2D Seismic Reflection Data Interpretation of Tajjal Sindh, Pakistan.

By

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BS Geophysics

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بسم الله الرحمن الرحيم

In the name of Allah,
the Most Beneficent,
the Most Merciful

Acknowledgement

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HUZAIFA FAROOQ

CERTIFICATE OF APPROVAL

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

RECOMMENDED BY

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Dedication

This work is dedicated to my beloved parents

and specially my uncle Mr. Nasir Siddique who spent his

whole life in continuous hard work and to provide

comfort to others.

HUZAIFA FAROOQ

BS Geophysics

Contents

Chapter 1

INTRODUCTION

1.1 An Introduction to Study Area

A country's economy depends upon the resources of that country. Hydrocarbons are among the earth's most important natural resources. Seismic method is the main exploration technique to locate hydrocarbons. Our area of interest is **Tajjal field** located in Lower Indus basin, Sindh, Pakistan. The Lower Indus Platform Basin is bounded to the north by the Central Indus Basin, to the northwest by the Sulaiman Foldbelt Basin and the Kirthar Fold Belt Basin in the south west. Several Oil and Gas fields were discovered in Lower Indus Basin. Lower Indus is characterized by extensional tectonics (Aslam, 2015). Fig 1.1 shows Tajjal field on the map of Pakistan.

The geographical coordinates of the area are:

- Latitude 26.00° 11'N to 27°18'58.2"N
- Longitude 69.10° 21' E to 69°20'08.1"E

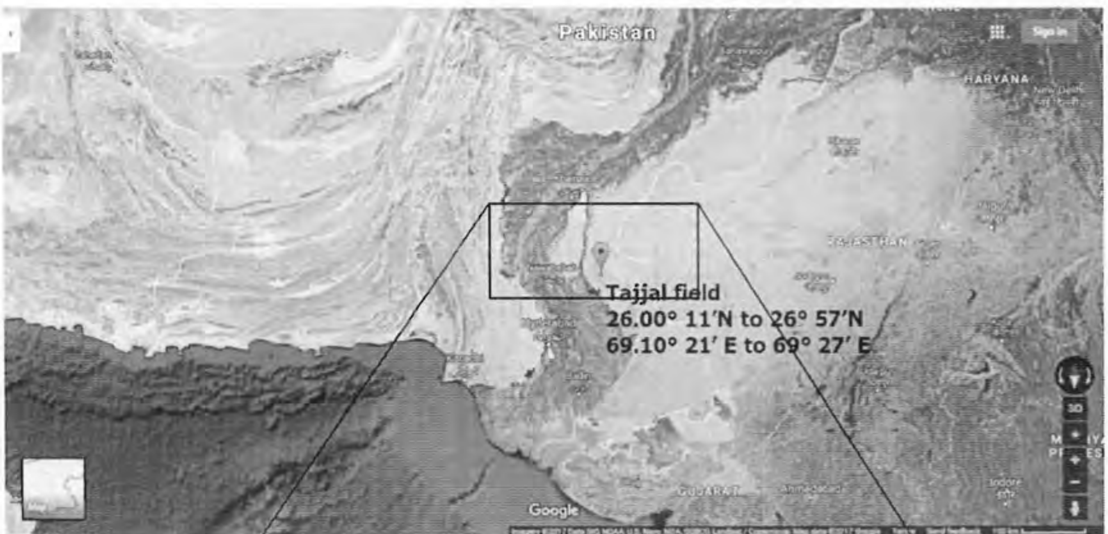


Fig 1.1.a Tajjal field on the map of Pakistan.

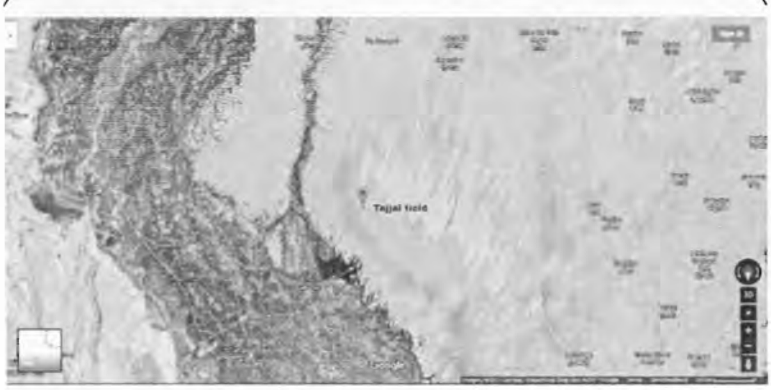


Fig 1.1.b Zoomed area of tajjal field.

1.2 Data Description

The Tajjal field data consists of 2D seismic reflection and well data is obtained from Landmark Resources (LMKR) by permission of Directorate General Petroleum Concessions (DGPC) of Pakistan. The given seismic data consists of a navigation folder, well data and SEG-Y folder.

1.2.1 Base Map

The navigation files and SEG-Y files are used to create the base map as shown in figure 1.2.a. Fig 1.2.b gives information about the base map.

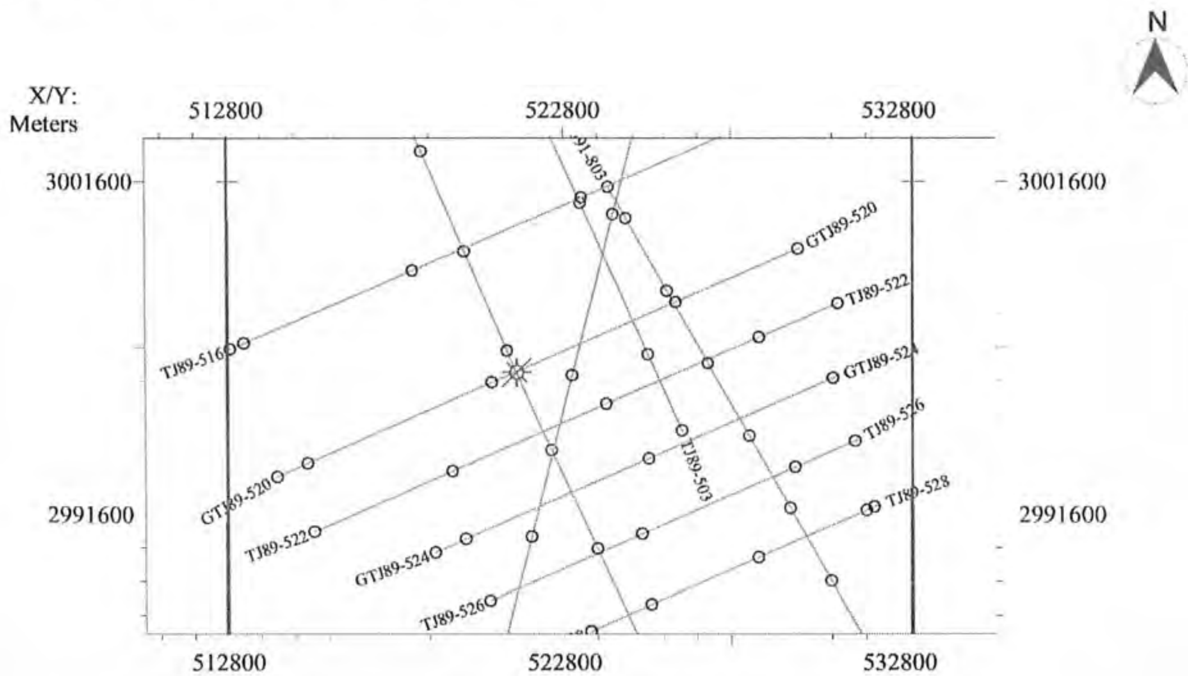


Fig 1.2.a Showing Base map of tajjal field. Red mark in the centre show well location.

Scale = 1:428316

0 4283 8566 12850 17133 21416 m

Group: Universal Transverse Mercator
System: Zone 42N (66 E to 72 E)
Datum: WGS 1984
Ellipsoid: WGS 1984
X(Min,Max): 512800.00 533200.00
Y(Min,Max): 2971600.00 3021500.00
Latitude(Min,Max): 26.865999 27.316176
Longitude(Min,Max): 69.128680 69.335508

Base Map

Fig 1.2.b Showing Base map information.

1.2.2 Seismic Lines

Seismic interpretation is done on lines (TJ89-516, GTJ89-520, TJ89-522, TJ89-503). The orientation and other information about these lines are given in Table 1.1 and shown in Fig 1.2.a.

Sr.No	Line Name	Orientation	Nature of line	Well
1	TJ89-516	NE-SW	Dip	N/A
2	GTJ89-520	NE-SW	Dip	GORWAR-01
3	TJ89-522	NE-SW	Dip	N/A
4	TJ89-503	NW-SE	Strike	N/A

Table 1.1 Information about seismic lines.

1.2.3 Well Information

The seismic interpretation is done with the help of well log data. Well data is required for both creation a synthetic seismogram and petrophysics. Information about the well is given in Table 1.2.

Sr.No	Well Name	Coordinates	Depth(m)	Elevation(KB)
1	GORWAR-01	27°05'05.2"N 69°12'57.3"E	3610	62

Table 1.2 Well information.

1.3 Seismic Data Parameters

To locate hydrocarbons, we geophysicist use seismic reflection method to gain knowledge about the geological structures in the subsurface. This method works by sending an acoustic or pressure wave into the earth, which get reflected back when it meets a geological boundary where there is contrast in rock properties (Onajite.E, 2014).

1.3.1 Recording Parameters

In seismic data acquisition, we concern ourselves only with the data gathering in the field, and making sure the data is of sufficient quality. To get the best results we must choose our survey parameters correctly (Drijkoningen and Verschuur, 2003). Quality of field data depends upon the setting of survey parameter. If the field parameters are selected appropriately then we get the good quality of data. Recording parameters are shown in Table 1.3 of given seismic data.

Name	Value
Recorded By	LOC
Recorded Date	November 1982
Source	Vibroseis
Cable	Split Spread

Shot Depth	6 m
Near Trace Offset	75 m
Charge Size	3 Kg
No. of Groups	120
No. of Holes	3
Group Interval	50 m
Shot Interval	50 m
Geophones per Group	1 Hydrophone or 36 Geophones

Table 1.3 Recording parameters seismic data.

1.3.2 Processing Parameters

In seismic processing, we want to manipulate our gathered data such that we obtain an accurate image of the subsurface. To do this properly, we have to understand the physical processes that are involved in seismic experiments. In addition to the importance of recording parameters of a data we also process an acquired data to remove noise and get the maximum signal. A seismic data may consist of many noises, to remove these noises we apply different processing techniques. Table 1.4 gives the processing parameters of given seismic data (Drijkoningen and Verschuur, 2003).

Name	Value
Processed By	LDC
Processing Date	Febrary 1992
Processing Record Length	6 S
Processing Sample Rate	4 m/s
Input SEG-D	2 MS Sample Rate
Output SEG-Y	4 MS Sample Rate
Deconvolution Type	Predictive
Surface Consistent Residual Stacking	20 CMPS In Pilot
Common Midpoint Stacking	24 Fold, 1/Root N Scaling
Static Correlation	Float Datum to M.S.L
FK Filter	Polygon Pass

Table 1.4 Processing parameters seismic data.

1.4 Software Used in Thesis

- HIS Kingdom
- Snagit 13
- SeiSee
- Microsoft Word
- Microsoft Excel

1.5 Objectives of Study

- Structural interpretation using 2D seismic reflection data to understand subsurface geologic framework and its relation with surface geology.
- Generate time and depth contour maps on different levels to find the favourable structure for Hydrocarbon.
- Petrophysical interpretation to find the zone of interest and find the petrophysical properties associated with that zone.

Chapter 2

GEOLOGY AND STRATIGRAPHY

2.1 General Geology of Study Area

The area of research is located in Tajjal district in Sindh province of Pakistan. It is located in Lower Indus basin(Southern) bounded by Sargodha high in the north, Indian Shield in the east, Kirthar and Suleiman ranges in the west and Indus Offshore in the south. The basin is separated from Upper Indus Basin by Sargodha High and Pezu uplift in the north. Pakistan is geologically divided into three main basins Indus, Baluchistan and Kakar Khorasan which are further sub-divided into different sub-basins. Our interested basin, Indus is divided into Upper and Lower basins. Upper Indus basin is subdivided into Kohat Sub-Basin and Potawar Basin and Lower Indus basin is divided into Central and Southern Indus Basins. Thar Platform, Karachi Trough, Kirthar Foredeep, Kirthar Fold Belt and Offshore Indus make up Lower Indus Basin (Kazmi & Jan, 1997). Fig 2.1 shows the position of Tajjal area with respect to other geological locations.

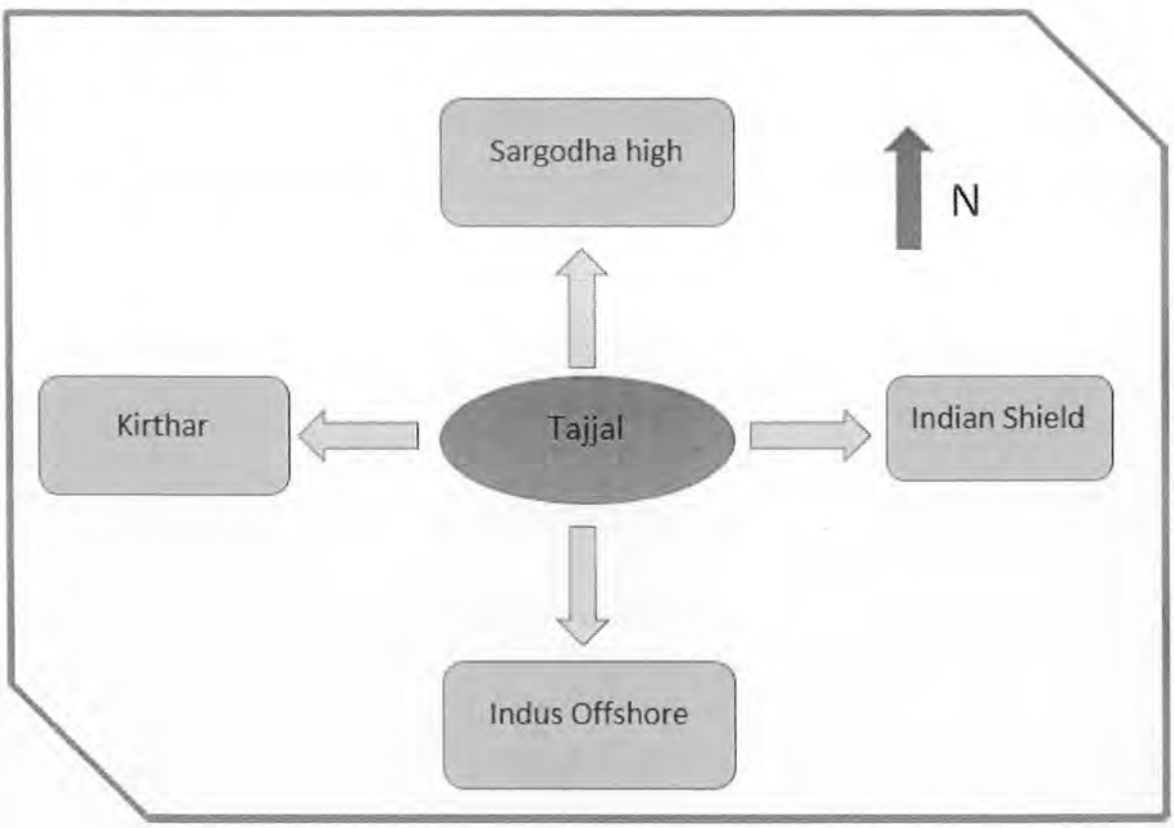


Fig 2.1 Geological position of study area

2.2 Indus Basin

The transboundary Indus river basin has a total area of 1.12 million km^2 distributed between Pakistan (47 percent), India (39 percent), China (8 percent) and Afghanistan (6 percent). The Indus river basin stretches from the Himalayan Mountains in the north to the dry alluvial plains of Sindh province in Pakistan in the south and finally flows out into the Arabian Sea. In Pakistan, the Indus river basin covers around 520 000 km^2, or 65 percent of the territory, comprising the whole of the provinces of Punjab and Khyber Pakhtunkhwa and most of the territory of Sindh province and the eastern part of Balochistan. The main tectonic features of Indus basin are the platform, the foredeep comprising depressions, and inner folded zone and outer folded zone (Kazmi & Jan, 1997).

Upper Indus Basin: Potowar Basin
Kohat Basin

Lower Indus Basin: Central Indus Basin
Southern Indus Basin

Our study area lies in Southern Indus Basin.

Fig 2.2 The major sedimentary basins of Pakistan, (Kadri, 1995).

Southern Indus Basin:

This basin is located just south of sukkur rift (a divide between central and southern Indus basin) (Kadri, 1995). It comprises of following main units as shown in Fig 2.3.

