Elf Fina drilled Pak G2-1, it was to test the deep water Eocene Carbonate buildup, well was dry; the possible reason could be its position, away from migration paths. The Indus Offshore is well covered by 2d seismic data of various vintages, which provides a good basis of preliminary prospectively evaluation, However, One 3D seismic evaluation was carried out by British Gas in 1999-2000, No well was drilled on this 3D seismic.

2.6 Tectonic Zones:

Two broad geological divisions of this region the Gondwanian and the Tethyan domains are discussed. In this scenario Pakistan is unique inasmuch as it is located at the junction of these two diverse domains. The southeastern part of the Pakistan belongs to Gondwanian domain and is sustained by the Indo-Pakistan crustal plate. The northern most and western regions Pakistan fall in tethyan domain and present a complicated geology and complex crustal structure. On the basis of plate tectonic features, geological structure, orogenic history (age and nature of deformation, magmatism and metamorphism) and lithofacies, Pakistan may be divided into the following broad tectonic zones which is modified after (Kazmi & Rana 1982) (see Map 2.4).

- Indus Plateform and Foredeep.
- East Balochistan fold-and-thrust belt.
- Northwest Himalayan fold-and-thrust belt.
- Kohistan-Ladakh magmatic arc.
- Karakoram bloack
- Kakar Khoarasan flysch basin and Makran accretionary zone.
- Chagai magmatic arc.
- Pakistan offshore. (Kazmi A.H, et al. 1997)

TABLE 1 SUMMARY OF DRILLING ACTIVITY IN THE OFFSHORE INDUS BASIN (AFTER QADRI, 1984 AND SHUAIB, 1994).

Well Name	Company	Year	Location	Objectives Reached	T.D. (Below MSL) in metres	Age/Formation Reached	Status
Dabbo Creek-01	Sun Oil	1963-64	24°20'02" N 67°16'42" E	Yes	4354 (-4335)	E.Cretaceous (Sembar Formation)	Minor gas shows in Cretaceous, Drilled on down thrown side of the fault. Plugged and abandoned.
Korangi Creek-01	Sun Oil	1964-65	24°42'42" N 67°04'14" E	Yes	4140 (-4124)	U.Cretaceous (Mughalkot Formation)	Gas shows in Paleocene-Eocene section. Plugged and abandoned.
Patiani Creek-01	Sun Oil	1964	24°27'00" N 67°17'30" E	Yes	2659 (-2643)	U.Cretaceous (Mughalkot Formation)	Gas shows in upper part of Mughalkot. Drilled on the flank of the structure. Plugged and abandoned.
Indus Marine-A1	Wintershall	1972	23°27'28" N 66°48'26" E	Partially	2841 (-2831)	M.Miocene (Gaj Formation)	Abandoned due to technical reasons after kicking.
Indus Marine-B1	Wintershall	1972-73	24°15'03" N 66°45'20" E	Partially	3804 (-3793)	E.Miocene (Gaj Formation)	Abandoned due to technical reasons after kicking.
Indus Marine-C1	Wintershall	1975	24°36'01" N 66°18'24" E	No	1942 (-1932)	E.Eocene (Ghazij Formation)	Formation pressure required mud weight greater than the fracture gradient at the bottom. Plugged and abandoned due to high pressure.
Karachi South-A1	Husky	1978	24°29'08" N 67°00'30" E	No	3353 (-3343)	U.Cretaceous (Mughalkot Formation)	Tops of formations were found lower than expected. Abandoned.
PakCan-01	OGDC	1985-86	23°44'33" N 66°57'36" E	Yes	3701 (-3684)	M.Miocene (Gaj Formation)	Non Commercial gas discovery in Miocene. Plugged and abandoned. DST-3 flowed, Gas 3.7 MMCF/day from 2743-2747 M.Miocene, Sandstone interval, confirming the presance of hydrocarbons in the area.
Sadaf-01	Occidental	1990	23°44'08" N 66°21'39" E	Yes	3981 (-3965)	M.E.Miocene (Gaj Formation)	Dry. Plugged and abandoned.

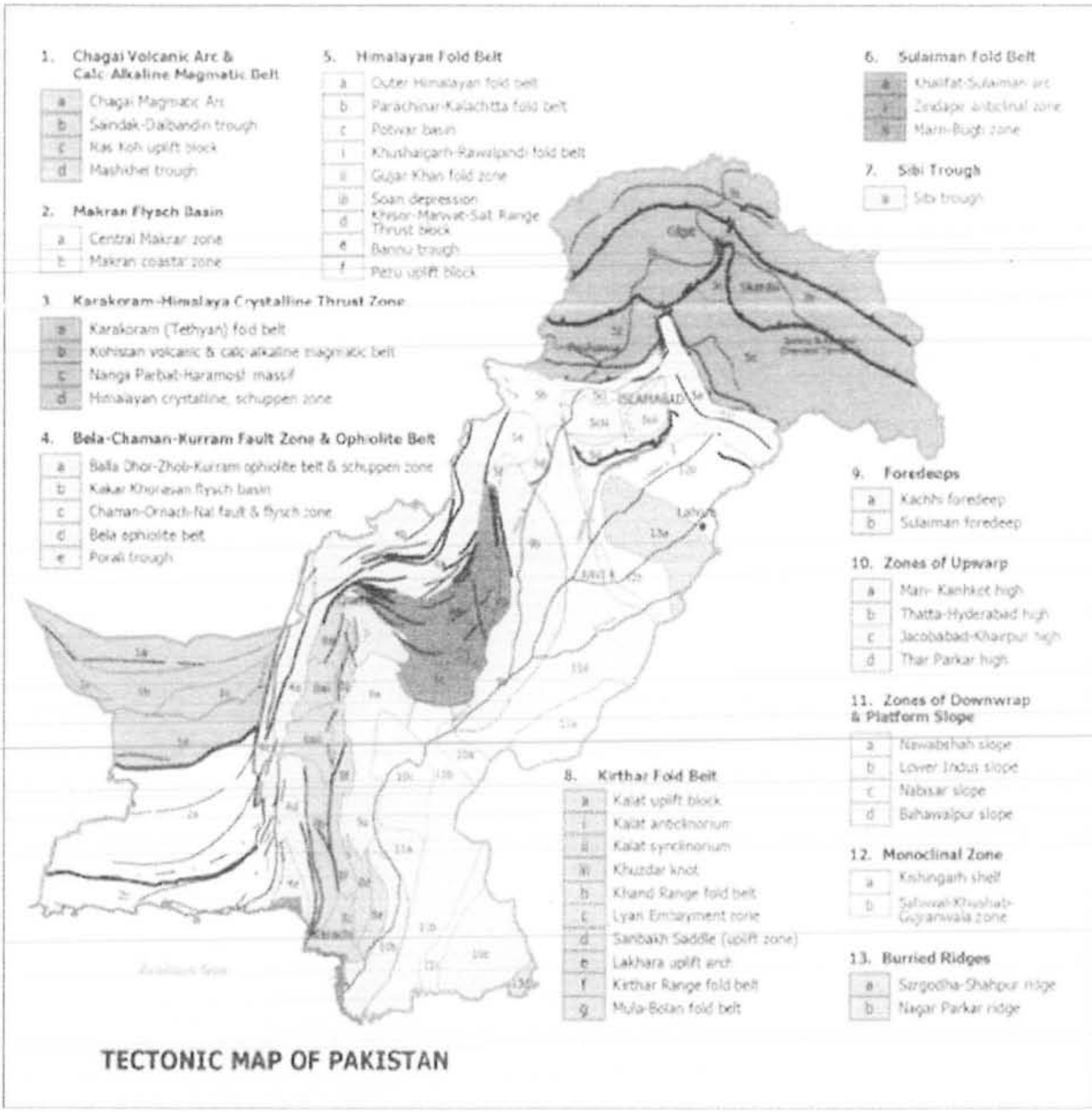

Figure 2.4: (Tectonic Zones of Pakistan) (www.gsp.com.pk)

2.6.1 Indus Platform and Foredeep:

This zone extends over an area exceeding 2500,000 km2 in southeastern Pakistan and includes the Indus plain and Thar–Cholistan deserts. It hosts more than 80% of Pakistan's population, extensive coal deposits, valuable oil and gas fields, potential for geothermal energy and vast groundwater reservoirs. (Kazmi & Jan, 1997).

Gravity and Seismic surveys, supported by limited bore whole data, indicate that in the eastern part Precambrian rocks form a gentle westward dipping monocline covered by veneers of Mesozoic to Cenozoic marine to deltaic sediments. However, there are broad zones of up warp and down warp which are well defined by gravity surveys. The sedimentary cover is relatively thin in the up warp zones. The down warp contains a thick sedimentary pile, particularly the foredeep at the western edge of platform slope where the sedimentary cover is up to 10,000 m thick. (Kazmi & Jan, 1997).

Structural Zones

The Indus platform and foredeep comprise the following main structural zones.

- ***Buried Ridges:***
  - Sargodha-Shahpur ridge
  - Nagarparker ridge
- ***Zones of upwarp:***
  - Mari-Khan dot High
  - Jacobabad-Khairpur High
  - Thatta-Hyderabad High
  - Tharparker High
- ***Zones of downwarp and slope:***
  - Northern Punjab monocline
  - Southern Punjab monocline
  - Cholistan shelf
  - Panno Aqil Graben
  - Nawabshah slope
  - Lower Indus trough
  - Nabisar slope
- ***Fore deeps:***
  - Suleiman foredeep
  - Kirther foredeep

It may be noted that the Jacobabad-Khairpur upwarp divides the Indus plat- form into two segments. The lower segment is comprised of the lower Indus trough. It is bounded by Nawabshah and Nabisar slopes which are in flanked by Thatta-Hyderabad and Tharparker highs. The upper segment in Punjab is traversed by Sargodha- Shahpur ridge, splitting it into northern Punjab monocline and southern Punjab monocline and Cholistan shelf. Westward the Indus platform sharply steepness to form the Suleiman and Kirther foredeep.

2.7 Petroleum Geology of Pakistan Basins:

Pakistan comprises of the following three sedimentary basins (Fig. 2.5):

- Balochistan Basin.
- Pashin Basin.
- Indus Basin.

Balochistan Basin :

It is the second largest sedimentary basin of Pakistan measuring 149,000 sq km on shore, where 8 wells have so far been drilled without success. It is a Cenozoic subduction basin created as a result of oceanic slab belonging to the Arabian plate under a block (Afghan) of the Eurasian plate. (Ahmed 1998).

Pashin Basin:

This basin is located between the Chaman Transform Fault Zone in the west and Muslim Bagh Waziristan Ophiolite and melange zone in the south and east. It extends into Afghanistan where it is known as Katawaz basin.

The pashin is a small extra continental median basin of Tertiary age (Ahmed 1998) developed as a remnant of the Neo-Tethys ocean basin before the collision of the western margin of the Indian plate with Afghan block of Eurasian plate. The basin is considered as "frontier" because it is totally unexplored but its north-east segment will be most attractive are for future exploration because of anticline structure. (Ahmed 1998).

Indus Basin :

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

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

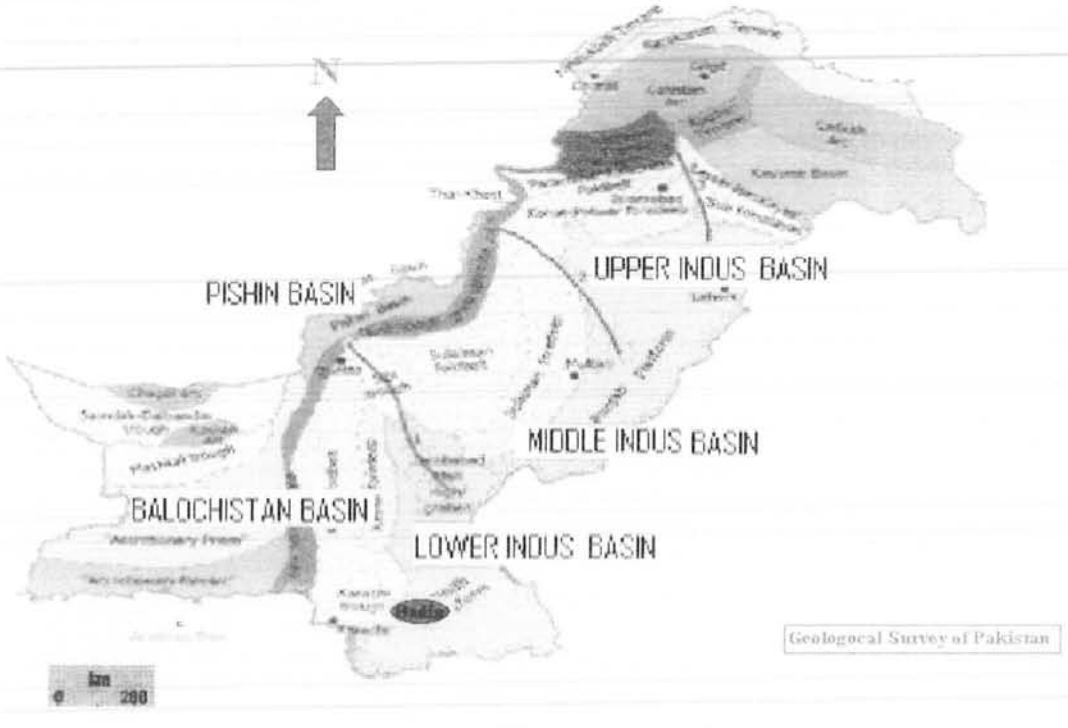

Figure 2.5: Map showing Basins of Pakistan (www.gsp.com.pk)

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

a) Northern Indus Basin:

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

- Indian Shield in the ***East***
- Kirthar and Sulaiman Ranges in ***West***
- Sargodha high in ***North***
- Offshore in ***South***

b) Central Indus Basin:

This basin is comprised of duplex structure characterized by large anticlines and domes in the passive roof sequence of Suleiman fold belt followed eastward by gently dipping strata of Punjab monocline. The basin contains a sedimentary sequence ranging from Precambrian to recent. It contains one of the biggest gas field called Sui gas field with 8.6 TCF. Central Indus basin is bounded by

- Indian Shield in ***East***
- Suleiman Foredeep in ***West***
- Sargodha high in ***North***
- Jacobabad high in ***South***

c) Southern Indus Basin:

The southern Indus basin (550 * 220 Km) extends approximately between Latitude 24 and 28 North and from Longitude 66 to eastern boundary of Pakistan (Qadri and Shoaib (1986)). It is characterized by several structural highs.

Thar slope forms the eastern limit of the lower Indus basin, which is bounded by the Indian shield in the east and folded axial belt toward the west. It extends to offshore in the south, where as in the north it is separated from central Indus basin by a positive feature, the Mari-Khandkot high (Ministry of Petroleum and Natural Resources of Pakistan). It comprises of following five main units:

1. Thar platform
2. Karachi trough
3. Kirthar fore deep
4. Kirthar fold belt
5. Offshore Indus.

The platform and trough extend into the Ofshore 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). Southern Indus Basin is bounded by

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

1. 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 stratistructural 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.

2. 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.

3. 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 Sulaman Depression, is the area of great potential for the maturation of source rock.

4. 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.

5. Tectonic settings of Offshore Indus Basin:

To review the Plate Tectonic Theory, the Pakistan continental margin has been characterized by active and passive margins. The Indus Offshore Basin is the continental shelf of Pakistan, which lies between Murray Ridge and the Indian Border. The Two different types of margins are formed from two different types of crustal plates. Geological and marine processes are different on these two continental margins (Akhtar Ali Khan, 1999). Geologically, the Offshore Pakistan can be divided into three important zones;

- Indus Delta And Indus Offshore Basin
- Makran Offshore
- Murray Ridge

Indus delta and Indus offshore basin:

Geologically, the Offshore Pakistan are can be divided into three important zones; Indus Delta and Indus Offshore Basin, Makran Offshore and Murray Ridge. The eastern coast of Pakistan between Cap Monz and Run Of Kutch comprises the Indus Delta region. This coast is tectonically a passive coast. Along this coast the Indus Delta and the Indus Offshore Basin are the most significant geomorphic features. Coastal morphology shows the shows a network of tidal creeks, small islands in tidal channels, mud banks, swamps and lagoons. The Indus Delta is one of the largest deltas of the world which is built by the deposition of sediments of the Indus River. The geological history of this delta began during Early Miocene when it was formed in the Bugti area550 km north of the Karachi.

During historic time i.e. 5000-6000 years B.P. the delta has propagated 150 km southward to the present location. The Fan shaped delta is complex spreads over an area of about 30,000 sq. km. Geological history of the submarine Indus Basin is linked with rifting of the Indian platform Gondwanaland and opening of the Indian Ocean and Himalayan tectonics. The Indus Offshore basin comprises approximately 20,000 sq. km area of the continental shelf.

The shelf area consists of Horst Graben complex (Khan, 1999). Shelf width is 100-150km of the Gulf Of Kutch- Indus Offshore Delta and widens to 350km off the Bombay farther south and the Shelf Break occurs at an average depth of about 100 m along the Pakistan India Border. Indus River through submarine canyons and levee channel systems has been supplying sediments since Miocene time.

The Indus Offshore basin is the continental shelf of Pakistan which lies between Murray Ridge and the Indian border. It has a width of about 120 to 140 km and is cut in the southeastern corner by a submarine canyon of Indus River. The basin can be divided into two large units; The Karachi Trough Offshore and Thar slope Offshore. The boundary between the two is roughly an extension of their onshore boundary. Karachi trough is roughly a rocky area and is characterized by the thick Post Early Cretaceous sediments where as the Thar Slope is mostly covered by alluvium. Post Early Cretaceous sediments are either lacking or thinning out in the Thar Slope (Shuaib, 1981).

