2D-SEISMIC REFLECTION DATA INTERPRETATION OF LINES GO-017-SNJ-03, GO-017-SNJ-08 AND GO-017-SNJ-22 OF SANJHORO AREA PAKISTAN

By

MUHAMMAD ZEESHAN YOOSUF

BS(GEOPHYSICS)

2013-2017

DEPARTMENT OF EARTH SCIENCES

QUAID-I- AZAM UNIVERSITY

ISLAMABAD, PAKISTAN.

بسم الله الرحمن الرحيم

“In The Name of ALLAH, the Most Merciful & Mighty”

“PAY THANKS TO ALLAH EVERY MOMENT AND GO TO EXPLORE THE HIDDEN TREASURES, ITS ALL FOR YOUR BENEFIT”

(AL-QURAN).

CERTIFICATE

This dissertation submitted **by M.Zeeshan Yoosuf** S/O **MUHAMMAD Yoosuf** 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 BS degree in Geophysics.

RECOMMENDED BY

Dr. M.Gulraiz Akhter ____________________
(Supervisor)

Dr. Mona lisa ____________________
(Chairperson Department of Earth Sciences)

EXTERNAL EXAMINER ____________________

ACKNOLEDGEMENT

In the name of Allah, the most Beneficent, the most Merciful. All praises to Almighty Allah, the creator of universe. I bear witness that there is no God but Allah, and Holy Prophet Hazrat Muhammad (P.B.U.H) is the last messenger of Allah, whose life is a perfect model for the whole mankind till the Day of Judgment. Allah blessed me with knowledge related to Earth. Without the blessing of Allah, I could not be able to complete my work as well as to be at such a place.

I am especially indebted to my dissertation supervisor Dr. Gulraiz Akhtar for giving me an initiative to this study. His inspiring guidance, dynamic supervision and constructive criticism, helped me to complete this work in time. I pay my thanks to whole faculty of department of Earth Sciences especially the teachers and senior students of Department of Earth Sciences especially Muhammad Asif whose valuable knowledge, assistance, cooperation and guidance enabled me to take initiative, develop and furnishing my academic carrier. I am thankful to all my friends, my class fellows and senior students of Department of Earth Sciences for giving their kind support during my dissertation work. I am also thankful to my parents, brothers and sisters my relatives for giving me all kind of support throughout my academic carrier.

MUHAMMAD ZEESHAN YOOSUF
BS-GEOPHYSICS
2013-2017

ABSTRACT

The dissertation work includes seismic data interpretation, seismic attribute analysis, Petrophysical analysis using well logs data; identification of possible resource plays as well as use of rock physics to estimate physical properties of rocks.Seismic and well log interpretation used for study of structural style, physical properties of rocks and identification of possible petroleum system of Sinjhoro area (Lower Indus Basin) Pakistan.

The seismic section shows Horst and Graben structure bounded by normal faults Time and depth contour maps were prepared to analyze the overall behavior of the structure. There are small anticlinal structures bounded by two normal faults which is clue towards either horst and graben structures to some extent.

Well locations are proposed by constructing time and a depth contour map which shows faulted anticline in study area. Seismic attribute analysis is then applied to confirm both structural and stratigraphic interpretation. Petrophysical analysis of wells Chack66-01 is carried out for Lower Goru in order to depict the probable hydrocarbon producing reservoir. The results suggest that Lower Goru Formation is more producing reservoir rock.Rock physics will be performed on Reservoir zone to find out the rock characterization.

Elastic Modulus decreases in the interested zone which shows that it is hydrocarbon saturated. Petrophysical results are confirmed by rock physics.

Seismic attributes analysis of seismic section helps in identifying the different lithological boundaries and further confirmed the structural and stratigraphic interpretation and petroleum play of the study area.

TABLE OF CONTENTS

CHAPTER-03 SEISMIC DATA INTERPRETATION

CHAPTER-04 PETROPHYSICAL ANALYSIS

CHAPTER NO:1

INTRODUCTION TO THE STUDY AREA

1.1 Introduction

Hydrocarbon is one of the most essential part of economics of any country. Even on the smaller scale hydrocarbon play a wide role in everyday life. Geoscientists are trying since a long time for the exploration of hydrocarbon and are applying different methods in this regard.

Geophysical methods are the most widely used methods in the exploration of hydrocarbon especially reflection seismology has a great importance in this regard. Seismic method is the leading exploration technique used now days. In order to carry out this study, seismic data of Sanjhoro area located in lower indus was used.

The given dissertation is to interpret the seismic section along the seismic lines GO-SNJ-03,GO-SNJ-08 and GO-SNJ-22 located in Sindh province. Sinjhoro development consists of a number of small fields discovered in proximity of each other with in the Sinjhoro Exploration License (such as Chak-2, Chak-63, Chak-63SE, Chak-66, Chak-66NE, Chak-7, Hakeem Daho, Lala Jamali and Resham) that are producing from the lower Goru formation of the early late cretaceous period (OGDCL,2014). It is extensional regime and normal faults are present here.Sinjhoro Gas Field is currently producing with full potential having 3000 BPD oil, 30 MMCFD gas and 155 MTD of LPG (OGDCL,2014).

The Sinjhoro field is located about 65 km NE of Hyderabad city of Sindh province in lower Indus basin and covers area of 102 acres. The main reservoirs are Basal and Massive sand and lower Guru formation in the area.

The Geographical coordinates of the Area **26° 00’ 00 N to 26°15’ 00 N, 68° 35’ 00 E to 69° 05 60 E** and its location is shown in Fig 1.1

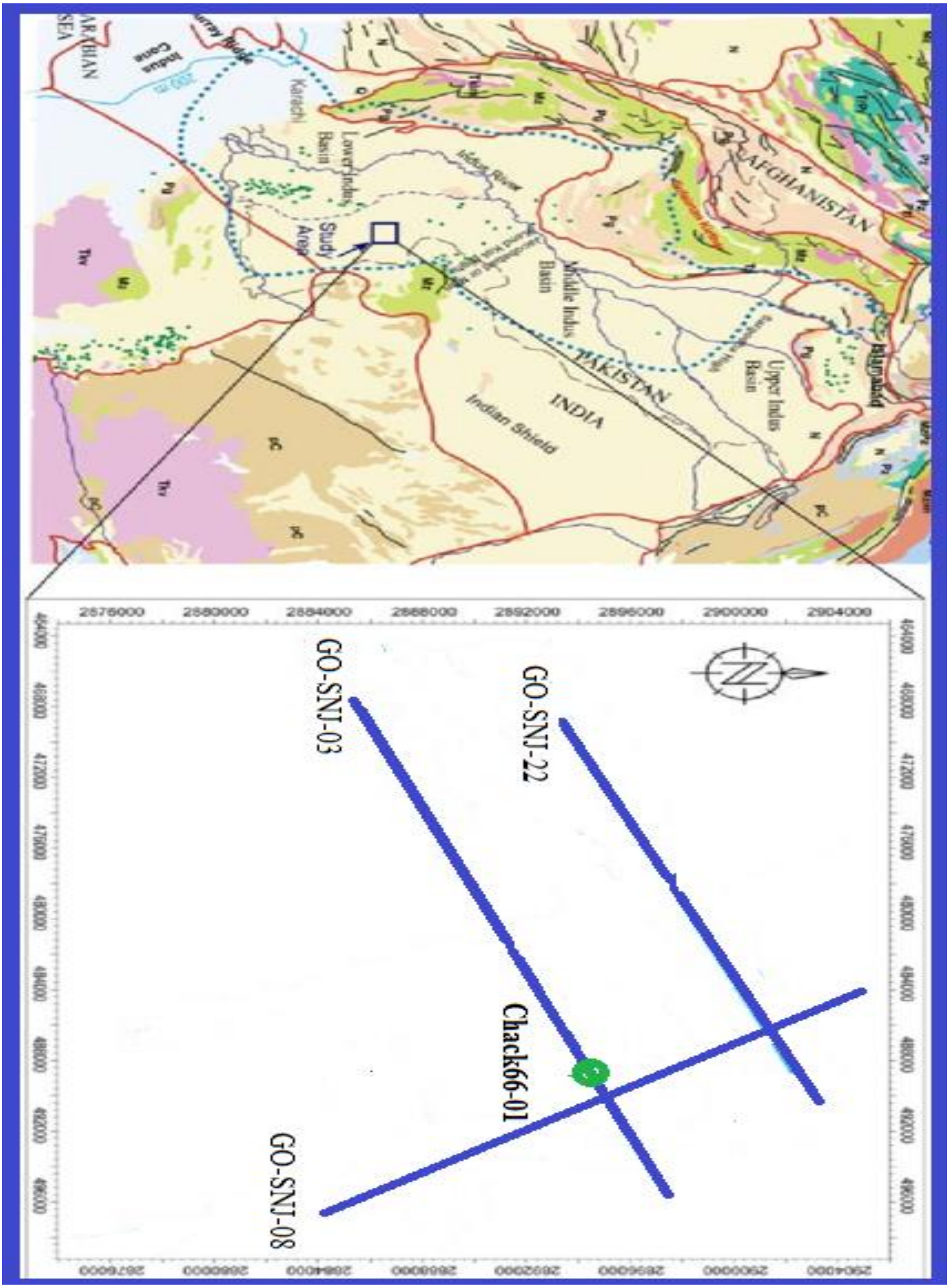


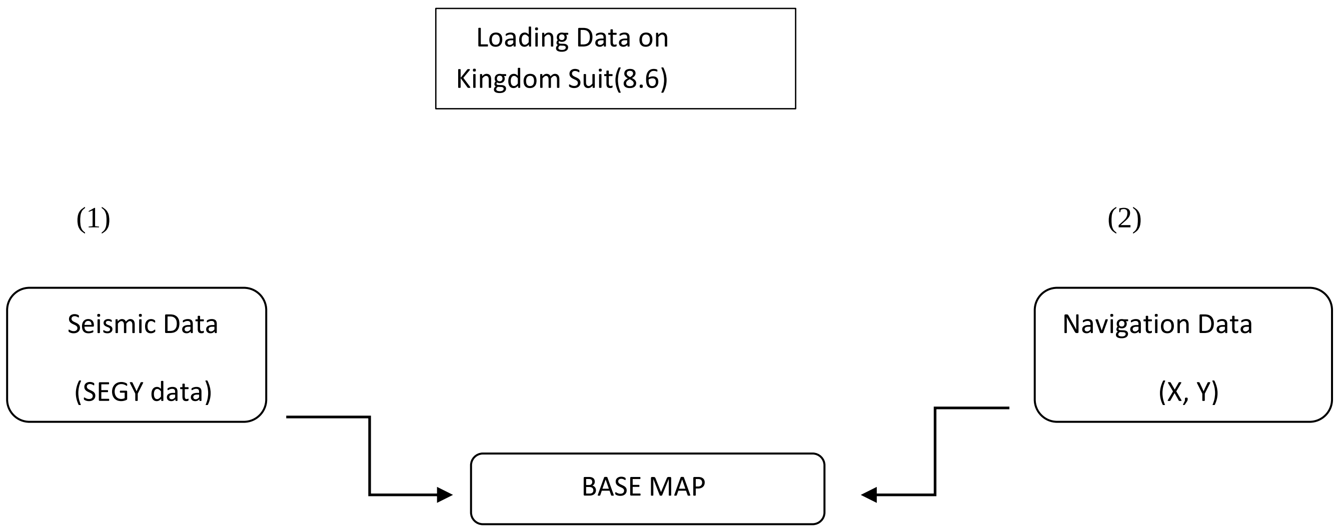
Figure 1.1: Satellite Image of the Area.(WWW.GoogleEarth.com)

1.2 Base Map of the Study Area

A base map is a map on which primary data and interpretation can be plotted. A base map typically includes location of concession boundaries, wells, seismic survey points and length of seismic spread, longitude and latitude of the study area. 2-D reflection seismic lines are used to construct the Base map Fig 1.2

Steps for the construction of base map

The major requirement for the construction of the base map is the Navigation file (DBO format) and SEGY files. Flow chart elaborated steps for the construction of the base map



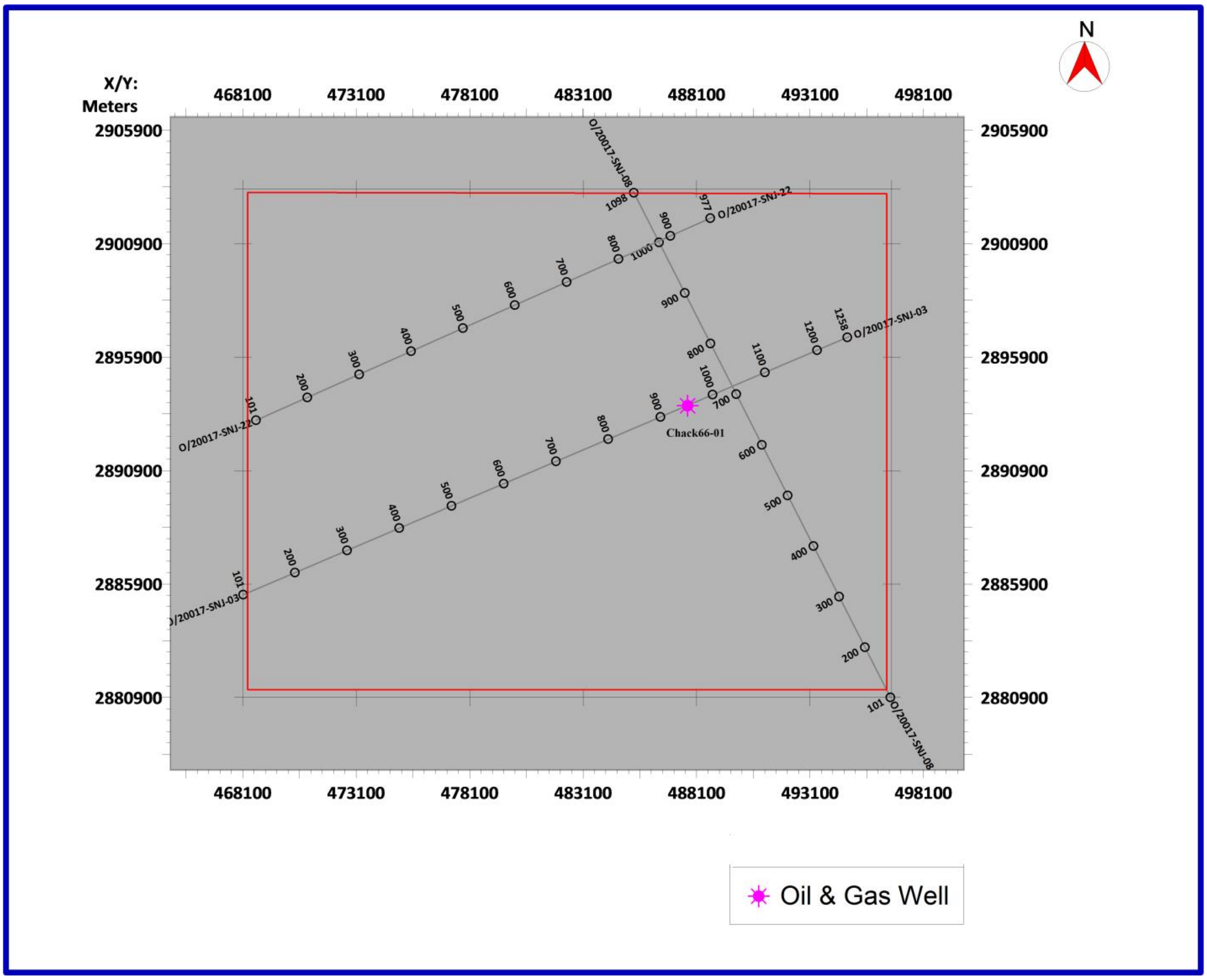


Figure 1.2: Base map of Study Area

1.3 Seismic Data

The Data set used in the study area consists of Three 2D-seismic lines and one well One in order to depict good understanding of the subsurface geology.