- Thar platform
- Karachi trough
- Kirther fore deep
- Kirther fore belt
- Offshore Indus

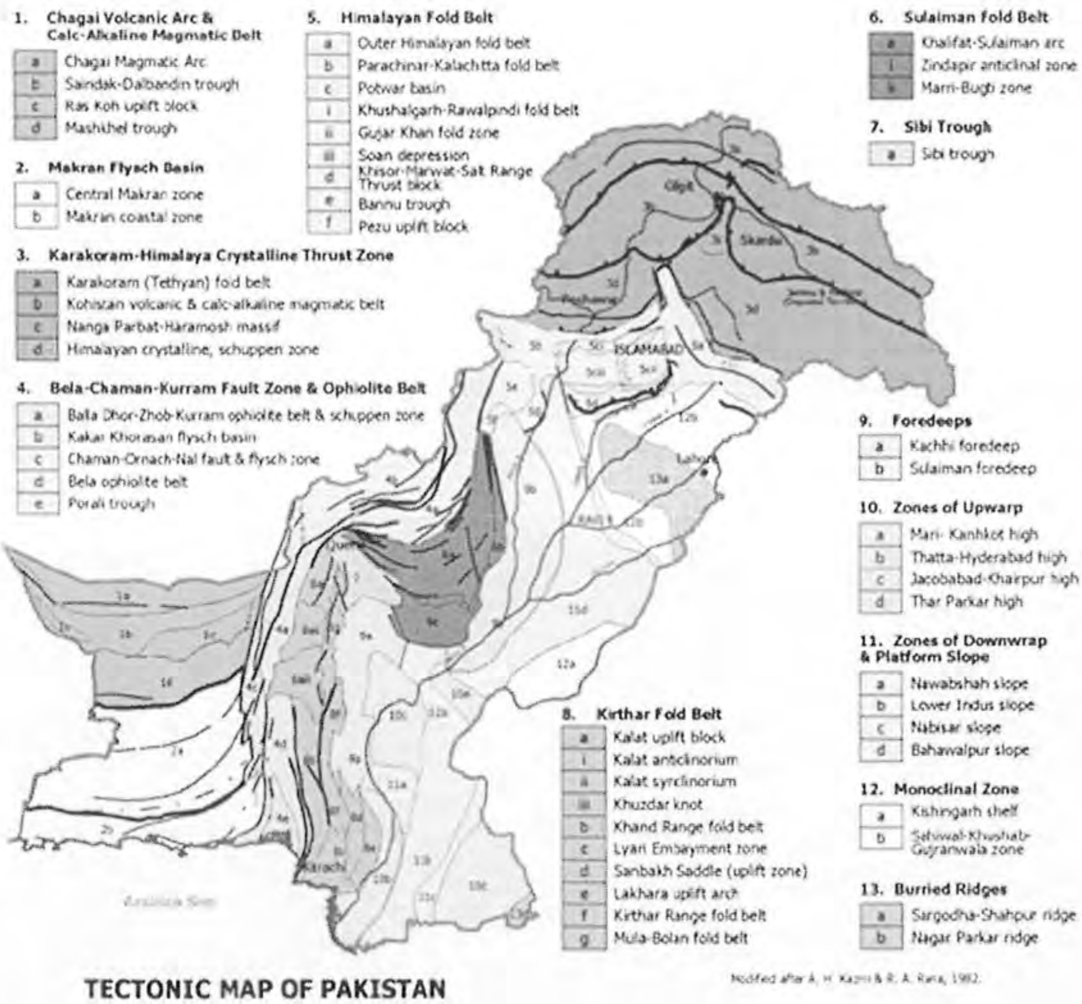


Fig 2.3 Tectonic map of Pakistan showing 13 tectonic subdivision and study area, (Kazmi & Jan, 1997).

1. Thar Platform:

Thar Platform is a 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 Parkar High. 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. The Platform marks very good development of Early/Middle Cretaceous Sands (Goru), which are the reservoirs for all the oil/gas fields in this region (Kadri, 1995).

2. Karachi Trough:

It is an embayment opening up in to 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 chain-like anticlines, some of which contains gas fields . The Early Middle and Late Cretaceous rocks are well preserved in the area. It has been a trough throughout the geological history. The Upper Cretaceous is marked by westward progradation of a marine delta (Kadri, 1995).

3. Kirthar Foredeep:

Kirthar Foredeep trends north south, which has received the sediments aggregating a thickness of over 15,000 meters. It has a faulted eastern boundary with Thar Platform. It is inferred that the sedimentation has 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 well developed in the depression but is missing from Khairpur – Jacobabad High area. This depression, like Suleiman Depression, is the area of great potential for the maturation of source rocks (Kadri, 1995).

4. Kirthar Fold Belt:

This north-south trending tectonic feature is similar to Suleiman fold belt in structural style and stratigraphic equivalence. Rocks from Triassic to Recent were deposited in this region. The configuration of the Kithara fold belt also marks the closing of Oligocene- Miocene seas (Kadri, 1995).

5. Offshore Indus:

The area forms part of passive continental margin and appears to have gone through two distinct phases of geological history (Cretaceous-Eocene and Oligocene- Recent). Sedimentation in offshore Indus region started from Cretaceous time. However deltaic and submarine fan sedimentation has occurred since middle Oligocene time with the inception of Proto-Indus System (Kadri, 1995).

2.4 Oil and Gas Traps

The movement of Earth's crust may cause different types of structural traps to be formed in subsurface while the deposition of different sediments in sequence can also contribute in the formation of traps that can cause accumulation of hydrocarbon. Various types of traps are discussed below

2.4.1 Structural Trap

A structural trap is a type of geologic trap that forms because of changes in the structure of the subsurface, due to tectonic, gravitational and compactional processes. These changes may block the upwards migration of hydrocarbons and can lead to the formation of a hydrocarbon reservoir. The three basic forms of structural traps are the fault trap, the anticline trap and the salt dome trap (Onajite, 2014). This type of trap is shown in Fig 2.4.

2.4.2 Synthetic Trap

If a fault is dipping towards the sedimentary basin it is called synthetic trap. A synthetic trap can be found in Fig 2.4.

2.4.3 Antithetic Trap

If a fault is dipping away from the sedimentary basin it is called antithetic trap. An antithetic trap can be found in Fig 2.4.

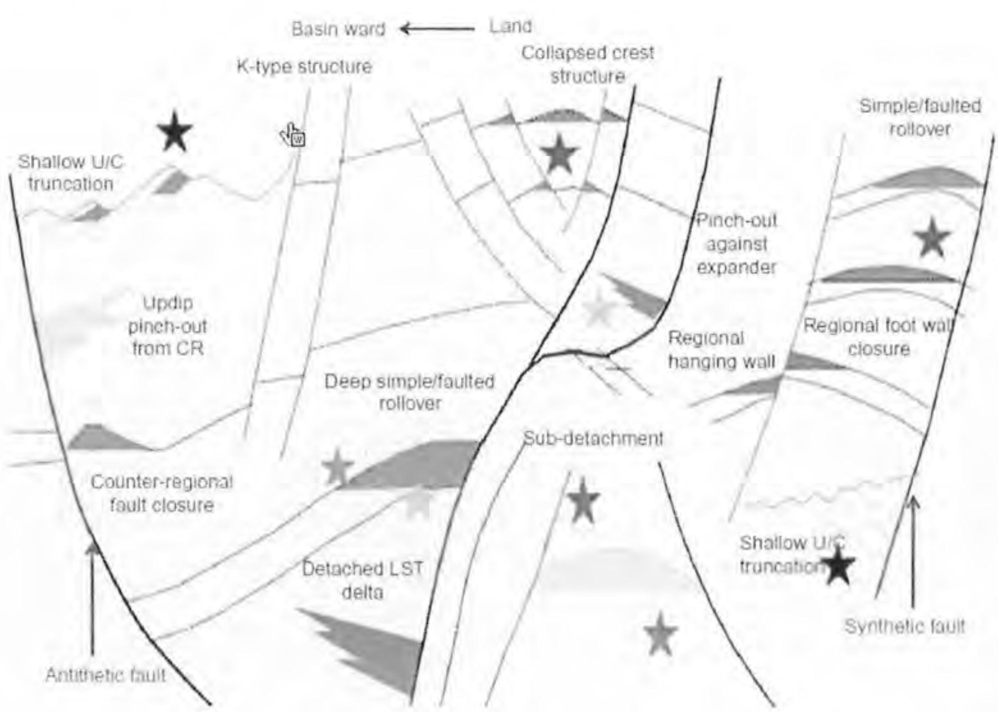


Fig 2.4 Different types of fault traps found in the Niger Delta, Basin, Nigeria. Source: Shell E&P (Onajite, 2014).

2.4.4 Horst

A horst is an up-thrown block lying between two down-thrown fault blocks. It can be seen in Fig 2.5.

2.4.5 Graben

A graben is a down-thrown block lying between two up-thrown fault blocks. An example of a graben, can be seen at the center of a collapsed crest structure, see Fig 2.5.

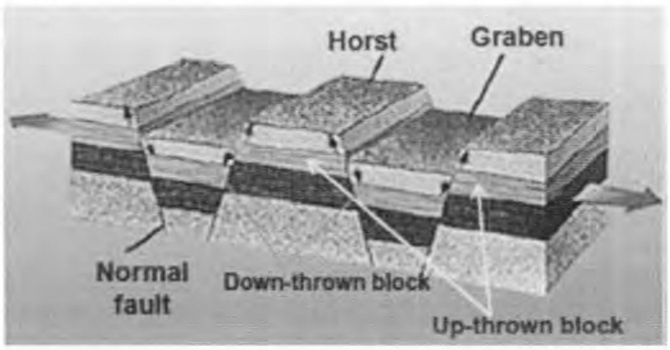


Fig 2.5 Horst and Graben. Source: USGS Earthquake Glossary (Onajite, 2014).

2.4.6 Anticline Trap

An anticline is a structural trap formed by the folding of rock strata into an arch-like shape. The rock layers in an anticlinal trap were originally laid down horizontally and then earth movement caused it to fold into an arch-like shape called an anticline. Fig 2.6 showing anticlinal trap.

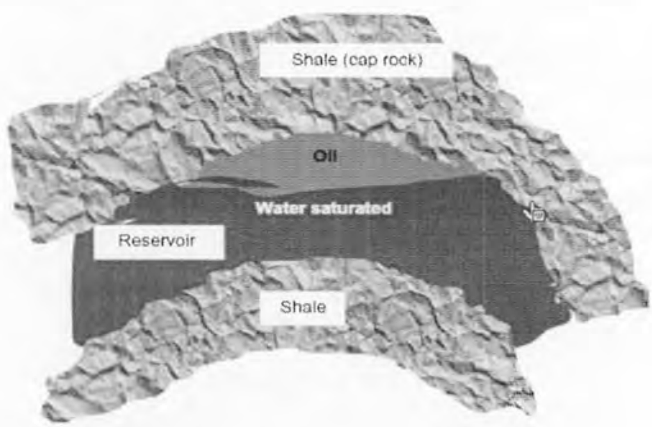


Fig 2.6 Anticlinal trap (Onajite, 2014).

2.4.7 Salt Dome

Salt dome is a trap created by intrusion of stratified rock layers from below by ductile nonporous salt. Hydrocarbon can be found at the flanks of a salt dome and can be found in the deformed layers above a salt dome as in Fig 2.7.

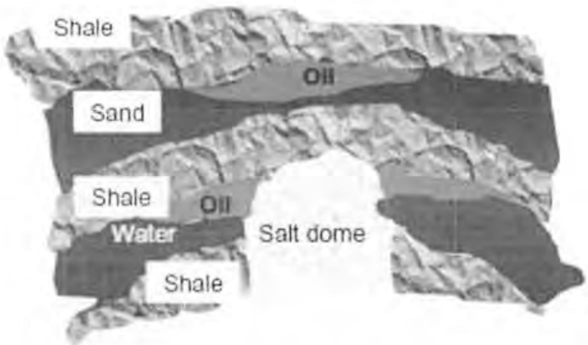


Fig 2.7 Salt dome acting as trap for hydrocarbon (Onajite, 2014).

2.4.8 Stratigraphic Trap

Stratigraphic traps are formed when there are changes in lithology, nature of the strata or depositional pattern. They prevent continued migration of hydrocarbons within reservoir beds. A sand body originating from river sand may shale out laterally into the area where clays had been deposited in swamps. The sand body may be a good reservoir, while the shale is a good seal (Onajite, 2014). Such a trap is shown in Fig 2.8

Fig 2.8 Structural trap acting as trap for hydrocarbon (Onajite, 2014).

2.5 Stratigraphy of the Lower Indus Basin:

The oldest rocks in Lower Indus Basin are of Triassic age encountered at Jhat Pat and Nabisar wells (Kadri, 1995).

Age			Lower Indus Basin		
ERA	PERIOD	EPOCH	Kirthat	Sulaiman	Lithology Description
CENOZOIC	QUATERNARY	PLEISTOCENE	LEI CONGLOMERATE		CONGLOMERATE
	TERTIARY	PLIOCENE	SIWALIK GROUP		SANDSTONE
		MIOCENE	GAJ FORMATION		SANDSTONE, SHALE, LIMESTONE
		OLIGOCENE	NARI FORMATION		LIMESTONE, SANDSTONE
		EOCENE	KIRTHAR FORMATION	DRAZINDA MEMBER	
				PIRKOH MEMBER	LIMESTONE
				DOMANDA MEMBER	
				HABB RAHI FORMATION	LIMESTONE
				BASKA SHALE	SHALE
			LAKI FORMATION	GHAZIJ FORMATION	LIMESTONE, SHALE
			SUI MAIN LIMESTONE		LIMESTONE
		PALEOCENE	LAKHRA	DUNGHAN FORMATION	LIMESTONE, SHALE
			BARA		LIMESTONE
			KHADRO	RANI KOT	SANDSTONE, LIMESTONE
MESOZOIC	CRETACEOUS	LATE	PAB SANDSTONE		SANDSTONE
			FORT MUNRO MEMBER		LIMESTONE
			MUHALKOT FORMATION		SANDSTONE, LIMESTONE, SHALE
		EARLY	PARH FORMATION		LIMESTONE
			GORU FORMATION		SANDSTONE, SHALE
			SEMBAR FORMATION		SANDSTONE, SHALE
	JURASSIC	LATE			
		MIDDLE	MAZARDRIK FORMATION		SHALE
			CHILTAN FORMATION		LIMESTONE
		EARLY	SHIRINAB FORMATION		SANDSTONE, LIMESTONE
	TRIASSIC	LATE	WULGAI FORMATION		SANDSTONE, SHALE, LIMESTONE
		MIDDLE			
		EARLY			
PALEOZOIC	PERMIAN	LATE			
		EARLY			

Table 2.1 Stratiraphic Chart of Lower Indus Basin (Kadri, 1995).

2.6 Formations Encountered in the Well Gorwar-01

Age			Gorwar-01			
ERA	PERIOD	EPOCH	FORMATION	DEPTH (m)	Thickness (m)	LITHOLOGY
CENOZOIC	TERTIARY	PLIOCENE	SIWALIK	7.75	293.25	Shale with Interbedded Sand
		EOCENE	DRAZINDA	301.00	113.00	Limestone
			PIRKOH	414.00	60.00	Limestone
			SIRKI	474.00	64.00	Limestone
			HABIB RAHI	538.00	136.00	Limestone
			GHAZIJ	674.00	585.50	Shale
			SUI MAIN LIMESTONE	1259.50	85.50	Limestone
		PALEOCENE	LAKHRA FORMATION	1345.00	109.00	Shale with Interbedded Sand
			BARA FORMATION	1454.00	68.00	Shale with Interbedded Sand
			KHADRO FORMATION	1522.00	479.50	Shale with Interbedded Sand
MESOZOIC	CRETACEOUS	EARLY	UPPER GORU	2001.50	543.50	Shale and sand
			LOWER GORU	2545.00	1065.00	

Table 2.2 Stratigraphic Chart of the formations encountered in the Well Gorwar-01.