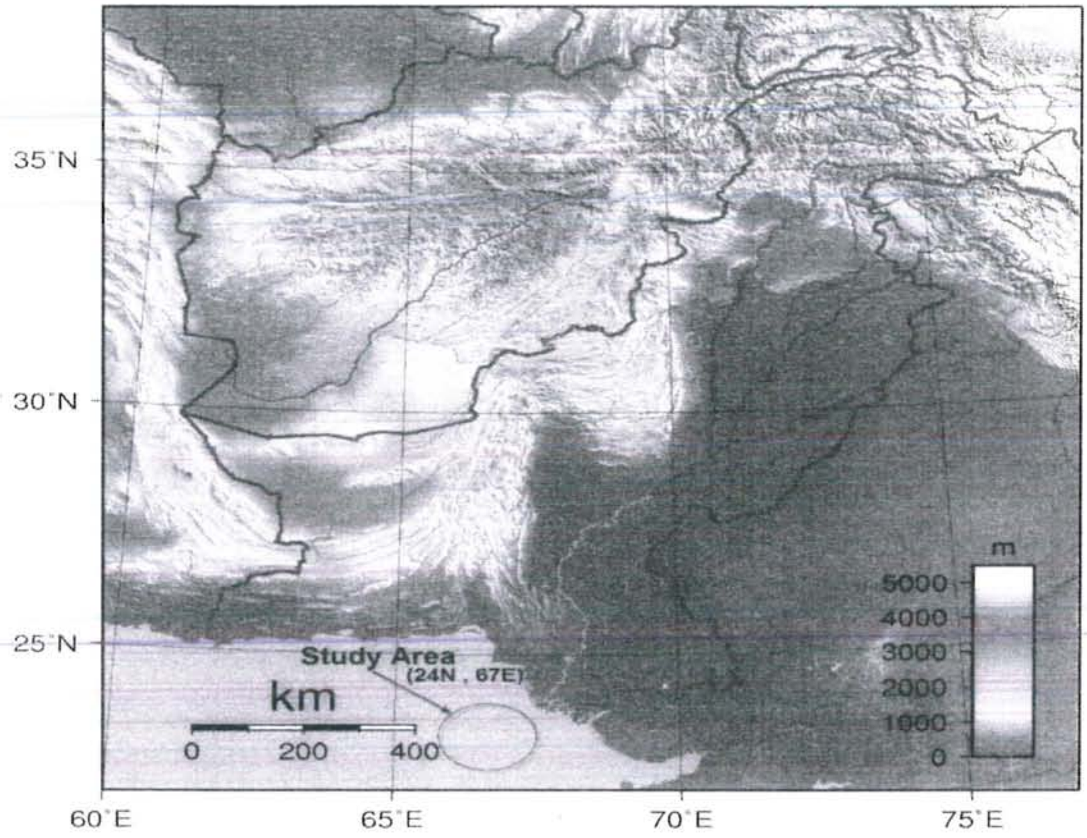

Fig.2.6: Shows the Location Map of Offshore Indus Basin (www.gsp.com.pk)

The most pronounced bathymetric feature of the shelf slope is the Indus canyon with anaverage width of 8 km and depth (relief) on the order of 800 m. This canyon is 170 km long and apparently commences around 20 to 30 m water depths on the inner shelf and ends at 1400 m depth at foot of continental slope where the canyon is about 20 km wide with the relief of about 325 m.

At the foot of the continental slop, a large Submarine Fan has been developed due to the continuous deposition of the sediments. The Indus submarine Fan is the second largest Fan in the world. It extends from the Pakistan passive margin in the south to Carlsberg Ridge in the south. Owen Murray Ridge Zone and Chagos-Lacadive Ridges mark the western and eastern boundary of the Fan respectively; also these ridges restrict the extension of the Fan. Sediment thickness is about 7 km in this fan. Turbidity currents and tractive bottom currents has been the most important in the transportation of the terrigenuous material (Khan, 1999).

Makran Offshore:

This zone is characterized by relatively narrow shelf and slope which form the northern margin of the Gulf of Oman Abyssal Plain. In this region the Arabian plate is being subducted beneath Makran and the subduction zone is located near the base of continental slope. The makran region is comprised of accretionary wedge of deformed sediments piled up at an oceanic subduction margin and it is a part of a vast trench-arc system. Seismic profiles indicate that the sediment pile on the Makran continental margin is about 5 km thick, in the Abyssal plain these sediments are horizontally deposited but shore ward they are abruptly deformed up to 50km wide fold and thrust belt. Only upper 2.5 km of the sedimentary sequence is folded and forms a decollement zone. As revealed by offshore drilling, most of this sequence consists of Early Miocene and younger sequence (Kazmi and Jan 1997).

Murray Ridge:

The north east to south west oriented Murray Ridge is the northern continuation of the Owen Fracture Zone in the Arabian Sea. Limited geologic and geophysical data restricts any conclusive remarks about their origin. However, the strong magnetization and dredge samples of tuff and basalt suggest that the Murray ridge is volcanic in origin. In pre –plate tectonic Studies, Murray ridge was treated as a branch of Carlsberg Ridge extending north through the Arabian Sea (Khan 1999).

2.8 Submarine Canyon:

A submarine canyon is a steep-sided valley cut into the sea floor of the continental slope, sometimes extending well onto the continental shelf. Some submarine canyons are found as extensions to large rivers; however most of them have no such association. Canyons cutting the continental slopes have been found at depths greater than 2 km below sea level. Many submarine canyons continue as submarine channels across continental rise areas and may extend for hundreds of kilometers. Figure 2.7 shows the Indus SubMarine Canyon

Formation of Canyon:

Many mechanisms have been proposed for the formation of submarine canyons, and during the 1940s and 1950s the primary causes of submarine canyons were subject to active debate.

An early and obvious theory was that the canyons present today were carved during glacial times, when sea level was about 125 meters below present sea level, and rivers flowed to the edge of the continental shelf. However, while many (but not all) canyons are found offshore from major rivers, subaerial river erosion cannot have been active to the water depths as great as 3000 meters where canyons have been mapped, as it is well established (by many lines of evidence) that sea levels did not fall to those depths.

The major mechanism of canyon erosion is now thought to be turbidity currents and underwater landslides. Turbidity currents are dense, sediment-laden currents which flow downslope when an unstable mass of sediment that has been rapidly deposited on the upper slope fails, perhaps triggered by earthquakes. There is a spectrum of turbidity- or density-current types ranging from "muddy water" to massive mudflow, and evidence of both these end members can be observed in deposits associated with the deeper parts of submarine canyons and channels, such as lobate deposits (mudflow) and levees along channels. (Haines P.W. & Mornane K. (2010))

2.9 The lithologic makeup of the Indus delta:

Correlation of the Indus Offshore basin is complicated by extreme lateral facies variation, both from north to south and from west to east. Karachi1 and 2 are the wells drilled onshore whereas four wells, Korangi Creek1, Patiani Creek1, Dabbo1 and Karachi South A were drilled on the Karachi Offshore platform, the remaining three wells Wintershall A-1, B1 and C-1 were drilled in the offshore depression.

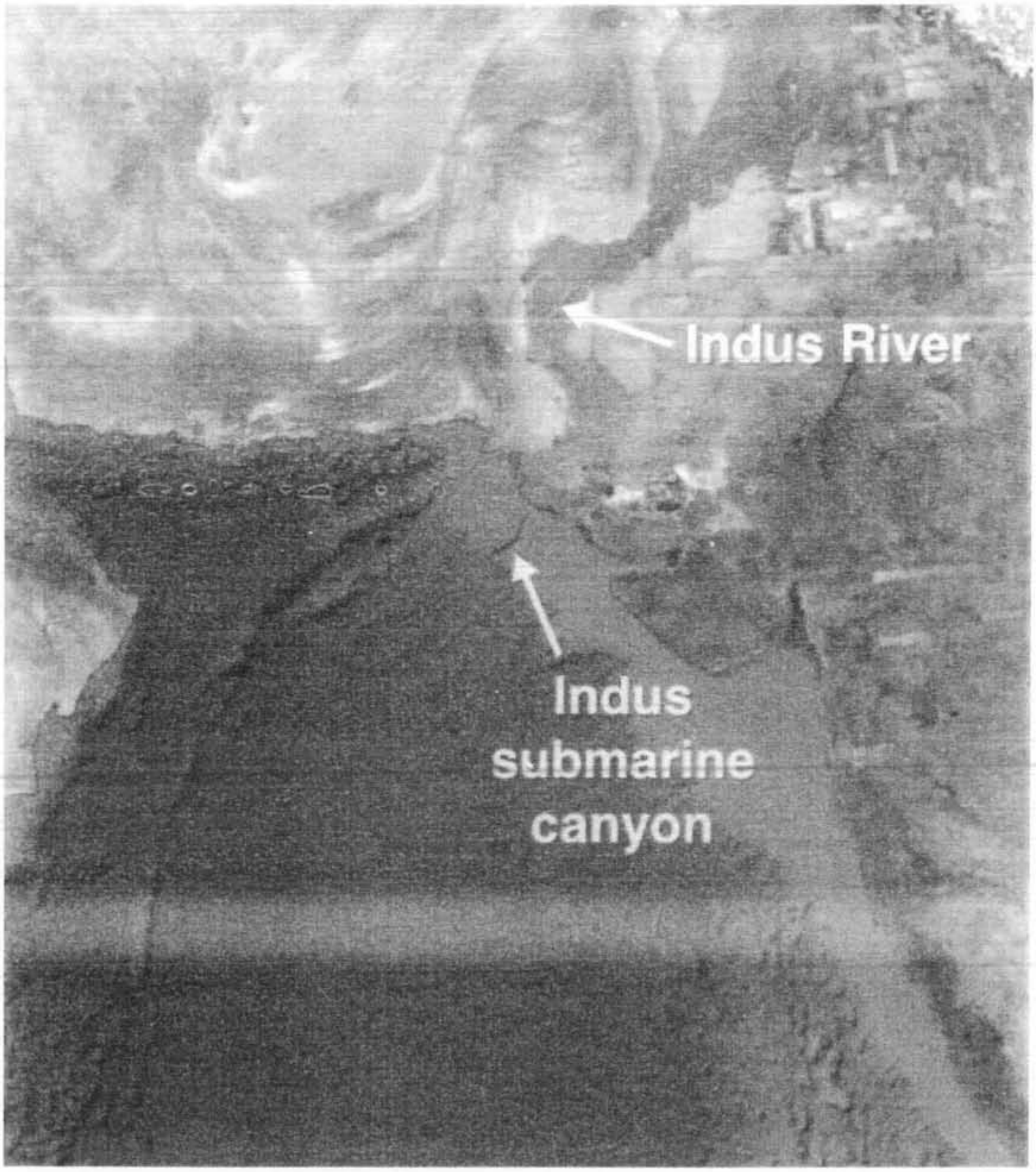

Figure 2.7: Indus Submarine Canyon

Paleocene:

The Ranikot Formation of Paleocene age is present in all four wells on the Karachi Offshore plateform, however Upper Ranikot is missing except in Patiani Creek-1 where it is about 590ft (180m) thick and consists mainly upon interbedded shale and limestone. The lower Ranikot is composed of clastics (sandstone interbedded with shale) and layers of Basalt and has a maximum thickness of about 4360 ft (1329m) in Korangi Creek-1 well where a gas show is recorded. Ranikot limestone and sandstone beds produce gas in Sari and Hundi wells situated at abot 70km and 80km respectively north east of Karachi city. However, it decreases in thickness southward along Karachi Offshore and is represented in the north by shaly facies (Korara shales) in onshore Karachi 1 and 2 wells.

Eocene:

The Lower Eocene Gazij/Laki Formation was encountered in all four wells drilled in Karachi Offshore plateform as well as in Indus Marine C-1 in the Offshore depression, it is represented mainly by shaly facies and bands of carbonate rocks and has a maximum thickness of 1460 ft (445m) in Korangi Creek-1 well in which a gas show was recorded and thins southward along Karachi Offshore, in the north it is entirely represented by shaly facies (Korara shales) in the both Karachi Onshore 1 and 2 wells.

The Late Eocene Kirthar Formation is present in four wells of Karachi Offshore Plateform, in one of the Offshore Depression wells, The Indus Marine C-1 and both of the Karachi Onshore wells 1 and 2. It consists mainly of limestone interbedded with marlstone and calcareous shale. The Kirthar Formation has a maximum thickness of 4210 ft (1283m) in the Korangi Creek well in which a gas show was recorded. From this well the formation thickness decreases in thickness both northward and southward.

Oligocene:

The Nari Formation is present in all four wells on Karachi Offshore Plateform, one of the wells in Offshore depression, The Indus Marine C-1 and Onshore wells Karachi 1 and 2 it consists mainly of limestone interbedded with marlstone and calcareous shale, commonly with bands of calcareous sandstone , especially in the upper part. It has a maximum thickness of about 5575 ft (1700m) in onshore Karachi wells but decreases in thickness southward along the Karachi Shoreline.

Miocene:

Miocene sediments are divided into lower, middle and upper units. The Lower Miocene Gaj Formation has a maximum thickness of about 2300 ft (700m) in onshore Karachi wells but decreases in thickness in Karachi Offshore wells and along the Karachi shoreline, it consists mainly of carbonate facies with intercalation of calcareous clasts (Calcareous shale, siltstone and sandstone).

Post Lower Miocene sediments are missing in wells drilled in Karachi Offshore Plateform as well as in the wells Karachi Onshore 1 and 2. However, they have an enormous thickness in Wintershall Indus Marine A-1, B-1 and C-1 wells drilled in the Offshore Depression. Miocene sediments in the Offshore Depression wells have a minimum thickness of about 5185 ft (1580m) and have a maximum thickness of more than 10660 ft (3249m) in the Indus Marine B-1 well. The Miocene is represented mainly by calcareous clastics, a monotonous silty shale sequence with minor sandstone and occasional bands of limestone.

Based upon above description, a Stratigraphic Column is sketched to help giving better image of the subsurface in Indus Offshore; this Stratigraphic column is shown in Figure 2.8.

2.10 Reservoir Rocks:

Cretaceous and Paleocene sandstones are proved oil and gas bearing zones in the onshore Thar Slope and Karachi Trough, respectively. The Khashkeli well situated about 150km east of Karachi city on the Thar Slope was drilled in may 1980 and encountered oil bearing Early Cretaceous Lower Goru sandstone at depth of about 3410 ft (1040m). The Sari and Hundi wells, situated about 70km and 80km respectively, northeast of the Karachi city in the Karachi Trough are producing gas from Paleocene sandstone and limestone at the depth of about 4100 ft (1250m).

Oil and gas deposits were discovered in Bombay offshore basin in India in its south east direction in Eocene and Miocene sandstone and limestone (biomicrite). Therefore Cretaceous and Paleocene sandstone in the offshore plate form and Miocene sandstone and limestone in the offshore depression maybe primary objectives of the hydrocarbon reservoirs.

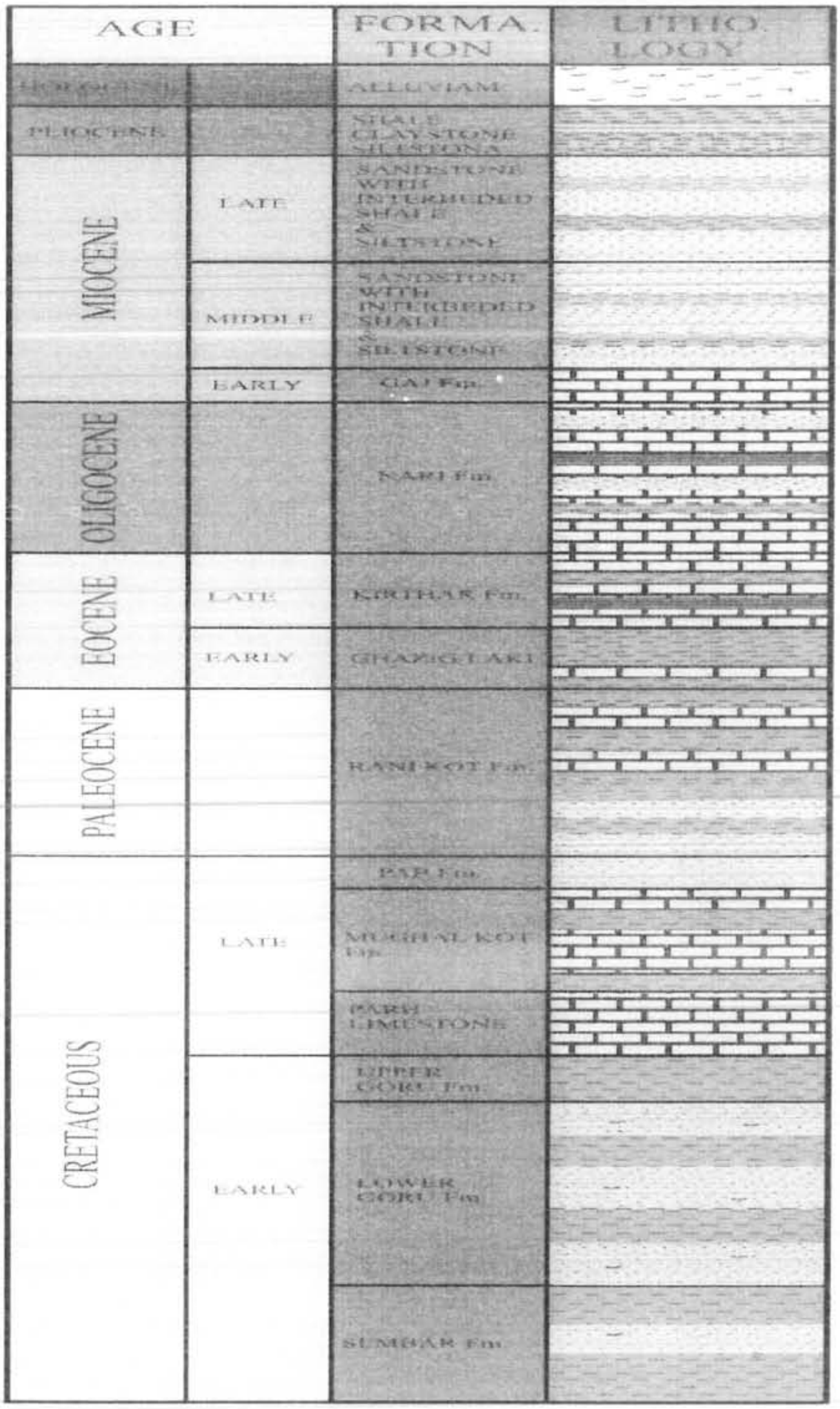

Figure 2.8: Generalized Stratigraphy of The Indus Offshore (khan, 1999)

The results of the three wells drilled in the offshore depression were not encouraging as no sandstone or carbonate beds with reservoir potential were found, instead: a monotonous silty-shale sequence with minor sandstone and beds of tight limestone were encountered. The results of these wells remain inconclusive because they did not reach the expected reservoir. The Sun drilled three wells in the Karachi shoreline and The Huskey drilled one well in the offshore palateform which penetrated the Cretaceous sediments , but no oil or gas deposit was found although gas shows and traces were encountered, However further investigation may be planned to investigate the development of potential reservoirs particularly in the hinge line zone.

2.11 Source Rocks:

Richness of the source can be determined from organic carbonate content and chloroform bitumen content. Source rock with less than 0.5% organic carbon is considered poor, 0.5% to 2% good and more than 2% very good. The ratio of the Chloroform extract to organic matter varies with maturity as well as with organic matter type. The stages of organic matter maturation can be evaluated in a stratigraphic sequence through geochemical parameters, if the nature of the organic matter is known. Maturity of the source rock can be determined by the depth of bituminization and Thermal Alteration Index (TAI) of Staplin (1969). The scale of TAI values is as follows; 1, fresh yellow; 2, brownish yellow; 3, brown; 4, black; and 5 black with structural deformation. TAI values of 3 and above indicate mature source rocks where as values of less than three indicate immature source rocks. Richness and maturity of source rocks can be determined by other methods as well, but the mentioned procedures are comparatively simple.