Data was recorded and processed by OGDCL. The line GO-017-SNJ-03 contains short point 101 to 1258, GO-017-SNJ-08 contains the short points 101 to 1099 and GO-017-SNJ-22 contain short points 101 to 978.

The Line direction for Dip line NE-SW, for Strike line NW-SE in Table1.1

Description Of Seismic Lines		
Line Number	**Shot Points**	**Type**
GO/200 17-SNJ-03	101-1258	Dip
GO/200 17-SNJ-08	101-1099	Strike
GO/200 17-SNJ-22	101-978	Dip

Table1.1 Discription of seismic lines

Well Data:

Well data information for well Chack66-01 is given in Table 1.2:

Well Name	Latitude	Longitude	Depth Reference	Total Depth(m)	Status
CHAK66-01	26º9’ 54”N	68º52’34”E	KB	2999	Oil&Gas

Table 1.2 Description of well Data

Other characteristics of the data set are given below:

1.4 Recording of Data

Crew

Constructer	OGDCL
Field party	SP-7
Recording date	October 2001
Direction of shoot	SW-NE
Datum velocity	1800 m/sec
Datum plane	M.S.L
Processing sampling interval	4 msec

Sources

Energy sources Hole depth Number of hole Charge	Dynamite 30m 01 03kg

Instrument

System	SN-358
Format	32-SEG D/ DMUX
Notch filter	IN
Field sampling interval	2MS
Record length	5 second
No. of data traces	240

1.5 Processing Sequence

1. Reformat to WGC code – 4
2. Sample 4 MSEC
3. Geometry update (Bade trace edit / reverse up hole time statics update)
4. Geometrical spreading compensation
5. Notch filter 50 HZ
6. CDP sorting
7. Zone anomaly process Surface consistent DE convolution
8. Trace balance after DECON
9. Velocity analysis
10. Velocity analysis
11. Normal move out
12. Start time mute
13. Datum reduction
14. Stack
15. Finite difference migration
16. Random noise attenuation

1.6 Objectives

The main objective of dissertation is to present a subsurface model, estimates the reservoir properties and to identify the new well location. All objectives are stated below in points

- For structural and stratigraphic interpretation, all the available geological and geophysical data (Seismic and Well data) have been utilized.
- Seismic interpretation has been performed to find the possible reservoir characteristic and estimate the extents of reservoir in the area.
- Petrophysical analysis has been performed using available wells to find the capability of storing and transmitting hydrocarbon.
- Rock physics will be performed to find characteristics of the subsurface material.
- Seismic attributes analysis to confirm the presence of hydrocarbon within identified structures and also to confirm interpretation.

CHAPTER NO: 02

GEOLOGY, STRATIGRAPHY AND TECTONICS

2.1 Regional Geological Setting:

The planet EARTH came into being about 4.6 billion years ago, up to the JURAISIC age there was only one land mass on the earth which was called Pangaea, this land mass started breaking about 200 million years ago and was divided into two parts, the northern part was called laurasia southern part was called Gondwana land. This breakage was initiated by two rifts, one in the northern part, between North America and Africa; it gave to the birth North Atlantic Ocean. Second rift was in the southern part, south America and Africa which gave the birth to the South Atlantic Ocean. Now due the rift that was produced between south America and Africa, a Y shaped crack was produced in the southern part of gondwana land due to which India was separated from the gondwana land, it was done about 130 million years ago (Tarbuck et al, 1997).

2.2 TECTONICS ZONE OF PAKISTAN:

On the basis of plate tectonic features, geological structure, organic history (age and nature of deformation, magmatic and metamorphism) and lithofacies, Pakistan may be divided into the following broad tectonic zones and these are also shown in Fig 2.1

- **Indus platform and fore deep.**
- **East Baluchistan folds and thrust belt.**
- **Northwest Himalayan fold and thrust belt.**
- **Kohistan-laddakh magmatic arc.**
- **Karakoram block.**
- **Kakar khorasan flysch basin and makran accretionary zone.**
- **Chagai magmatic arc.**
- **Pakistan offshore.**

Within these broad tectonic zones these are subtle differences in tectonic and change in structure style to merit further subdivision into smaller subdivision. Here we are not concern about those; we are going to discuss the relevant that is the Indus platform and fore deep which is our area of interest as from all above mentioned tectonic zones our seismic line belongs to this area.

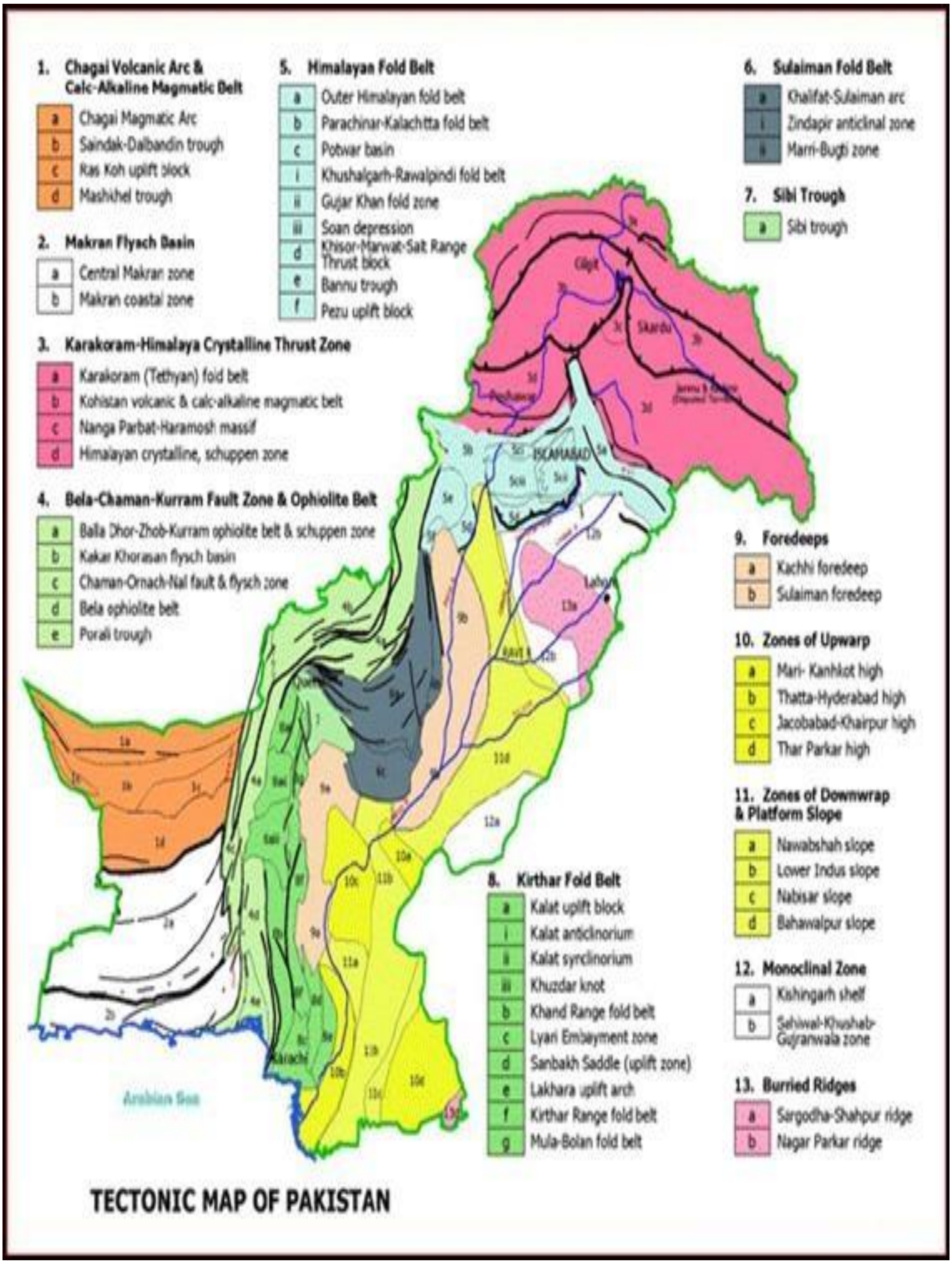


Figure 2.1 Tectonic Map of Pakistan (www.google .com)

2.3 Sedimentary Basins:

The basin is an area characterized by regional subsidence and in which sediments are preserved for longer periods of time. In a basin a receptacle or container, which is the basin's substratum is called the Basement**.** The container is filled or content, which is the accumulation of sediments resting on the basement, is called a Sedimentarycover**.** The gradual settling of the basin is called Subsidence**.** The point of maximum sedimentary accumulation is called the Depocenter**.** The datacenter may not correspond to the zone of maximum subsidence. Pakistan comprises following three sedimentary basins Fig 2.2

- Indus basin
- Pashin basin
- Baluchistan basin

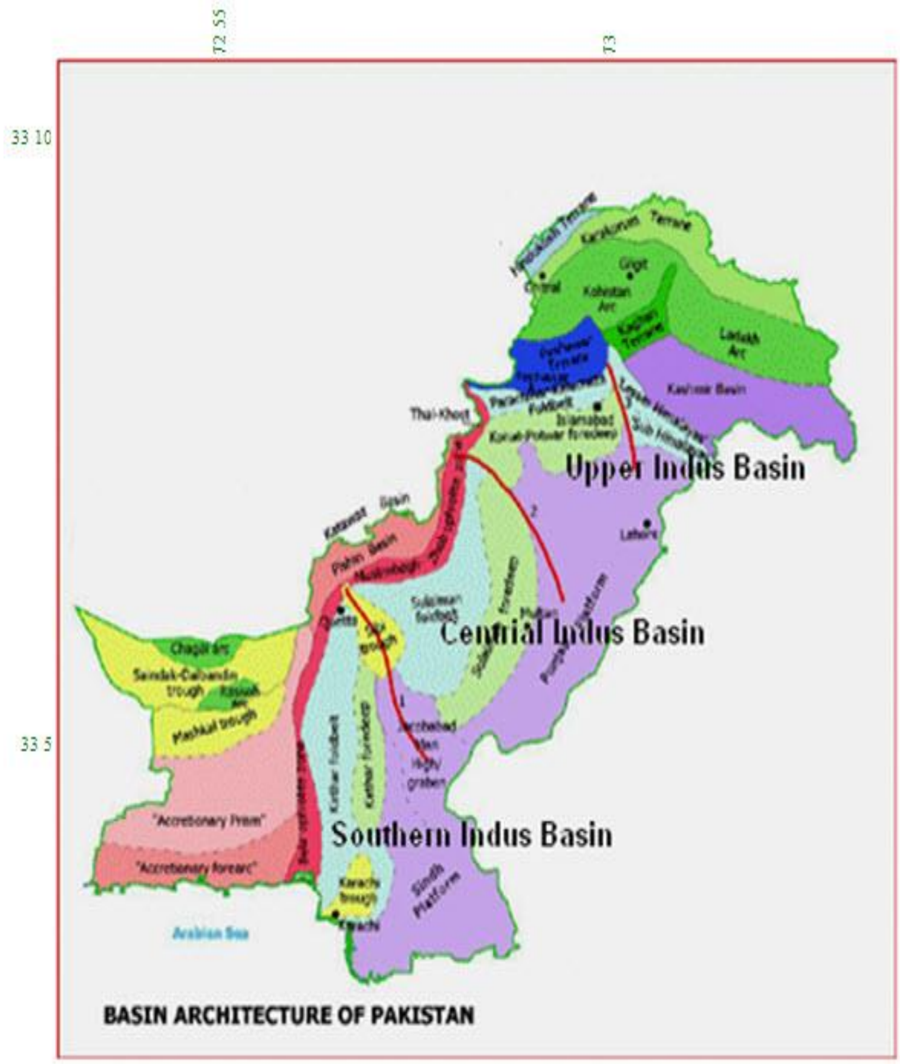


Figure 2.2: Basin Architecture of Pakistan, (www.Google.com)

2.3.1 Indus basin:

The Indus basin belongs to the class of extra continental trough down warp basins. It is the largest and so far only producing sedimentary basin of Pakistan. The basin is oriented in NE - SW direction. Basement exposed at two places, one in NE (Sargodha high) and second in SE corner (Nagar parker high). The convergence between Indian and Eurasian plate has resulted in partitioning of the basin into three parts. Upper, middle and lower called as northern, central.