2.7 Geology of Tajjal:

2.71 Stratigraphic Units:

Jurassic:

Jurassic is well represented across Pakistan but restricted to lower and middle and the upper Jurassic is missing. These are best represented in the Kirthar range in the South. Southern Indus basin in Jurassic is divided into following three members (Fig 2.9):

- Mazardrik Formation
- Chiltan Limestone
- Shirinab Formation

Mazardrik contain interbedded grey limestone and dark shales. It is less than 30m and not developed in Sulaiman Range. (Qadri, 1995). The shirinab formation is sub-divided into three members on the basis of shale content:

- Spingwar Member (648m thick)
- Loralai Limestone Member (424m thick)
- Anjira Member (90m that ranges about 367m in Khuzdar)

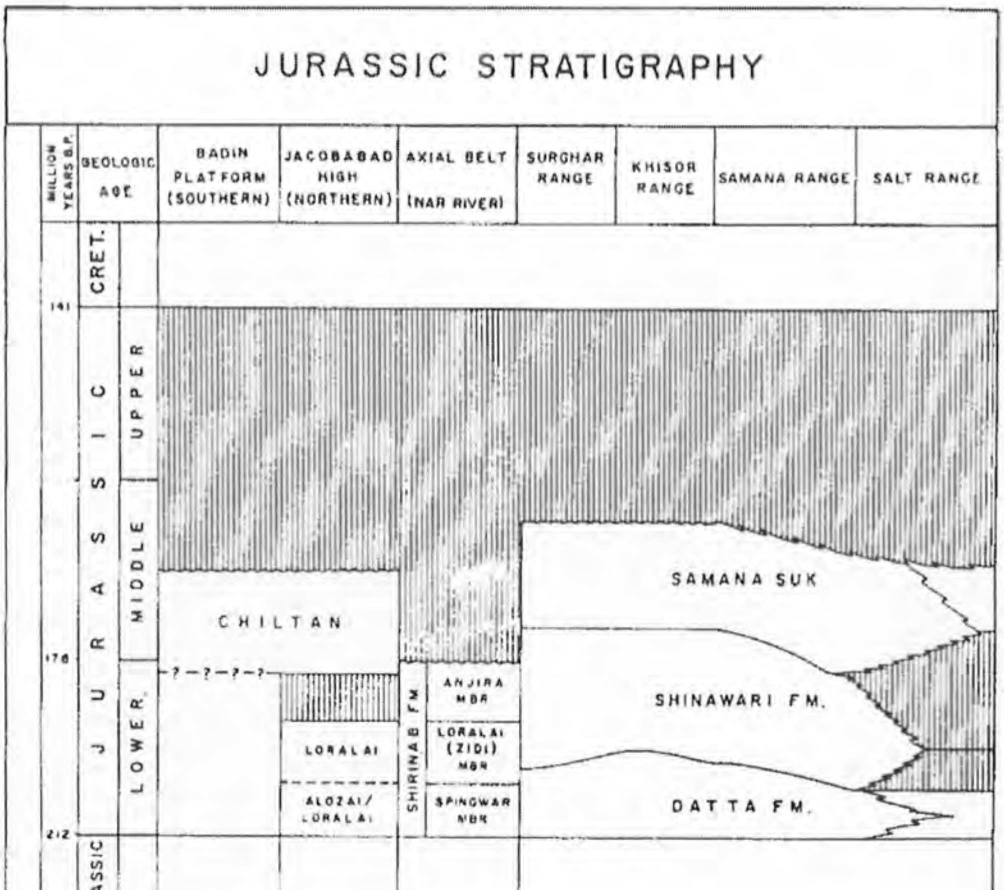


Fig 2.9 Stratigraphy of Jurassic (Fatmi, 1972).

Cretaceous:

The cretaceous system in Pakistan covers an area of approximately 280,000 sq. km. In lower Indus basin and adjoining Axial Belt it's thickness is few hundred that further reduces towards North in Kohat-Potwar Province. Karachi embayment has maximum thickness that is about 4500m (Nagappa, 1960). Fig 2.10 precisely shows the stratigraphy of the Cretaceous:

Southern Indus basin has following stratigraphic units related to Cretaceous:

- Sembar Formation
- Goru Formation

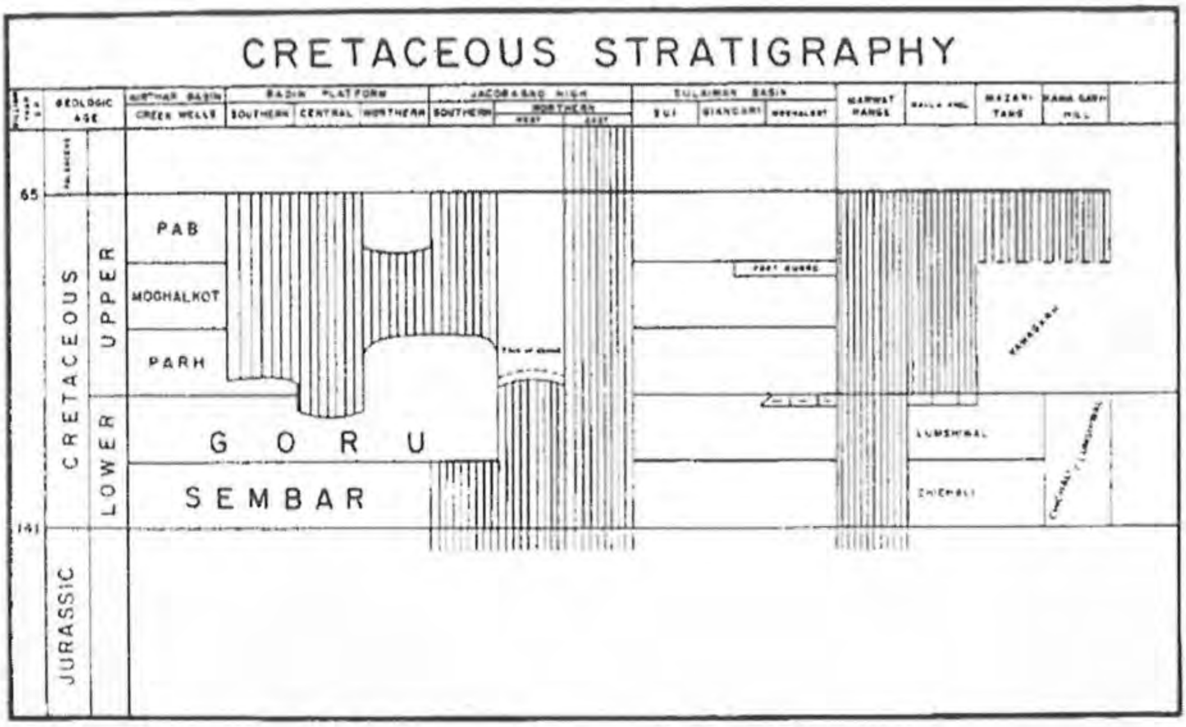


Fig 2.10 Cretaceous Stratigraphy (Nagappa, 1960).

Paleocene:

Rocks of Paleocene are widely distributed over Indus Basin. In the Lower Indus Basin, these are limited towards East by a surface erosional edge. The Western edge is parallel to the Axial Belt i.e. a belt of folded rocks separates the Indus Basin from the Balochistan Basin (Meissner and Rahman, 1973).

The response of the well log is not complex. The lower boundary of Paleocene is marked by the unconformity that can easily be observed. Rw values of Ranikot sand are variable and got up to 0.1 Ohm-m with salinity about 30,000 PPM. Top and base of Paleocene is easily recognizeable on the Seismic. However, it is difficult to recognize each formation due to great thickness and heterogeneity. No abnormal formation pressure or serious drilling problems have been observed in the wells (Meissner and Rahman, 1973).

Eocene:

The area is widely distributed from Offshore Karachi (South) to the Attock-Cherat Range (North). Western boundary is the Axial Belt which is mostly erosional structure. Eastern boundary roughly follow the Pakistan-India geographical boundary through Jaisalmir and Cutch areas. Thickness ranges from few hundred meters to 4200m (Northern Sulaiman Range) (Siddiqui and Khan, 1992).

The Eocene can be explained on the basis of Shale and Limestone lithologies:

i- Sui Main Limestone (SML)

ii- Sui Upper Limestone (SUL)

iii- Ghazij Shale

iv- Habib Rahi Limestone (HRL)

v- Pirkoh Limestone (PKL)

Eocene are likely to generate hydrocarbons. The source rock analysis of early Eocene rocks shows the hydrocarbon potential with Total Organic Carbon (TOC) ranging from 0.2 to 2.5%. potential yield of some of the samples is over 15,000 ppm that is indicative of good quality source rock. Middle Eocene Habib Rahi Limestone shows TOC 5.25% and potential yield of as much as 32,560 ppm. In outcrops, Habib Rahi is organic rich and burns when it is lightened (Siddiqui and Khan, 1992). However, the explored areas do not show the maturity of these source rocks. Moreover, these areas may be subjected to maturity in the trough areas of Sibi Trough and area West of Jacobabad-Khairpur High (Fig 2.11).

Fig 2.11 Map Showing Location of Khairpur-Jacobabad High (Siddiqui and Khan, 1992)

It is known that most of the hydrocarbons are discovered from this section in the Indus Basin. It suggests that in the Middle Indus Bain, Eocene Limestone is an excellent reservoir. Sui Main Limestone is gas producing in many fields when we talk about Early Eocene. However, Matrix Microporosity is developed by the clay sized carbonate matrix and interconnection as well as bigger voidage is provided by vugs and mouldic porositie (Siddiqui and Khan, 1992).

Post-Eocene:

Excluding Nari and Gaj formations of post-Eocene, all other formations covers the entire Pakistan. Oligocene is represented by Nari formation and is present in limited area between Karachi and Quetta. In East, it does not go beyond the Laki Ranges and in West, it is confined to both sides of the Axial Belt (Lewis, 1937).

Miocene is represented by Gaj formation and it I also present between Karachi and Quetta i.e. coinciding with the eastern portion of the Nari formation. Rocks of Siwalik group and sub-recent to recent sediments occur from Murree (North) to Cutch area (South).

In the post-Eocene, the Lower Indus Basin has following stratigraphic units (Lewis, 1937):

- Lei Conglomerate (Pleistocene)
- Soan Formation (Lt. Plio-Pleistocene)
- Siwalik Group (Lt. Pliocene-Pliocene)
- Gaj Formation (Early-Middle Miocene)
- Nari Formation (Oligocene)

Chapter 3

SEISMIC INTRODUCTION

3.1 Seismic

Fundamental purpose of seismic data acquisition is to record the ground motion caused by a known source in a known location. First step in seismic data acquisition is to generate a seismic pulse with a suitable source. Second is to detect and record the seismic waves propagating through ground with a suitable receiver (geophone/seismometer), digital or analogue form. Third is the registration of data on a chart or tape recorder (Kearey et al, 2002).

3.2 Type of Seismic Methods

There are two types of seismic methods:

- Reflection method
- Refraction method

3.2.1 Reflection Method

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

3.2.2 Refraction Method

The Seismic Refraction method is based on the study of the elastic waves refracted along the geological layers in which the velocity of propagation of elastic waves is greater than the overlying strata. This method is based on Snell's law which is when wave is incident in a medium some part of it is bounces back while the other is transmitted to another medium (Fig 3.1).

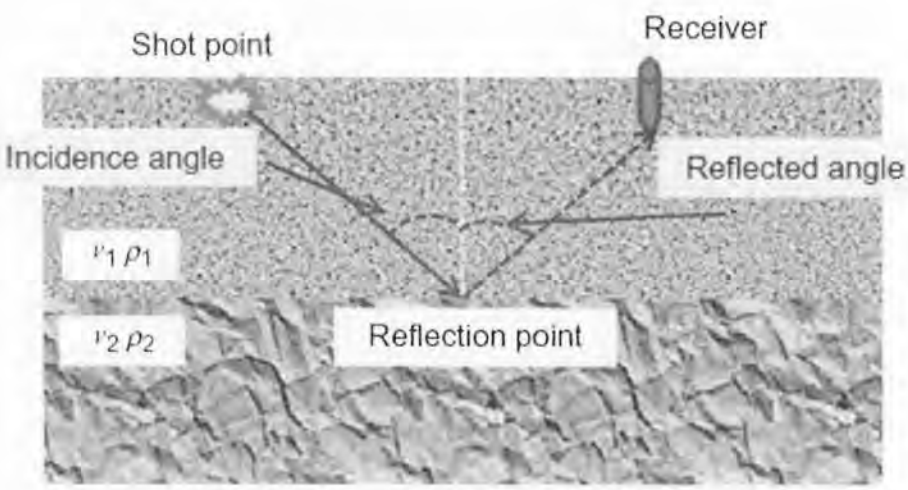


Fig 3.1 Model of seismic refraction (Onajite, 2014).

3.2.3 Snell's Law

It states that the ratio of the sine of the angle of incident to the sine of the angle of refraction is a constant for a given pair of lithology, illustration of Snell's law in Fig 3.2.

$$n = \frac{\sin \theta_i}{\sin \theta_r}$$

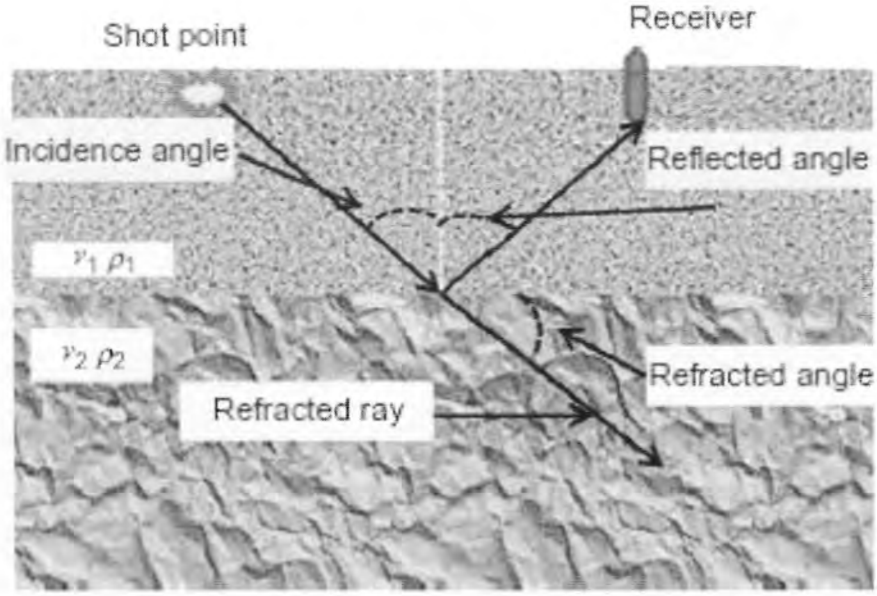


Fig 3.2 Demonstrating Snell's law.

3.2.4 Critical Angle

As the incident angle increases, a point is finally reached when the refracted ray does not penetrate second layer and run along the interface. This particular angle of incidence is called critical angle. At this critical angle of incidence, the refracted angle becomes 90°. At and above critical angle there is no transmition and we get high reflected ray. Fig 3.3 showing critical angle.

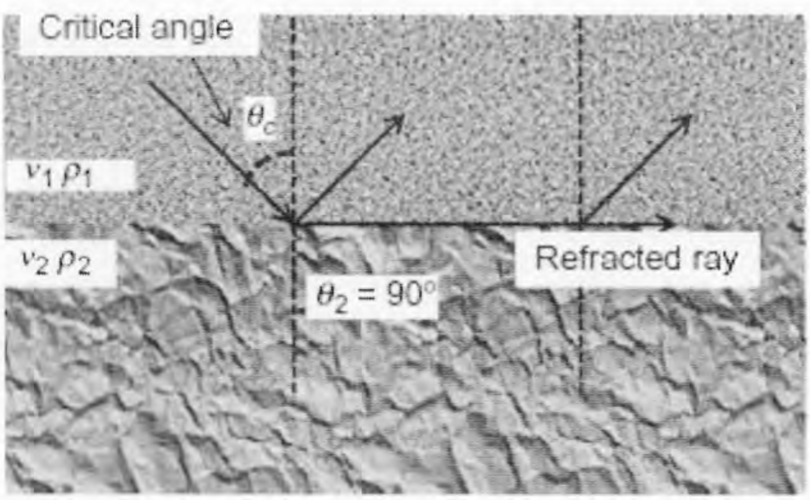


Fig 3.3 Conceptualized critical angle.

3.2.5 Reflection Coefficient

Each layer in Earth subsurface has its own velocity and density. The product of velocity and density is a material property of the layers and is known as acoustic impedance. The acoustic impedance is an important property of a rock layer. This is because it determines the reflection response of the earth. In the earth, reflections occur at the interfaces between layers and the reflection amplitudes depend mostly on the difference of acoustic impedance from layer to layer. The term AI unit is used for the unit of acoustic impedance (Fig 3.4).