Data regarding richness and maturity of sediments encountered in wells drilled in the area are lacking although gas shows and traces are recorded. However, geochemical data on four offshore wells (Indus Marine A-1, B-1, C-1 and Karachi South –A) are available. Generally no rich source rocks are present in any of these wells, due to insufficient hydrocarbon content and poor quality of organic material. In Indus Marine A-1 well, the maturity corresponds to the initial forming stage. Argillaceous samples of Middle Miocene age , at depth of 7641, 7700, and 8330 ft (2329, 2347, and 2539m) seem to contain very faint traces of brownish yellow flourescencence (TAI value 2) which indicate immaturity.

In Indus Marine B-1 well, hydrocarbon maturation took place in Lower Miocene rocks between 7999 and 12500 ft (2438 and 3810m) depths. Below 12500 ft (3810m) liquid hydrocarbons are not likely to be found because of relatively well developed degree of maturity of the hydrocarbon spectra and high reflectance values (organzolites).

In Indus Marine C-1 well, sediments in the interval from 3297 to 4899 ft (1005 to 1493 M)are of Early to Middle Miocene age and contain dominantly oil proven matter (oil window), whereas those in interval from 4899 to 6319 ft (1493 to 1926 m) range in age from Early Eocene to Early Miocene and are mainly gas proven matter (gas window).In Karachi South-A well, the oil window occurs in sediments ranging in age from Late Cretaceous to Oligocene, between depths of 6500ft and 11500ft (1981m and 3505m).

CHAPTER # 3

SEISMIC METHOD

SEISMIC METHODS

3.1 Seismic Methods:

According to Coffeen (1986), conventional seismic method is used for the exploration of hydrocarbons underground by the use of seismic waves. Seismic wave frequency range that is usually used for exploration is between 20-100 cycles per second. People can hear sounds about 20 to 20,000 cycles per second. So the seismic wave frequency range is right around the deepest tones people can hear. In a seismic method a range of frequencies are used, that travel deep in to the earth and return, bringing back the information about the earth.

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).

"The basic technique of seismic exploration involves the generation of waves and measuring the time required for the waves to travel from the source to a series of geophones planted on the surface of earth after refraction, reflection and diffraction from subsurface horizons. The travel time depends upon the physical properties of rock and the attitude of the beds". (Telford et al,1976). The seismic method of geophysical exploration utilizes the fact that elastic waves travel with different velocities in different rocks. The seismic method has three principal applications:

- Engineering seismology
- Earthquake seismology
- Exploration seismology

Engineering Seismology:

The seismic method applied to near-surface studies is known as engineering seismology. (Yilmaz,2001).

Earthquake Seismology:

The seismic method applied to the crustal and earthquake studies is known as earthquake seismology. (Yilmaz, 2001).

Exploration Seismology:

The seismic method applied to the exploration and development of oil and gas fields is known as exploration seismology. (Yilmaz, 2001). In exploration seismology, the two main techniques of seismic methods for exploration are:

- Seismic Reflection Method.
- Seismic Refraction Method.

3.1.1 Seismic Reflection Method:

The basic technique of seismic exploration consists of generating seismic waves and measuring the time required for the waves to travel from the source to a series of geophones, usually disposed along a straight line directed toward the source. From a knowledge of travel times to the various geophones, and the velocity of the waves, one attempts to reconstruct the paths of the seismic waves.

Structural information is derived principally from paths that fall into two main categories: refracted paths in which the principal portion of the path is along the interface between two rock layers and hence is approximately horizontal; and reflected paths in which the wave travels downward initially and at some point is reflected back to the surface, the overall path being essentially vertical. For both types of path, the travel times depend on the physical properties of the rocks and the attitudes of the beds.

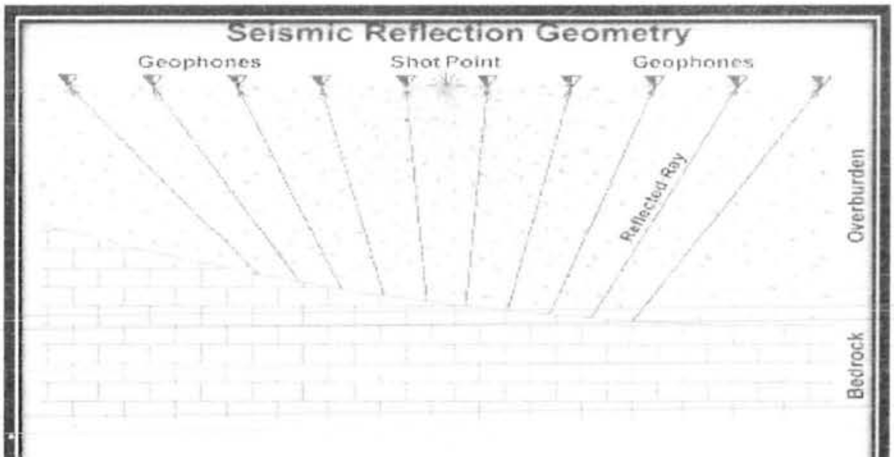

Figure 3.1 (Seismic Reflection Geometry)

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.

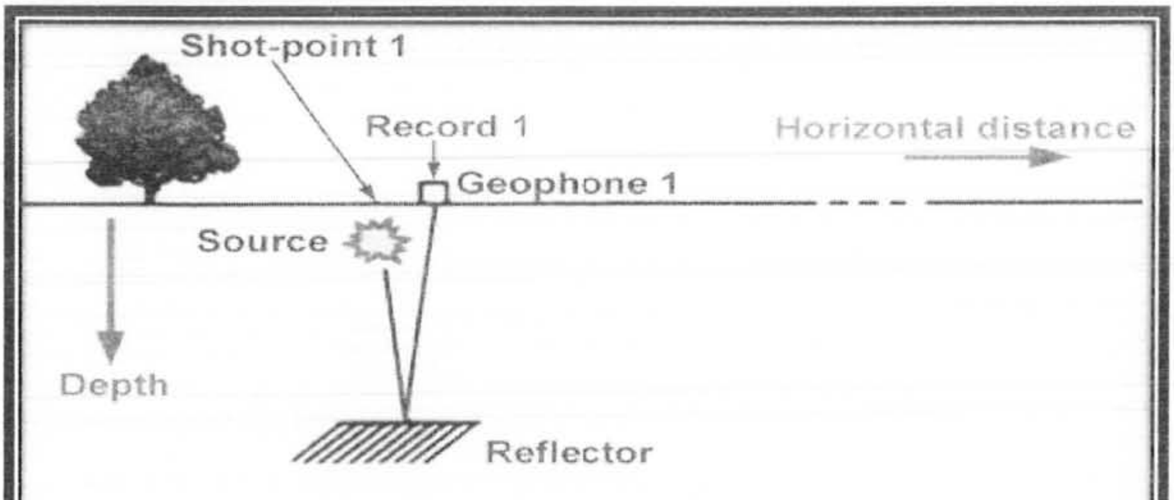

Figure 3.2 (Basic layout for Seismic Reflection Acquisition)

Fundamental Law of Reflection:

This law states that "the angle of incidence is equal to the angle of reflection. That is the angle at which the wave is strikes a surface is equal to the angle at which the wave is reflected back in the same medium. Mathematically it can be written as;

□i = □r;

Where □i is the angle of incidence and □r is the angle of reflection.

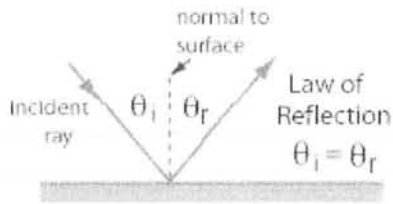

Figure 3.3 (Fundamental Law of reflection)

3.1.2 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) When an incidence wave crosses an interface between layers of two different velocities, the wave is refracted. That is, 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.

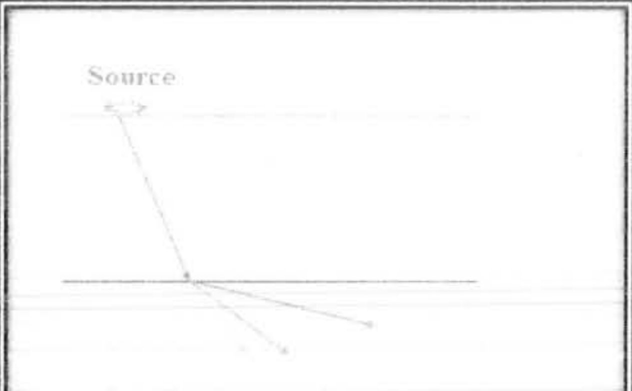

Figure 3.4 (Fundamental concept of refraction)

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. This refracted wave is then the first arrival at all subsequent geophones, at least until it is in turn overtaken by a deeper, faster refraction. The difference in travel time of this wave arrival between geophones depends on the velocity of the lower layer. If that layer is plane and level, the refraction arrivals form a straight line whose slope corresponds directly to that velocity. 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.

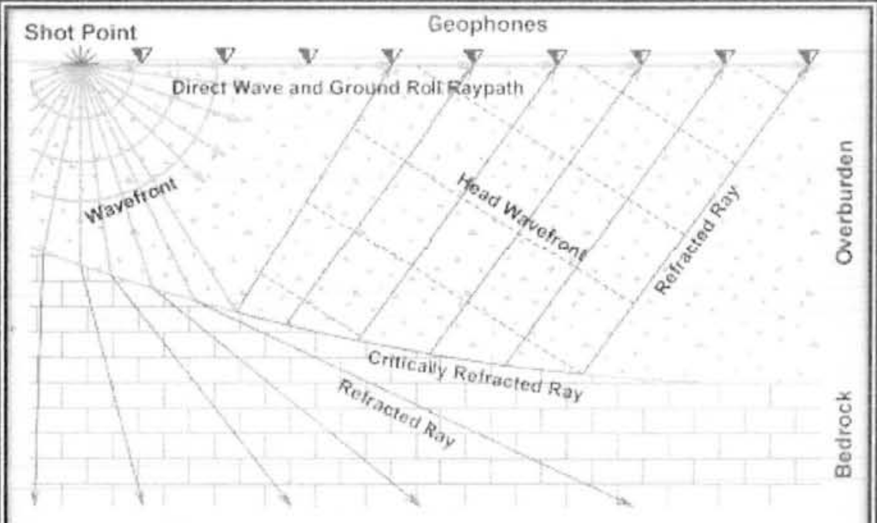

Figure 3.5 (Seismic Refraction Geometry)

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 is the angle of incidence, & r is the angle of refraction.

3.1.3 Critical Refraction:

Every wave from a source in the upper layer when reaches the boundary at different angles of incidence then it continues in the lower layer according to Snell's Law. 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 figure 3.7.

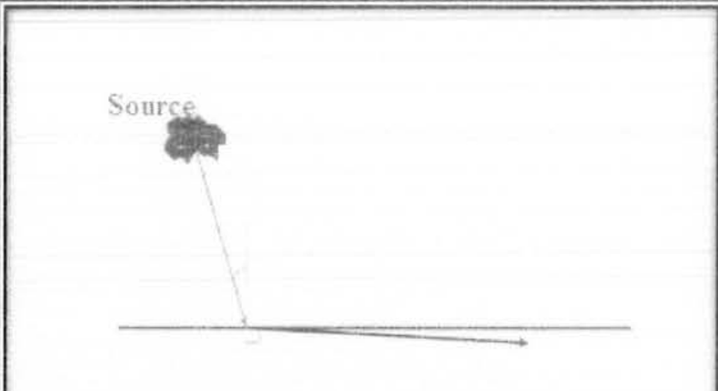

Figure 3.6 (Critical refraction between two Mediums)

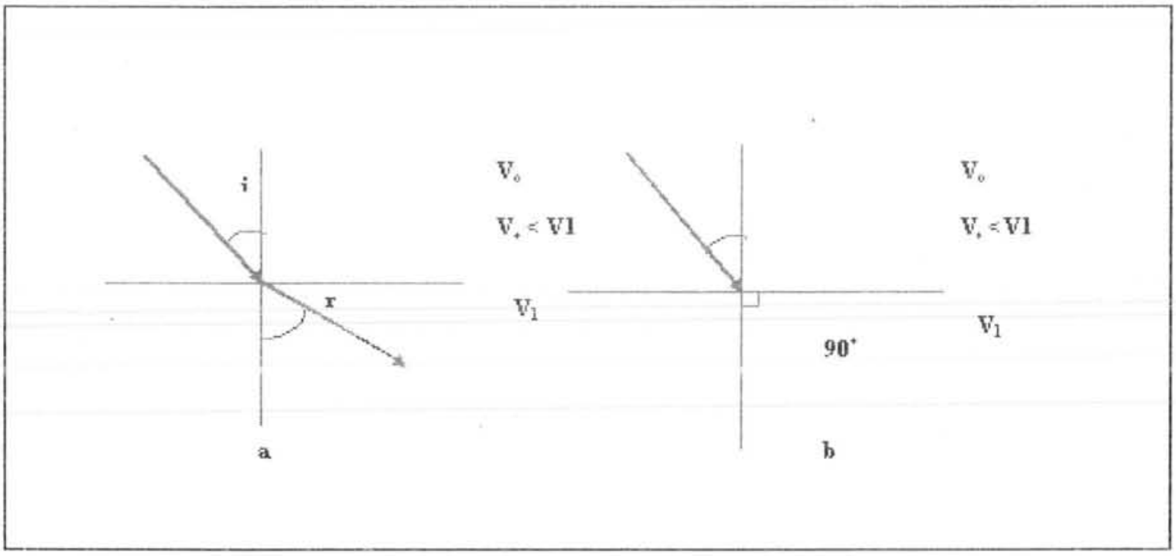

Figure 3.7: showing Refraction and angle of incidence.

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

$$Sin(i)_c = \left(\frac{V_1}{V_2}\right)$$

Where

(i)c = Critical angle.

3.1.4 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)

3.2 Types of Seismic Waves:

There are two major type of seismic waves:

- Body waves.
- Surface waves.

Body Waves:

These are the waves propagating inside the elastic material or these waves are the waves traveling within the medium. There are two types of body waves.

- Longitudinal waves (Compressionl / Primary).
- Transverse waves (Shear / Secondary).

Longitudinal Waves:

These are the waves in which the particle motion is in the same direction in which the wave is moving. These are the waves we seek to generate and record in exploration seismology.

Transverse Waves:

This is the type of seismic wave in which the particle motion is at the right angle to the direction in which the wave is moving.

Relationship between Vp and Vs:

Both Vp and Vs are interrelated as

$$\frac{V_p}{V_s} = \frac{K}{\mu + 4/3}$$

For most consolidated rocks Vp / Vs is between 1.5 - 2.0.

Surface Waves:

At the free boundary of the medium there may be the surface waves of two types.

- Rayleigh Waves.
- Love Waves.

Rayleigh Waves:

The surface waves of most interest in seismic work are called Rayleigh waves and occur as ground roll along the air-rock interface.

Love Waves:

These waves are only observed when there is a low velocity layer overlying a medium in which elastic waves have a higher speed. The wave motion is orizontal and perpendicular to the direction of propagation.

3.3 Laws Governing the 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:

According to this principal, "Every point on a wave front is a source of new wave that travels away from it in all directions" Figure 3.8 shows the generation of wave fronts by succeeding waves. "A wave front is the line or curve of crest and troughs."

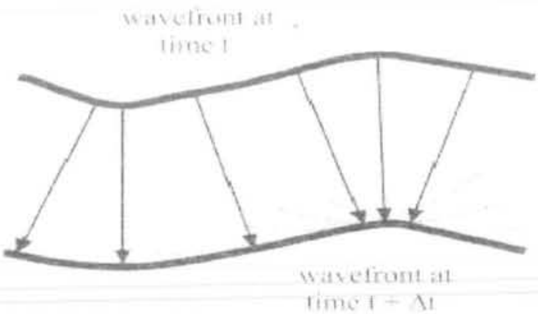

Figure 3.8: (Huygens's Principle) (Robinson &Coruh,1988).

Fermat's Principle:

It states that "elastic waves travel between two points along the paths requiring the least time". (Robinson & Coruh,1988).

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".

$$\left(\frac{Sin(i)}{Sin(r)}\right)=\left(\frac{V_i}{V_r}\right)$$

Where Vi = Speed of incident wave Vr = Speed of refracted wave.

I = Angle of incident wave.

r = Angle of refracted wave. (Robinson &Coruh, 1988).

3.4 Seismic Acquisition:

Seismic Acquisition:In Seismic activities first step is data acquisition. Data acquisition is to collect the data in field, using well-defined field parameters like source and spread configuration, for required objectives. Seismic data acquisition consists of placing some receivers at different locations and then using them to detect vibration produced by an energy source. The receivers convert the mechanical vibration into electrical current that is transmitted to a recorder, the recorder is designed to preserve information in a form that can be displayed andanalyzed. The aims of all the recording systems and field layouts are essentially designed to enhance signal and reduce noise. The basic field activity in seismic surveying is the collection of seismograms. The acquisition if seismograms involve conversion of the seismic ground motion into electrical signals, amplification and filtering of the signal and their registration on a chart recorder or tape recorder. Modern recording systems utilize digital tape recording so that the data are available in a suitable form for input to computers (Kearey & Brooks, 1991).In addition, seismic data acquisition technique consists of generating seismic waves and measuring the travel time and velocity of the wave from the source to a series of geophones, in a straight line towards the source (Telford et at, 1976).

3.4.1 Seismic Surveying:

In seismic surveying seismic waves are propagated through the Earth's interior and travel time is measured of waves that return to the surface after refraction and reflection at geological boundaries within the ground. Seismic surveying provides a clear and uniquely detailed picture of subsurface geology. It is the most important geophysical surveying method (Kearey & Brooks, 1991).

Classical Shooting Vs CDP:

The classical shooting procedure involves the use of a fixed-shape, which moves along a linear profile at a regular move-u rate. Such a spread is made-up of equal inter-trace distance and a defined offset. In modern reflection survey, however no regularity in the shooting technique is necessary. The profile may be crooked, move-up rate may be irregular and spread configuration need not remain fixed as shooting progress along the line (Al-Sadi, 1980). Figure 3.9 shows classical shooting.