Division of Indus basin:

- **Upper Indus basin**
- **Central Indus basin**
- **Lower Indus basin**

LOWER INDUS BASIN CLASSIFICATION:

This basin is located just south of Sukkur rift, a divided between central and southern Indus basin (Fig 2.1). It comprises the following units:

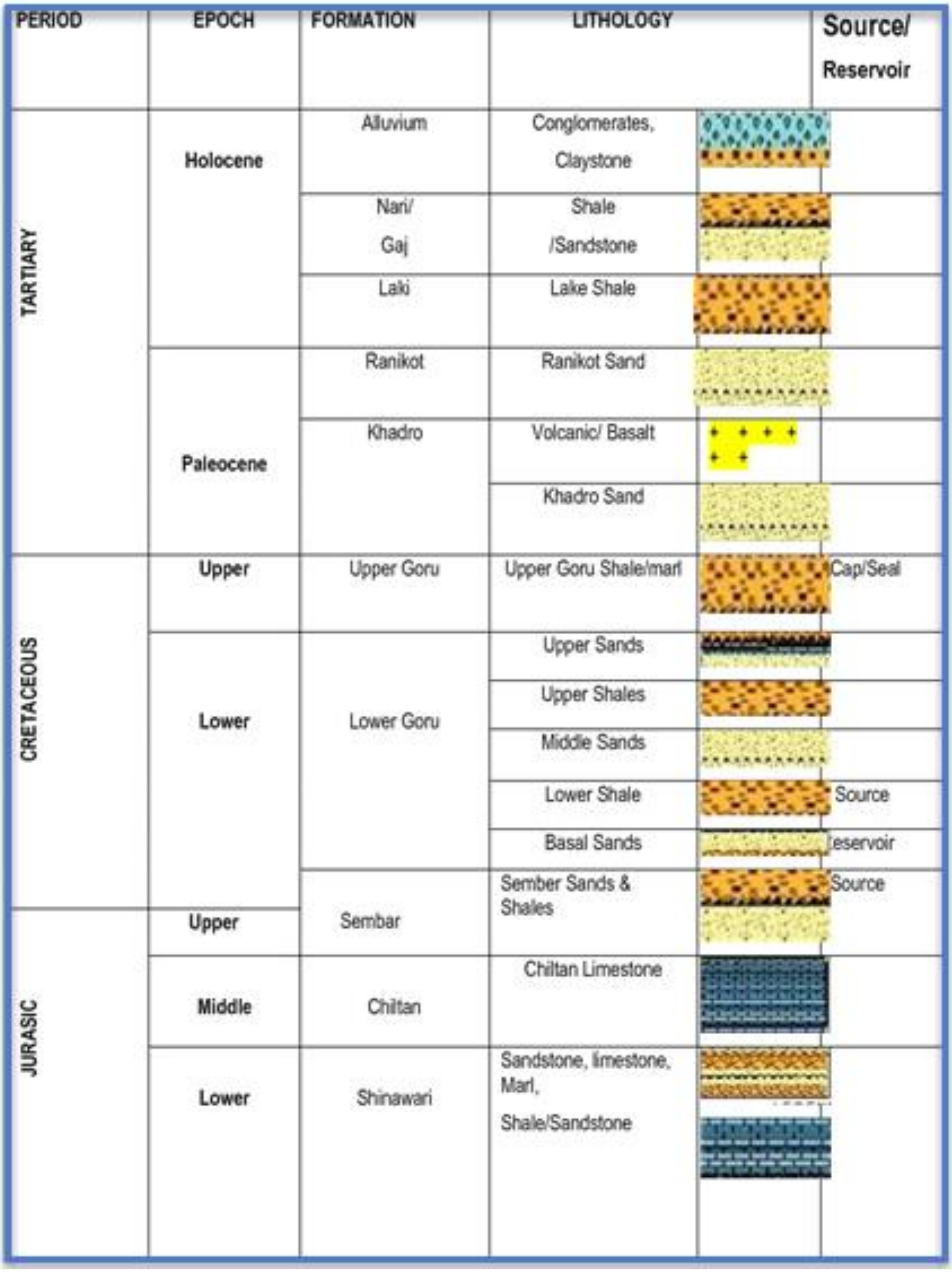
1. Thar platform
2. Karachi trough
3. Kirthar fore deep
4. Kirthar fold belt
5. Offshore Indus

The platform and trough extend into the offshore Indus. The southern Indus basin is bounded by the Indian shield to the east and the marginal zone of Indian plate to the west. It is southward extension is confined by offshore muray ridge- oven fracture plate boundary . The oldest rocks encountered in the area are the Triassic age.

Central and southern Indus basins were undivided until khairpur- Jacobabad high became a prominent positive feature. This is indicated by homogeneous lithologies of Chilton limestone (Jurassic) and sember formation (lower cretaceous) across the high. Sand facies of Guro formation (lower middle cretaceous) are also extending up to kandhkot and Giandari area.

STRATIGRAPHY OF LOWER INDUS BASIN

Stratigraphy column of lower Indus basin is shown in Fig 2.3



PERIOD	EPOCH	FORMATION	LITHOLOGY	Source/ Reservoir
TARTIARY	Holocene	Alluvium	Conglomerates, Claystone	
		Nari/ Gaj	Shale /Sandstone	
		Laki	Lake Shale	
	Paleocene	Ranikot	Ranikot Sand	
		Khadro	Volcanic/ Basalt	
			Khadro Sand	
CRETACEOUS	Upper	Upper Goru	Upper Goru Shale/marl	Cap/Seal
	Lower	Lower Goru	Upper Sands	
			Upper Shales	
			Middle Sands	
			Lower Shale	Source
			Basal Sands	eservoir
		Sembar	Sember Sands & Shales	Source
JURASIC	Upper			
	Middle	Chiltan	Chiltan Limestone	
	Lower	Shinawari	Sandstone, limestone, Marl, Shale/Sandstone	

Figure 2.3: Generalized Stratigraphy of lower Indus Basin

2.4 Structures of the project area:

The structure is the result of a normal faulting on the west dipping Indus plain. The fault planes act as way for the migrating fluids from underlying shaly source sequence. Trends of faults and contour are mapped utilizing all well and seismic control for the field.

Seismic interpretation constitutes the basis for the structural interpretation as no surface outcrops are found over the field. The lower Guru hydrocarbon accumulation in project area is bounded on the east and on the west by regional extension faults dipping to the east and trending NW-SE.

2.5 Petroleum Play of the Area:

Source Rocks:

The Lower Cretaceous Shale of Sembar Formation is proven source for oil and gas discovered in the area because of its organic richness and thermal maturity. The organic matter in the Sembar Formation is mainly type-III kerogen, capable of generating gas. Shale of Sembar and Lower Goru Formations have been established as main source rocks Lower and Middle Indus basin (Raza et al,1989). Carbonates and shale of deeper horizon may also act as source. The geothermal gradient in the region ranges from 2.0C0/100m to 4.0 C0/100m.The gas window is in the range of 2625m to 5250m, compatible with depth range of Sembar, Lower Goru and deeper horizons source rocks at various structural positions, created due to rifting.

Reservoirs Rocks:

Basal sands lower guru (cretaceous) formation is the primary objective in this area. These sands are proven in this area. Average porosities for these sands are around 11% in the prospect area.

Cap Rocks:

A thick Stratigraphy sequence of shale and marl of upper guru formation serve as cap rock for underlying lower guru sand reservoir. Shale of lower guru formation also the same properties.

2.6 Stratigraphy of the Area:

The area comprises a full range of formation with oldest rock in the area from Pre-Mesozoic to till most recent formation of Eocene age. But major focus in the area due to petroleum play is on Lower Goru Formation which is of Cretaceous age which is acting as reservoir in the entire basin, Generalized Stratigraphy Column of the area is in Fig 2.4

2.6.1 Goru formation:-

Goru formation (early Cretaceous) consists of interbedded limestone, shale, marls, sandstone and siltstone. The environment of deposition is shelf to shallow marine. Different parts of this thick formation have enough reflectivity indexes to produced very clear reflections. Goru formation is divided into two parts (Kadri ,1995).

- Upper Goru
- Lower Goru

Upper Goru:

It is comprised of marl calcareous clay- stone occasionally with inter-beds of silt and limestone (Kadri ,1995).

Lower Goru:

The lower Goru is main reservoir rock within the area. It consists of

- The basal sand unit
- Lower shale
- Middle sand unit (which is a very good reservoir rock)
- Upper shale
- Upper sand

2.6.2 Parh limestone:

The Parh limestone is a lithologically very distinct unit. It is a hard, light grey, white, cream, olive green, thin-to-medium-bedded, lithographic and argillaceous limestone, with subordinate calcareous shale and marl intercalations. The formation is widely distributed in parts of the Axial Belt and Lower Indus Basin (Sulaiman and Kirther Province). The lower contact with the Goru formation is transitional and conformable Environment of deposition is shallow marine (Shah ,1997).

2.6.3 Ranikot Formation

One division of Ranikot group suggests that it comprise of three formations which are Khadro formation, consists of olive, yellowish brown sandstone and shale with inter beds of limestone. Keeping ascending Stratigraphy order, Above Khadro formation is Bara formation (Lower Ranikot sandstone) consists of variegated sandstone and shale. and the upper one is the Lakhra formation (Upper Ranikot limestone) consists of grey limestone, grey to brown sandstone and shale. Various authors have given it different divisions. Below are explained the three formations as part of the Ranikot group with details(Shah, 1997). Ranikot formation is considered to be a good source rock for the gas reservoir in the area. It also act as a seal rock (Shah ,1997)

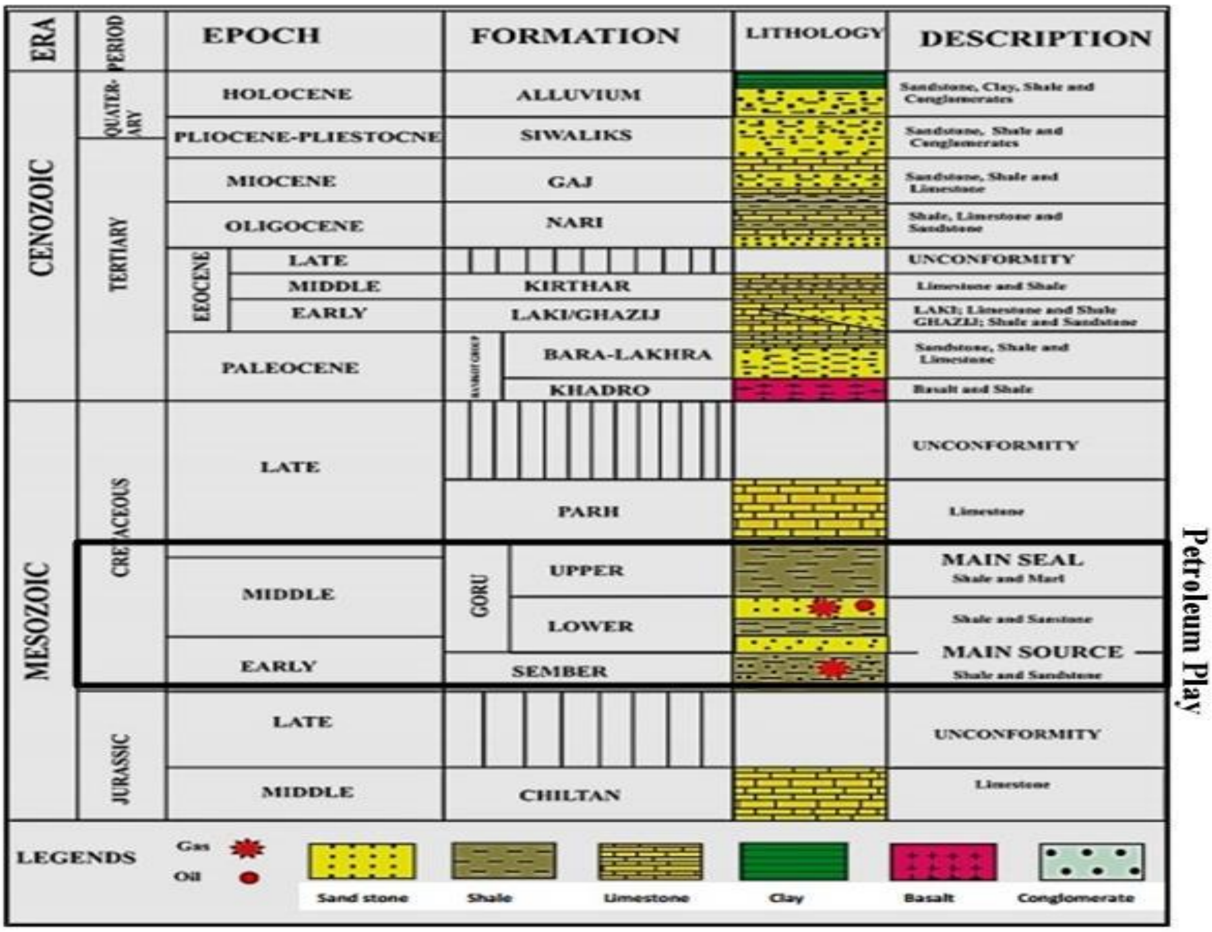


Fig 2.4 The generalized stratigraphy of the study area (www.Google.com)

CHAPTER NO:03

SEISMIC DATA INTERPRETATION

3.1 INTRODUCTION

Seismic interpretation and subsurface modeling are key skills used in oil industry. It is use to generate the reserve able model and predictions about the properties and structure of subsurface.

Seismic interpretation, sometimes, may not be sufficient to provide enough details about subsurface geology, so along with it other geophysical methods like area knowledge etc should also be considered(Telford, 2004) .

In seismic reflection surveys seismic energy pulses are recorded which are reflected back from the subsurface interfaces. The travel times are measured and can be converted into estimates of depths to the interfaces (Kearey & Brooks , 1984).Depth of reflecting interfaces can be estimating from the recorded time and velocity information that can be obtain either from reflected signal themselves or from surveys in well.(Dobrin & Savit, 1976). Velocity may also vary horizontally, due to lateral lithological changes within the individual layers (Kearey & Brooks , 1984).

The word interpretation has been given many different meanings to geophysicist who handle seismic reflection records and by geologists who put the information from them to use.

After seismic map is constructed, an important part of it is its interpretation which is integrating the seismic data on it with geologic information from surface and subsurface sources e.g. fault traces or geologic contacts. This involves identifying reflectors and making tie to wells or surface features. All this depends upon the amount of information available.

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

3.2 Discrimination among different Formation

To distinguish different formations by means of seismic reflection is an important question in interpreting seismic reflection data. For this purpose we correlate the data with the well data and geology of the area under observation. The well data provides links between lithologies and seismic reflections. The reflector identification is the next stage by which the actual interpretation starts and it establishes a Stratigraphic frame block for the main interpretation.

Extracting from seismic data the geological structures, such as folding and faulting are referred to as structural interpretation (Dobrin & Savit ,1976). On the other hand, extracting non-structural information from seismic data is called, "Seismic Facies Analysis".

3.3 Main approaches for the Interpretation

There are two main approaches for the interpretation of seismic section

- **Stratigraphic Analysis**
- **Structural Analysis**

3.3.1 Stratigraphic Analysis

Stratigraphic analysis involves the subdivision of seismic sections into sequences of reflections that are interpreted as the seismic expression of genetically related sedimentary sequences. Basic principle in the seismic Stratigraphic analysis is that reflections are taken to define chronostratigraphic units because interfaces that produce them are the strata surfaces. Unconformities can be mapped from the divergence pattern of reflections on a seismic section. The presence of unconformable contacts on a seismic section provides important information about the depositional and erosional history of the area and environment existing during the time, when the movement took place. The success

Disconformities, Facies changes, pinch-outs and other erosional truncations. (Sheriff, 1999).

Some of the parameters used in seismic Stratigraphic interpretation are:

3.3.2 Structural Analysis

In structural interpretation main emphasis is on the structural traps in which tectonics play an important role. Tectonic setting usually governs which types of structures are present and how the structural features are correlated with each other's, so tectonics of the area is helpful in determining the structural style of the area and to locate the traps. Structural traps include the faults, anticlines, duplex etc. (Sheriff, 1999).

Seismic sections can predict the structure that scale up to few tens of kilometers. For large scale interpretation we have to use the grids of seismic lines. Immigrated section is not suitable for structure interpretation, because it creates many problems like synclines becomes narrows and vice versa. Even a migrated section not fully fit for complex area like the area of study.

Some seismic section contains images that can be interpreted without any difficulty. Discontinuous reflectors clearly indicate faults and undulating reflections reveals folded beds. Most interpretation of structural features are directly marked on seismic time sections (Robinson & Coruh, 1988).