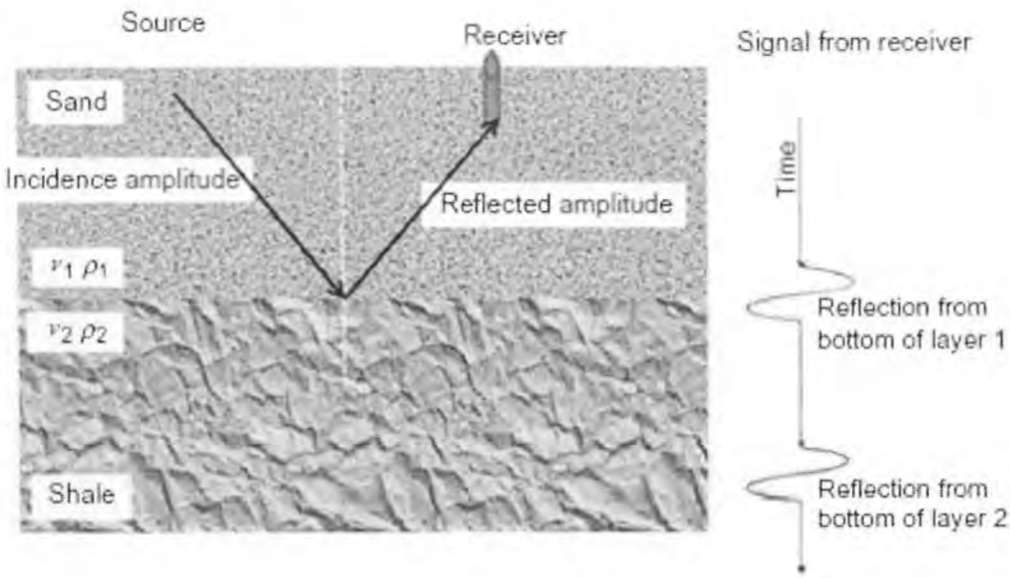


Fig 3.4 Reflection coefficient (Onajite, 2014).

Reflected amplitude is the difference between the two impedances of each layer divided by their sum. The ratio of the reflected amplitude to the incidence amplitude is called the reflection coefficient and is given by the difference in acoustic impedance divided by their sum.

$$RC = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

3.3 Applications of Seismic Methods

Seismic methods are used:

- To find out the structural traps (such as anticlines, faults, salt domes and reefs).
- To investigate the Stratigraphic features like discontinuous layers.
- Reflection data can be used to determine the average velocities of seismic waves provide a good indication of Lithology. (Dobrin and Savit, 1988)
- Seismic method is also used in search for ground water, in civil engineering, mineral exploration and locating subsurface features. (Robinson and Coruh, 1988)

3.4 SEISMIC DATA ACQUSITION:

The basic field activity in seismic surveying is the recording of seismic data which may be defined as analog or digital time series that register the amplitude of ground motion as a function of time during the passage of seismic wave train. Acquisition starts from shot and ends at recording the seismic events through various steps. Different energy sources are used to produce seismic waves and array of geophones are used to detect the resulting motion of earth. The data is recorded in digital as well as analogue form (Dobrin, 1988).

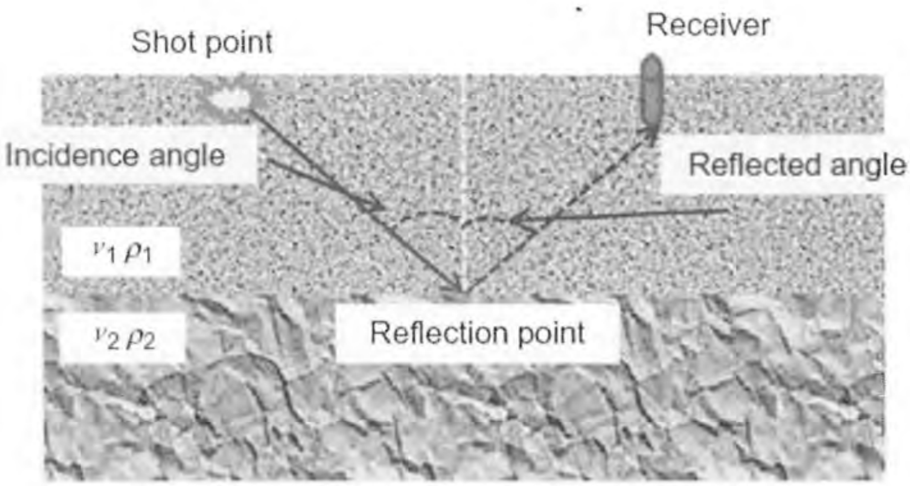


Fig 3.5 Acquiring seismic data on a receiver from one source (Onajite, 2014).

The fundamental purpose of seismic surveys is to accurately record ground motion caused by known sources in a known location. The record of ground motion with time constitutes seismograms shown in Fig 3.5.

The acquisition of seismic data involves conversation of the seismic ground motion into electrical signals, amplification and filtering of the signals and their registration on a chart recorder and / or take recorder. The components which are involved in collection of seismic data are (Robinson, 1988):

- Seismic Source.
- Profile Array.
- Recording Instruments.

3.4.1 Seismic Sources:

Seismic source releases energy in the form of elastic waves which propagate through the earth's medium. This energy has an amplitude and phase over a frequency band.

Types Of Seismic Sources Are Classified Below:

1. Land Sources:

Dynamite:

Several Kilograms of dynamite used to generate a short duration, high energy impulse containing a wide range of frequencies. Dynamite based seismic data is minimum phase.

Vibroseis:

A truck with a base plate driven by a hydraulic system to generate a long duration, low energy sweep of defined frequency range. The vibroseis data needs to be correlated with the pilot sweep. vibroseis based seismic data is zero phase.

Buried Primacord:

Explosive extruded into rope-like form having length of several 100 ft and ploughed into ground at 2-3 ft depth. When detonated at one end or centre, the explosive disturbance propagates at22,000 ft/sec, much higher than seismic velocity in near surface layer.

2. Marine Sources:

There are two types of marine sources , explosive and non-explosive. These sources are used in offshore surveys.

Explosive Sources using Dynamite

Flexotir:

Small pellet of dynamite embedded in a plastic cartridge. Thischarge is detonated at the center of a cast-iron spherical shell towedbehind the ship at 40 ft depth. It pumps out water under high pressure.

MaxiPulse:

Charge packed in a can, injected into the water at 40 ft depth by a delivery device trailed from the ship. On detonation it forms a bubble.

Non-Explosive Sources

Sparker:

Sudden discharge of current between electrodes in water generates seismic waves.

Boomer:

Current passes through Coil which moves a plate against water.

Air Gun:

High pressure bubble released in water.

Aqua Pulse:

Enclosed underwater chamber (elongated heavy-rubber cylinder) filled with propane and oxygen. It is detonated by electric spark. The explosion causes ballooning of the chamber which introduces pressure pulse in water.

3.4.2 Seismic Recorder:

Seismic Recorder picks seismic signals (vibrations) from geophone/hydrophone sensors and records them on magnetic media in a digital format. It consists of multiple channels, each connected to a geophone group. It is like an audio tape recorder which picks audio signals from microphone and records them on a magnetic tape (cassette). A geophone is a transducer which transforms mechanical energy (seismic vibration) into electrical energy. It consists of a moving coil and a stationary magnet. The movement of the coil due to vibration creates electromagnetic flux proportional to the magnitude of vibration. The block diagram of a digital seismic recorder is given below in Fig 3.6 followed by description of all main modules (Khan, 2010).

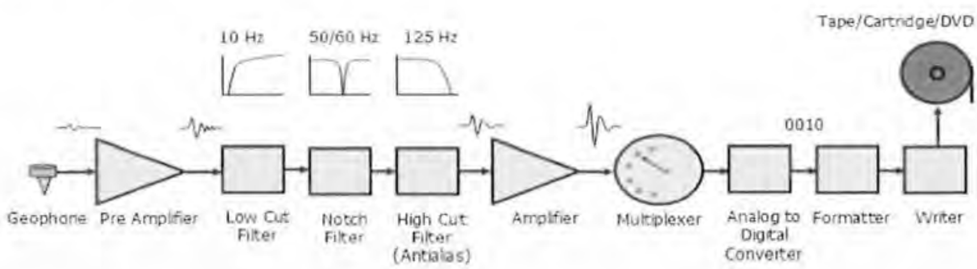


Fig 3.6 Seismic data filters and processing in field (Khan, 2010)

Types of Seismic Recorder

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

- Analog recording system
- Digital recording system

Analog Recording System:

Analog techniques are old techniques which produce continuous graphs. The graphs are obtained either on papers or magnetic tape that represents the variation in amplitude with respect to time, of seismic waves.

DigitalL Recording System:

The technique of recording the geophone output at discrete moments is called digital recording because the recording consists of series of digits or numbers. Later these numbers can be plotted and the seismogram prepared by connecting the points. The digital data is recorded on a magnetic tape in the form of binary numbers. Each digit of binary number on the tape is called a byte. If the recording head magnetize this byte then it indicates "1" otherwise it is "0 (Robinson, 1988).

Recording Instruments

Geophone

The receiver used to detect ground vibrations is called a geophone or a seismometer. It is used for seismic surveying on land and it can be operated on ocean floor if mounted in a suitable container. Most common type of geophone is moving coil geophone.

Hydrophone

Hydrophone is the standard receiver in marine seismic survey and responds to variations in pressure. Principle of the hydrophone is the measurement of the change in pressure with a piezoelectric crystal placed in the hydrophone. Due to the bending of the crystal, a voltage occurs.

3.5 Types of Seismic Waves

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

There are mainly two types of Seismic Waves:

- Body waves
- Surface waves

3.5.1 Body Waves

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

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

P- Waves (Primary Waves)

The particular kinds of waves of most interest to seismologists are the compressional or P-waves also called as compressional waves, longitudinal waves, primary waves, pressure waves, and dilatation waves, see Fig 3.7. In this case the vibrating particles move back and forth in the same direction as the direction of propagation of waves. P-waves can pass through any kind of material - solid liquid or gas. The P-waves velocity depends upon density and elastic constants. (Dobrin, 1976)

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

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

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

Where:

μ is the shear modulus.

k is the bulk modulus.

ρ is the density of the medium.

Fig 3.7 The propagation of P-waves in an Elastic Medium.

S- Waves (Secondary waves)

In shear waves, the particles vibrate in a direction perpendicular to the direction of propagation of waves, see Fig 3.8.

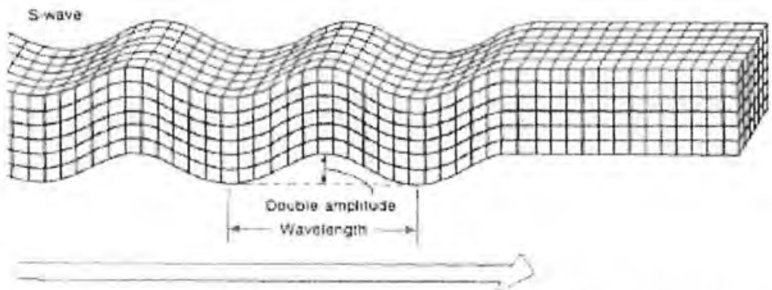


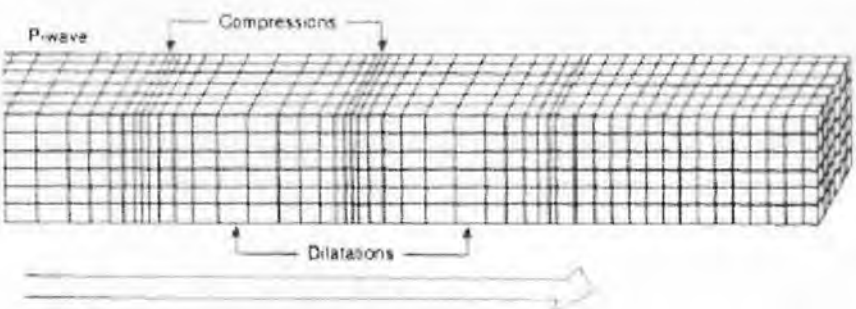
Fig 3.8 The propagation of S-waves in an Elastic Medium.

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

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

Characteristics of Body Waves

These waves travel with low speed through layers close to the earth's surface, as well in weathered



layers (Robinson & Coruch,).

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

3.5.2 Surface Waves

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

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

Surface waves are also of two types:

- Raleigh waves
- Love waves

Raleigh Waves

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

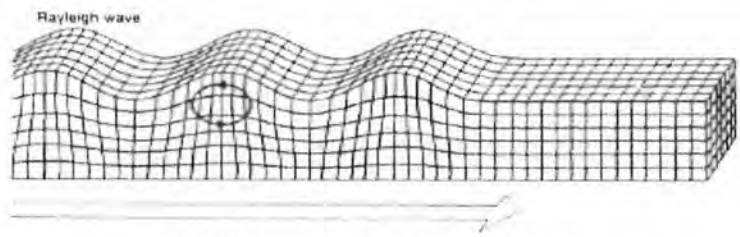


Fig 3.9 Propagation of Raleigh waves

Love Waves

A type of surface waves having a horizontal motion i.e. transverse to the direction of propagation. The velocity of these waves depends on the density and modulus of rigidity and not depends upon the bulk modulus (k). The Fig 3.10 shows the propagation of Love-waves in an elastic medium (Kearey, 2002).

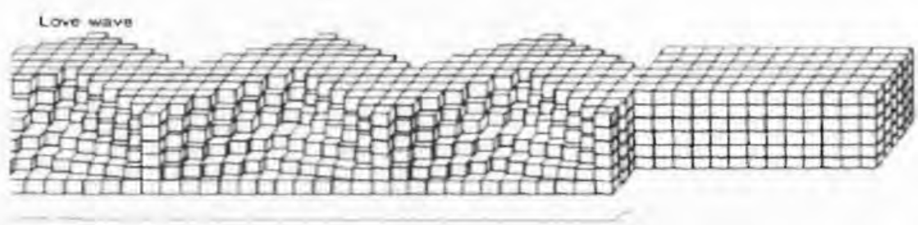


Fig 3.10 Propagation of Love waves in an Elastic Medium

3.6 Attenuation of Seismic Waves

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

Fall of energy can be due to:

- Spherical Divergence
- Absorption

3.6.1 Spherical Divergence

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

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

Where: H: amplitude at distance x.

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

X: distance from source.

3.6.2 Absorption

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

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

Where:

α: absorption coefficient.

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

3.7 Seismic Velocities

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

3.7.1 Effects of physical properties of rocks on seismic velocities

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

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

3.7.2 Velocity estimation

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

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

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

3.7.3 Variations in seismic velocities

There are two types of variations in seismic velocities;

- Lateral variation in seismic velocity
- Vertical variation in seismic velocity

Lateral variations in seismic velocities

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

Vertical variations in seismic velocities

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

3.8 Data Processing

Data Processing is sequence of operations which is carried out according to a pre-define program to extract useful information from a set of raw data. It can be said "as an approach by which the raw data recorded in the field is enhanced to the extent that it can be used for the geological interpretation".

Seismic data processing strategies and results are strongly affected by field acquisition parameters. Additionally, surface conditions have a significant impact on the quality of data collected in the field. Lack of seismic reflected events on seismic section is not the result of a subsurface void of reflectors.

Rather it is caused by low signal-to-noise ratio (S/N) resulting from energy scattering and absorption in the medium of propagation. In the following discussion, basic steps of the generalized processing flow are going to be explained fig 3.11 shows a simplified a generalized seismic data processing flowchart (Khan, 2010).

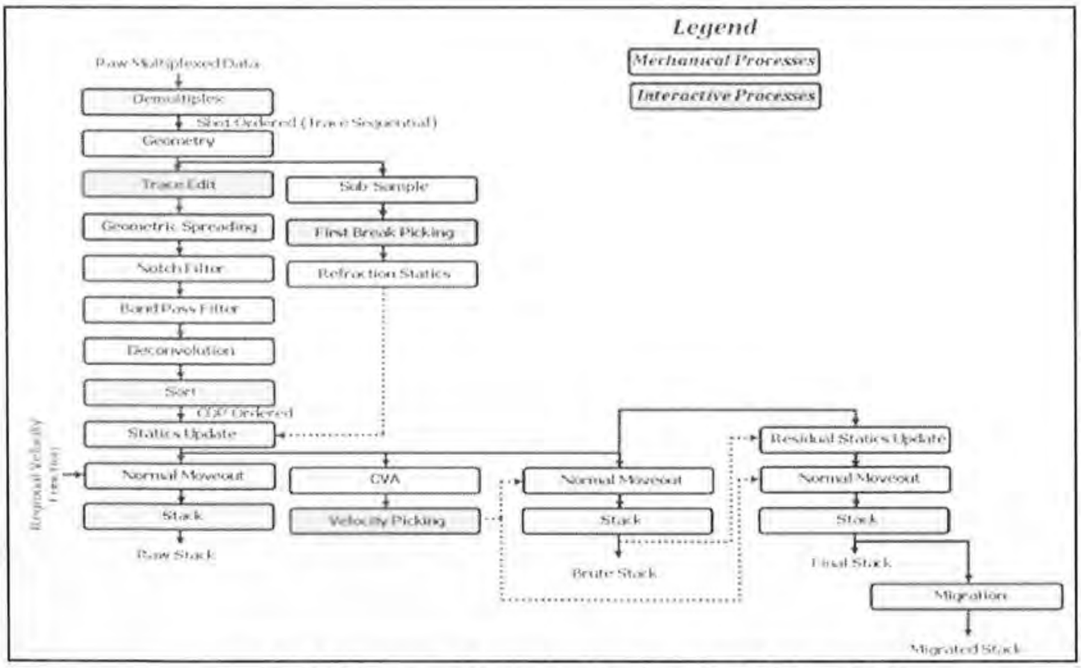


Fig.3.11 Seismic data processing flow chart (Khan, 2010).