CDP Shooting:

CDP shooting defines the signals associated with a given reflection point in the subsurface but recorded at different shot and geophones positions. CDP data acquisition involves an end spread with an inline off-set sources, such that CDP shooting yields greater number of shot points per unit distance along the line causing repetition of reflection point at an interface. It means there

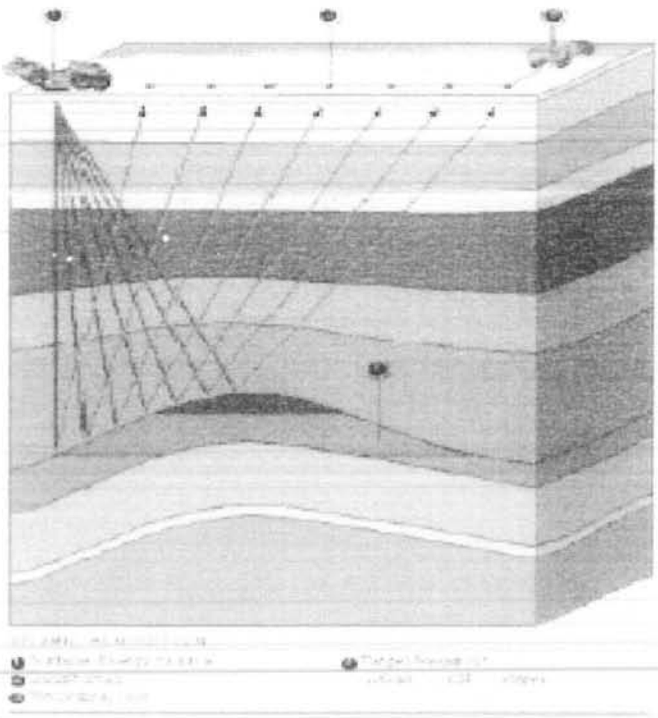

Figure 3.9: Shooting at the field

would be two seismic traces corresponding to that point, so it admits two-fold acquisition or it can be designated as 200% data (Robinson & Coruh, 1988). The data fold can be evaluates from the following relation.

Fold = $N\Delta Y/2\Delta X$

Where

N = Number of recording channels

ΔY= Geophone interval

ΔX= Shot Interval

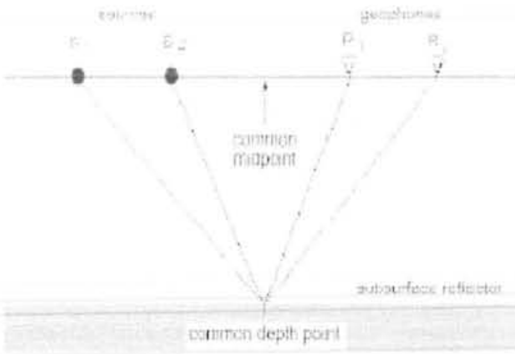

Figure 3.10: Common Depth Point (CDP)

3.4.2 Instruments of Seismic Surveying:

Seismic surveying consists of placing some receivers or geophones at different location and then using them to detect ground vibrations produced by an energy source. The receivers convert the mechanical vibrations into electric current that is transmitted to a recorder, recorder is designed to preserve the information in the form that can be displayed and analyzed. The surveying instruments include the Geophones (receivers), the Cables or other transmitters that connect them and energy sources (Robinson & Coruh, 1988).

Geophone:

Geophone is an electromechanical instrument, which produces an electrical out-put which is linearly dependent on the vertical component of the motion of ground in which it is planted. Geophones are used on land detect seismic ground motions. The most commonly used geophone is a moving coil geophone. Most commercial seismic reflection surveys used geophones with a frequency between 4 and 15 Hz (Kearey & Brooks, 1991).

Seismic Cable:

The geophone signal, which is electric current produced by ground vibration, is transmitted to a recording system by means of a seismic cable. Each geophone requires two wire conductors. At regular intervals along the cable are "Takeout" points where a geophone can be connected to its pair of conductors (Robinson & Coruh, 1988).

Figure 3.11: High precission low Distrotion Seiemic Geophone

3.4.3 *Energy Sources:*

Energy source is one of the most important tools, used to produce seismic waves in the seismic surveys. A seismic source releases a sudden energy, which stresses the surrounding medium. Most seismic sources generate the compressional waves energy that is used in seismic surveying. Generally, a seismic source consists a wide range of frequency, from 1 Hz to a few hundred Hz. There are different kinds of seismic sources that are divided into

- Explosive sources
- Non-Explosive sources.

Explosive Energy Sources:

Explosive energy sources include dynamite and ammonium nitrate, which are available in different sizes. For most seismic surveying the explosive charge is detonated in a hole. The depth of the shot hole can range from a few feet to a few hundred feet dependent on various circumstances (Robinson & Coruh, 1988).

Dynamite:

This is the most common energy source used in seismic prospecting. Normally it is expended inside a drilled hole at a depth ranging from a few meters to several tens of meters. It is placed below the base of weathering layer as it absorbs high frequency components. The amount of charge per shot point depends on the shooting pattern. The charge weight is 10 to 50 Kg of dynamite, as a rough estimation.

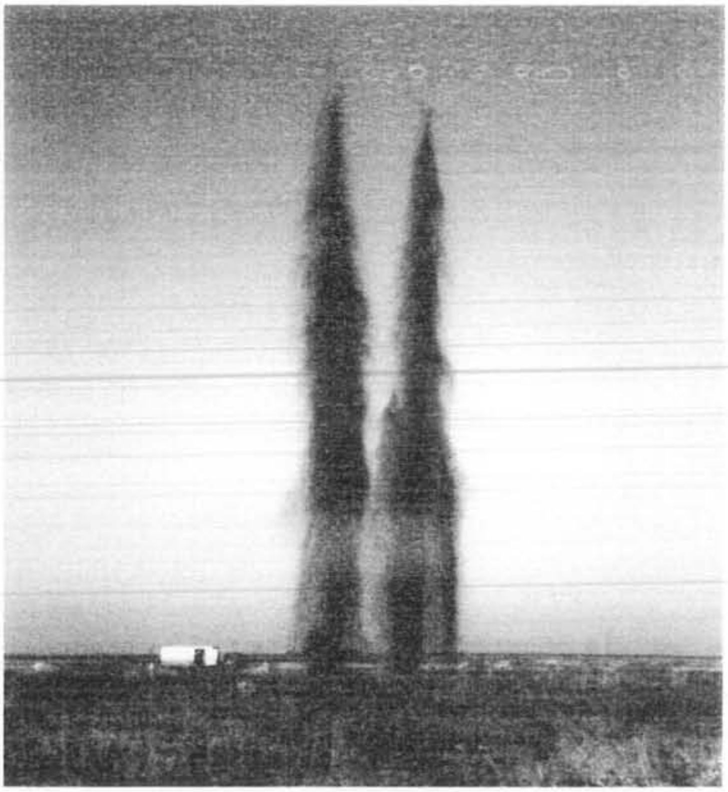

Figure 3.12: Dynamite shot

Non-Explosive Energy Source:

These sources involve mechanical impact upon the earth's surfaces or shaking of the surfaces with a mechanical vibrator. All sources of this type are so disposed in the field that signals received from impacts are applied to the earth over a linear distance comparable to what would be used for a line of shot holes at a shot point or over an area that would be used for two dimensional arrays of shot holes (Robinson & Coruh, 1988).

- Vibroseis
- Geograph (Dropping of weight)
- Dinoseis (By exploding gas mixture by air gun)
- Geoflex (Explosive cord buried in the ground at a shallow depth)

Vibroseis:

Non-explosive energy source is used in the form of a vibrating truck, called the Vibroseis. It used a mechanical vibrator, which is hydraulically or electrically driven to exert a force of oscillating magnitude. One frequency of vibration is called a "Sweep". The sweep time, starting and ending frequencies, usually in the range of 10 to 100Hz, can be set by means of electronic controls (Al-Sadi, 1980).

Air gun:

An air gun is used for marine reflection and refraction surveys. It consists of one or more pneumatic chambers that are pressurized with compressed air at pressures from 2,000 pounds per square inch to 3,000 pounds per square inch .The air gun array is submerged below the water surface, and is towed behind a ship. When the air gun is fired, a solenoid is triggered, which releases air into a fire chamber which in turn causes a piston to move and thereby allowing the air to escape the main chamber and to produce a pulse of acoustic energy. Air gun arrays are built up of up to 48 individual air guns with different size chambers, the aim being to create the optimum initial shock wave with minimum reverberation of the bubble after the first shot.

Gun arrays can be fired in flip-flop mode; typically this would be 48 guns per source, which would be selected and fired alternately. Large chambers (i.e., greater than 70 cubic inches or 1.15 L) tend to give low frequency signals, and the small chambers (less than 70 cubic inches) give higher frequency signals. The air gun is made from the highest grades of corrosion resistant stainless steel.

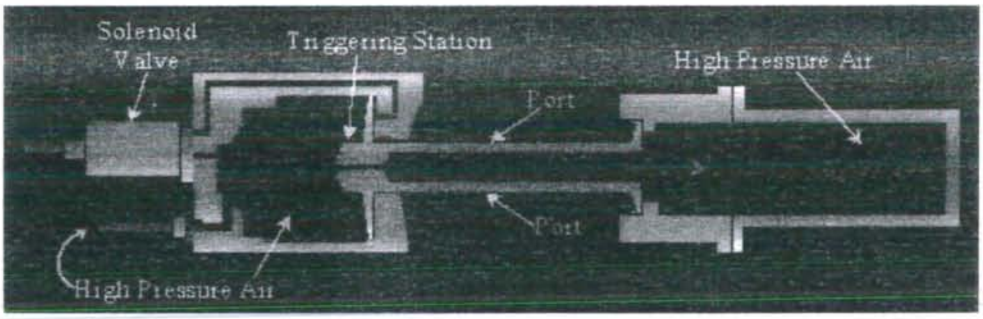

Figure 3.13: Air gun

3.4.4 Recording System:

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

- Analog Recording System
- Digital Recording System

Analog Recording System:

A seismogram is a graph that shows how amplitude of signal varies with time. An analog seismogram is a continuous record of ground motions as a function of time. The analog recording system is made up of an electric unit normally housed in recording station. Before the signal is recorded by analog system, it can be electronically amplified and filtered. The amplifier is used to increase the strength of weak geophone signals. Some of the signals may be removed by means of electronic filtering before recording the signals. An analog seismic recording system is equipped with a separate amplifier, filter circuit and a magnetic tape for each geophone. These components make up one channel of the recording system.

Digital Recording System:

One of the most significant developments in seismic technology has been introduction of the digital recording in the field. A digital recorder makes use of binary numbers to store the measuring of geophone signal strength. In a multi channel system, each geophone signal is first amplified and filtered by analogue to digital converters (A/D Converter) and a procedure is accomplished by mean of a high speed switch called a Multiplexer. One of the most important advantages of digital seismic recording system is the large increase in dynamic range (i.e. 100 DB) over analogue system (Robinson & Coruh, 1988).

3.4.5 Seismic Noise:

Seismic noise being recorder in the field includes seismic signals and the seismic noise. Noise is divided into two types.

- Coherent Noise
- Incoherent Noise

Coherent Noise:

Coherent noise displays some regular patterns on a seismogram. Often it consists of recognizable waves such as surface waves, refracted waves and multiples that are produced by the source. By examining the patterns of coherent noise, we can devise field procedures to reduce it. There are some sources of coherent noise:

- Multiple reflection
- Refracted events
- Diffraction events
- Ground roll
- Direct waves

Incoherent Noise:

It is also known as Random Noise. It displays no systematic pattern. It many arrive simultaneously from many sources such as wind blowing on trees, from near surface irregularities and inhomogeneties such as boulders, small faulting and also produce due to passing traffic. Incoherent noise displays no systematic pattern on seismogram. There are some sources of random noise, which are:

- Water flow noise

- Small movements with in the earth
- Local noise (people, Traffic etc.)
- Wind noise
- Short wave length propagation noise
- Short wave length propagation noise

Noise Control

The basic tools available for controlling noise in the field include:

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

3.4.6 Spread Configuration:

Spread is defined as the layout on the surface of the geophones, which give recorded outputs for each source. The number of geophones in a single spread is determined by the recording channels of the employed recording equipments. The most common practice followed nowadays is to record 48 to 96 detector output for each shot. The true related to a channel is normally made up of a group of geophones arranged in a certain geometrical configuration. There are many types of spread being used in seismic reflection prospecting. Following are some types of spread configuration.

- End Spread
- Split Spread
- Cross Spread
- L-Spread

End Spread:

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

Split Spread:

The most commonly used is split spread. Geophones are arranged in two opposite lines with the source at the center.

Cross Spread:

In this type of spread the source is placed at the center of two lines of geophone.

L- Spread :

In this type of spread the source is placed at the corner of the two lines of geophone.

Figure 3.14(a): End Spread

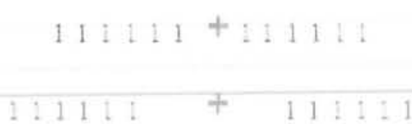

Figure 3.14(b): Split Spread

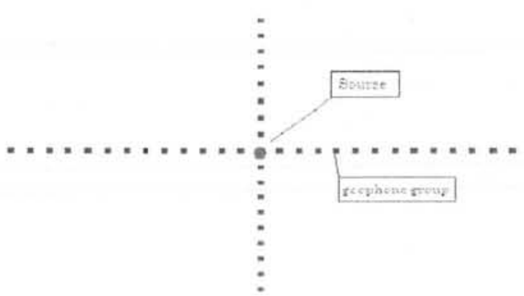

Figure 3.14(c): Cross Spread

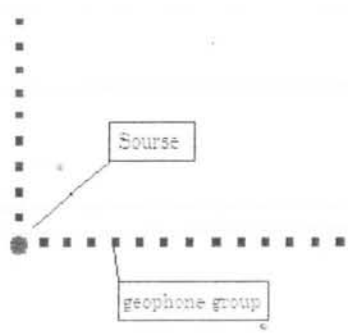

Figure 3.14(d): L-Spread

3.5 *Seismic Data Processing:*

Seismic data processing is composed basically of five types of corrections and adjustments, i.e. time, amplitude, frequency, phase content, data stacking and data positioning, i.e. Migration. The adjustment increases the signal to noise ratio (S/N), correct the data for physical that obscure the desired information of the seismic data and reduce the volume of data that a Geophysicist must analyze. Seismic data are recorded in the field on the magnetic tape. Then this information is transmitted to the interpreter on a seismic section.

Field Tapes ⇒ ***Data Processing*** ⇒ ***Seismic Section***

Seismic data processing strategies and results are strongly affected by the field acquisition parameters. The common midpoint (CMP) recording is the most widely used seismic data acquisition technique. By providing the redundancy (measured the as the fold of coverage) in the seismic experiments, it improves the signal quality (Dobrin & Savit, 1988).

Other conditions such as weather conditions and the condition of the equipment itself can give an influence over the data quality. Hence, we have to suppress the noise and enhance the signal in processing to the extent allowed by the quality of data acquisition. We consider three principal processes in seismic data processing technique.

- Deconvolution
- CMP Stacking
- Migration

In the following discussion basic steps of the generalized processing flow are going to be explained. Figure 3.15 shows a simplified and generalized seismic data processing flow chart (Khan, 2009).

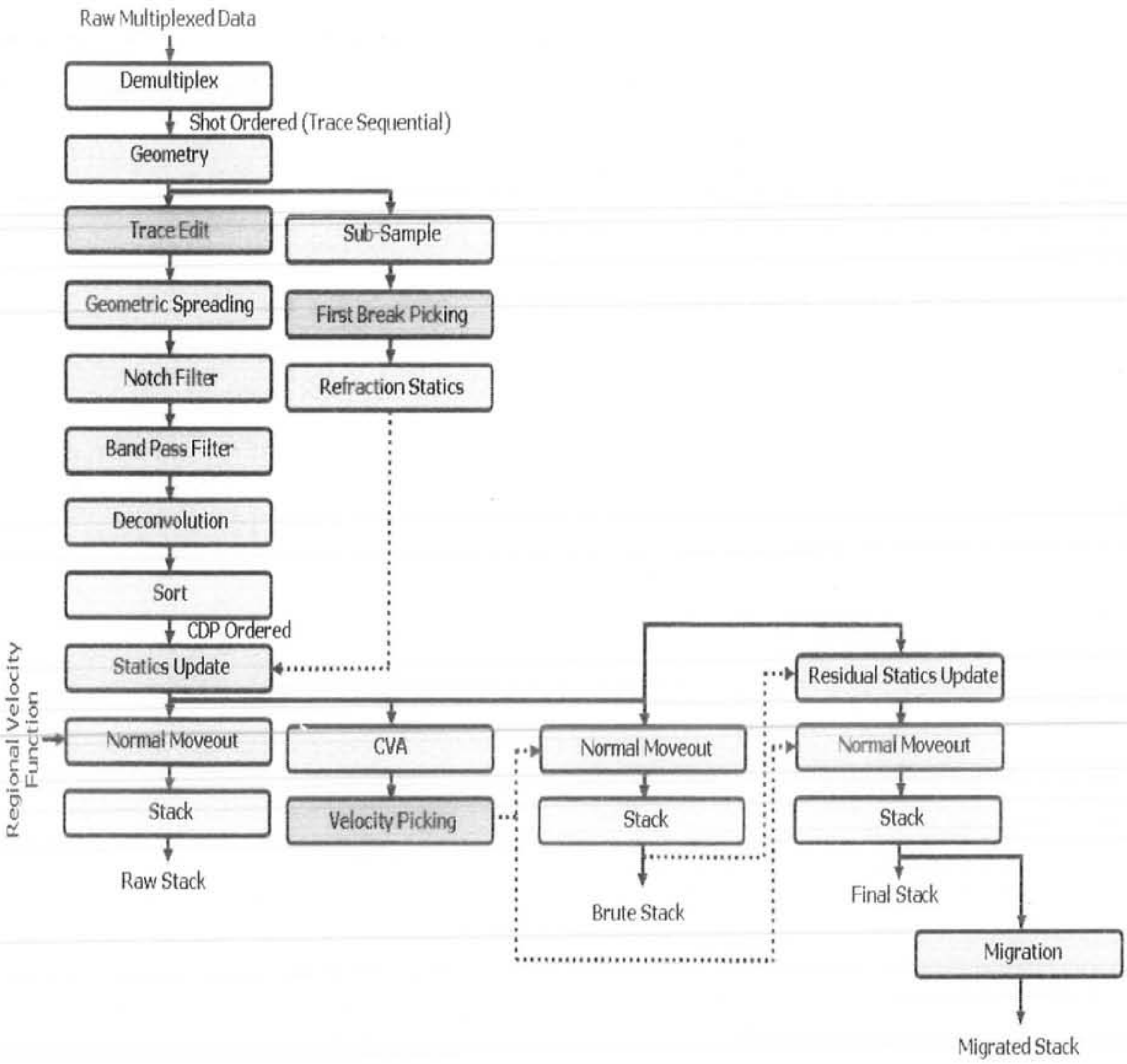

Figure 3.15: Seismic data processing flowchart (Khan, 2009)

Demultiplex:

The process of arranging the time slice data, which is acquired I the field with the action of a multiplexer, in to trace sequential data is known as demultiplexing.

Trace edit:

The processes of editing a trace, due to poor quality of the data some traces need to be edited in order to make the seismic data better.

Filters:

It pass a certain range of frequencies and attenuate the rest.