3.4 Seismic Interpretation Workflow

Seismic interpretation is the process of determining subsurface structures from seismic data to locate prospect for exploratory wells. The structural interpretation of an area is usually carried out on the basis of staratigraphy and available well logs .

Procedure adapted for interpretation is given in Fig 3.1. Base map is prepared by loading navigation data and Seg-y in software Kingdom (8.6). Horizons of interest are marked manual and also by 2D hunt technique. In this process faults are identified and also marked. Faults polygons are generated and horizons are contoured to find out structural highs and lows. The different important steps involved in the interpretation workflow shown in Fig 3.1

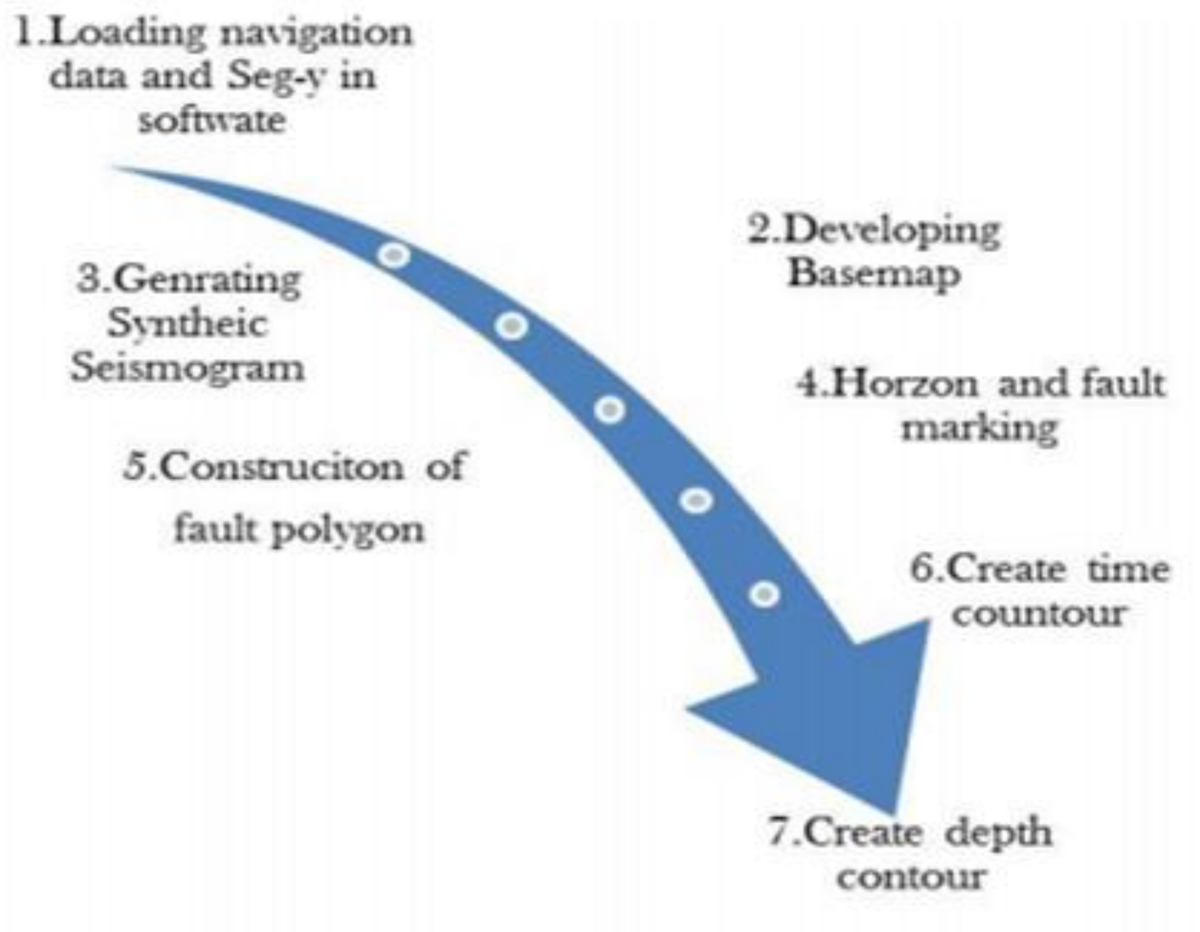


Figure 3.1: Seismic interpretation work flow

3.5 Synthetic seismogram and formation signature

Synthetic seismograms are constructed from sonic and density log. Synthetic seismograms facilitate correlation between the synthetic seismograms and seismic. Several high-amplitude reflectors in the seismic data correlate with high-amplitude events in the synthetic seismogram and are the result of changes in velocity and/or density of the cored interval.

Step for generating synthetic

- Load formation tops, T_D (time-depth) chart and log curve on the well.
- Select a well on which you need synthetic seismogram.
- For velocity used sonic log (DT). Software is automatically using it.
- Now select RHOB (density log) for the density.
- Choose a reference log, GR (Gamma Ray) is selected as reference log here.
- Extract Kaluder wavelet that convolved with refraction coefficient.
- Extract traces from nearest seismic line.

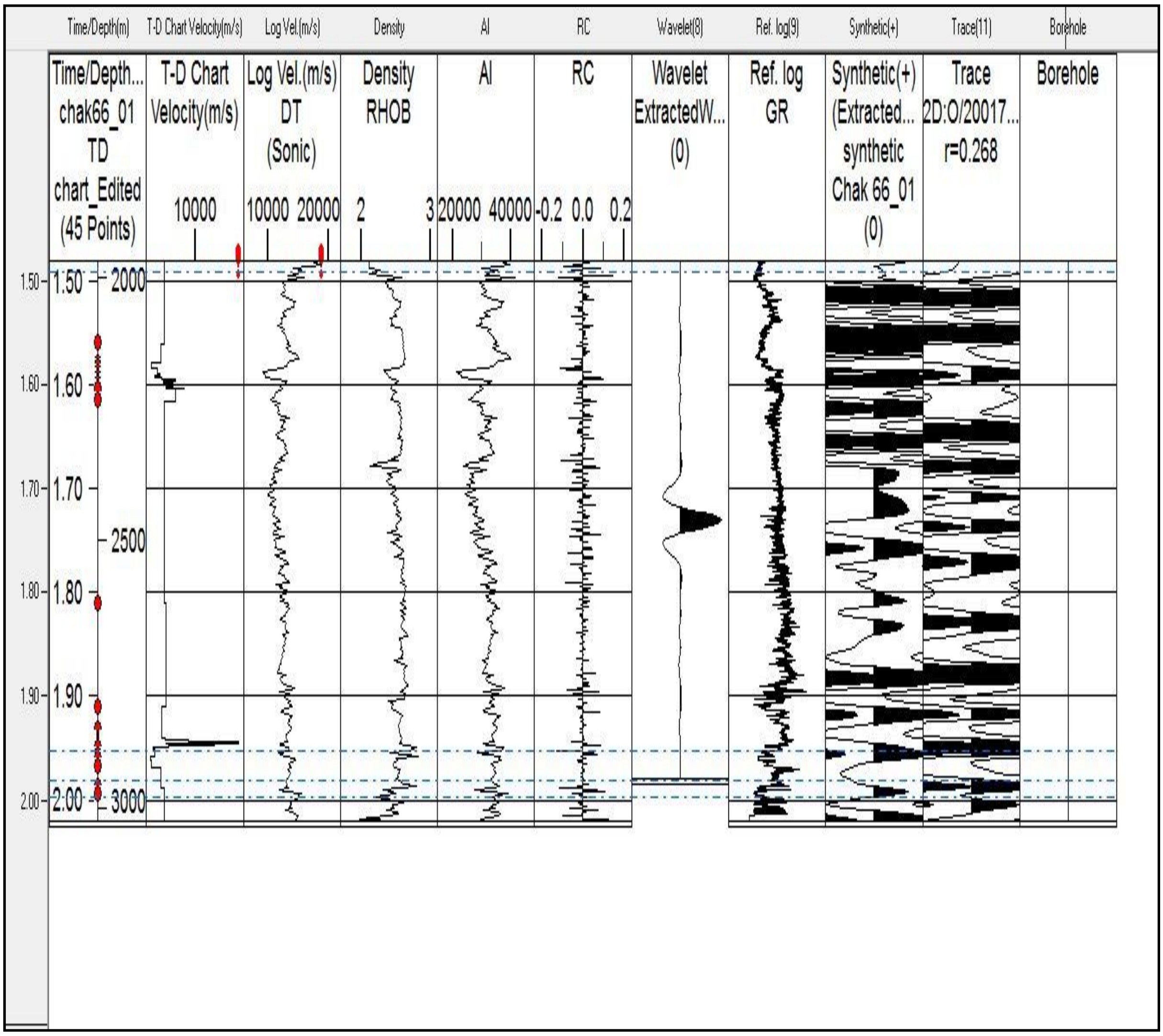


Figure 3.2 Seismic Synthetic Seismogram of CHAK 66-01

3.6 Seismic Tie

After marking horizons on a seismic section the next step is to tie the seismic section with the other intersecting seismic lines of the area. In this study horizons on the seismic line **SNJ-03** are marked first because the well Chack66-01 is lies on it. The tie points of the lines are confirmed from the base map, where tie points of the lines have been mentioned. At the tie point of both intersecting seismic lines have same horizons at the same time. If the horizon does not have same time then there may be miss tie that may be removed later on. Taking seismic line **SNJ-08** as a reference line, all other seismic sections used in the study are marked. At the tie point we not only mark the horizons but also marked the points of faults in the same manner all the faults were correlated.

3.7 Seismic Interpretation

The main (Prominent) reflections that are present on the seismic sections are marked, and then selected those reflectors that have good characteristics and continuity, and they can also be traced well over the whole seismic section.

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 and poor data quality in the subsurface at these locations. The seismic data was interpreted using kingdom which is used for interpretation. The SEG -Y format data of seismic line **SNJ-03** and **SNJ-22** is loaded by kingdom software for interpretation. After loading data in kingdom software of lines using the interactive tools and applications of Kingdom Software prominent horizons are marked following the trend and continuity of the reflectors. The lines comprise normal faulting this shows horst and graben geometry. Marked seismic section of the line is shown in Fig 3.3 and Fig 3.4 In the first step the prominent reflector are picked and correlated with the well tops of Chack66-01 and the reflectors are identified. Also the lines are correlated with the synthetic seismogram of this well. Four horizons are marked on the seismic section that is used in the study area and the horizons are named, with the help of the well data. Horizon 1 is the top of Laki Formation (blue), Horizon 2 is the Ranikot Formation (yellow),Horizon 3 is the Lower Goru Formation (green) and last horizon is the Basal Sand.Throughout the study color scheme is kept constant for each horizon. The NS trending lines are strike lines and on strike lines the faults cannot be clearly observed so the fault tie points from dip lines were highlighted on these lines.Six Normal faults with Horst and Graben Structure are marked on the seismic lines as the area is in extensional regime.

The seismic lines **SNJ-03** and **SNJ-22** are the dip lines all of the above mentioned horizons are marked as shown in Fig 3.2 and Fig 3.3 Normal faults with Horst and Graben Structure are marked on both the section showing extentional regime. In line **SNJ-22** there are four Normal fault with Horst and Graben Structure. The time of the horizons on seismic sections is given as; Laki is at 0.61340s to 1.01135s , Ranikot is at 1.01135s to 1.3095s , Lower Goru is at 1.5116s to 1.9089s and Basal Sand is at 1.91073s to 2.13492s. The interpreted seismic sections of the lines **SNJ-03** and **SNJ-03** are shown in Fig 3.2 and Fig 3.3 respectively. On the basis of discontinuity in Horizons, many Normal faults have been marked on the seismic sections forming the Horst and Graben features.