Chapter 4

LOADING SEISMIC DATA

4.1 Introduction

In this modern age of technology computers help us do our work quickly and easily. Huge amount of work can be done in minutes with the help of computer software. Software is a program which perform some specific operations that it is programed for. For seismic prospect generation, different software are programed to load data and make different models of subsurface. Some of the seismic software are:

- Kingdom
- Petrel
- OMEGA
- Promax

4.2 Kingdom 8.8

The software I use for the thesis is IHS Kingdom 8.8 as shown in Fig 4.1. The reason for choosing this software is its availability in the university and we were taught to use Kingdom in our course work.

Fig 4.1 IHS Kingdom 8.8 as it is first started.

The given data consists of three type files:

- Navigation file (las file)

- SEG-Y file
- Well data file(T-D chart and Formation top)

4.3 Creating Project

We use navigation, SEG-Y and well data files to create a project in Kingdom. To create project we first assign author name and project name as shown in Fig 4.2a and 4.2b.

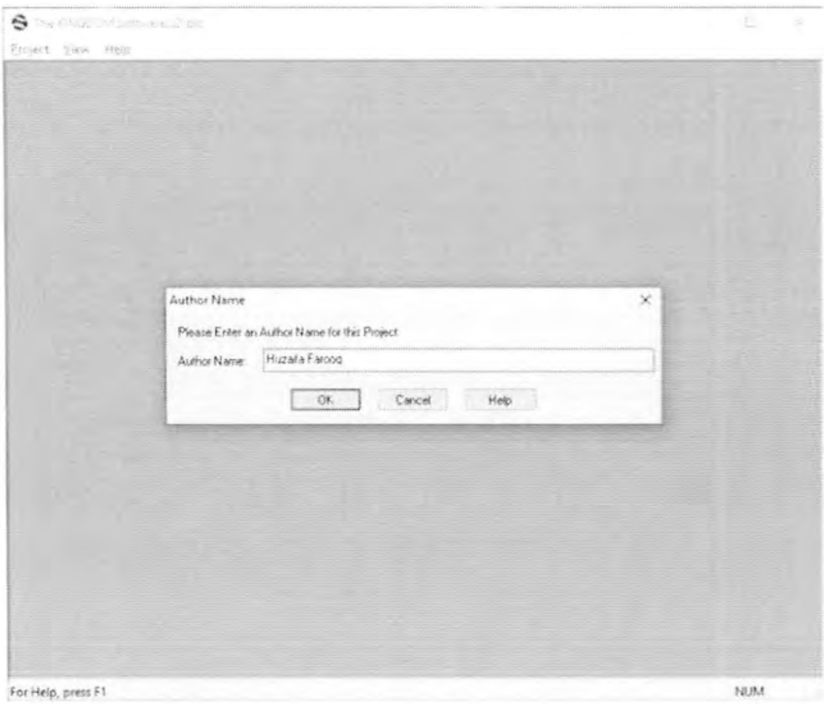


Fig 4.2a Showing Author name in Kingdom.

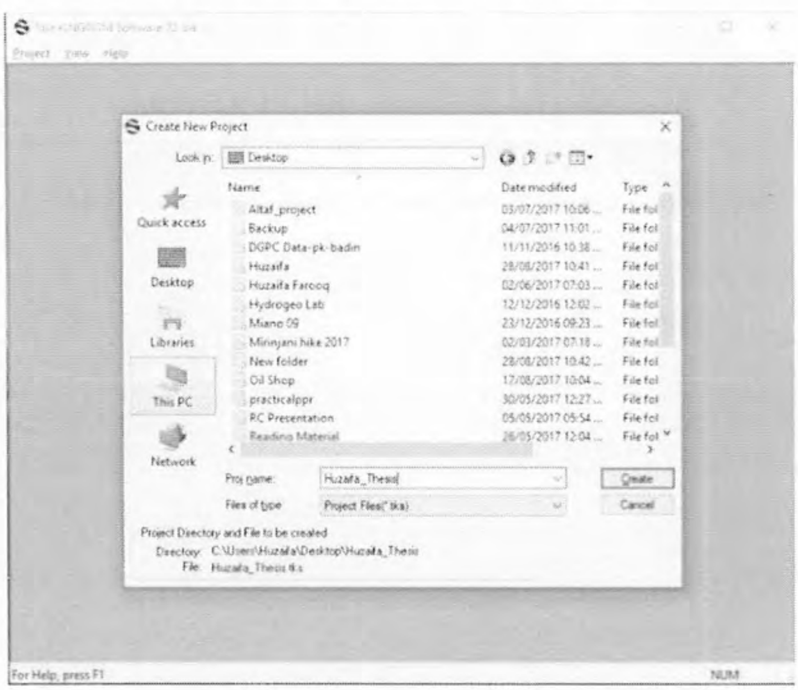


Fig 4.2b New project being created in Kingdom.

4.4 Create Base Map

4.4.1 Loading Navigation Files

After creating project, load navigation files in Kingdom to create the Base map of the seismic observation area. This base map shows the orientation and pattern of seismic lines no which the data is acquired. Fig 4.3 showing the process of loading navigation files to create Base map in Kingdom. In navigation files data is stored in form of columns, while loading it in Kingdom we have to select the specific columns for:

- Line name
- Shot point
- Degrees Latitude
- Minutes Latitude
- Seconds Latitude
- Latitude Direction (N or S)
- Degrees Longitude
- Minutes Longitude
- Seconds Longitude
- Longitude Direction (E or W)

Fig 4.3 Selecting data columns from navigation text file in Kingdom.

4.4.2 Selecting Zone and Coordinate System

After selecting navigation files, we have to select the coordinate system in which latitude and longitudes are measured and also the zone in which seismic survey has been planned. i.e. in this case the zone of interest is Zone 42N (66 E to 72 E) for Pakistan as shown in Fig 4.4. selecting this zone correctly is very important for placing the base map in correct position and according to this the north arrow is placed.

Fig 4.4 Coordinates being selected in Kingdom.

4.5 Importing SEG-Y Files

4.5.1 Selecting Multiple Files

After loading navigation file data, we must load the SEG-Y file on each line. Navigation file create the base map and place lines in the base map per their orientation but these lines have no seismic data in them. In SEG-Y files we have a file for each line. In Kingdom 8.8 we can either import SEG-Y data one by one on each line or can import multiple SEG-Y files for multiple lines. Fig 4.5a and 4.5b showing the importing multiple SEG-Y files on multiple lines in amplitude format.

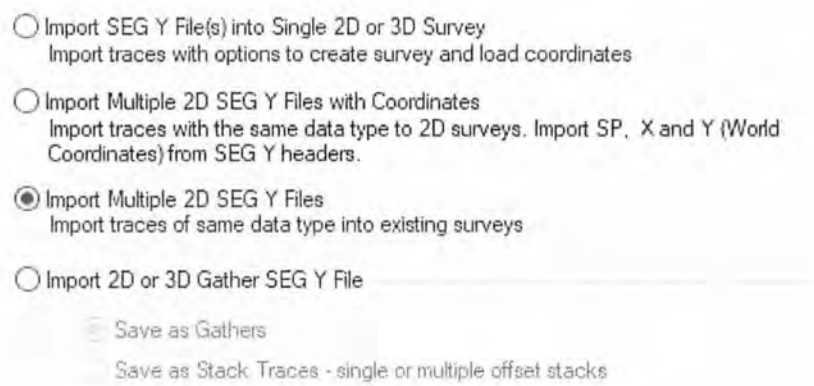


Fig 4.5a Kingdom giving option to import single or multiple SEG-Y, 2D or 3D survey lines.

Fig 4.5b Selecting seismic data type for SEG-Y file.

4.5.2 Importing SEG-Y Files

In this project, I selected import multiple SEG-Y files to import number of lines simultaneously. The multiple lines imported simultaneously are:

- TJ88-207_Final_Filtered_Migration
- TJ89-503
- TJ89-512
- TJ89-516
- TJ89-520
- TJ89-522
- TJ89-524
- TJ89-526
- TJ89-528
- TJ90-709
- TJ91-803

These all files are in SEG-Y format. Fig 4.6 shows importing of these files in Kingdom.

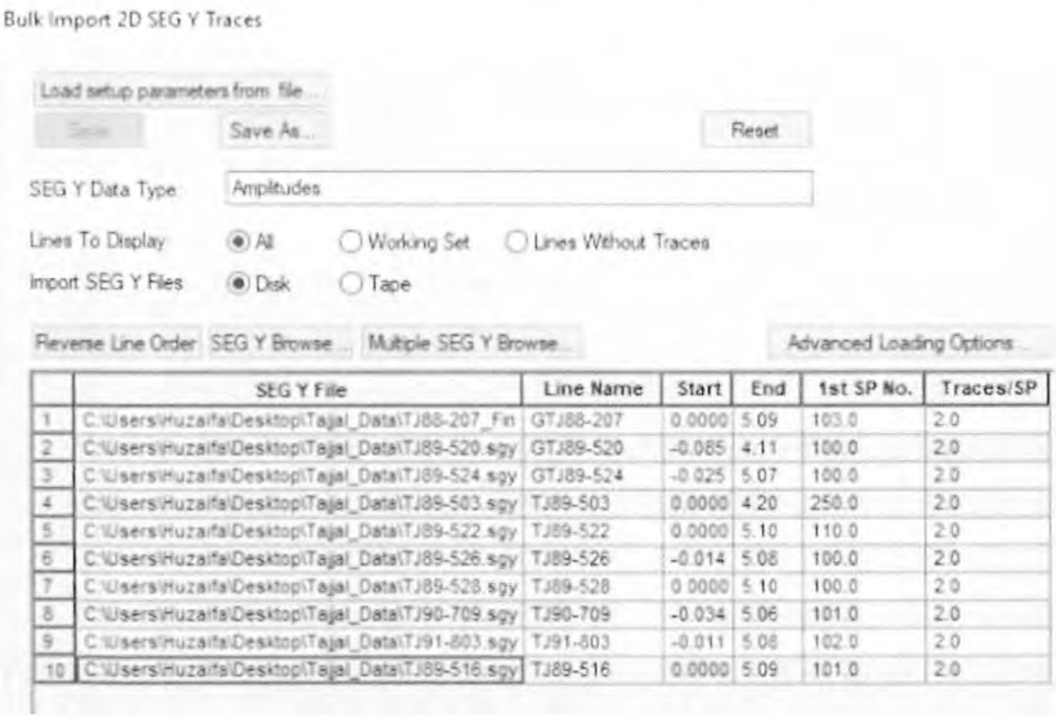


Fig 4.6 SEG-Y files being imported in Kingdom simultaneously.

4.6 Add Well in Kingdom

4.6.1 Well Information

After importing the SEG-Y files in Kingdom, we can view the line data as a seismic gather in Kingdom. Now we can mark the horizons in seismic lines but we don't know about the depth of lithology and what horizon they are represented with for this purpose we must import the well data in Kingdom and make a synthetic seismogram to make a well seismic tie. Now I import the well data. To do this in Kingdom we have an option of 'Add well' as shown in Fig 4.7 below. In the well data file, we have all the information to put in the well data dialog. Following information is required to add a well in Kingdom:

- Well Name
- Well Number
- Elevation
- UWI
- Elevation Reference
- Location Unit
- Operator Name
- Well Symbol
- Coordinates(X,Y)
- Surface Elevation
- Total Depth

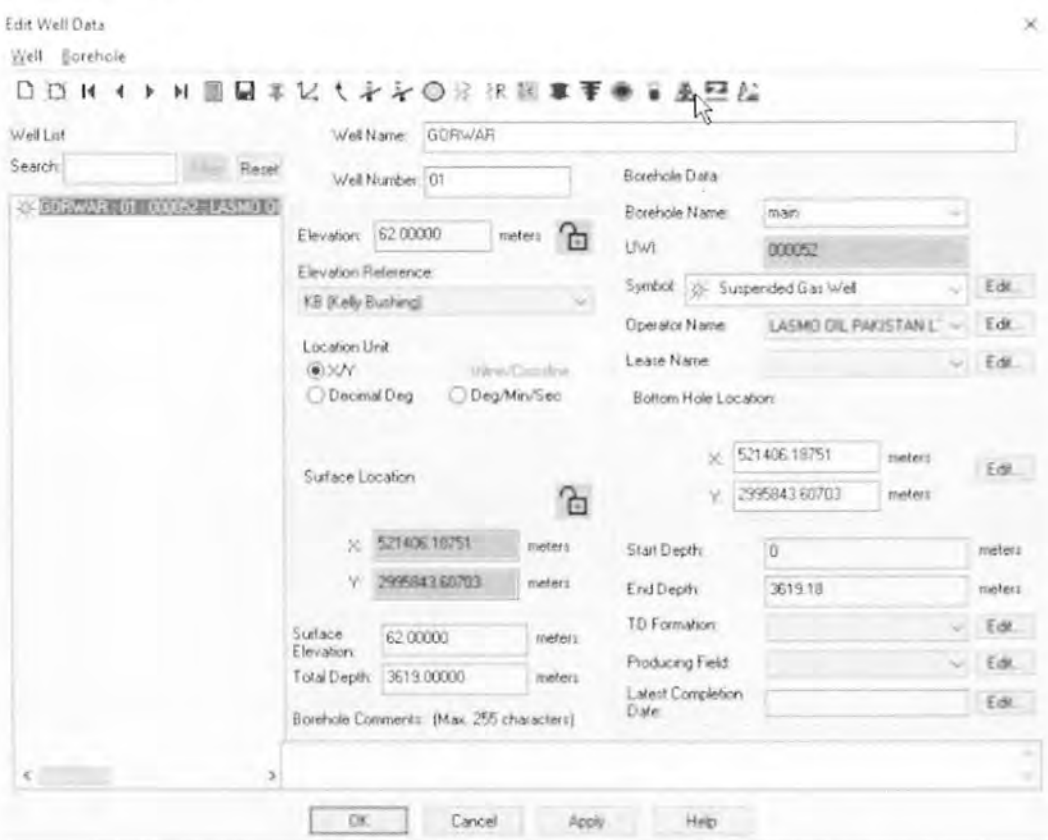


Fig 4.7 Well data being added in Kingdom.

The above step created a well location in Kingdom Base map as shown in Fig 4.8 but the information about the encountered lithology and their relationship with time is missing for that we must add the time depth chart also called T-D chart and bore hole.

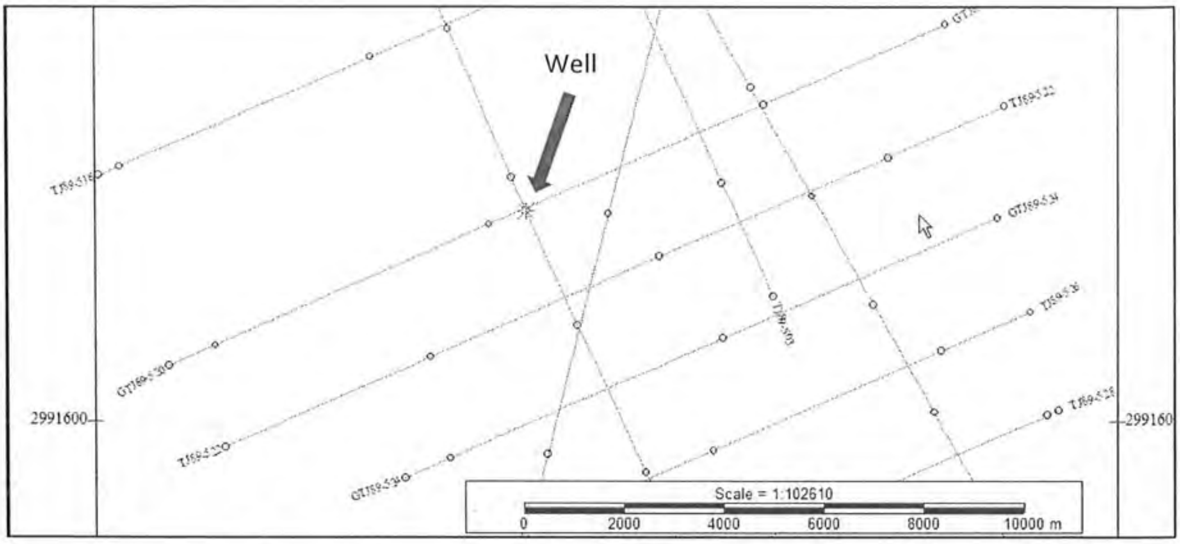


Fig 4.8 Showing well on base map as a red marker.

4.6.2 Time-Depth Chart

The seismic data is in form of time vs amplitude. To convert this time section into depth a time depth chart is needed. Now we add the time depth information in Kingdom. This chart will also be used in generating synthetic seismogram. Fig 4.9 below show time-depth chart dialogue in Kingdom.