➢ *Notch filter:*

It is used to remove a noise of known frequency from the seismic data.

➢ *Band pass filter:*

The filter applied in order to allow a specific band of frequency to be shown in seismic data. The frequencies which do not lie in that specific band are rejected.

Deconvolution:

The process used to recover desirable higher frequencies.

Sort:

The process through which Shot ordered data is changed in to common depth point (CDP) ordered data.

Stack:

The process through which all the traces of a single CDP are added up at zero offset and by using a suitable 'stacking velocity'.

Constant Velocity Analysis:

The process through which the velocities are picked at different CDPs to find Root mean square velocities and ultimately a suitable 'stacking velocity'.

Normal Moveout correction:

Also known as dynamic correction, a time shift in the seismic trace. It is applied to remove the effect of increasing offset distance creating a parabolic shape of traces at the same CDP.

Migration:

A process that takes in to account the dip of the reflector, and applies correction to move the reflector in the seismic data to its original position. 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.

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.

- Pre-stack migration
- Post-stack migration

Pre-Stack Migration:

This type of migration is applied before the stacking process is applied, and is more significant as compared to the post-stack migration.

Post-Stack Migration:

This type of migration is applied to data after the stacking process

3.6 *Seismic Velocities:*

Introduction:

An accurate measurement of seismic P-wave velocities in various rock types is a crucial and an important step in seismic data interpretation. The accuracy of the data reduction, processing and interpretation of seismic data depends mainly on the correction of velocity measurements. The velocity of propagating wave depends upon the physical characteristics of the medium.

Root Mean Square Velocity:

When the subsurface layers are horizontal having interval velocities as V_1, V_2,..... V_n and two way time to the respective interfaces as t_1, t_2,....... t_n ; then V_{RMS} for an n layer model is defined as:

$$V^2{}_{RMS,n} = \frac{\sum_{i=1}^{n} V_i^2 t_i}{\sum_{i=1}^{n} t_i}$$

Root Mean Square velocity is always measured from the surface to a perpendicular interface. V_{RMS} may be derived approximately from CDP shooting.

Average Velocity:

Average Velocity V_{avg}, can be simply obtained by dividing depth (h_n) by its travel time (t_n), where n = 1, 2, 3.......k

$$V_{avg} = \sum_{i=1}^{k} h_n \Big/ \sum_{i=1}^{k} t_n$$

V_{vg} is also measured from the surface down to the reflecting surface.

Interval Velocity:

It is the velocity within a chosen time interval and may be expressed as:

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

Where h is the layer thickness and t is two way travel time

Dix's Interval Velocity is obtained by the Dix Formula (Dix 1955) given by:

$$V_{int,n}^2 = \frac{V_{rms,n}^2 T_n - V_{rms,n-1} T_{n-1}}{T_n - T_{n-1}}$$

T denotes two ways travel time to horizontal interfaces and $V_{RMS}$is the Root Mean Square Velocity.

Stacking Velocity:

It is the velocity obtained from the application of normal move out (NMO) correction to common depth point (CDP) gather. The travel time equation for homogeneous two layer model with flat horizontal interface is written in term of horizontal distance source and receiver (X). velocity (V_{NMO}) zero offset two way time to the reflection (T_o).

$$T_x = (T_o^2 + X^2/V_{NMO}^2)^{1/2}$$

V_{NMO} obtained by the equation:

$$V_{NMO} = (X^2 \cdot (T_x^2 - T_o^2))$$

It is the velocity that is used to migrate seismic data.

$$V_{mig} = V_{NMO} \cdot \text{COS}\ \alpha$$

The best migration velocities are the borehole average velocities. Sometimes stacking velocities are straight away used for migration.

Uses of Seismic Velocities:

The seismic velocities may be used to establish the following:

- True depth.
- Stacking of seismic data.
- Migration of seismic data.
- Possible lithology determination.
- Possible porosity estimates.
- Overpressure-zone.

CHAPTER # 4

SEISMIC INTERPRETATION

SEISMIC INTERPRETATION

4.1 Introduction:

The translation of seismic information into geologic terms is called interpretation. This process call for the greatest possible coordination between geology and geophysics, if it is carried out successfully (Dobrin & Savit, 1988). According to Dobrin and Savit (1998) interpretation is the transformation of the seismic reflection data into a structural picture by the application of correction, migration and time depth conversion.

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

Acoustic impedance = interval velocity *density

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

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

So from the discussion above it is very clear that there are two schools of thoughts when it comes to seismic interpretation, earlier it was considered that if the structural interpretation is done accurately and demarcation of a trap is done successfully then there would be a favourable prospect. But due to constant depletion of structural traps, seismic stratigraphic techniques came into play and they have proven to be quite successful over the years.

Here both of these concepts are discussed, keeping in view that, 2-D seismic reflection data is at our disposal to carry out both kinds of interpretational techniques.

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

- Structural Analysis
- Stratigraphic Analysis

4.1.1 Structural Analysis:

The main application of the structural analysis of the seismic sections is in the search for structural traps containing hydrocarbons. An initial interpretation of reflections displayed on seismic section may lack geological control at some point, but the geological nature of the reflectors can be established by tracing reflection events back either to outcrop or to an existing borehole for stratigraphic control. Generally, the structural interpretation is carried out in units of two way reflection time rather than depth, and time structure maps are constructed to display the geometry of selected reflection events by means of contours of equal reflection time. Depth structural contour maps can be produced from time structure maps by converting the reflection time into depth using appropriate mathematical expression involving velocity information.

4.1.2 Stratigraphic Analysis:

Seismic stratigraphy is used to find out the depositional processes and environmental settings, because genetically related sedimentary sequence normally consists of concordant strata that show discordance with sequence above and below it. It also helps to identify formations, stratigraphic traps and unconformity. This method also facilitate for the identification of the major pro-gradational sedimentary sequences which offer the main potential for hydrocarbon generation and accumulation. Stratigraphic analysis therefore greatly enhances the chances of successfully locating hydrocarbon traps in sedimentary basin environments.

4.2 *Time-Velocity Function:*

Seismic section of line PC 9029-86 was provided with 52 time-velocity functions and from shot poin 4161-5361 there are 11 time-function, these functions included time and corresponding root mean square (RMS) velocity, consequently making a time-velocity pair. By using these velocities, interval velocity and average velocity is calculated. Interval velocity is more accurate than the Vrms so the average velocity, which is used to find depth, is calculated by using Vint. With the help of average velocities of different subsurface layers, depth is calculated and so the seismic time section is converted into depth section. Figure 4.1 showing the graph between Time and Root Mean Square (RMS) velocity Functions.

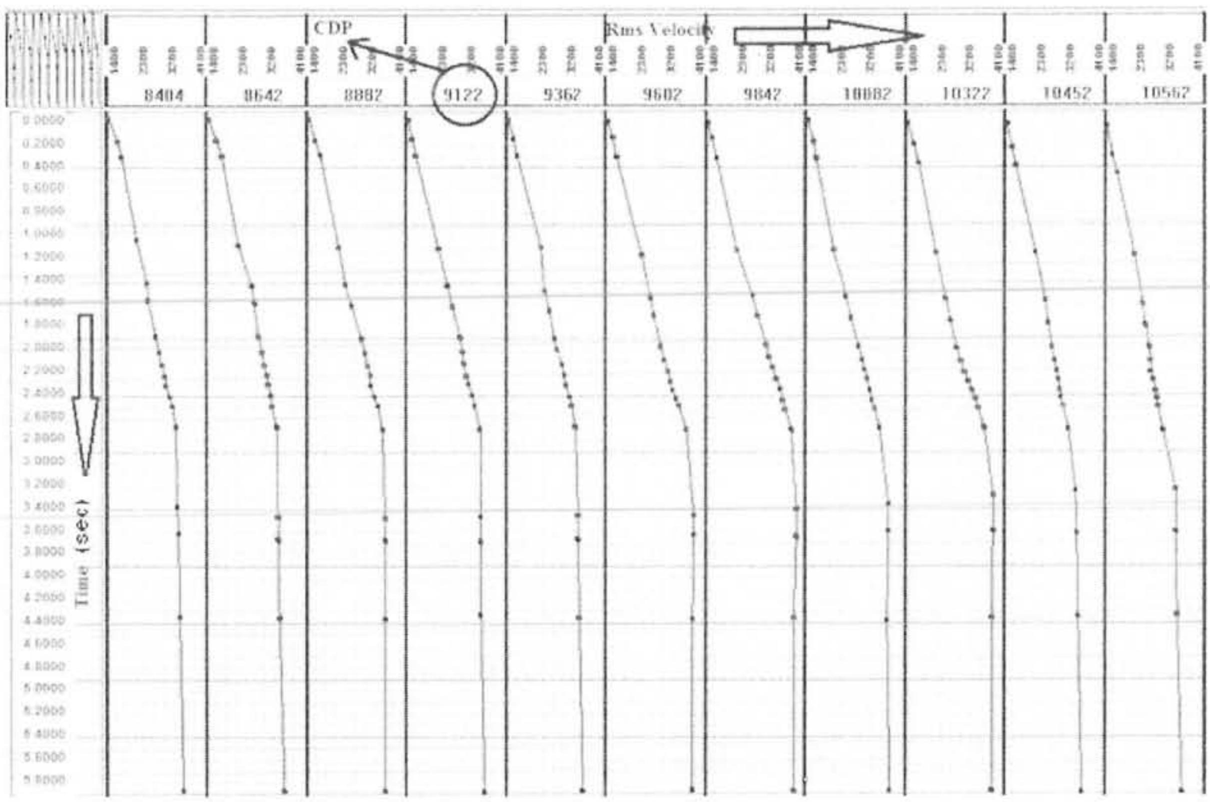

Figure: 4.1 RMS Velocities

4.2.1 *Interval Velocity:*

Interval velocity is the average velocity over some interval of travel path of the wave. It becomes difficult to determine the interval velocity if the reflectors are spaced less than 100m. Interval velocity is important because it is used to determine the lithology, especially across the faults, these velocities is also used to determine the reflection coefficient of any particular reflector. Sonic log also gives us the values of interval velocity. Figure 4.2 showing the graph between Time and Interval Velocity.

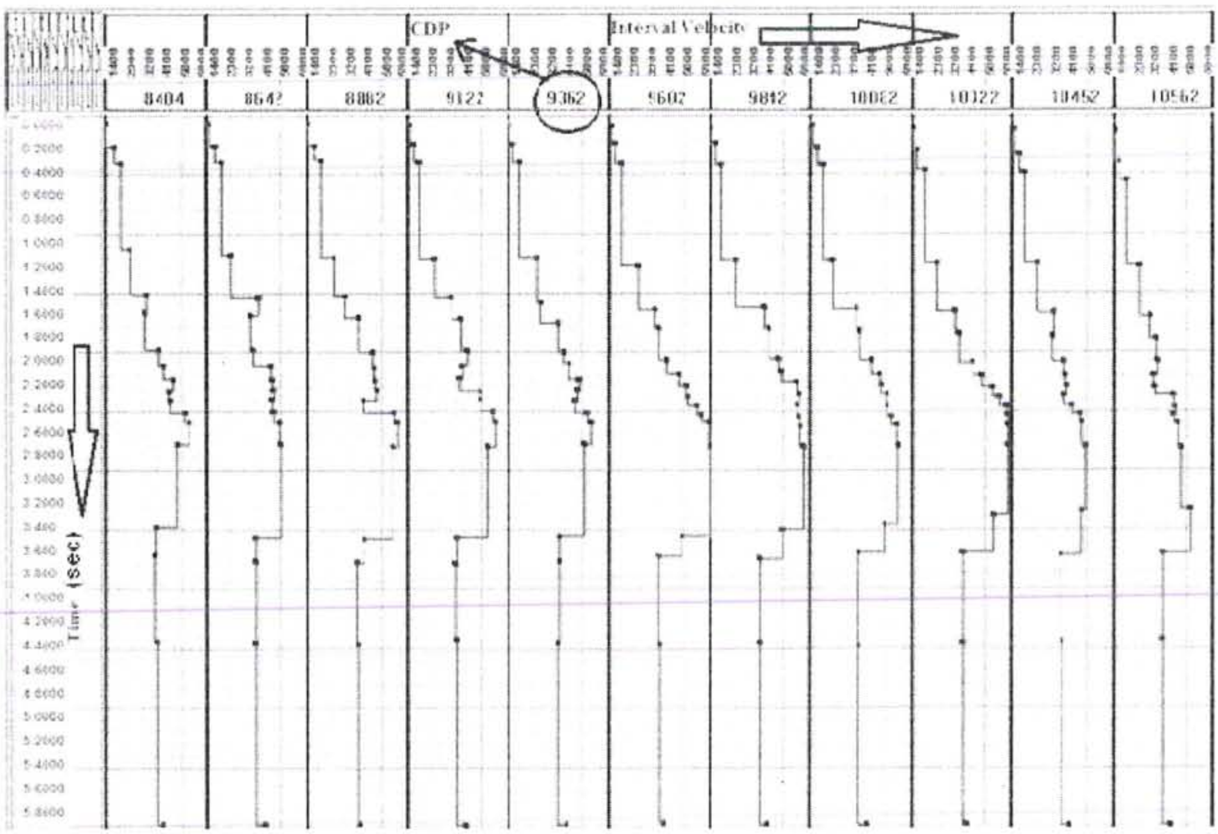

Figure: 4.2 Interval Velocities

4.2.2 Average Velocity:

Average velocity (Vav) is simply the ratio of the depth (Z) of the reflector to one way zero off set travel time (T) of the seismic wave (Dobrin and Savit, 1988). Average velocity is few percent smaller than the root mean square because it deals with layer thickness only not the path direction as in case of root mean square velocity. Interval velocity used that is given in the velocity function to calculate the average velocity at specific interval of time for all the velocity function given in the section.

Average velocity graph is generated between average velocity functions and time as shown in figure 4.3. Average velocity graph shows the variation of seismic velocity with time for each CDP of the seismic section. These different lines shows different behaviors of average velocities with the increasing time at each shot point.

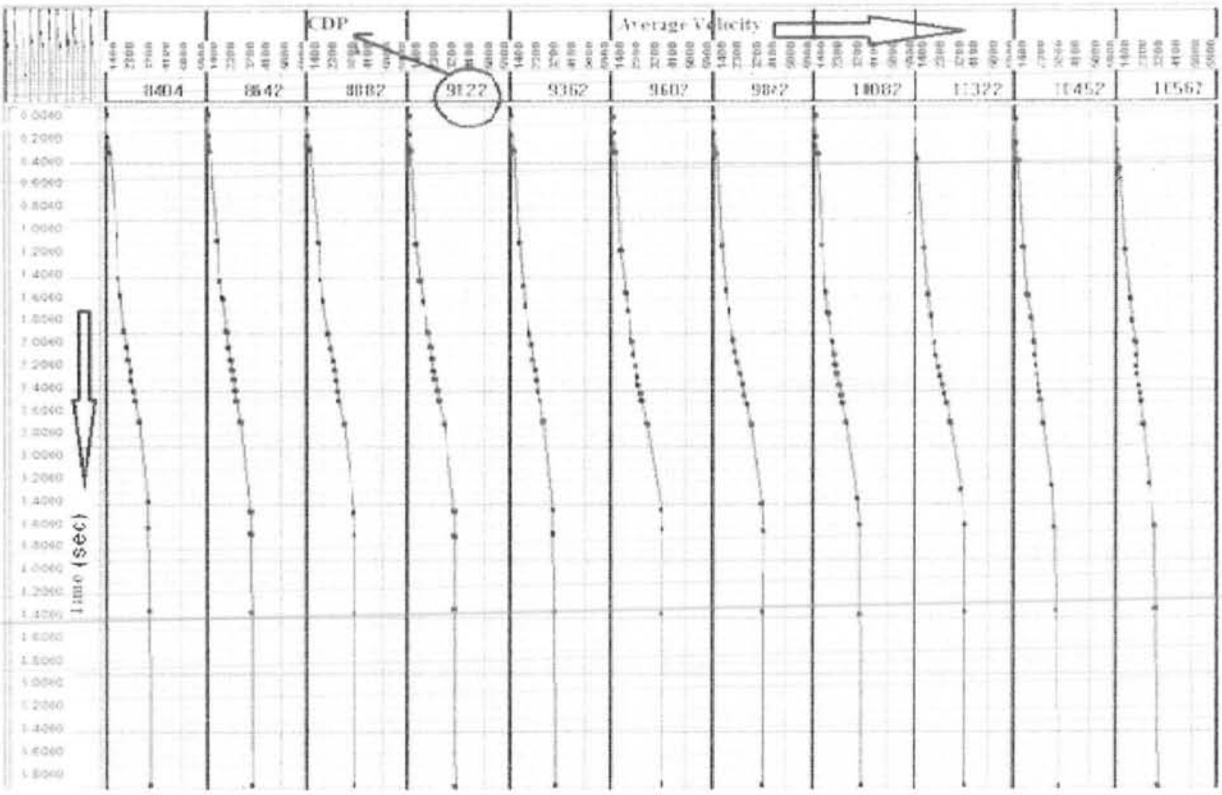

Figure: 4.3 Average Velocities

4.2.3 *Mean Average Velocity:*

This is simply calculated by dividing the sum of average velocities at constant intervals of time with the total number of observations. Mean average velocity represents the mean of all the average velocities at any particular time. Mean average velocities for the given seismic line PC 9029-86 shown in figure 4.4. It shows the overall trend of the average velocity. It is also used to calculate the depth of reflectors at any given time which are used in the construction of depth section.

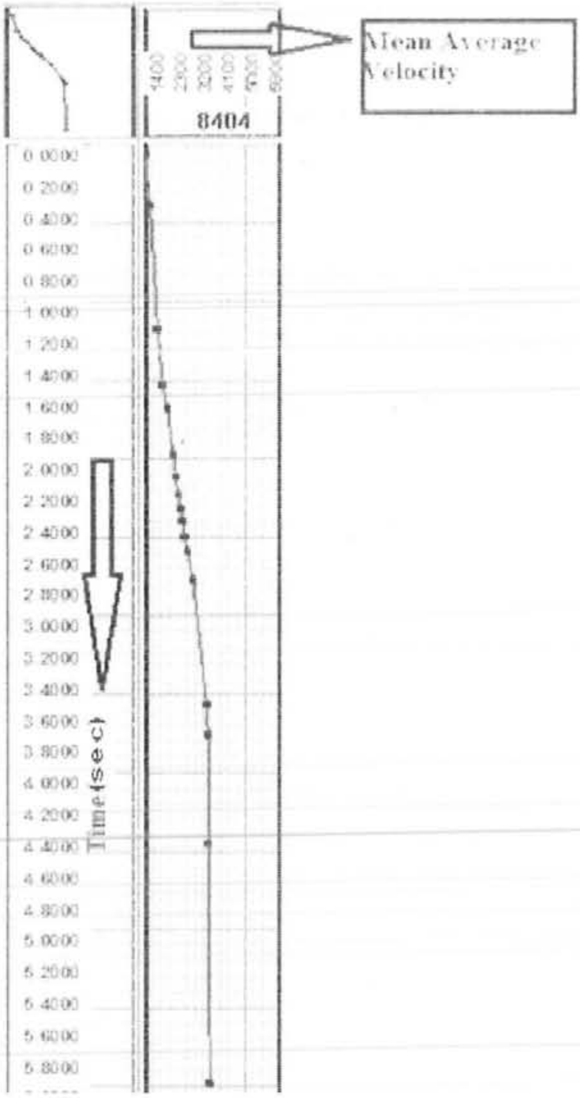

Figure: 4.4 Mean Average Velocity

4.3 *Iso-Velocity Contour Map:*

It is a contour map showing the variation of velocity along the CDPs and time; it is also be regarded as a velocity section. Iso-velocity contour map of average velocity is created, due to its application in time to depth conversion. To create the iso-velocity map following steps are used

- Convert RMS velocities to interval velocities using K-tron VAS.
- Convert Interval velocity function to Average Velocity.
- Save it as a separate *.vel extension file.