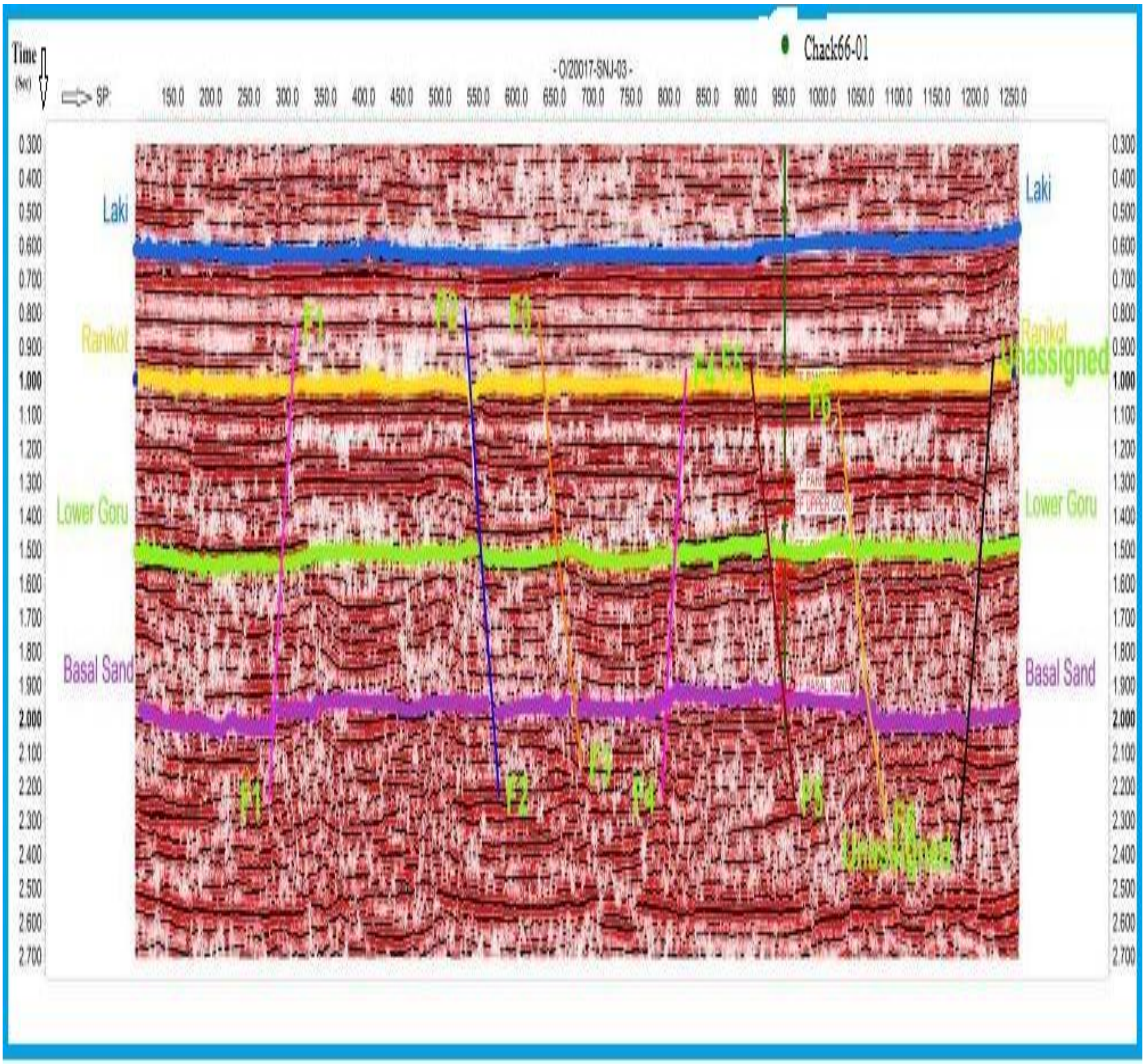


Figure 3.3: Marked seismic section of line GO-017- SNJ 03

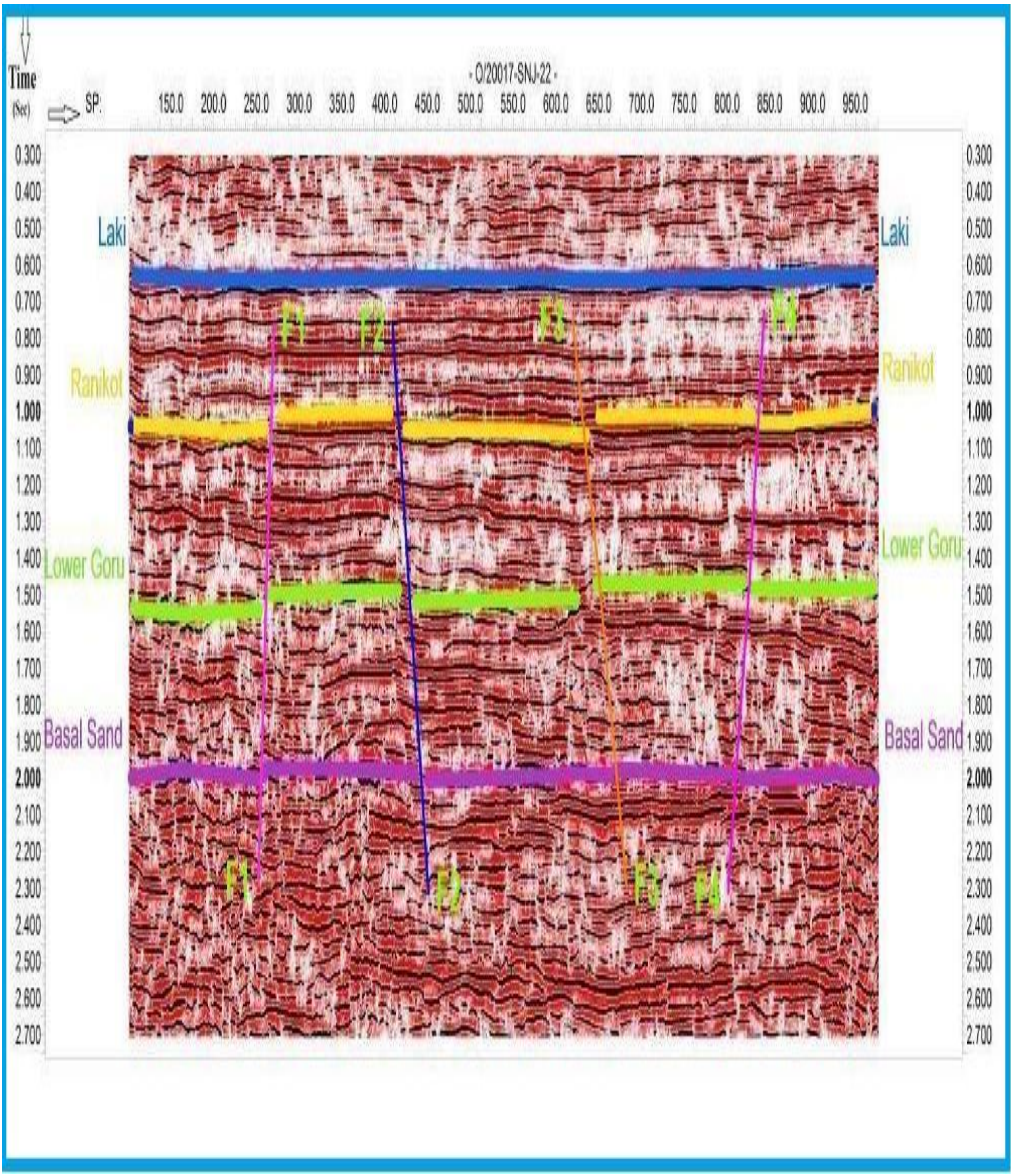


Figure 3.4: Marked seismic section of line 20017- SNJ 22

3.8 Contour Maps

Contouring is the main tool used in the seismic interpretation. After contouring it becomes obvious that what sort of structure is forming a particular horizon. The contour map of reflector is prepared. The main objective of the time contouring is to get information about undulation in the time horizon due to folding and faulting.

Time Contour Map of Lower Goru and Basal Sand

Two way time maps are made at different levels which show the position of that formation in time. Time contour map for Lower Goru and Basal Sand is constructed having Contour interval is 2 msec. Time contour maps show the different closures on which already wells have drilled and these are gas condensate.

Values of time are associated with shallow levels(green color) which represent Horst blocks high values of time are associated with deeper levels (blue color) which represent Graben in both Lower Goru and Basal Sand Time Contour map shown in Fig 3.5 and Fig 3.6 respectively.The contours which are observed in the time contour map for the Lower Goru start from at 1.5116 s to 1.9089 s and for Basal Sand the contour start from1.91073 s to 2.13492 s. Time contour map shows that Lower Goru and Basal Sand are shallower in the East and deeper in the West.

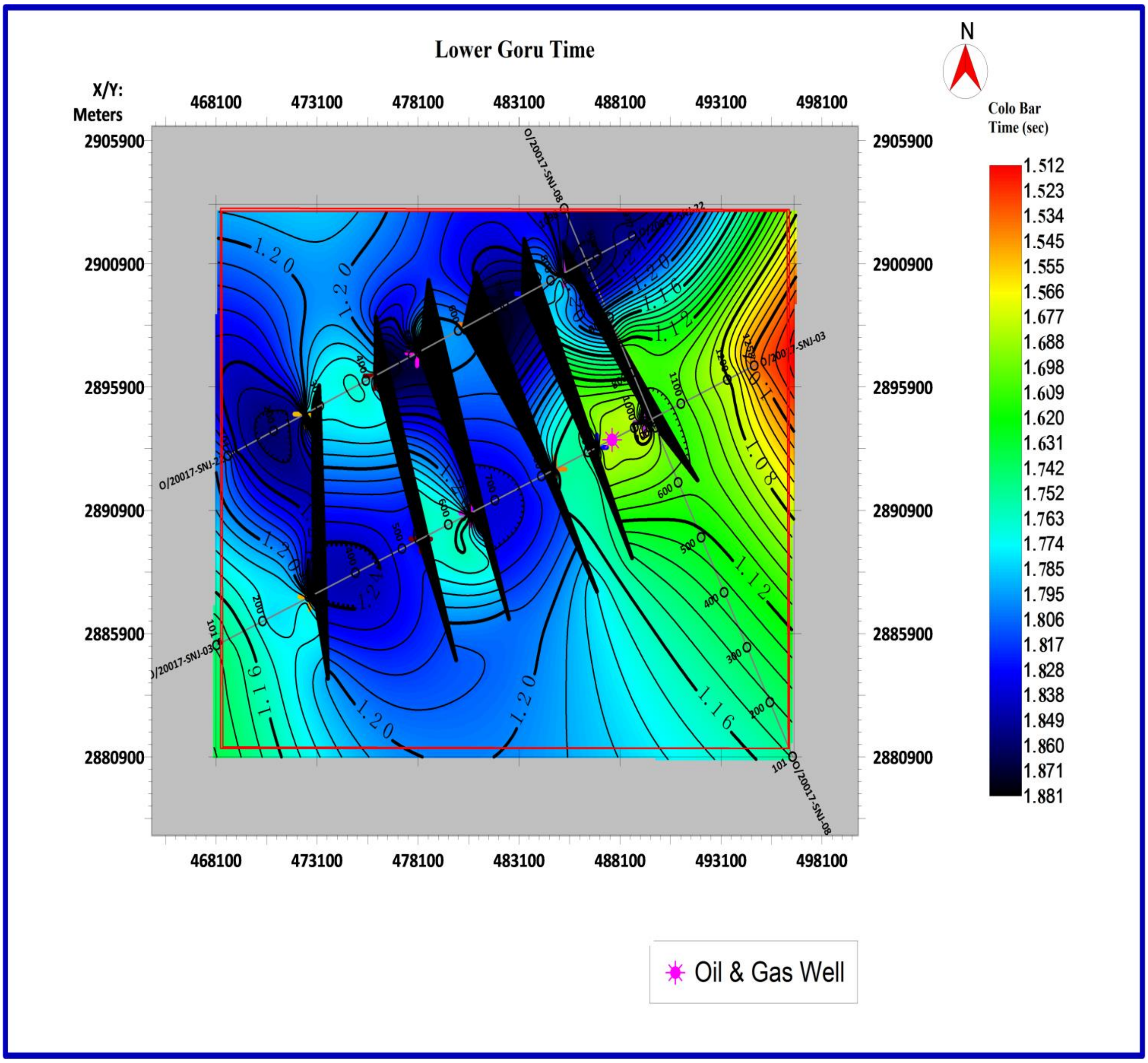


Figure 3.6:Time contour map of Lower Goru

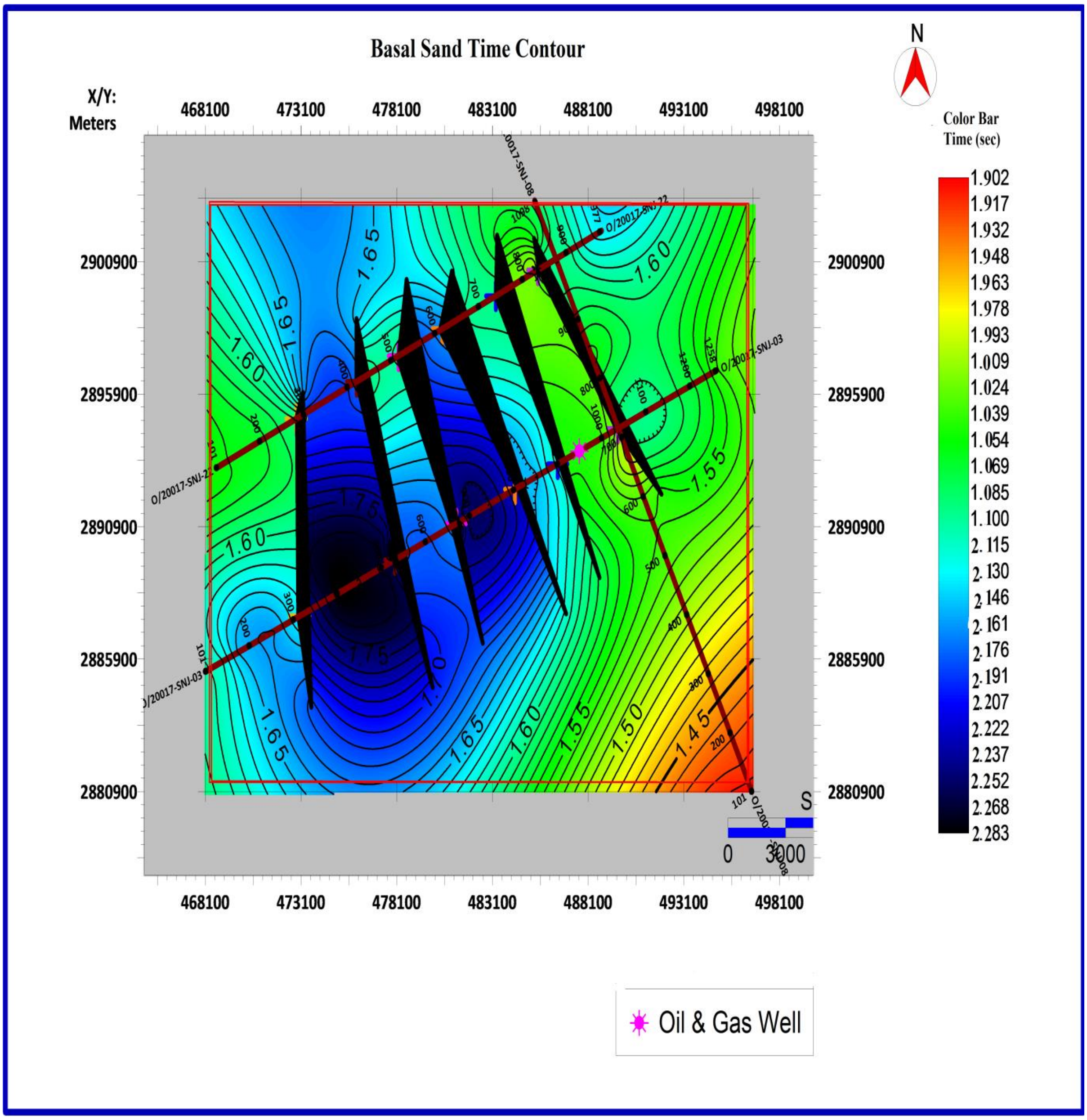


Figure 3.7:Time contour map of Basal Sand

Depth Contour Map of Lower Goru and Basal Sand

The depth map is truly related to the subsurface shapes and structures.Depth must be calculated from the time contour map by using the velocity of the horizons from the sonic log or velocity functions of seismic data. For this purpose depth contour maps of reservoir formations of the area generated. Starting depth for Lower Goru is 1164m and it ends up to 1473m where as for Basal Sand it is from 1612m to 2050m .

Two way time maps are made at different levels which show the position of that formation in time. In this study, depth maps are constructed for Basal sand and Lower Goru shown in Fig 3.6. Contour intervals is kept to 2 m. Depth contour maps show the different closures on which already wells have drilled and these are gas condensate. Low values of depth are associated with shallow levels which represent horst blocks. High values of depth are associated with deeper levels which represent graben .Here, faults polygons represent the structure geometry of the area. In study area (Sinjhoro) mostly fault forming structural traps for hydrocarbon accumulation in the form of Horst blocks. Six fault polygons are marked in these maps showing faults orientation from NW to SE. Green colored part of map showing shallowest zone of formation whereas Blue colored part is indicator of deepest zone. So the west part is deeper as compared East part in depth contouring.