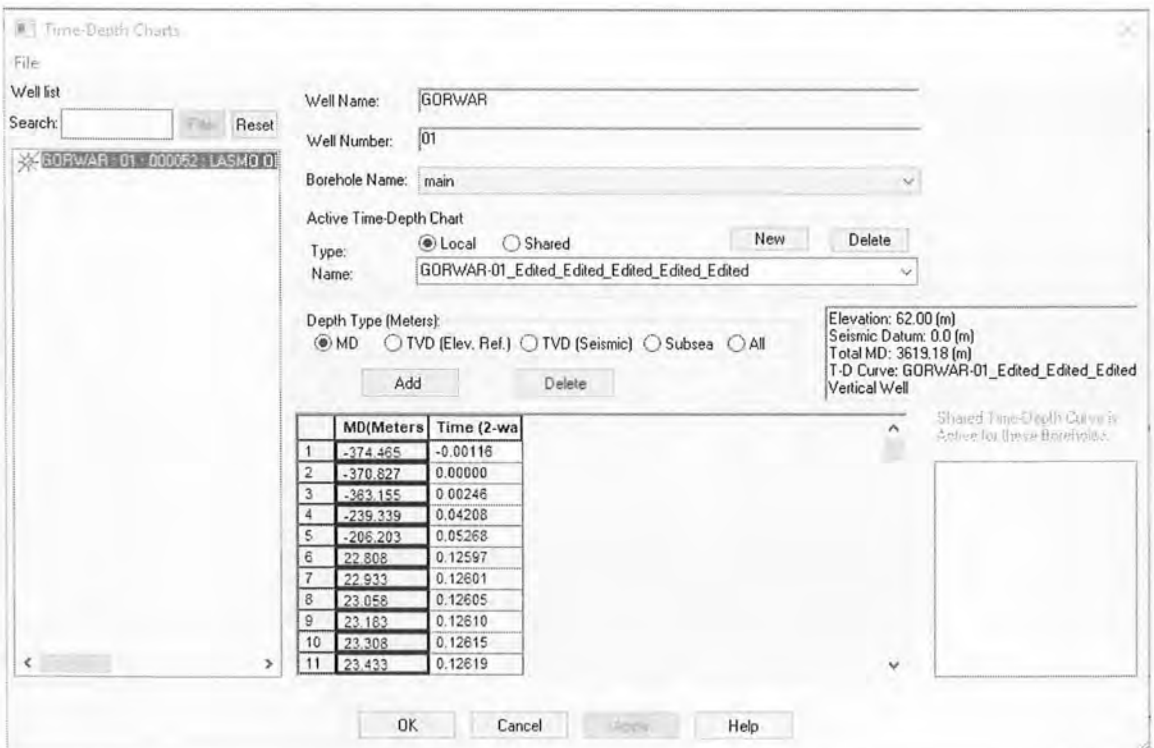


Fig 4.9 shows time-depth chart being added to Kingdom.

4.6.2 Formation Tops

With the help of time-depth chart we can convert the seismic time section into depth section but still we don't know the formation tops to mark the horizons in the seismic section so formation tops are imported to the Kingdom as a final step in loading data to Kingdom. Process of importing formation tops is shown in Fig 4.10.

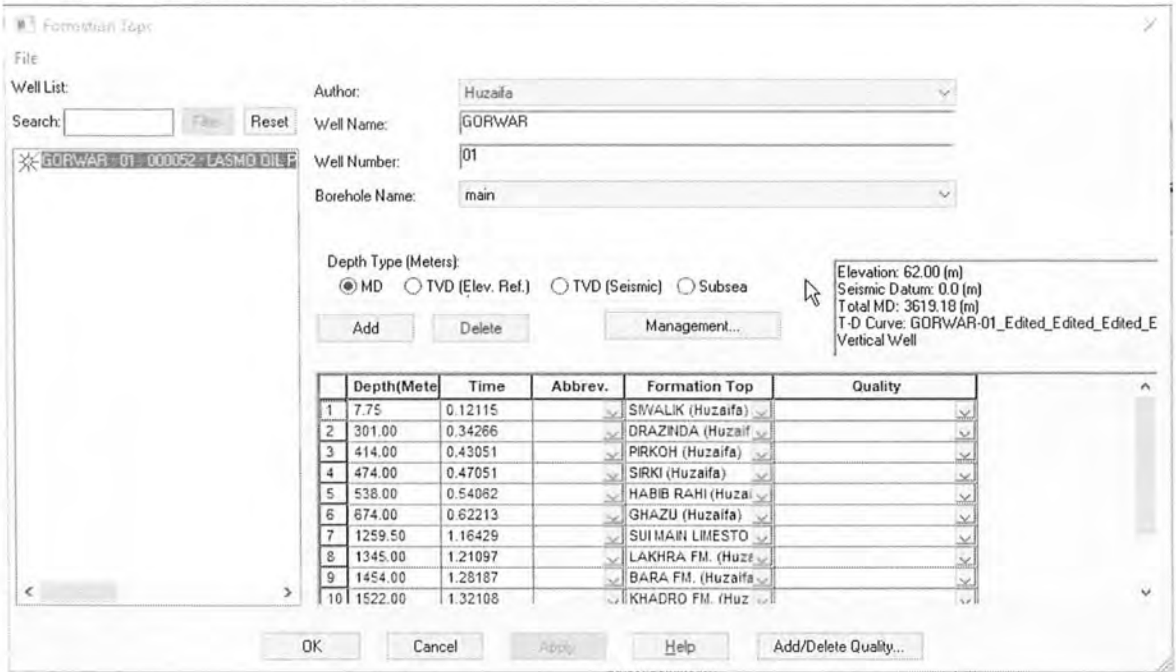


Fig 4.10 Importing formation tops.

After all this loading process, the process of generating synthetic seismogram, marking faults and horizons starts.

Chapter 5

SEISMIC DATA INTERPRETATION

5.1 Introduction

The objective of seismic data interpretation is to extract all available subsurface information from the processed seismic data. This includes structure, stratigraphy, subsurface rock properties, velocity, stress and perhaps reservoir fluid changes in time and space. This process requires the best possible acquisition and processing to have been performed on the seismic data and also requires analogue knowledge of local geology (study area) from outcrop and pre-existing wells. A good knowledge of geologic history of the area to be studied is important in making quality decisions during interpretation of the seismic data. It is important for the seismic interpreters to have a developed understanding of the factors influencing regional tectonic sedimentation in the basin (area) to work on (Onajite, 2014).

After the work of loading data in Kingdom the actual work of interpretation starts. Now a well to seismic tie is created to get high resolution of data and get a time to depth conversion in seismic section.

5.2 Well to Seismic Tie

A well tie compares seismic data at a well location with log data from the well. To perform well to seismic tie, processed seismic data is required. The processed data gives a real seismic trace at the wellbore location that must be tied with well. A synthetic seismogram is generated for this purpose. Synthetic seismogram is a seismic trace created from sonic and density logs and it is used to compare the original seismic data collected near the well location (Onajite, 2014).

Following items are required to generate a synthetic seismogram:

- Sonic log
- Density log
- Extracted wavelet

5.2.1 Sonic Log

Sonic logs are the principle source of well velocity data. They provide direct information about the borehole and the rocks penetrated by the drill bit. The sonic log is a measure of the time necessary for a sound wave to traverse one unit of the earth along the well bore, usually labelled 'DT' and the reciprocal of DT is the velocity (in m/s). The unit for sonic log is microseconds per foot or microseconds per metre.

Sonic logging tools measure the transit time of an acoustic wave between a down-hole source and receiver. The logging tool is an average over a couple of metres and is typically recorded two samples per foot, while the tool is pulled up along the borehole(Onajite, 2014).

5.2.2 Density Log

The density log usually labelled 'RHOB' measures the density of the borehole and the rocks penetrated by the drill bit. The unit for density is gram per cubic centimetre.

The logs (sonic and density) measurements are usually made every 6 in. down hole, but must be aligned to be 'on-depth' with each other. If we take aligned DT and RHOB logs and convert the depths to metres, we have a reading roughly every 15 cm. We then multiply the sonic and density data to produce an acoustic impedance data for each reflecting interface in the subsurface. From the acoustic impedance, we compute the reflection coefficients for each reflecting interface (Onajite, 2014).

5.2.3 Extracted Wavelet

We have sonic and density from well data and extract a trace from seismic section to make a well to seismic tie. The extracted wavelet for this project is shown in fig 5.1. We need a source wavelet to generate a synthetic trace. Software is used to estimate the source wavelet from the processed seismic data, for a given window of the real data. Usually, this window would be at the wellbore location and near the reservoir zone of interest we aim to tie with the real seismic trace.

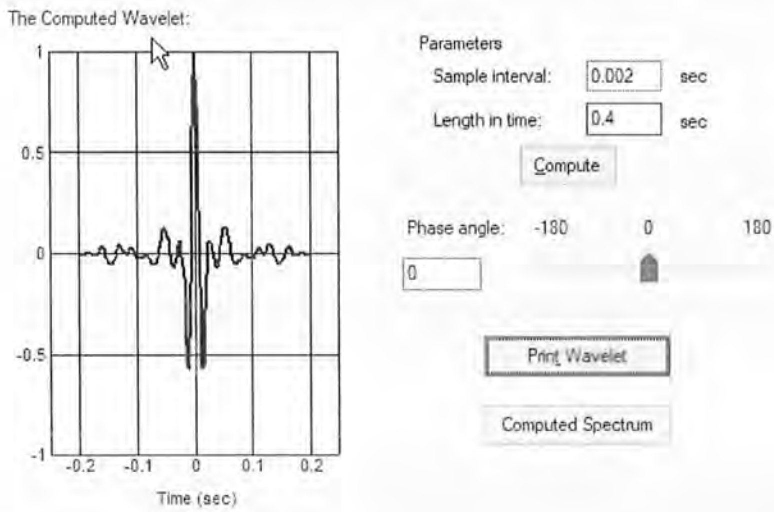


Fig 5.1 Extracted wavelet in Kingdom.

5.3 Generating Synthetic Seismogram

From the above collected data we generate a synthetic seismogram. A synthetic seismogram is generated my first taking the product of sonic and density logs and then convolving this product with extracted wavelet. Synthetic seismogram generated in this project is shown in fig 5.2.

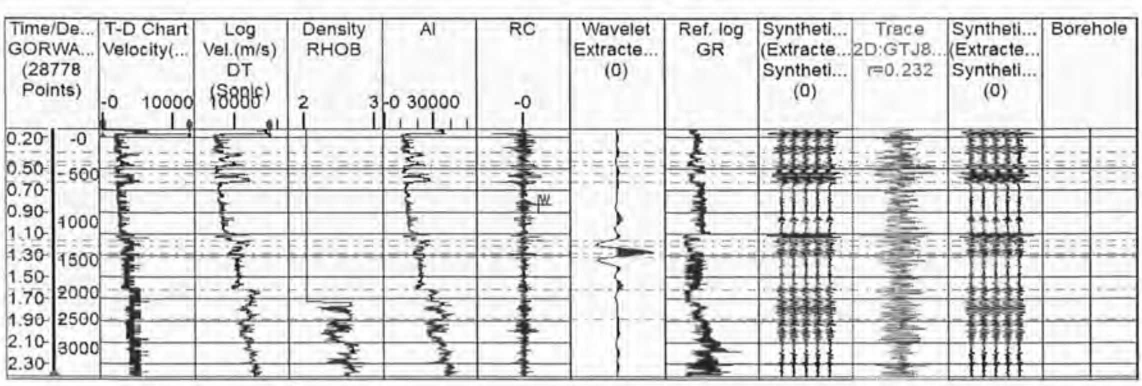


Fig 5.2 Synthetic seismogram

5.4 Fault picking

Now we have a well to seismic tie through the generated synthetic seismogram. We can mark the faults on the lines given in data by using the geological and stratigraphic information we have. Structural styles often provide a broad context for understanding the pattern of faulting that may be expected in a region. Its basic utility lies in identifying certain basic patterns of deformation that are repeated in geologic provinces. Faults picked on line TJ89-520 is shown in fig 5.3.

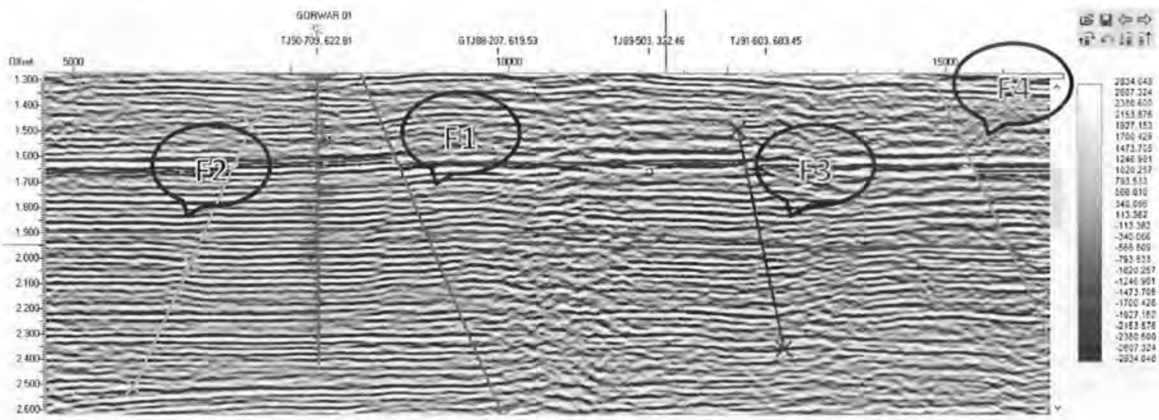


Fig 5.3 Four faults picked on line TJ89-520 in Kingdom.

Fault Interpretation

What are some of the clues to look for on seismic data to recognize faults? They are listed here:

- Termination of reflections
- Offset in stratigraphy markers
- Abrupt changes in dip, abrupt changes in seismic patterns - e.g. a strong, continuous reflection turns into a low amplitude region,
- Fault plane reflections – only when fault dips less than about 30
- Associated folding (Onajite, 2014).

Faults are recognized most often on a seismic section by the terminations of the strata reflections at the fault, see fig 5.3. These reflections terminations are not abrupt. When the fault throw is small enough that the displaced horizon can be identified on both sides of the fault, the fault throw can be measured by noting the difference of travel time between the two horizons.

5.5 Seismic Horizon picking

To the exploration geophysicists, a horizon is an event, a reflection, in the seismic data, something you could pick with an automatic tracking tool available in Kingdom. The quality is subject to the data itself. A change in the data, or seismic processing, may change the horizon. Well to seismic tie helps us mark the specific horizon as a lithology as shown in fig 5.4 some faults and horizons are marked of line TJ89-16, TJ89-520, TJ89-522 and TJ89-503.

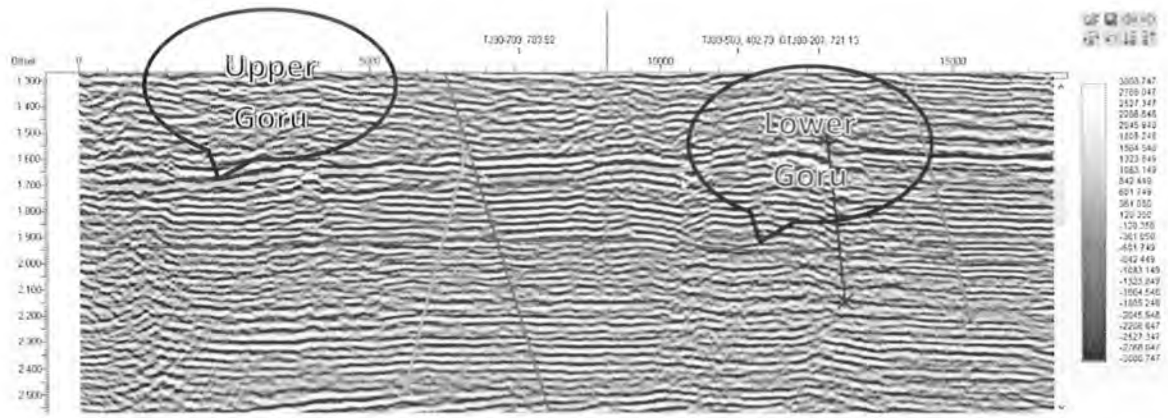


Fig 5.4a Faults and horizons are marked of line TJ89-16.