- By using K-tron Visual OIL (Khan et al. 2010), convert velocity file into XYZ file, which would be a *.DAT file.
- Using Golden Software Surfer, make surfer grid file from the *.DAT file created earlier by Visual OIL.
- Using the grid file make a contour map.

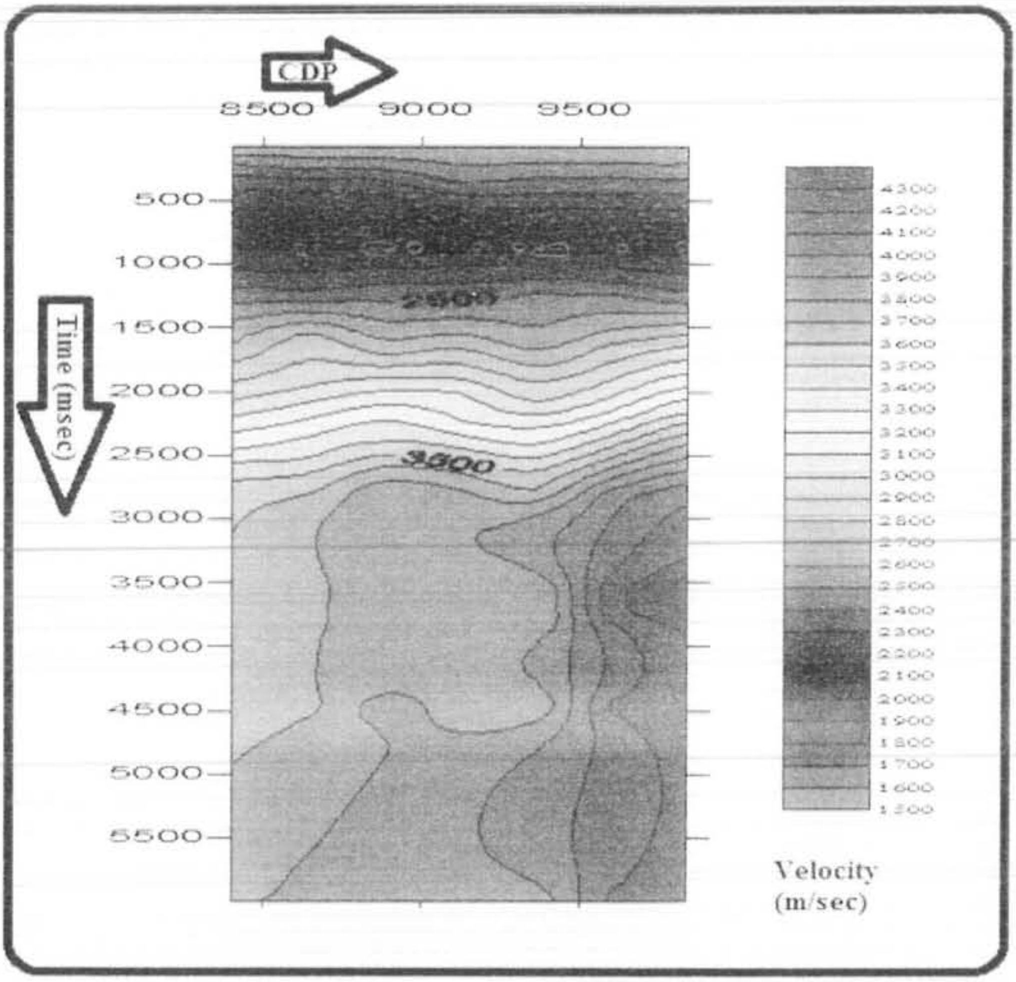

Figure: 4.5 Iso-Velocity Contour Map

By following the simple steps given above iso-velocity map is generated using the software, contours are filled and a clearer picture of the velocity variations is seen. Aim of generating the iso-velocity map is to observe any anomaly in the velocity, which may be regarded as a velocity pull-up or a velocity push down. Iso-velocity contour map of average velocity function is shown by figure 4.5. The map shows lateral as well as temporal change in the velocity and also shows a general pattern of the average velocity that it increases as the depth increases.

4.4 Seismic Section:

The seismic section is simply a diagram of a cross section of the earth, composed of data of individual shots. It is composed of many wiggly lines, called traces. Each seismic section has two scales as shown in Figure 4.6.

- Horizontal scale
- Vertical scale

Horizontal scale shows the no. of traces/cm and the vertical scale is in msec/cm. The variation in these scales enhances the physical appearance of the seismic section. Each wiggle on the seismic section shows the change in the impedance in the rock body. Each seismic section has its own header, having the basic information about the acquisition and the processing the seismic section. A combination of the wiggles extending laterally is called horizon. The main objective here is picking of the horizon. Fig (4.6) shows the seismic section of the line # PC 9029-86 and my shot points ranges from 4161-5361.

4.4.1 Seismic Horizons:

Using K-tron X-Works software prominent reflectors are marked and then selected those that showed good characteristics and continuity and can be traced well over the whole seismic section, are marked. There are difficulties in continuing the reflectors at the end of the seismic section and confusions are arrived where reflectors are mixed that may be due to sudden change in lithology, seismic noises, poor data quality or presence of Salt in the subsurface at these locations. The seismic data was interpreted using K-tron X-Works application which provides interactive tools for marking horizons and faults. As seismic data was not available in SEG-Y digital format, therefore it was scanned as an image and its three corners were locked with Data references. In this process we click on the upper left, upper right and lower left corners of seismic section image and assign the CDP/Shot Point numbers and Time information at these points. After referencing the software can pick the horizon time and CDP numbers, similar to an

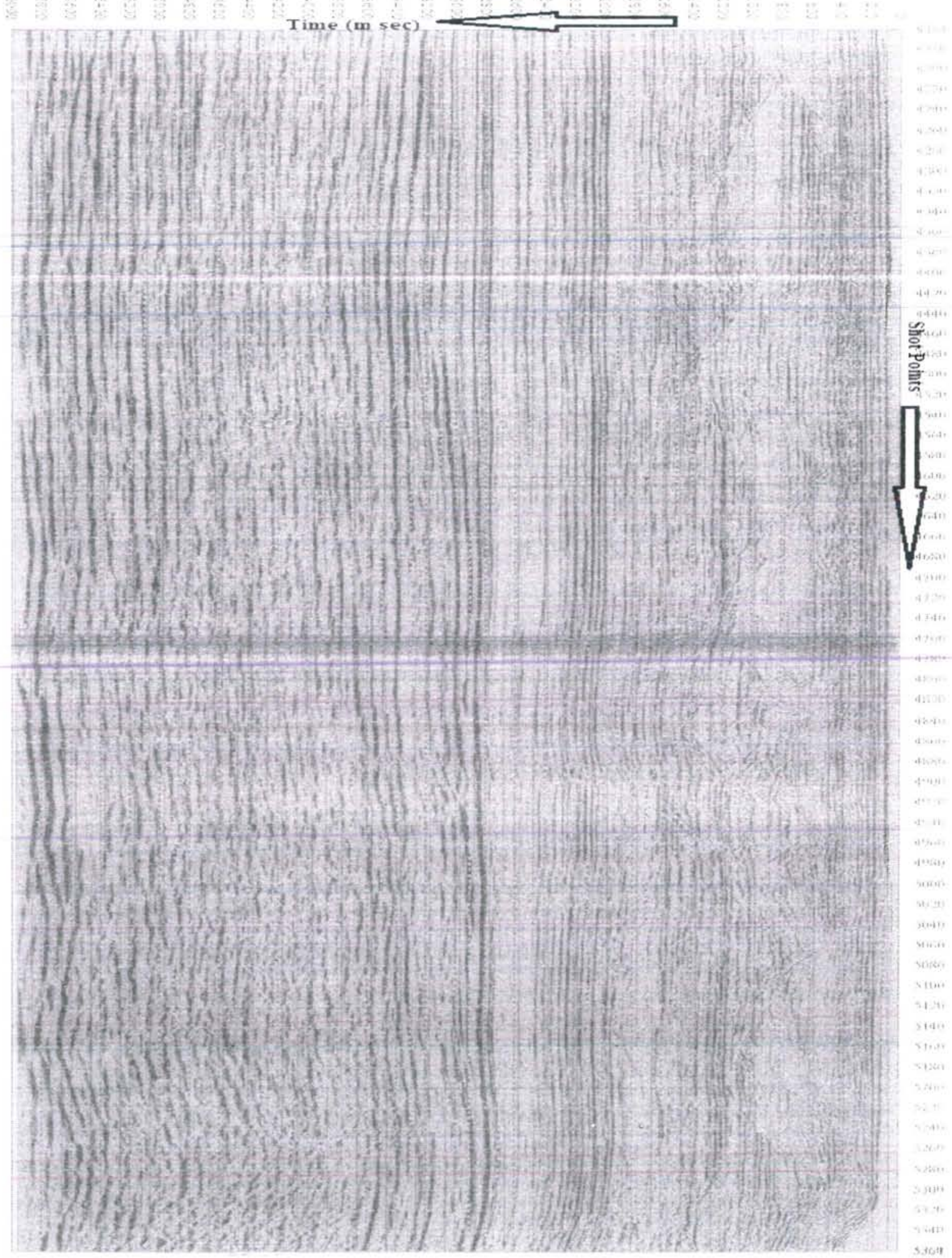

Figure:4.6 Seismic section of the line # PC 9029-86(shot points 4161-5361)

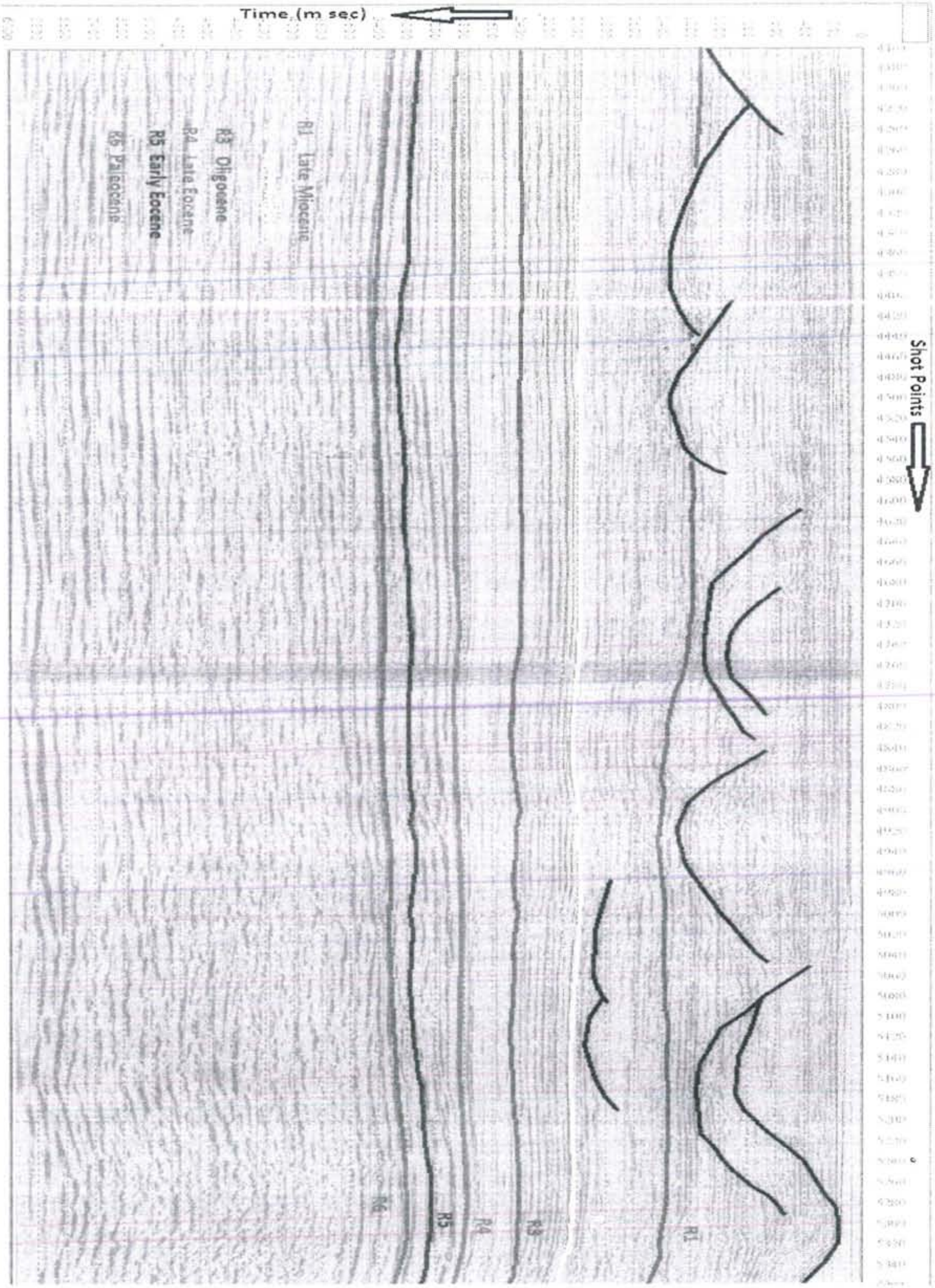

Figure: 4.7 Seismic section with marked horizons of line PC 9029-86 interpretation workstation. The interpreted information is stored in a digital format. Another advantage of the application is that the times for the prospective horizon can be sent to gridding and contouring software for generating time and depth contour maps.

The software can also load the velocity functions and convert the time section into depth section. Since velocity varies vertically as well as laterally it does not apply a regional velocity function. instead it generates a velocity section which is used in time to depth conversion. In Fig 4.6 seismic migrated section is shown where the horizons are easily seen different reflectors on seismic section are marked using the K-tron X-Works software and their time across different shot points is being picked as shown in figure 4.7. In the section mark the six horizons and named on the basis of their ages because there is a mixture of Formation and specific stratigraphy of the interested area is not done and ages are probably followings:

- R1 ***Late Miocene***
- R2 ***Early Miocene***
- R3 ***Oligocene***
- R4 ***Late Eocene***
- R5 ***Early Eocene***
- R6 ***Paleocene***

4.4.2 Seismic Time Section:

Seismic time section is simple reproduction of an interpreted seismic section. Seismic time section is generated by plotting the two-way travel time of the reflectors on y-axis against the source points on x-axis.

Seismic time section of the given seismic line PC 9029-86 is shown in figure 4.8. Time section is the developed section of reflectors, which shows subsurface structure in time domain. In this section mark the six horizons.

Figure: 4.8 Seismic Time Section of line PC 9029-86

4.4.3 Seismic Depth Section:

Vertical unit of seismic section represents two-way time it does not show the true picture of sub-surface structure, so we convert the time section into depth section. Depth section is the conversion of seismic data from time to depth by using the relation.

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

Where

D = Depth

T = Two way reflection time

V = Dix average velocity (in meter/second)

Depth section of the given seismic line is generated by plotting the depth of the reflectors on y-axis against the CDP #s (velocities are the functions of CDP #s) on x-axis as shown in figure 4.9.

4.4.4 Generation of Synthetic Seismic Section:

Synthetic seismic section can also generated using the geological section and synthetic source wavelet. This is done using X Works software; by loading a geological section each horizon is assigned a reflection coefficient, the geological section is convolved with source wavelet to generate a seismic model. Synthetic seismic section of lines is illustrated in figure 4.11. The shape of synthetic seismic section is similar to actual section.