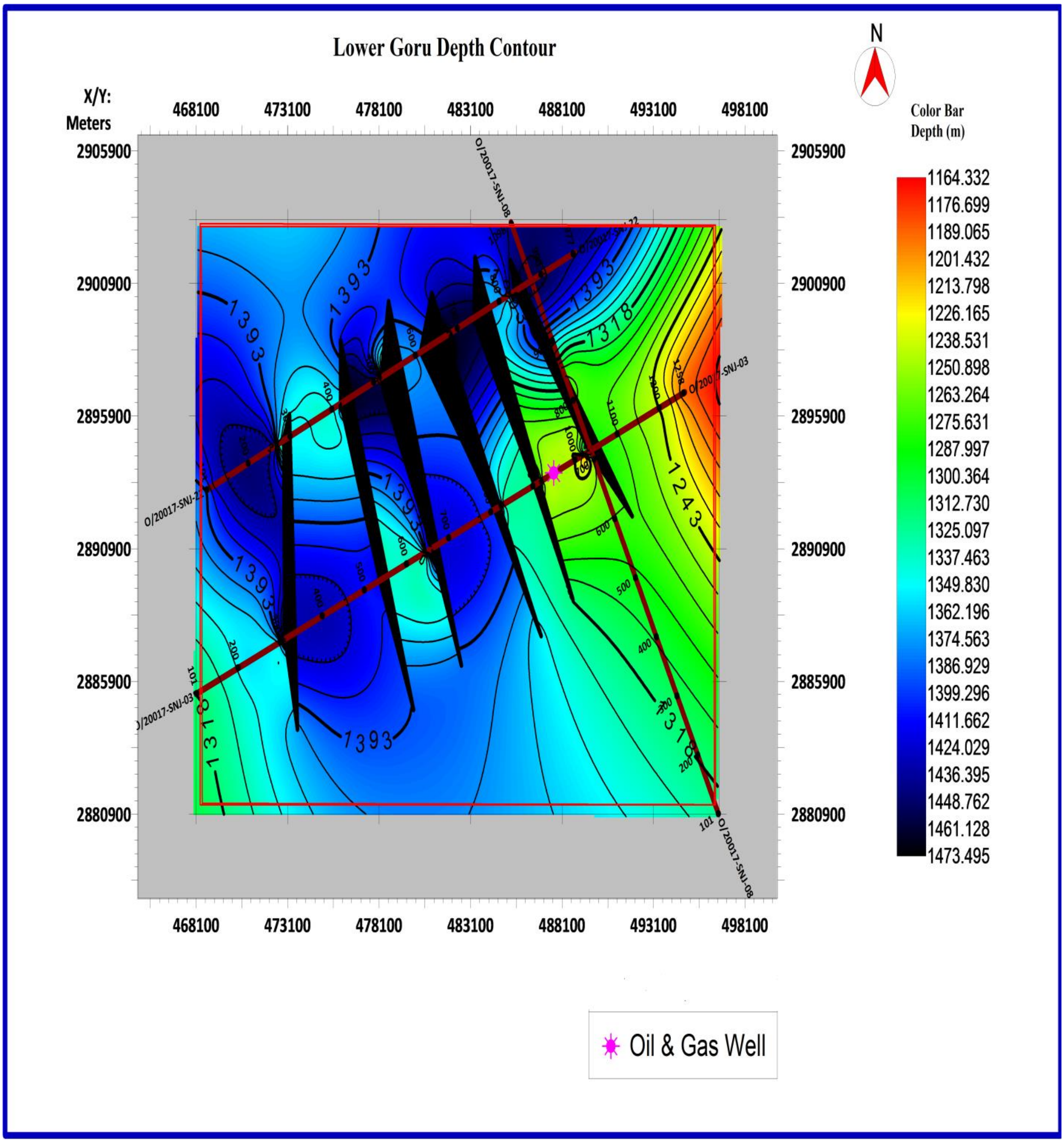


Figure 3.8: Depth Contour Map of Lower Goru

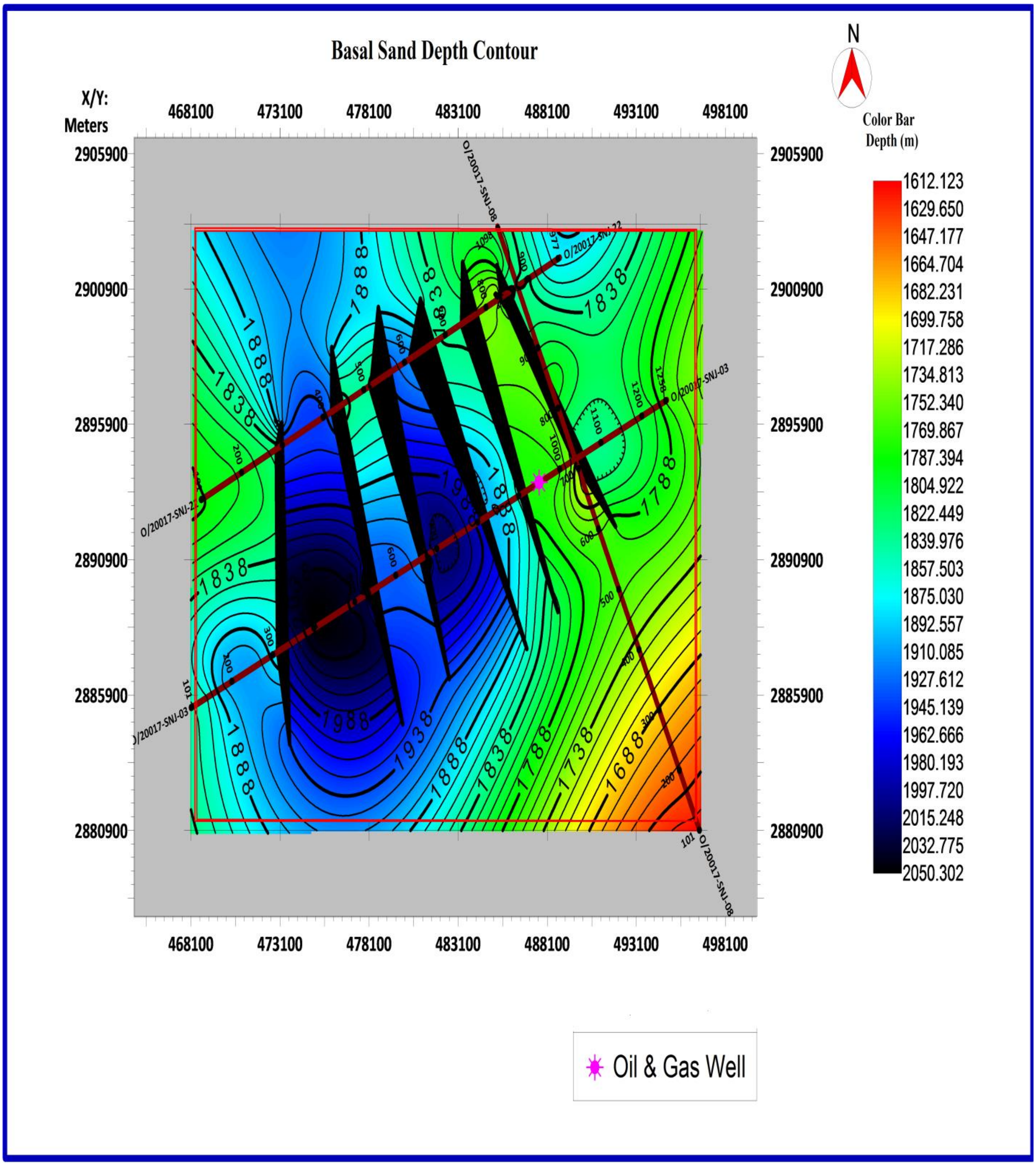


Figure 3.9: Depth Contour Map of Basal Sand

3.9 Siesmic Attribute

The quantities that are measured computed or implied from the seismic data. From the time of their introduction in early 1970's seismic attributes gone a long way and they became an aid for geoscientists for reservoir characterization and also as a tool for quality control .Development of a wide variety of seismic attributes warrants a systematic classification. Also a systematic approach is needed to understand the use of each of these attributes and also their limitations under different circumstances (Subrahmanyam &Rao, 2008).

3.10 Classification of Seismic Attributes

Attributes can be classified in many different ways. Seismic attributes can be classified on the following basis.

Seismic Data Domain based Classification:

- Pre-Stack Attributes
- Post-Stack Attributes

Computational Characteristics based Classification:

- Instantaneous Attributes
- Wavelet Attributes

For current work, seismic attributes are formed using seismic data domain based classification.

3.10.1 Pre-Stack Attributes

Input data are CDP or image gathers traces. They will have directional (azimuth) and offset related information. These computations generate huge amounts of data; hence they are not practical for initial studies. However, they contain considerable amounts of information that can be directly related to fluid content and fracture orientation. AVO, velocities and azimuthal variation of all attributes are included in this class (Taner et al, 1994).

3.10.2 Post-Stack Attributes

Post stack attributes are derived from the stacked data. The Attribute is a result of the properties derived from the complex seismic signal. Azimuth related information. Input data could be CDP stacked or migrated. One should note that time migrated data will maintain their time relationships, hence temporal variables, such as frequency, will also retain their physical dimensions. For depth migrated sections, frequency is replaced by wave number, which is a function of propagation velocity and frequency. Post-stack attributes are a more manageable approach for observing large amounts of data in initial reconnaissance investigations (Taner et al, 1994).

Seismic data attributes provide the seismic interpreter with new images that enhance the physical and geometric descriptions of the subsurface. Geometric attributes facilitate the definition of both the structural and stratigraphic framework of the seismic interpretation, while physical attributes may be used as direct hydrocarbon or lithology indicators. When the seismic response is more complex, attributes may be used to drive advanced interpretation and analysis processes (Subrahmanyam &Rao, 2008).

3.11 Signal Envelope (E) or Reflection Strength

The Signal Envelope (E) is calculated from the complex trace by the formula:

$$E(t) = \sqrt{T^2(t) + H^2(t)}$$

Where:

T(t) = seismic trace

H(t) =Hilbert's transform

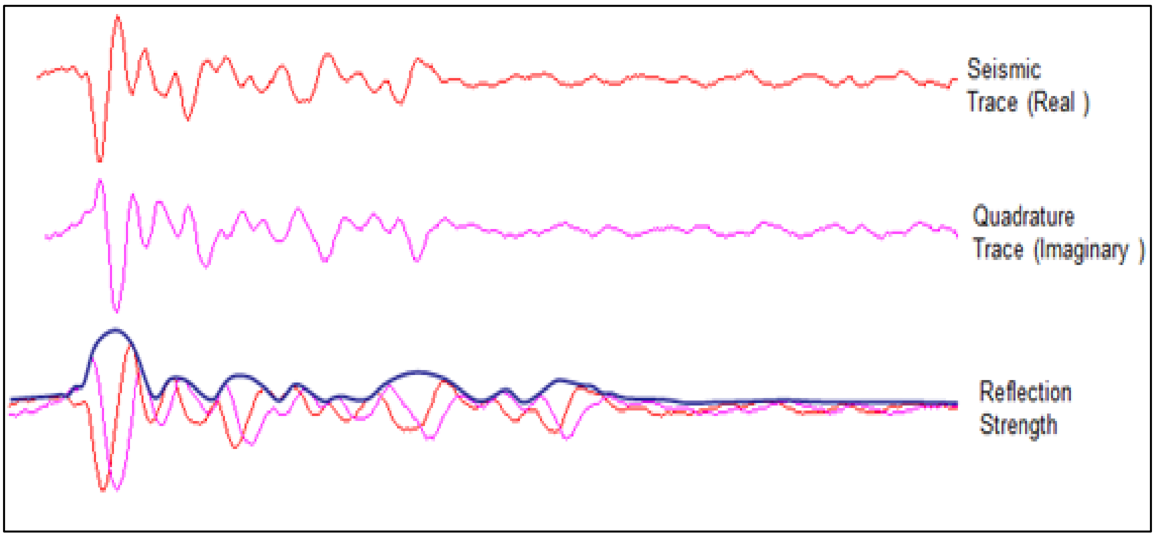


Figure 3.10: Envelope traces attribute for real seismic trace

The Hilbert Transform of the real seismic trace is generates an imaginary trace and using both these traces the envelope trace is computed. Fig 3.8 shows the real, imaginary and envelope trace. The envelope is the envelope of the seismic signal. It has a low frequency appearance and only positive amplitudes. It often highlights main seismic features. The envelope represents the instantaneous energy of the signal and is proportional in its magnitude to the reflection coefficient (Subrahmanyam &Rao, 2008).

Envelop (Amplitude) section of line GO-SNJ-22

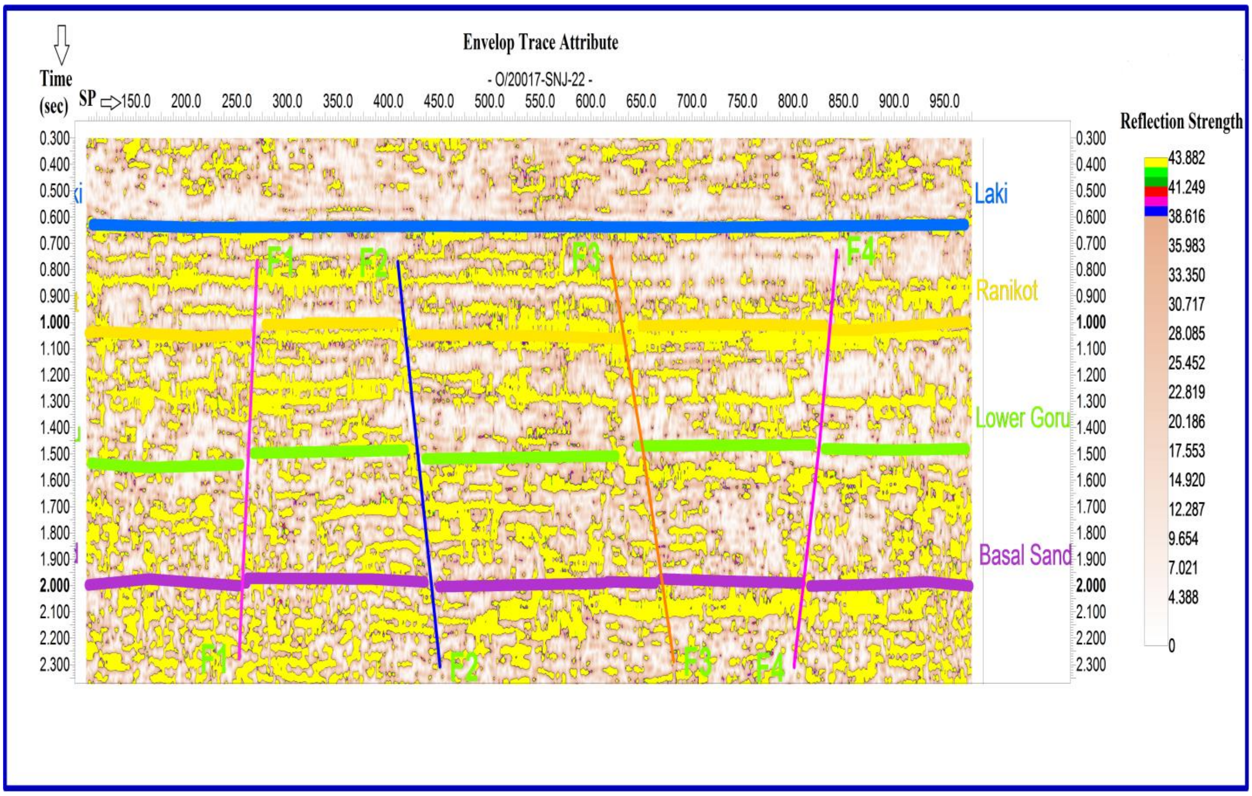


Figure 3.11: Envelop attribute map calculated for seismic line **GO-SNJ-22**

Envelop attribute is computed for seismic line GO-SNJ-22 Fig 3.9, which shows major changes in lithologies A thick (yellow) package indicates the maximum reflection strength corresponding to the reservoir and seal rocks. Also along faults the reflection strength is not prominent, it shows a discontinous reflection. It justified the major part of interpretation, tops of horizons and the fault surfaces. At some places like edges of the line we are unable to see prominent reflectivity that is due to the limitation of the data.