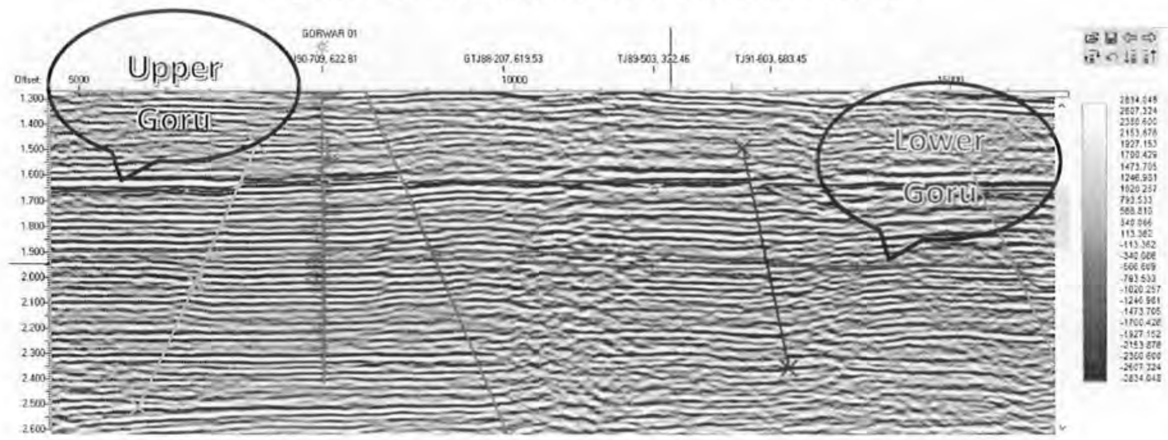


Fig 5.4b Faults and horizons are marked of line TJ89-20.

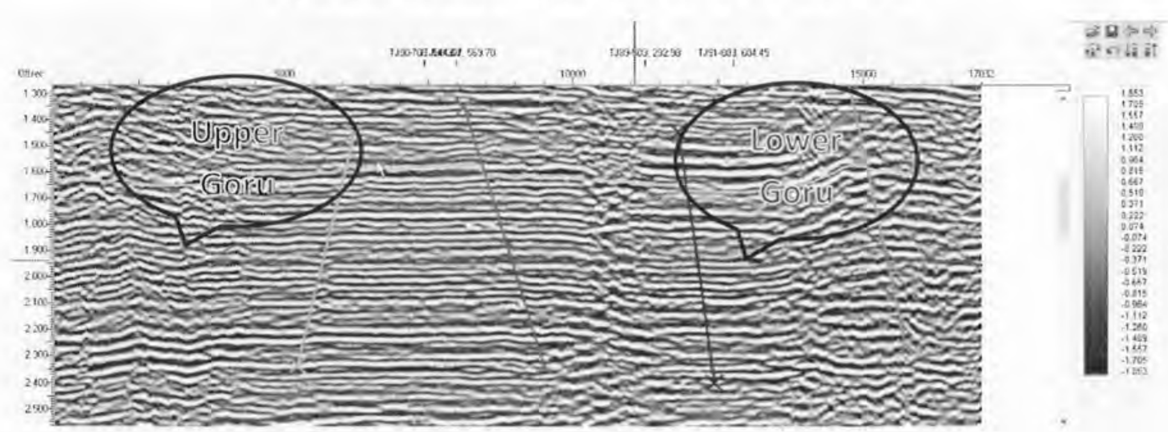


Fig 5.4c Faults and horizons are marked of line TJ89-522.

From the figure above we can see that the lines TJ89-16, TJ89-520 and TJ89-522 are dip lines and have faults. We can observe horst and graben structures formed in these marked sections. These structures can provide a trap for the hydrocarbon to accumulate in them and later extracted by drilling wells in them. It is known from the literature that lower Indus basin has extensional regime and contain horst and graben structures, no stratigraphic traps are found in southern Indus basin.

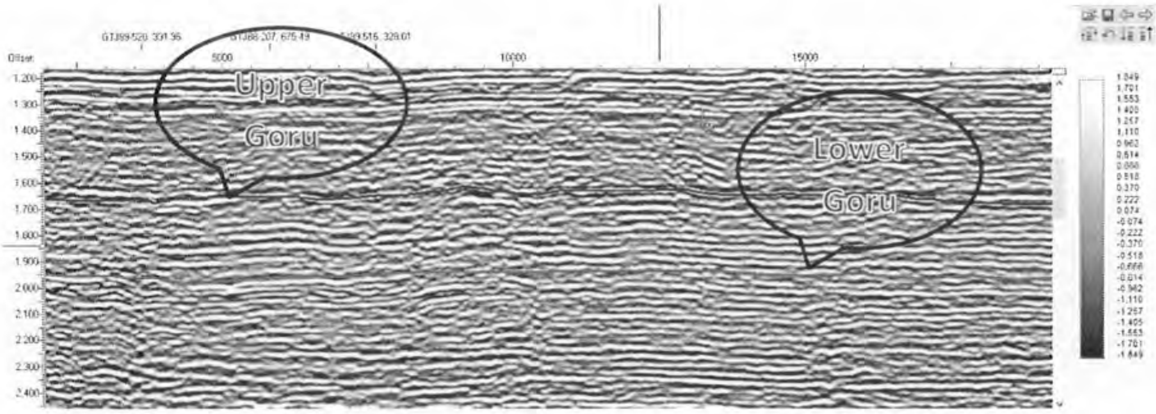


Fig 5.4d Horizons are marked of line TJ89-503.

Line TJ89-503 shown in Fig 5.4d is a strike line so have no faults but may have micro faults on local scale. Horizon marked with blue is Upper Goru while Lower Goru is marked with red colour.

5.6 Time Contour Maps

Contour maps show the variation of values in a region. Time contour maps are generated to see the variation of two-way travel time for a particular horizon, this means we are creating a time contour map to see the variations in a reflector with respect to time. Time contour maps of Upper Goru and Lower Goru are shown in fig 5.5a and 5.5b. Low time values(red) are showing shallow region and high time values(blue) are showing deeper regions.

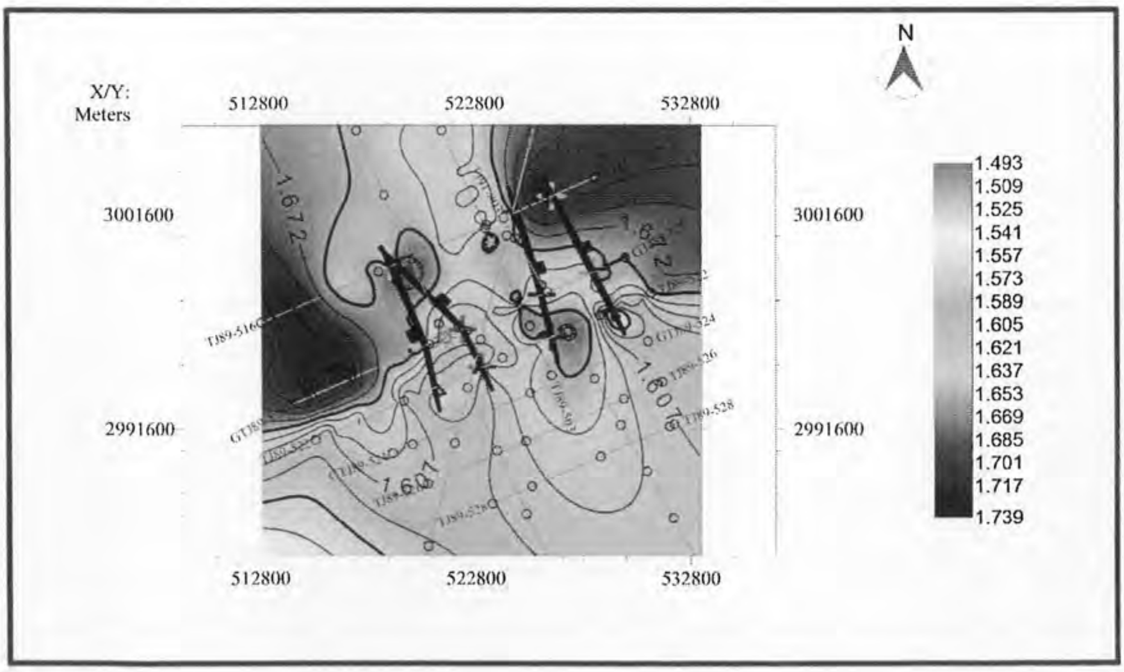


Fig 5.5a Time Contour Map of Upper Goru

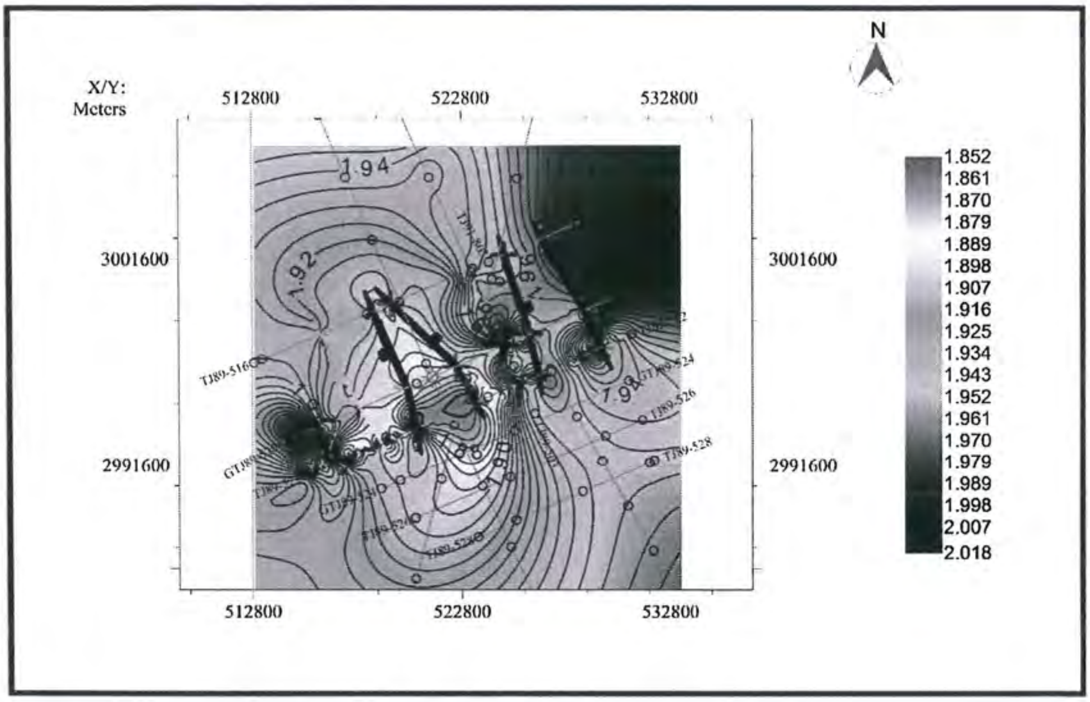


Fig 5.5b Time Contour Map of Lower Goru

Time contour maps cannot show the real structures of subsurface because of the variable velocities that are encountered by the waves on the way to reflector and back that is why we generate depth contour maps.

5.7 Depth Contour Maps

Depth contour maps are showing depth values in meter with the colour in maps. Both depth maps are shown in fig 5.6a and 5.6b.

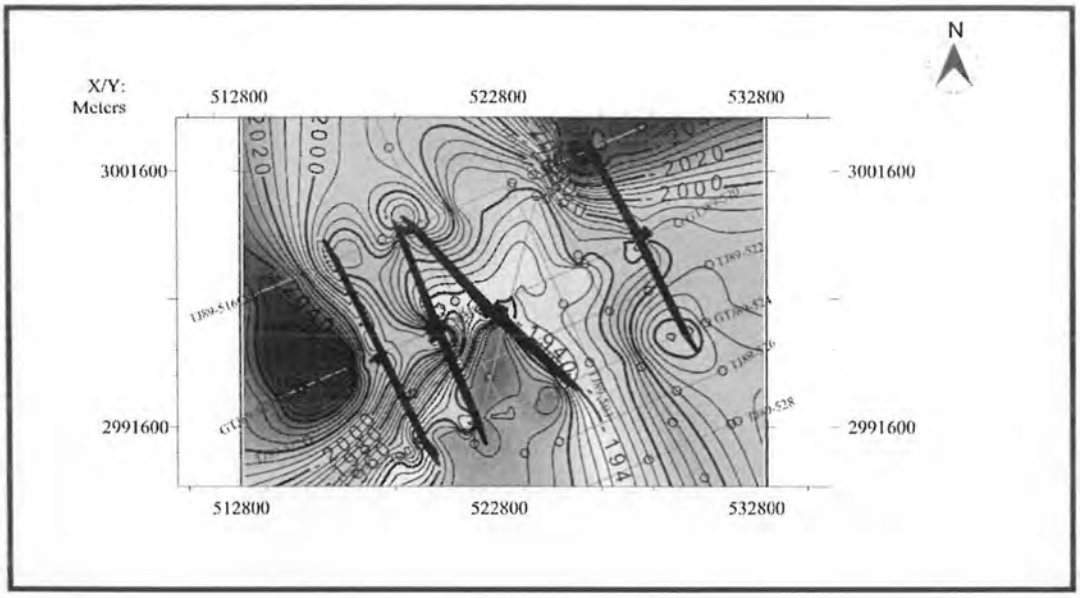


Fig. 5.6a Depth Contour Map of Upper Goru

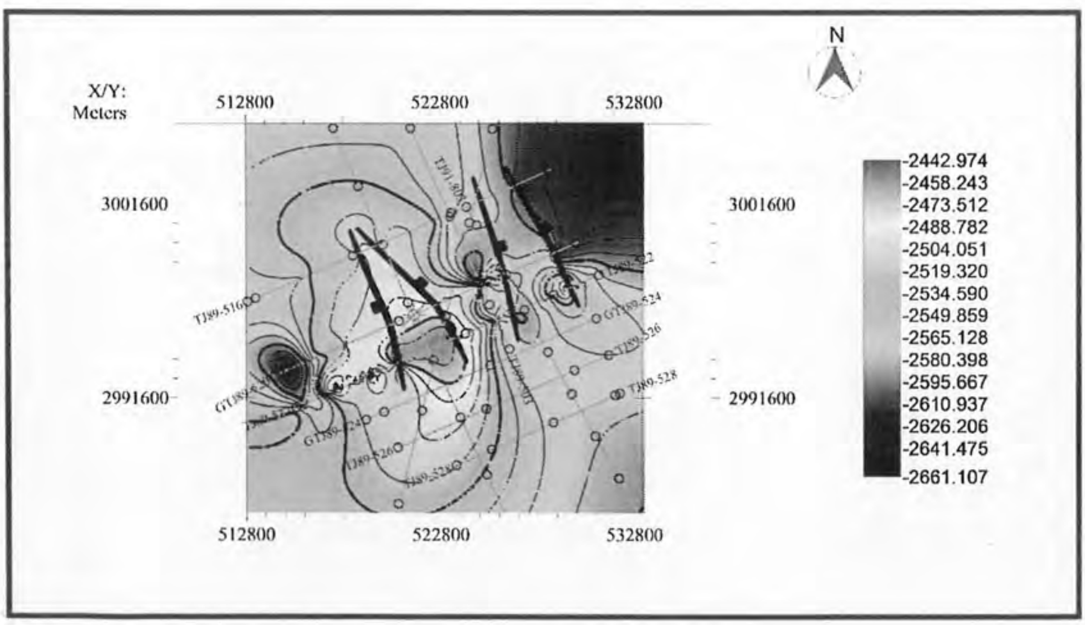


Fig. 5.6b Depth Contour Map of Lower Goru

5.8 Interpretation

1. Horizons are marked on the basis of continuity and character of seismic traces and are named as Upper Goru and Lower Goru.
2. Reflectors are marked with the help of well data present on line TJ89-520 and synthetic seismogram.
3. From the time and depth contour maps we can see the well location is in a horst structure.
4. The Depth Section is further confirmed by correlation with Synthetic Seismogram.
5. Time to Depth conversion of seismic section gave a true picture of sub-surface structure.

Chapter 6

PETROPHYSICS

6.1 Introduction

Well logging is the technique to measure the properties of the earth's subsurface. By using this technique, various physical, chemical, electrical or other properties of rock /fluid mixtures penetrated by drilling a well into the earth are recorded. Petrophysics is the study of the physical and chemical properties that describe the occurrence and behaviour of rocks, soils and fluids (Rider, 1996). This also defined "The petrophysics is description of physical properties relating the occurrence, behaviour of rocks and fluids inside the rocks.". Petrophysics uses well logs (calliper, resistivity, GR, DT, RHOB, Neutron logs etc.) and all pertinent information is obtained by use these well logs. Every well log has its own importance and these logs play very important role in quantifying the precise reservoir parameters such as porosity, permeability, net pay zone, fluid content and shale volume. Petrophysical interpretation generally has less concern with the seismic and more concerned with using well bore measurements to contribute to reservoir description. (Krygowski, 2004).

6.2 Well Logs

Different classifications and some short explanation of geophysical well logs is as follow. The logs are explained according to the tracks in which they are run and this is clear from the flow chart given below.

6.2.1 Lithology Logs

In lithology track the following three logs are displayed which are explained as follow.