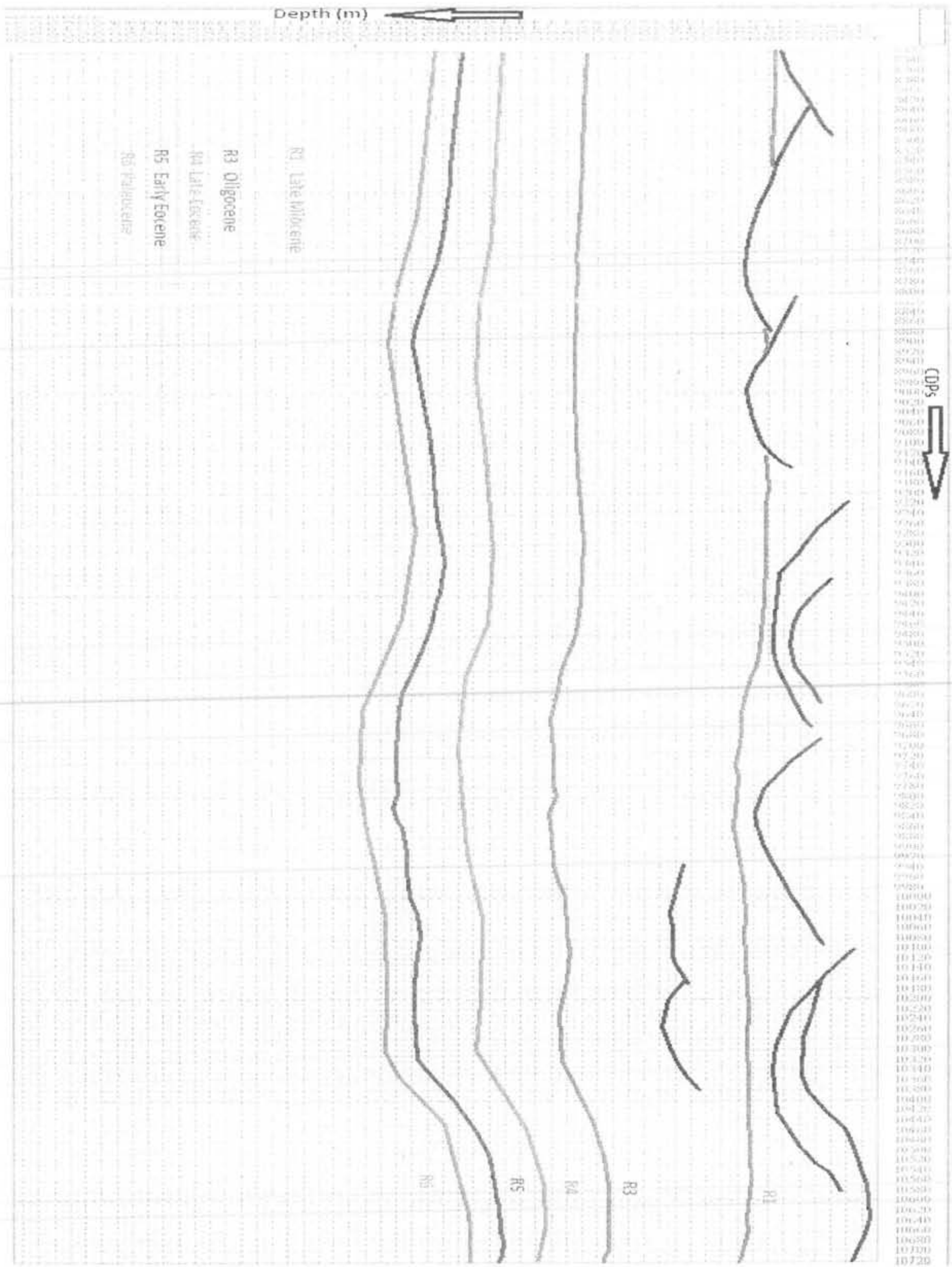

Figure: 4.9 Seismic Depth Section of line PC 9029-86

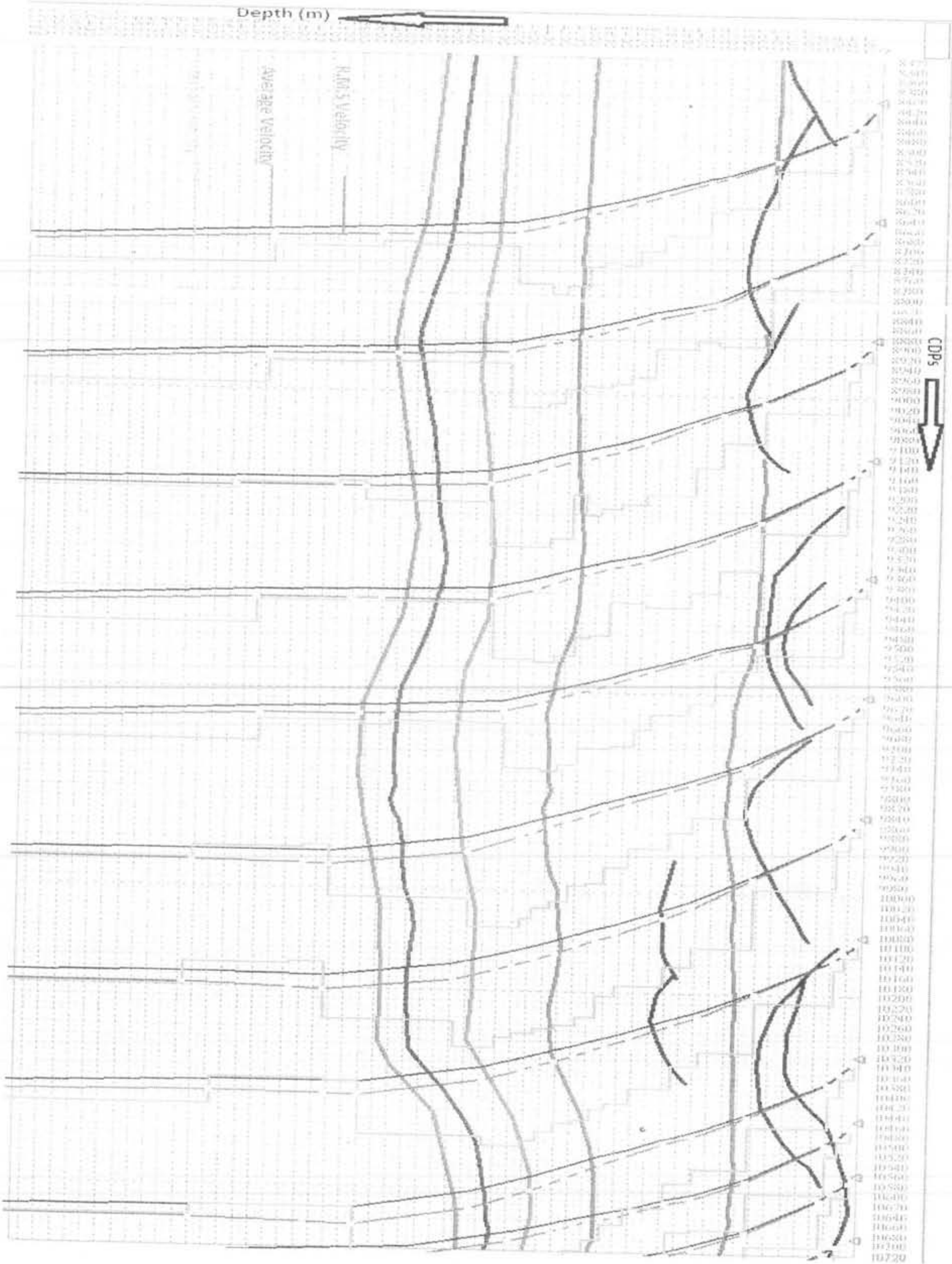

Figure: 4.10 Velocities loaded in X-Works

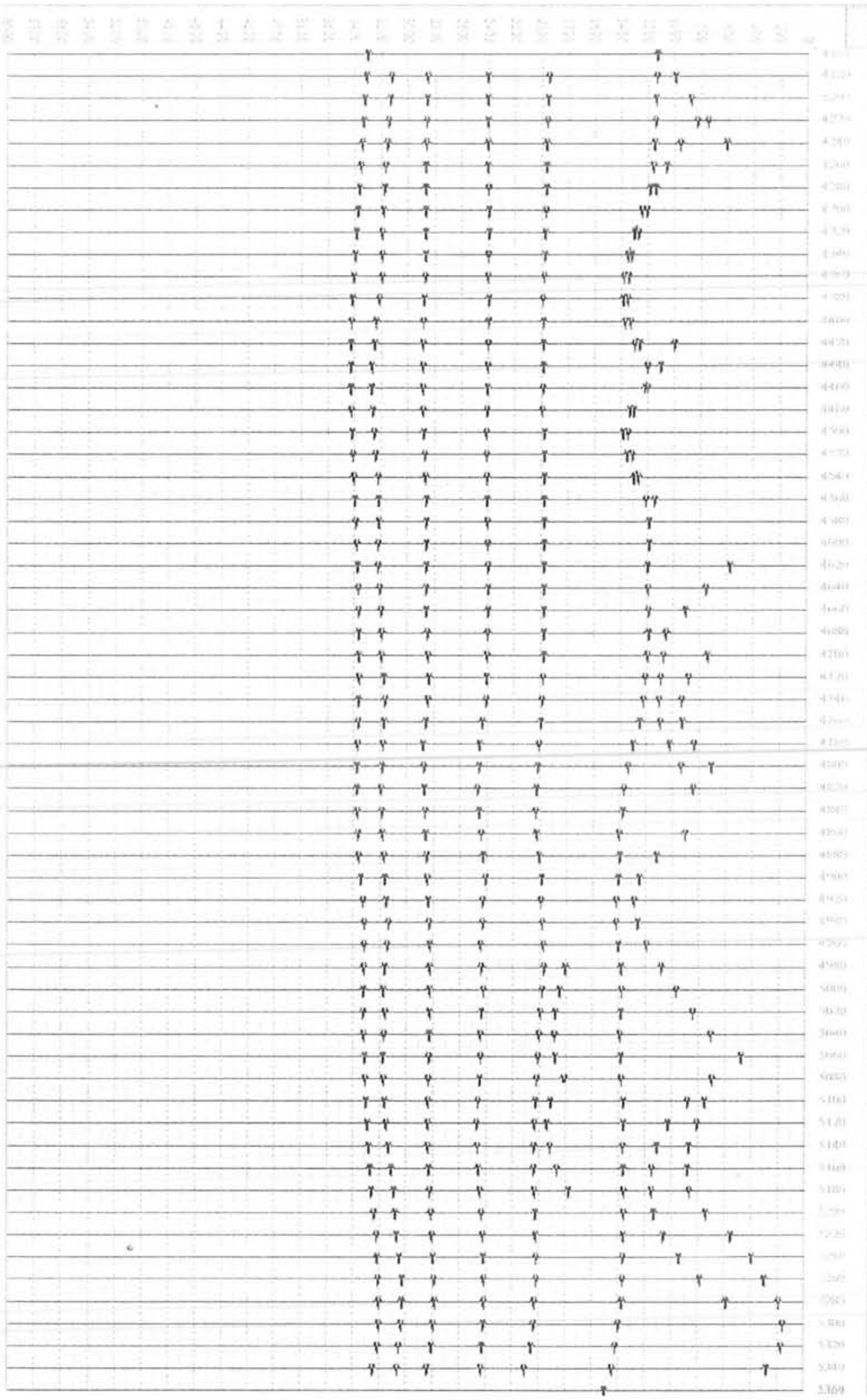

Figure: 4.11 Synthetic seismic section

4.5 Contour Map:

Contour lines are representative of the same events. Proficiency in contouring is the quest for a two dimensional representation of a three-dimensional surface is a basic skill that should be in the armory of every exploration. Contouring attempts to accurately depict shape by honoring data values, it also endeavors to convey geological message that shape may carry. For the contouring of the Time & Depth data of available lines we proceed as follows;

- First of all, we need navigation **dbo** file of these particular lines.
- Then load the marked sections of all lines in the X-Works and load the **dbo** files of all the lines that are used in contour map.
- Export the time of Top Lower Goru Formation of all the lines. This will save as **xyz** format.
- Convert the **xyz** file into **dat** format by using Visual Oil software then out put of Oil is used in Surfer software to make contour map

4.5.1 Time And Depth Contour Map of Miocene:

Contour is the representative of equal value for some particular event. In this context time contour map represents the lines where the arrival time (two way time) is same. Also the depth contour map represents same depths. The time contour map shows that where the contours are closer and tend to merge in each other. .

The depth contours give a real picture of the subsurface and also in these contours, same trend can be seen; which confirm the faulty subsurface picture. The contour also shows the Canyons and valleys on shallow depth which are due to the discharge of Indus river and also due to fluctuations in the sea level.