3.12 Instantaneous Phase

Instantaneous phase attribute is given by

$$\emptyset(t) = \tan^{-1}\left| {H(t)}/{T(t)} \right|$$

The seismic trace T (t) and its Hilbert transform H(t) are related to the envelope E(t) and the phase Ø(t) by the following relation:

$$T(t) = E(t)\cos(\emptyset(t))$$
$$H(t) = E(t)\sin(\emptyset(t))$$

Instantaneous phase is measured in degrees (-π, π). It is independent of amplitude and shows continuity and discontinuity of events. It shows bedding very well. Phase along horizon should not change in principle, changes can arise if there is a picking problem, or if the layer changes laterally due to “sink-holes” or other phenomena (Subrahmanyam &Rao, 2008).

Phase Section of line GO-SNJ-22

This attribute shows continuity and discontinuity of the reflection event. A general interpreted phase section is shown in the Fig 3.10, which justifies the marked horizons and faults surfaces. Every horizon responds a continuous reflection while along fault there is discontinuous reflection as highlighted in the Fig 3.10

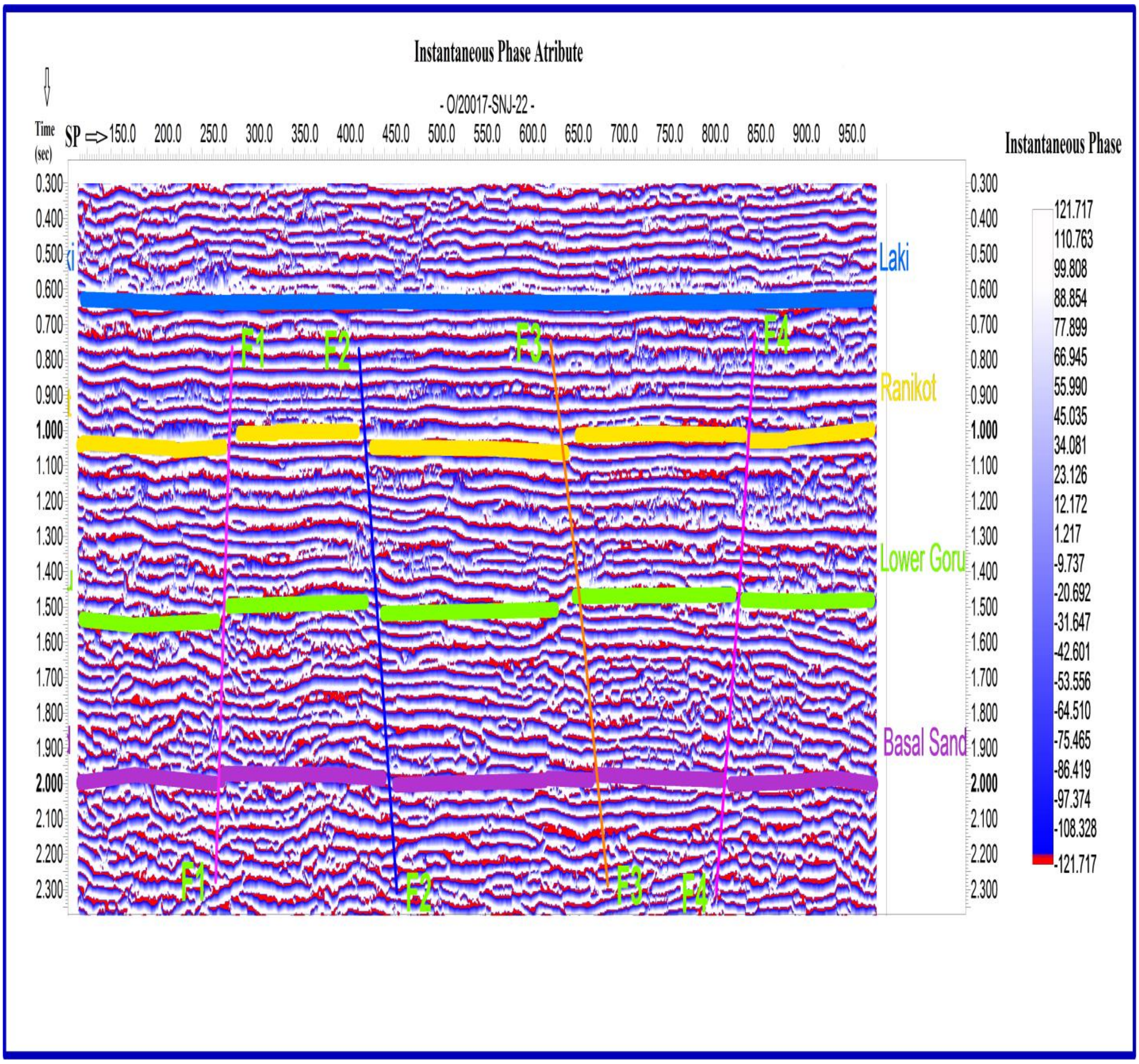


Figure 3.12: Interpreted Phase Section of line GO-SNJ-22

3.13 Instantaneous Frequency

Instantaneous frequency is the time derivative of the phase, i.e., the rate of change of the phase:

$$F(t) = \frac{d(\emptyset(t))}{dt}$$

Instantaneous frequency represents the mean amplitude of the wavelet (Subrahmanyam &Rao, 2008).

Frequency Section of line GO-SNJ-22

Frequency Attribute GO-SNJ-22 is shown in Fig 3.11, which shows frequency changes along different lithologies. At shallow level in the section low frequency values, even negative values which indicates low impedance and thin beds same behavior also observed along the fault surfaces. The continuity of both the interpreted horizons and discontinuous layering along fault surfaces are to some extent justified by the calculated frequency attribute.

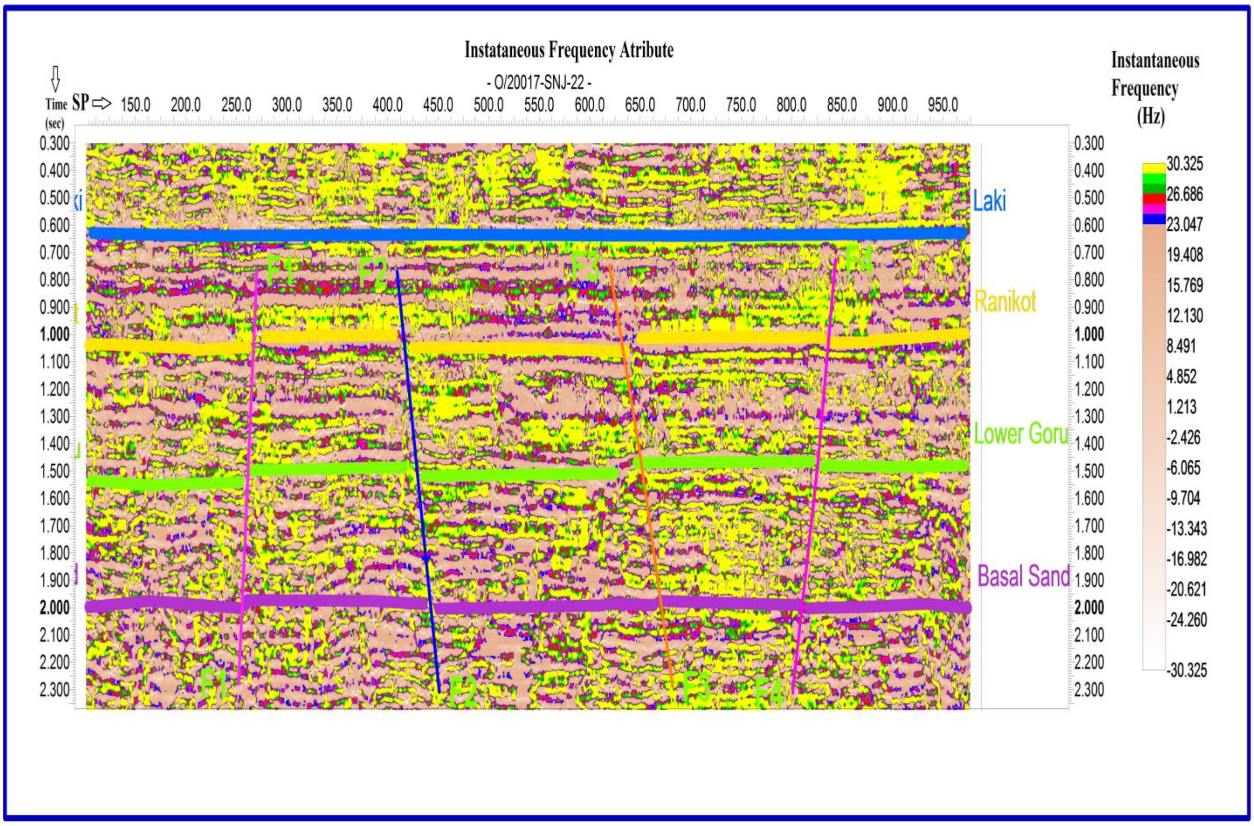


Figure 3.13: Frequency Attribute Calculated For Seismic Line **GO-SNJ-22**

CHAPTER NO : 4

PETROPHYSICAL ANALYSIS

4.1 Introduction

Well logging is tool to measure the properties of the earth's subsurface. Through this process, various physical, chemical, electrical or other properties of rock and 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 presence and behavior of rocks, soils and fluids (Rider, 1996). This also defined "Petrophysics is description of that physical properties which relating the occurrence, behavior of rocks and fluids inside the rocks" (Asquith et al, 2004). Petrophysics uses well logs (caliper, resistivity, GR, DT, RHOB, Neutron logs etc.) and all pertinent information is obtain 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. Petophysical interpretation generally has less concern for seismic while more concerned with using well bore measurements to contribute to reservoir description (Asquith et al, 2004) The work flow of well log interpretation in Fig 4.1

Figure 4.1: Workflow of PetrophysicalAnalysis

4.2 Classification of geophysical well logs

Geophysical well logs can be classified into three categories

- Lithology logs
- Resistivity logs
- Porosity logs

4.2.1 Lithology Logs

Lithology log are mostly used to identify the boundaries between the permeable and non-permeable formation, information about the permeable formations provide lithology data for the correlation with other well logs.

- Caliper (CALI)
- Spontaneous potential (SP)
- Gamma Ray (GR)

a) Caliper (CALI)

Caliper logs measure the diameter of the borehole. It records the cavities where the well is caved in, and also the hardness of the rock cut during drilling. Where there is the porous material, mud cake will be formed that cause the hole diameter to become smaller. Variation in the diameter of the borehole influence the record of the different logs .Therefore it is important to consult with the caliper logs any artifacts (Croizé et al, 2010).

b) Gamma Ray Log

Gamma ray logs are lithology logs that are used to measure the natural radioactivity of a formation. The radioactive material's concentrations are present in shale, as shale has high gamma ray reading. Therefore shale free sand and the carbonates have low gamma ray reading. Volume of shall can be calculated by the following formula,

$$\text{Igr} = \frac{\text{GR}_{\text{LOG}} - \text{GR}_{\text{min}}}{\text{GR}_{\text{max}} - \text{GR}_{\text{min}}},$$

Where GR_{min} is minimum value and GR_{max} is the maximum value of the gamma ray, Igr is the gamma ray index and GR_{LOG} represent the gamma ray log. Gamma ray logs are used to identify lithology, the volume of the shale and the correlation between the formations
(Asquith et al, 2004).

4.2.2 Resistivity well logs

Resistivity well logs give the thickness of the formation, accurate value for the true formation resistivity and information for the correlation purposes. All these logs are plotted on the logarithmic scale due to more variation in resistivity (0.2 to 2000 ohm) with depth.

Resistivity well logs are

- Deep laterolog (LLD)
- Shallow laterolog (LLS)

a) Deep laterolog (LLD)

Deep laterolog is the electrode logs and are designed to measure formation resistivity in the borehole filled with saltwater muds (R_{mf}). The effective depth of the laterolog investigation is controlled by the extent to which the surveying current is focused (Asquith et al, 2004).

b) Shallow laterolog (LLS)

Shallow laterolog measure the resistivity of in the invade zone (R_i).In water-bearing zone, the shallow laterolog records a low resistivity because mud filtrate resistivity (R_{mf}) is approximately equal to mud resistivity (R_m), (Asquith et al, 2004).

4.2.3 Porosity well logs

Porosity well logs are provide the data through which the water saturation can be determine, provide the accurate lithologic and porosity determination and provide data to distinguish between oil and gas.

Porosity well logs are

- Sonic/Acoustic (DT)
- Neutron Porosity (NPHI)
- Density (RHOB)

a) Sonic/Acoustic (DT)

Sonic logs measure the interval transit time (delta t) of the compressional sound wave through the formation. The interval transit time is related to the porosity of the formation. The unit of measure is the microseconds per foot or microseconds per meter

(Asquith et al,2004).

Relation for the calculation of the porosity from the sonic log

Porosity of the formation can be calculated by using the following formula

$$\emptyset_s = \frac{\Delta t_{log} - \Delta t_m}{\Delta t_f - \Delta t_m}$$

Where $\emptyset_s$ represent the calculation that derived from the sonic log, Δt_m is the interval transient time of the matrix, Δt_{log} interval transient time of formation, represents the transient time of the fluid (salt mud=185 and fresh mud=189).the interval transient time of the formation depends upon the matrix material, its shape and cementation (Wyllie et al , 1956).If fluid (hydrocarbon or water) is present in the formation, transient interval time is increases and this behavior shows increase in porosity which can be calculated by using sonic log (Asquith et al , 2004).

b) Neutron Porosity (Φ_n)

Neutron log is the porosity log that measure hydrogen ion (HI) concentration in a formation (Asquith et al , 2004).In the shale free formations where the porosity is filled with the water, the neutron log is related to the water filled porosity (NPHI).In gas reservoir, porosity measured by the neutron log is low then the formation true porosity as the hydrogen ions concentration are less in gas reservoir then that of oil and water (Asquith et al, 2004).It is the one limitation of neutron log that is known as the Gas effect.

c) Density (RHOB)

Density log is the porosity log that measure electron density of the formation, (Asquith et al, 2004). Formation electron density is actually related to bulks density of formation. It is actually the sum of fluid density multiplies its relative volume plus matrix density time relative volume.