- Gamma ray (GR)
- Spontaneous Potential log (SP)
- Calliper Log (CALI)

Gamma ray (GR)

With the help of this log we measure the natural radio activity of the formation. Basically, the gamma ray log is the passive logging because we measure only the formation property without using any source. The gamma ray emits from the formation in the form of the formation in the form of the electromagnetic energy which are called the photon. When photon collide with the formation electron hence they transfer the energy to the formation electron so the phenomenon of the Compton scattering occurs. Now these emitted gramma ray reached to the detector of the gamma ray and counted and displayed as count per second which is termed as the Gamma ray. Basic purpose of this log is to differentiate between the shale and non-shale (Acquith and Gibson, 2004).

Spontaneous Potential log (SP)

The SP log is also passive log which record the naturally occurring potential in the well bore. In this log, we used the single moving electrode in the bore hole and reference electrode at the surface, located in the mud pit. Hence the SP log therefore record the potential difference between the reference electrode and the moving electrode in the borehole (Gibson, 2004). This log is used for the following purposes according to the (Danial 2003).

- Identification of the permeable and non-permeable zone.
- Detection of the bed boundaries.
- Determination of the shale volume.
- Determination of the resistivity of the formation.
- Up to some extent the qualitative measure of the permeability.

Calliper Log (CALI)

Calliper log use to measure the borehole size. This log give us help to identify the cavity washouts and break outs. Hence this log is also called the quality check for other logs. Because if any where there is say wash out then in front of the wash out the porosity and resistivity log will not give the correct reading. Hence calliper log is very important in petrophysical logs.

6.2.2 Porosity Logs

Porosity logs measure the porosity in the volume of the rock. These logs are also helpful to distinguish between the oil, gas and water in combination with the resistivity log.

Porosity log include

- Sonic logging (DT)
- Density logging (ROHB)
- Neutron logging (NPHI)

Sonic Log (DT)

Sonic log device consists of a transmitter that emit sound waves and a receiver that picks and record the compressional waves as it reaches the receiver. This log is a recording verses depth of time (t) which is required by a compressional wave to go across 1 feet of formation, called interval transient time Δt, while it is the reciprocal of the velocity of sound wave. This time (Δt) is depended upon lithology and porosity of the formation (Asquith and Gibson, 2004). Sonic log can also be used for the following purposes in combination of other logs as given by (Daniel, 2004).

1. Porosity (using interval transit Time)
2. Lithology identification (with Neutron and/or Density).
3. Synthetic seismograms (with Density).
4. Mechanical properties of formation with (Density).
5. Porosity (using interval transit time).
6. Lithology identification (with Neutron and/or Density).
7. Synthetic seismograms (with Density).

8. Mechanical properties of formation (with Density)
9. Abnormal formation pressures detection.

Density Log(RHOB)

In the density logging gamma ray collide with the electron in the formation and scattered gamma ray (Compton scattering) received on the detector which indicate the density of the formation. Increase in the bulk density of the formation causing the decrease in the count rate and vice versa.

Bulk density which is obtained from the density log is considered the sum of the density of the fluid density and the matrix density of the formation. However, density log used separately and also along with the other log to achieve the various goals (Tittman and Wahal, 1965).

Neutron log (NPHI)

This is the type of porosity log which measure concentration of Hydrogen ions in the formation. Neutron is continuously emitted from chemical source in the tool of the neutron logging. When these neutrons collide with nuclei in the formation and results in loss of some energy. Hydrogen atom has same mass as that of neutron, maximum loss of energy occurs when electron collides with hydrogen atoms.

Hydrogen is an indication of the presence of the fluid in the formation pores, hence loss of energy is related to the porosity of the formation.

The neutron porosity is very low when the pores in the formation are filled with the gas instead of the water and oil, the reason is that gas having les concentration of the hydrogen as compared to water and oil. This less porosity by the neutron PHI due to the presence of the gas called the Gas effect (Asquith and Gibson, 2004).

6.2.3 Electrical Resistivity Logs

Basically, there are different types of electrical Resistivity Logs. But in my work, I have only two logs available in my data which are simply explained as follow.

These logs measure the resistivity of the subsurface, but actually they measure the resistivity of the formation fluids. They are very helpful in order to differentiate between water filled formation and the hydrocarbon filled formations. Resistivity logs includes the following.

- Laterolog Deep (LLD)
- Laterolog Shallow (LLS)

Laterolog Deep (LLD)

Laterolog deep is used for the deep investigation of the quietly undisturbed (Uninvaded zone) and it is called Laterolog deep (LLD). This log is also used for saline muds also in case of fresh mud. This log is generally used for measuring the formation resistivity. LLD has deep penetration as compared to the (LLS).

Laterolog Shallow (LLS)

Laterolog shallow (LLS), used for shallow investigation of the transition zone / invaded zone. Because the depth of the investigation is smaller than the LLD

6.3 Workflow for Petrophysical Analysis

Petrophysical interpretation is carried out using the kingdom software. First of all the raw log curves are loaded step by step and different log properties are calculated. Different mathematical equations and the Schlumberger charts are used in order for the calculation of the different log properties. Work flow is given in Fig 6.1.

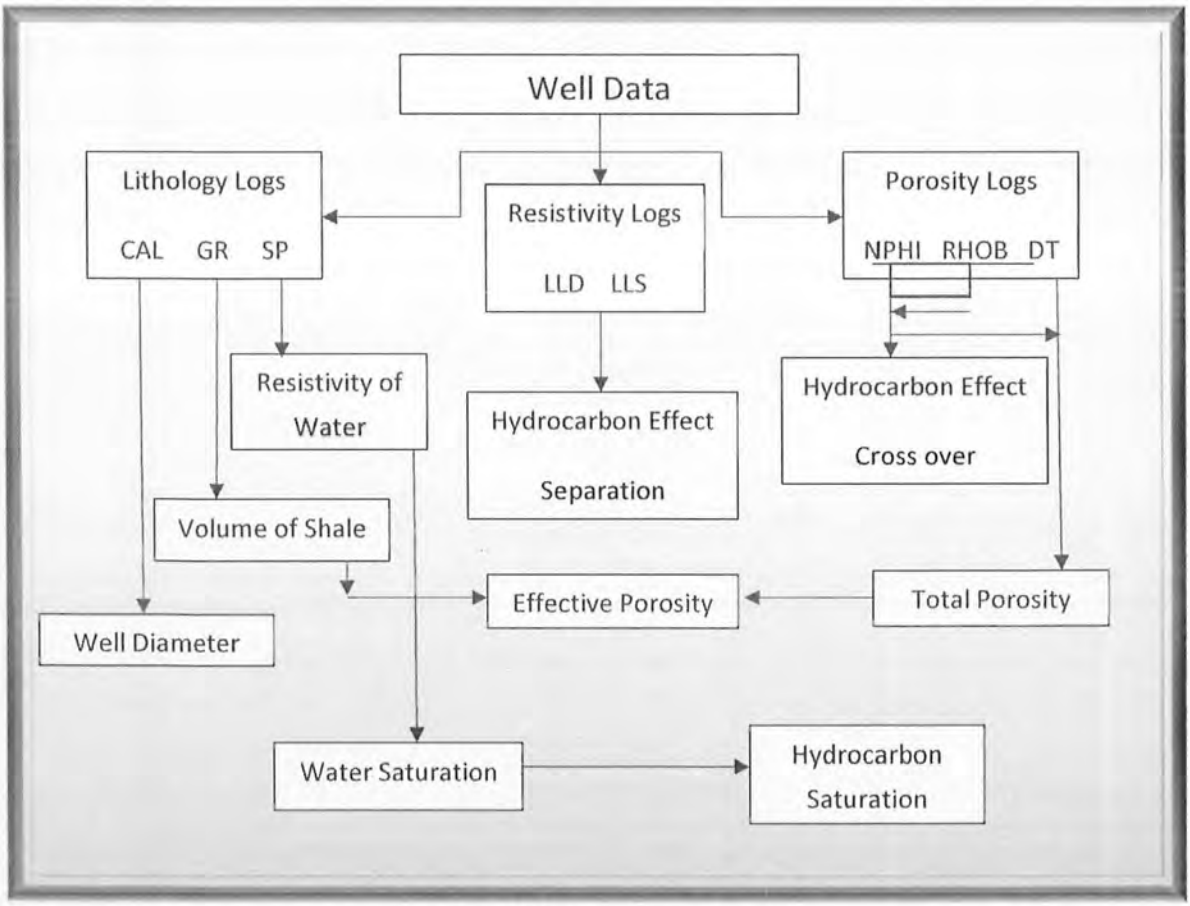


Fig 6.1 Workflow of petrophysics.

6.4 Petrophysical Calculations

The combined effect of different logs provides us enough information about the presence of a prospect zone in the subsurface. As shown in above Fig 6.1 we use different logs in a form of a flow chart to get desired results. Calliper log lets us about the bore hole diameter so we ignore the effect of bore hole in the log interpretation by looking at calliper log. Gr log gives us indirect information about the volume of shale at a particular depth, for the presence of hydrocarbon we mark the zone having low shale as a result high sand zones.

Resistivity logs like LLD and LLS are used to check the hydrocarbon effect in the subsurface LLS gives near borehole (invaded zone) area resistivity while LLD gives resistivity of uninvaded zone. A cross over between these logs gives the hint about the presence of hydrocarbon.

Neutron porosity (NPHI) and Density log (RHOB) also give a crossover in the presence of hydrocarbon. But these logs are taken in reverse order to get a cross over i.e. One is increasing from left to right then other is increasing from right to left. Table 6.1 shows the units and scale use in the petrophysical analysis.

No.	Logs	Abbreviations	Scale	Units
1	Calliper Log	CALI	6 -- 16	Inches
2	Gamma ray Log	GR	10 -- 200	API
3	Laterolog Deep	LLD	0.2 -- 2000	Ωm
4	Laterolog Shallow	LLS	0.2 -- 2000	Ωm
5	Density Log	RHOB	1.95 -- 2.95	gm/cm^3
6	Neutron Log	NPHI	0.45 -- (-0.15)	p.u.

Table 6.1 Scale and units used in different logs.

From these logs (GR, RHOB and NPHI) we calculate values of density porosity, neutron density porosity, volume of shale, effective porosity, water saturation and hydrocarbon saturation. All the logs used in petrophysical analysis are shown in Fig 6.2.

CALI		LLD	RHOB			VSH			
6.00 16.0		0.20 2000	1.95 2.95			0.00 1.00			
GR		LLS	NPHI	PHID	PHIND	VSHC	PHIE	SW 0.04	HC
10.0 200		0.20 2000	0.45 -0.15	-0.15 0.50	-0.15 0.45	0.00 1.00	0.00 0.30	0.00 1.00	0.00 1.00

Fig 6.2 Logs and their representation use in petrophysical analysis.

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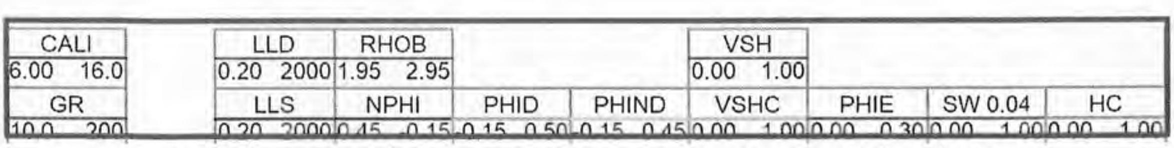

Fig 6.2 Logs and their representation use in petrophysical analysis.

6.4.1 Calculation of Density Porosity

Density porosity(PHID) is calculated from the following formula:

$$PHID = \frac{\rho_m - \rho_{log}}{\rho_m - \rho_f}$$

Where,

ρ_f is the fluid density (constant)

ρ_m is the matrix density (constant)

ρ_{log} is the log density (RHOB)

6.4.2 Calculation of Neutron-Density Porosity

Neutron-Density porosity(PHIND) is calculated from the following formula:

$$PHIND = \frac{1}{3} * \rho_N + \frac{2}{3} * \rho_D$$

Where,

ρ_N is the neutron porosity (NPHI)

ρ_D is the density porosity (RHOB)

6.4.3 Calculation of Volume of Shale

Volume of shale can be calculated from GR log. From GR log we can calculate volume of shale as:

$$IGR = \frac{GR_{log} + GR_{min}}{GR_{max} + GR_{min}}$$

Where,

$GR_{max}$the maximum deflection of GR log (constant)

GR_{min} Is the minimum deflection of GR log (constant)

GR_{log} Is gamma ray log (GR)

Another method used for calculating volume of shale(VSH) is **Clavier method**

$$VSH = \sqrt{1.7 - (3.38(IGR + 0.7)^2)}$$

6.4.4 Calculation of Effective porosity:

Effective porosity is the pore spaces that are available for the fluid flow or permeability in a reservoir. *It* excludes isolated pores and pore volume that are occupied by water adsorbed by the clay minerals or other grains. Effective porosity is essentially less than total porosity. Log of effective porosity can be obtained by using Density porosity, Neutron porosity and VSH logs.

$$PHIE = \frac{(PHID+NPHI)\times(1-VSH)}{2.0}$$

This shows that effective porosity is the total porosity less than the fraction of the pore space occupied by shale. PHI

6.4.4 Calculation of Water Saturation

Water Saturation (S_w) is the percentage of water present in the pore spaces. Water saturation can be calculated through following formula:

$$S_w = \sqrt[n]{\frac{a\times R_w}{\varphi\times m\times R_t}}$$

Where,

R_w is the resistivity of formation water (Schlumberger chart)

a, m and n are the Archie's constant

φ is the average porosity of formation (PHIE)

R_t is the true resistivity of formation (log)

6.4.5 Calculation of Water Saturation

Hydrocarbon saturation can be calculated by simply subtracting the water saturation (S_w) from one. The remaining part represents the concentration of hydrocarbons.

$$S_H=1-S_W$$

6.5 Petrophysical log Interpretation

Two potential Zones are marked in the Fig 6.3 as zone A and zone B. Zone B is from 3338 m to 3353 m, having a thickness of 15m. The zone is marked on the bases of logs. In zone B GR values are low representing the presence of sand and there is a separation between LLD and LLS plus there is a cross over between RHOB and NPHI also confirming hydrocarbon. In this zone the values of porosities are also high. The only thing remaining to observe is the percentage of water and hydrocarbon present in pores. Water saturation is also low resulting in increase in hydrocarbon saturation.

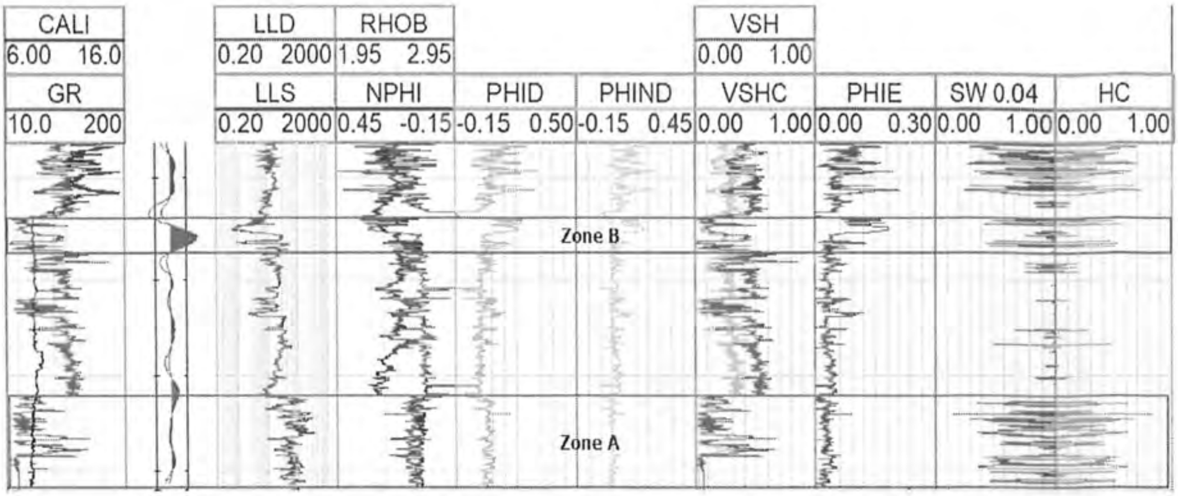

Fig 6.3 Petrophysical log with zone of interest marked.

Zone A is from 3537 m to 3559 m, having a thickness of 22m. The zone is marked on the bases of logs. In zone A GR values are low representing the presence of sand and there is a separation between LLD and LLS plus there is a cross over between RHOB and NPHI also confirming hydrocarbon. In this zone the values of porosities are also high. Present pores must have hydrocarbon in them to give us a prospect zone, for this purpose we find the values of water saturation and hydrocarbon saturation. Water saturation is also low resulting in increase in hydrocarbon saturation. Table 6.1 gives information about the zone parameters.

Parameters	Zone A	Zone B
Porosity	2.3	12
Volume of shale	5.0	8.6
Water saturation	76.64	88
Hydrocarbon saturation	23.36	12

Table 6.1 Parameters of zone of interest.

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