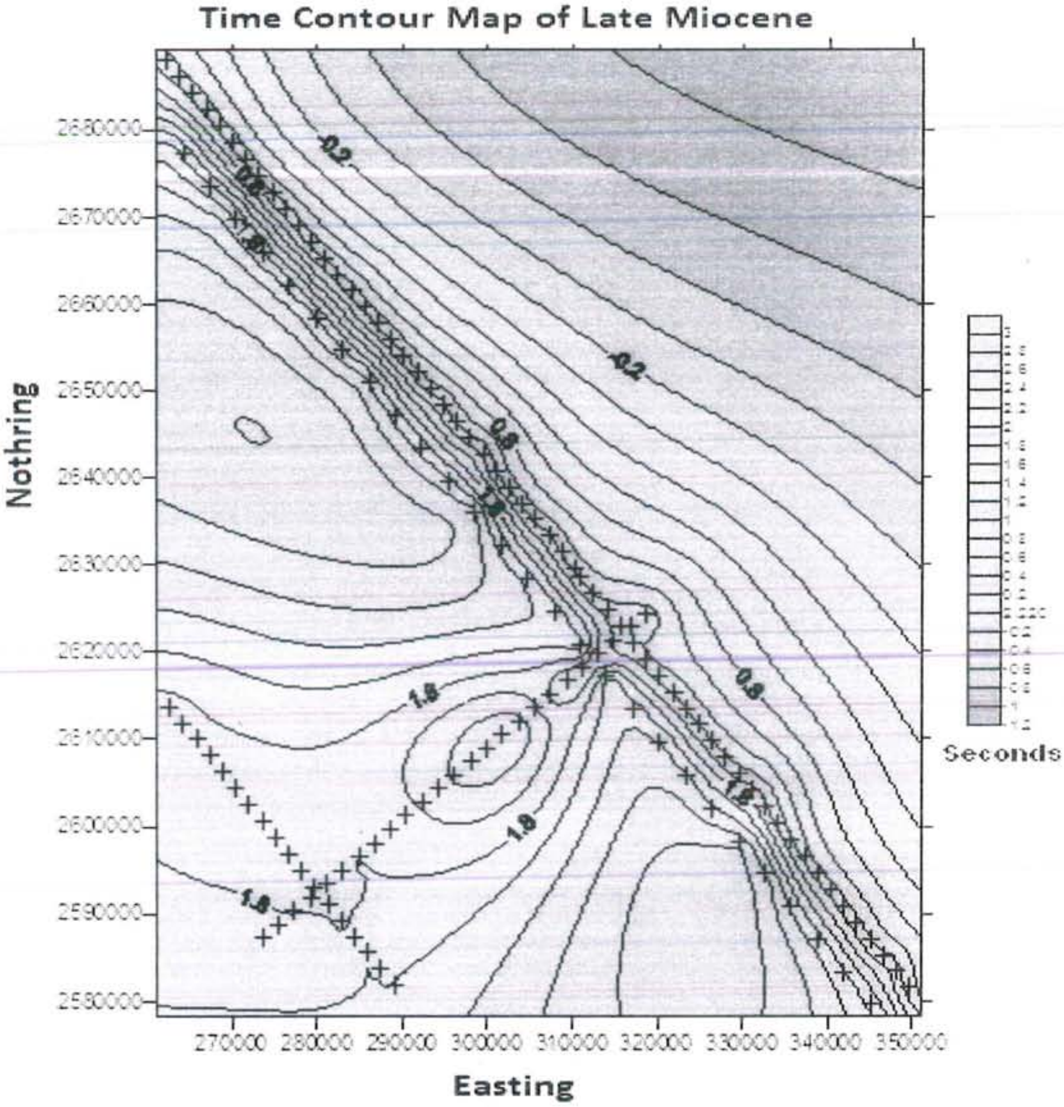

Figure: 4.12a Time contour map of Late Miocene

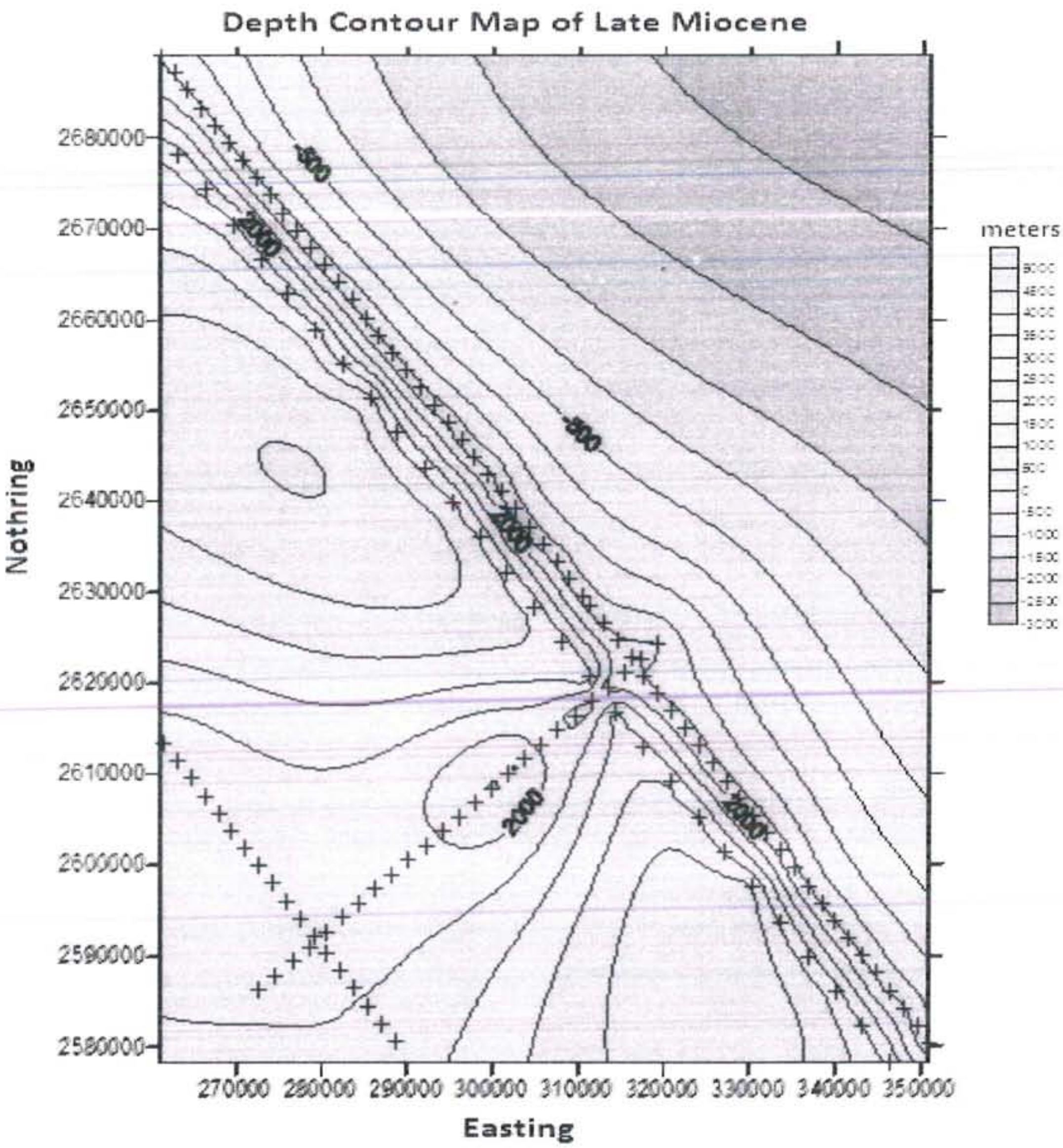

Figure: 4.12b Depth contour map of Late Miocene

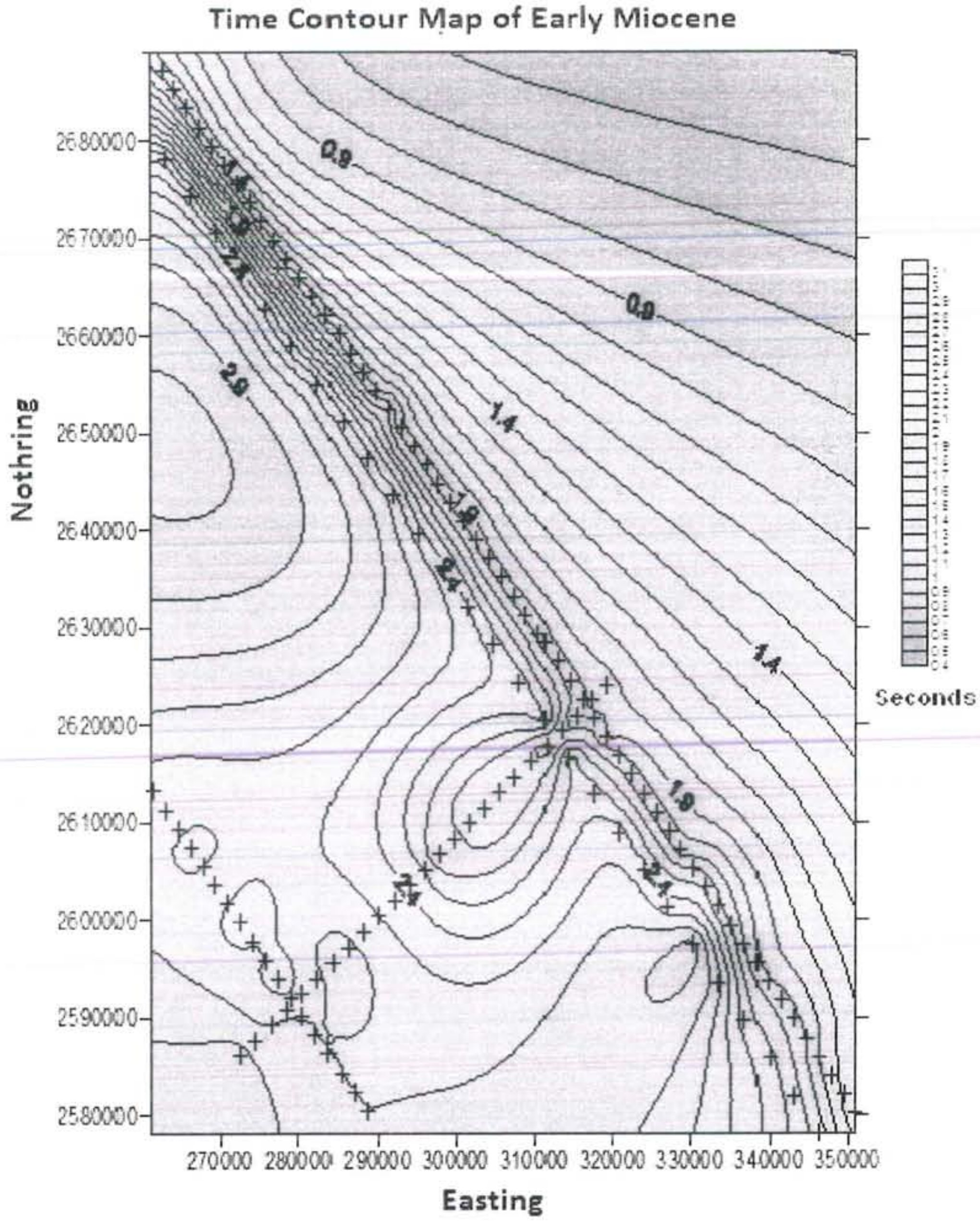

Figure: 4.12c Time contour map of Early Miocene

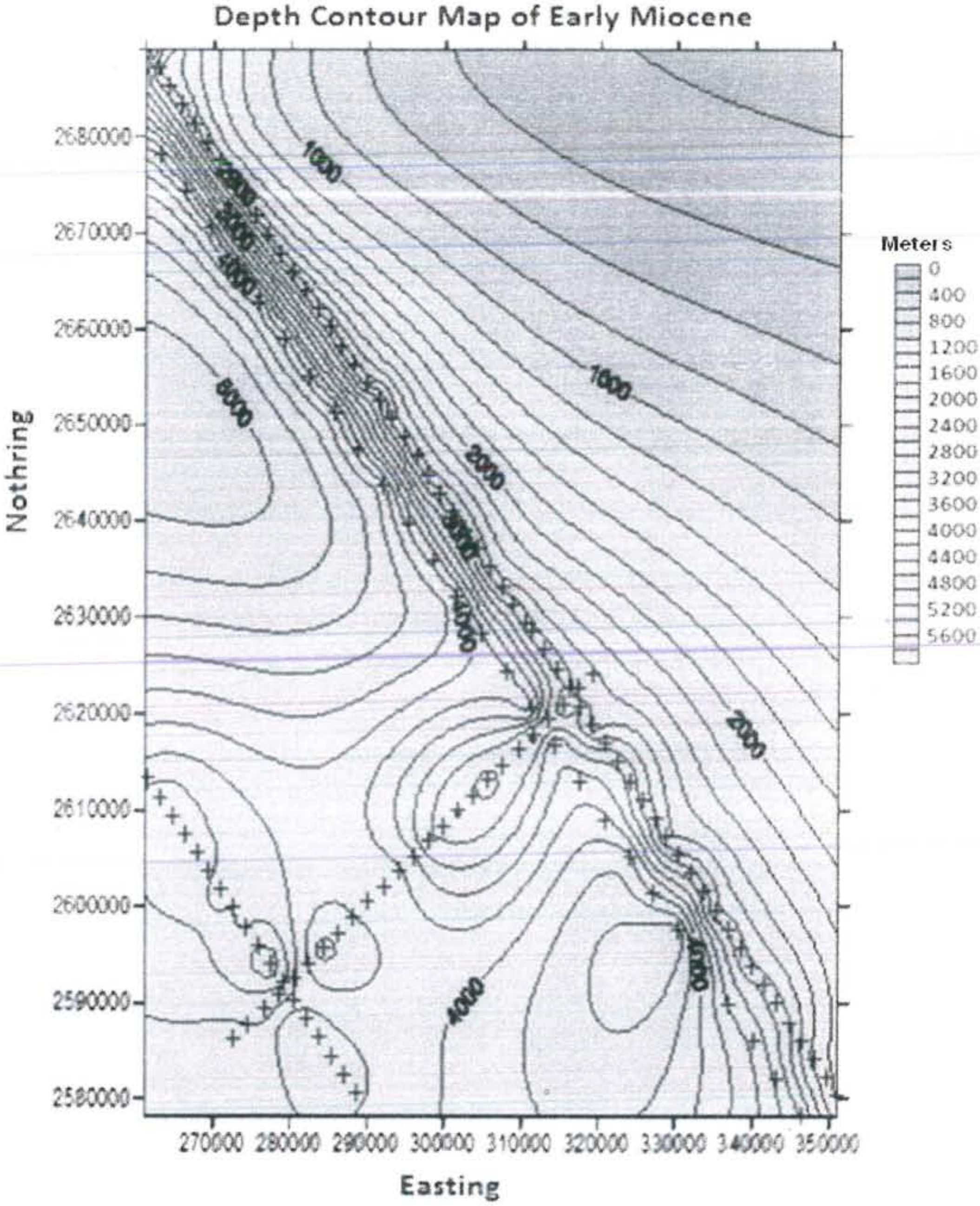

Figure: 4.12d Depth contour map of Early Miocene

4.5.2 Surface Contour Map of Miocene

Time contours are representative of the subsurface level, having equal time (arrival time), and the time surface map gives the actual picture of subsurface.

Comparison of time surface maps of all the expected formations of the area give a good understanding to know about the exact pattern of the subsurface. Also the depth surface map gives the confirmation of actual subsurface picture.

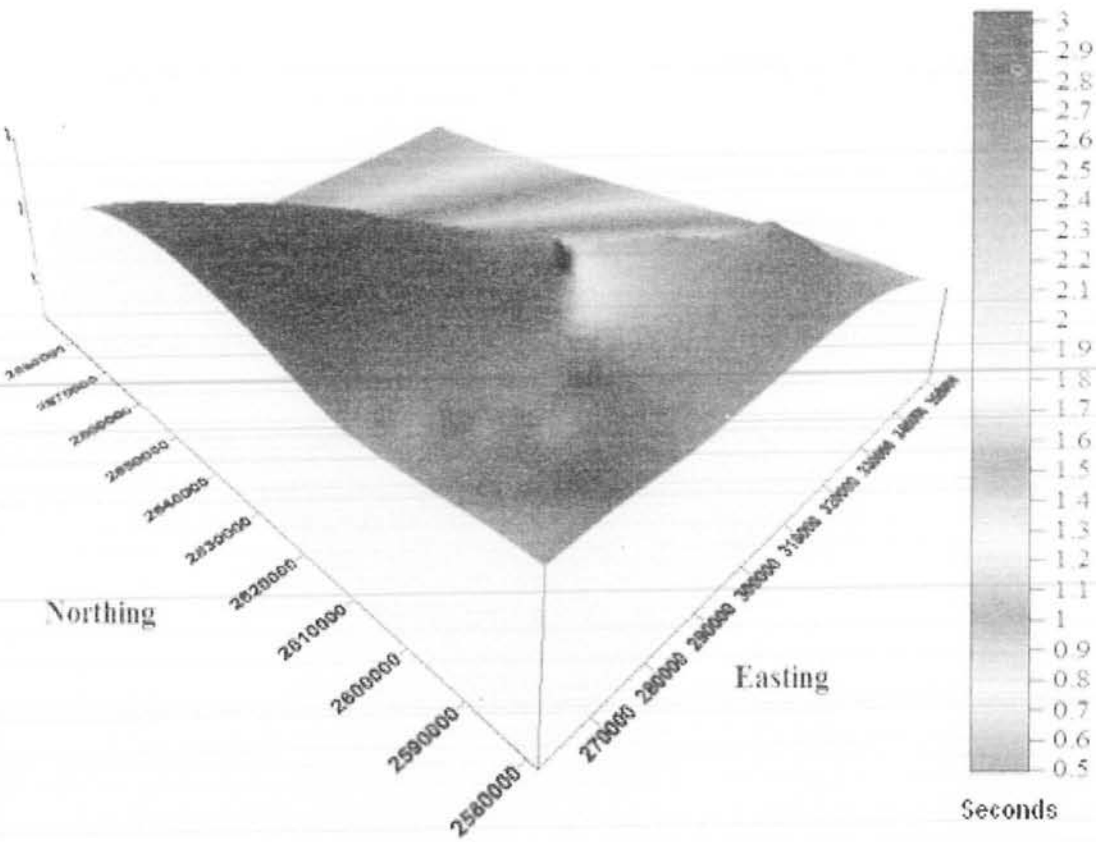

Figure: 4.13a Time surface map of Late Miocene

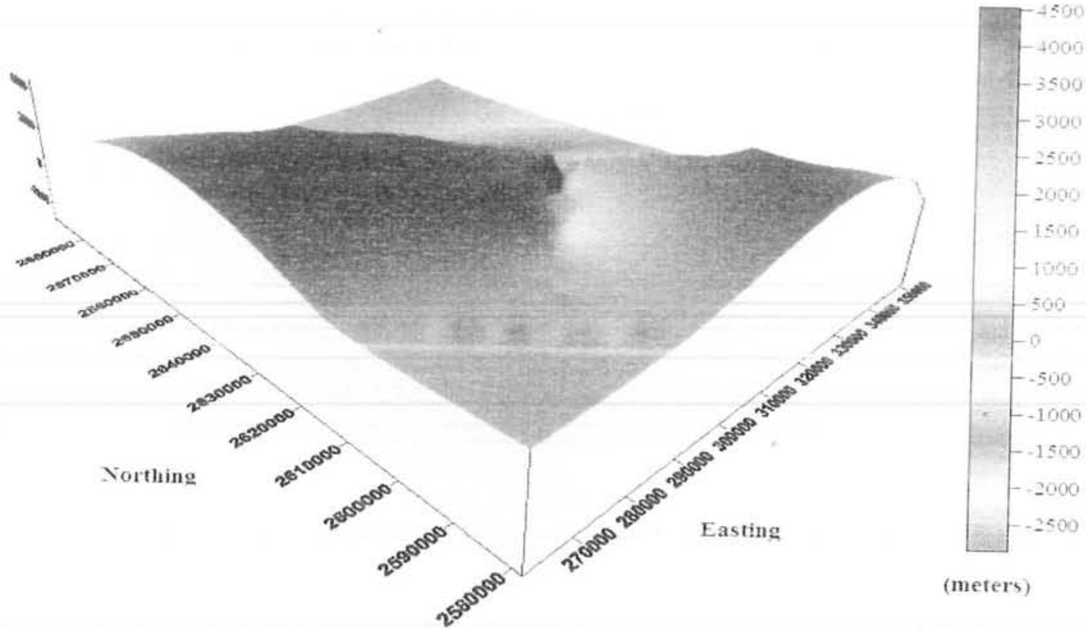

Figure: 4.13b Depth surface map of the Late Miocene

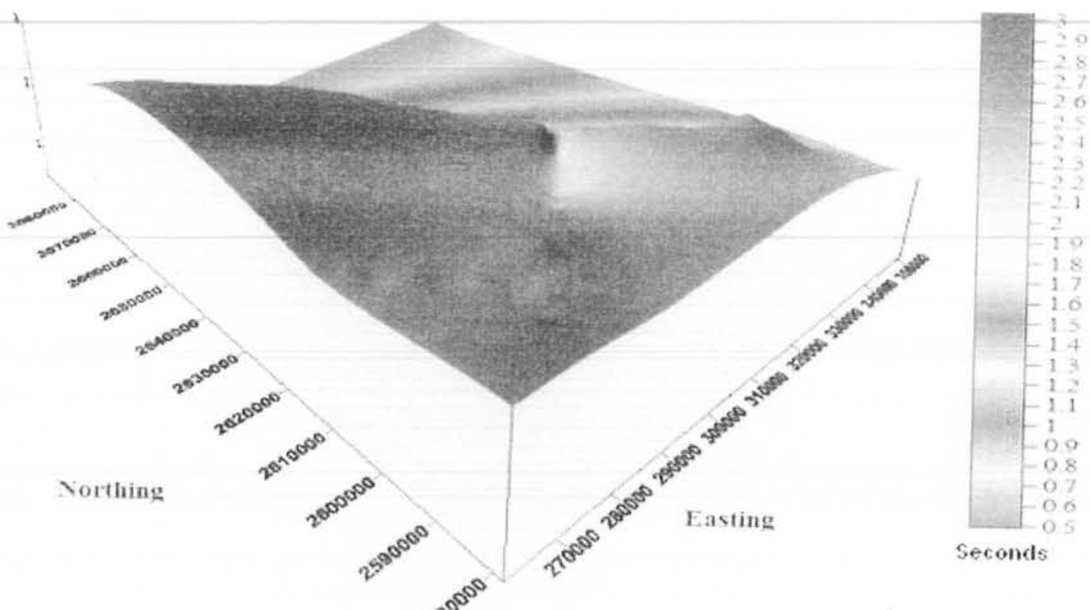

Figure: 4.13c Time surface map of the Early Miocene

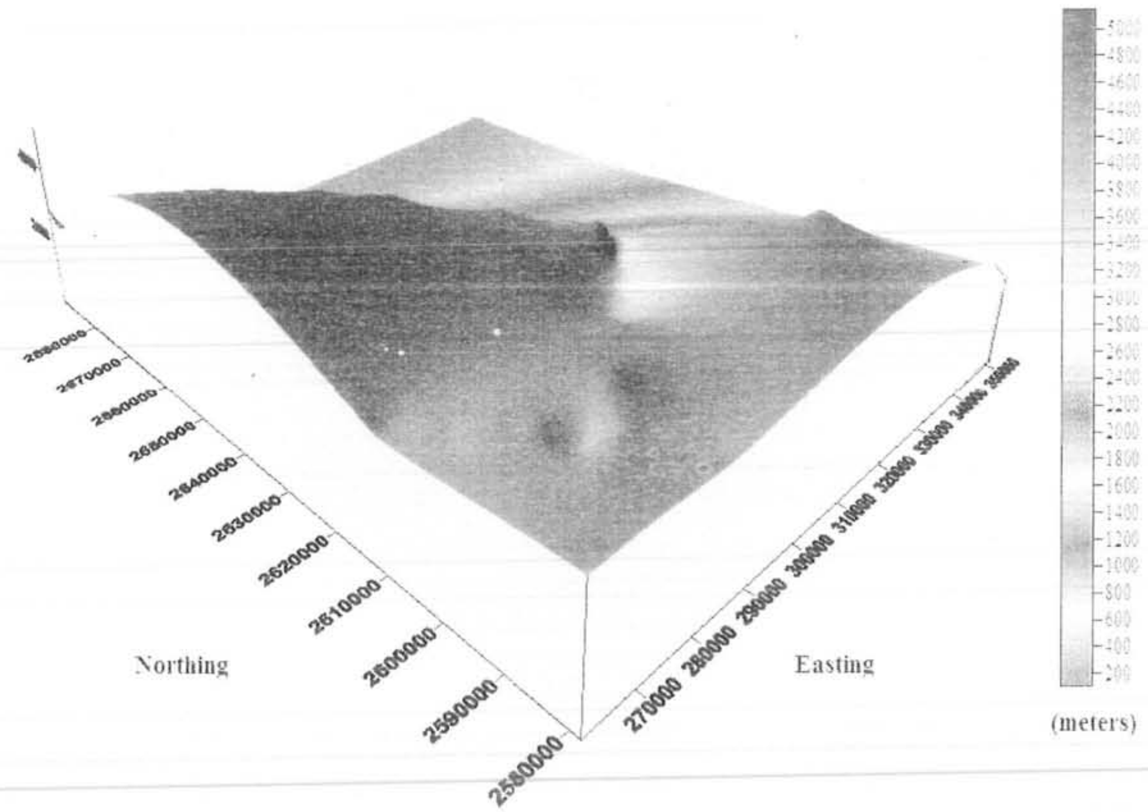

Figure: 4.13d Depth surface map of the Early Miocene

4.6 Conclusions:

Seismic Line **PC 9029-86** of Indus Offshore area is interoperated, which leads to the following conclusions:

- Horizons are marked on the basis of continuity and character of seismic traces and are named as R1, R2, R3,R4,R5 and R6.
- Reflectors were not named because there was no well data available but the possible ages of reflectors were given.
- Reflector R1 may be of Late Miocene.
- Reflector R2 may be of Early Miocene.
- Reflector R3 may be of Oligocene.
- Reflector R4 may be of Late Eocene.
- Reflector R5 may be of Early Eocene.
- Reflector R6 may be of Paleocene.

- Since the area is under extensional Stress so normal faulting is present. The seismic section shows a system of minor normal faults and variety of channel fills, valleys and canyons.
- The Iso velocity map shows the horizental variation in velocity. The horizontal variations are mainly due to the lithological changes.
- Time and depth section shows variable thickness of reflectors
- Time to Depth conversion of seismic section gave a true picture of sub-surface structure.
- 3D Visualization provides relative variation in the six main reflectors.
- The Depth Section is further confirmed by correlation with Synthetic Seismogram.
- The depth contours map gives a real picture of the subsurface.
- Time surface map and Depth surface map gives the actual picture of subsurface.