Relation for the calculation of the porosity from the Density log ($\emptyset_d$)

Density log can be used to find out the correct porosity of the formation, if the matrix densities in the formation or rock type are known (Asquith et al, 2004). The rock type in my research work is sandstone and shale. By using following mathematical relation, density porosity can be related as

$$\emptyset_d = \frac{\rho_m - \rho_b}{\rho_m - \rho_f},$$

where,

- $\emptyset_d$ represent porosity derived from the density log
- ρ_b represent bulk density of formation
- ρ_m represent matrix density and for sandstone it is 2.65
- ρ_f represent density of fluid.

The main purpose of present petrophysics is to obtain calculation about porosity, saturation of water and hydrocarbon.

4.3 Average porosity calculation

Sum of the porosities that are obtained from the different logs divided by number of logs from which porosity is calculated. Here Lower Goru formation is reservoir of cretaceous age for which the average porosity is calculated, to zone of interest reservoir, all the logs are interpreted. The relation is given below through which average porosity is calculated.

$\emptyset_{avg} = \frac{\Phi n + \emptyset_d + \emptyset_s}{3}$,

where,

- $\emptyset_{avg}$ is the average porosity calculated from the available porosities
- Φn represents neutron porosity
- $\emptyset_d$ represent the density porosity
- $\emptyset_s$ represent the sonic porosity.

4.4 Effective porosity ($\emptyset_e$)

This will define as "the ratio of the volume of interconnected pore spaces in a rock unit to the total volume of the rock by removing shale effect that rock unit". The zone which rich in the shale, effective porosity will be zero. Effective porosity is used to mark the saturated zone. The effective porosity can be calculated by the following formula (Asquith et al, 2004).

$\emptyset_e = \emptyset_{avg} \times (1 - Vsh)$,

Where,

- $\emptyset_e$ effective porosity which to be calculated
- $\emptyset_{avg}$ represent the average porosity
- Vsh represent volume of the shale.

4.5 Mathematical relation for Water Saturation (S_w)

Water saturation in the formation can be defined as "The percentage of the pore volume filled by water in the formation". The saturation of water in the formation can be calculated by the following Archie equation

$S_w = \sqrt[n]{\frac{F \times R_w}{R_t}}$,

where,

- F is formation factor which is

$F = \frac{a}{\emptyset^m}$

- R_w represent the resistivity of water
- R_t represent the true formation resistivity

- n represents the saturation exponent
- a is the constant and its value is 0.62 in case of sand
- Ø represent effective porosity
- m represents the cementation factor and it value is taken 2.15 for the sandstone.

Mathematical relation for Hydrocarbon Saturation (S_h),

S_h=1-S_w

Hydrocarbon saturation can be defined as "the pore in formation is filled with hydrocarbon". It can be calculated by using the following mathematical relation

Where S_w represent Hydrocarbon saturation, S_h represent hydrocarbon saturation.

4.6 Interpretation of well log

IHS Kingdom software is used for the analysis of well Chack66-01; within the depth range 2110m to 2270m. Due to collapsing of wellbore Ruguosity effect will be occur.

Therefore in the depth ranges, if there is Ruguosity, the value of the other log is not consistent GR log, Caliper log are displayed in track-1.LLD while LLS log are displayed in track 2. DT, NPHI and RHOB are displayed in track-3. The crossover of NPHI and RHOB is important, if depth of NPHI is remain same but value of the RHOB is changed within that depth, it indicate fluid contact (Fig 4.2). Volume of shale $V_{(sh)}$ is displayed in track-5. Shale and sand can be separated by applying 40% cut-off value. Below this cut-off value, there is sand and above this cut-off, there is shale. Density porosity is displayed in track-6, calculated from DT4P.Average porosity (PHIT) is displayed in track-7 and actually is the sum of NPHI and DT4P divided by 2. Effective porosity is displayed in track-8 after removal of the shale effect. Water saturation (SW) is displayed in track-9.

Petrophysics is done to depth from 2110 m to 2270 m. The reservoir zone consists of sandstone is marked at depth of 2118m to 2142m om the basis of following signatures of logs. Caliper log should be consistent.In the same track study GR log it must be decreased.There should be separation between LLD and LLS in next track.In next track there would be crossover between RHOB and NPHI this is indication of Hydrocarbon.In next track Volume of shale should be decreased which is indication of sand.In next track study Effective porosity,porosity and total porosity lies between 10-15%.In the last track saturation of water its values lies between 30-40%.The various parameter estimated within reservoir zone is shown in Table.

Table:

Serial Number	Calculation Parameter	Percentage %
1	Average Volume of Shale=V(sh)	31
2	Average Porosity Obtained From Density log= $\emptyset_{davg}$	16
3	Average Porosity in(PHIT) Percentage=$\emptyset_{avg}$	17
4	Average Effective Porosity in Percentage= $\emptyset_{eavg}$	11.5
5	Average water Saturation in Percentage=S_{wavg}	43
6	Average Hydrocarbon in Percentage= S_{havg}	57

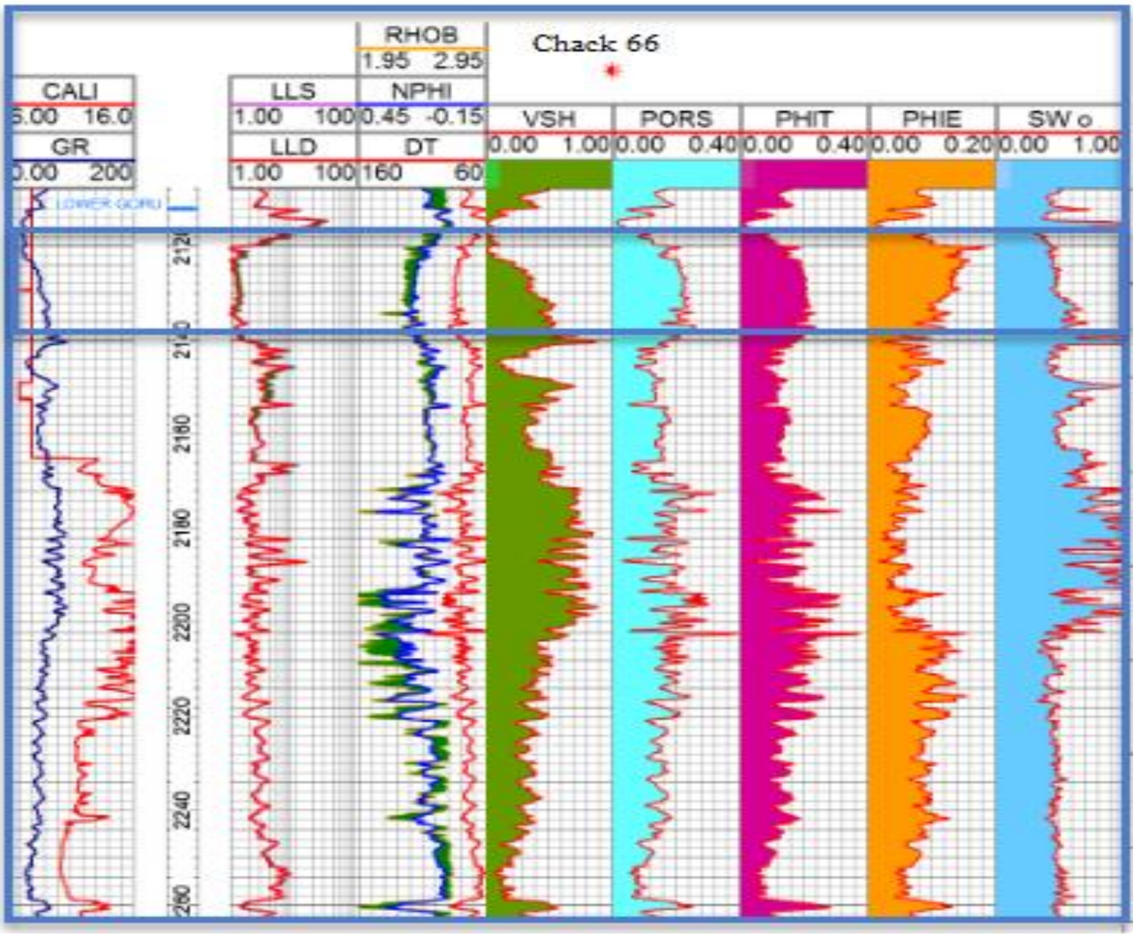


Figure 4.2 Petrophysical analysis of Well Chack66-01

CHAPTER NO: 05

ROCK PHYSICS

Rock Physics

5.1 Introduction

Through rock physics, the physical properties of the rocks in the real earth can be determined that varies vertically as well as laterally. According to (Mavko et al, 2009) regional averaged velocity function are used that shows the mean trend of the velocity with the depth. The RMS and the average velocities are not give the true representation of the earth subsurface so they cannot used for determined the rock properties. This provides an integrated methodology and practical tools for quantitative interpretation, characterization of reservoirs in the subsurface and assessment of uncertainty, using seismic and well-log data. RMS velocity is converted into interval velocities to compute several rock properties and generate graphs of P wave, S-wave, Density, Shear Modulus, Bulk Modulus, Young's Modulus, Poisson Ratio and Impedance for the subsurface layers to observe the behavior of these layers. The following formulas are used for computing Rock properties, for this purpose these formulas are inserted in the excel sheet to show the graphical representation of the above discussed rock properties (Mavko et al, 2009).

5.2 Rock Physics analysis

The term Rock Physics relates the geological properties of a rock at certain physical conditions with the corresponding elastic and seismic properties (e.g. elastic modulus, velocity, impedance).

1. Rock physics uses the sonic log, density log.

2. Rock physics establish the Vp, Vs and density and the relation between them.

3. Rock physics give the information about the rock property, impact of fluid and porosity on the Vp, Vs and Elastic Modulus.

5.3 Young's Modulus (E)

In the solid mechanics, Young modulus (E) is known to measure the stiffness of an isotropic elastic material. It is also known as the modulus of elasticity. It is defined as," the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hook's Law holds" (Mavko et al., 2009).

The Young modulus can be calculated by using equation (1);

$E=\sigma/\epsilon$

where,

- E = young's modulus
- σ = Tensile stress

The Young modulus behavior, from depth 2110m to 2280m of well Chack66-01, shows that the stiffness of the subsurface strata shows the fluctuation Fig 5.1

5.4 Bulk Modulus

The bulk modulus can be defined as the ratio of volume of stress to strain and it basically explain the substance's resistance to uniform pressure (Mavko et al., 2009).For fluid only bulk modulus is meaningful. The bulk modulus is shown in Fig 5.1. This also shows the fluctuation in the bulk modulus curve with respect to depth of well 66 of Sanjhoro area. There are two ranges of bulk modulus as shown in Fig 5.1. The zone where the value of bulk modulus is high it may indicate the presence of less resistive material and high resistive material may be present in the zone where bulk modulus has low value.If the value of K is infinity (∞), then material is said to be incompressible. On the other hand, if the value of K is zero (0), then the material can be easily compressed

5.5 Shear Modulus

Shear modulus is defined as, " the ratio of the shear stress to the shera strain". This mostly concern with the deformation of a solid as it experices a force parallel to one of its surface while its opposite face experience an opposing force for fluid it is near above equal to zero.

$\mu = \rho * Vs$

where,

- μ = Shear modulus
- ρ= Density and Vs is S-wave velocity.

Shear Stress is shown in Fig 5.1. This figure shows the decrease in the Shear stress in the reservoir zone that is from 2118 to 2142 m.

5.6 Velocity Relation With depth

Reservoir data set is obtain from the Chack66-01 well .Sonic log used to find the velocities Vs and Vp, Gr-log, Effective porosity is also calculated by using the sonic log and Neutron log and for the calculation of the saturation of water , LLD log and well borehole information were used .In the first track of Fig 5.1, there is the DT log and in track two there is a Vp velocity. In track three, there is the Vs and in track five, there is Shear Modulus.In next tracks Bulk and Young Modulus.

The main purpose of this calculation is to find out the behavior of velocity within depth in the reservoir and impact of the hydrocarbon on the velocity. In the reservoir 2118m to 2142m, V_p and V_s decreases and Young Modulus at that interval are decreases that indicated hydrocarbon. Because it indicate resistive rock.

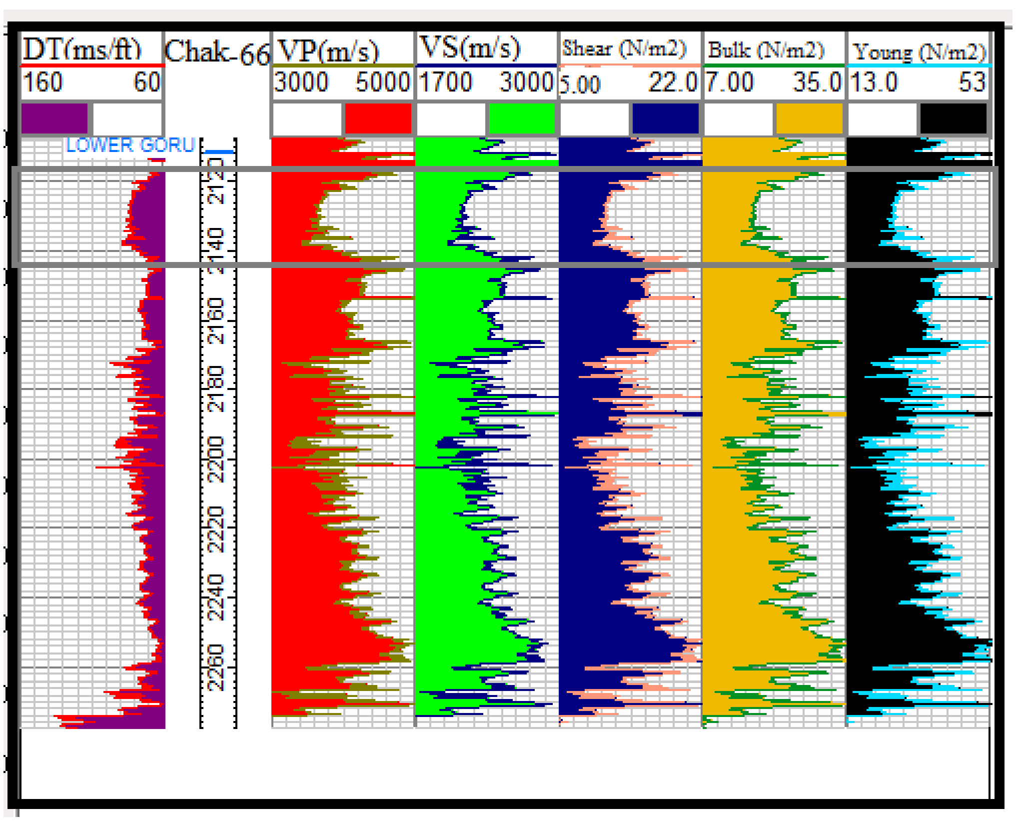


Figure 5.1: Velocity and Elastic Modulus relations with depth

CONCLUSIONS

- Six fault were marked and also Four prominent reflectors were marked on the basis of the synthetic seismogram.
- Seismic interpretation results have identified horst and graben structures forming favorable structures for the accumulation of hydrocarbons.
- Time and depth contour maps were prepared to analyze the overall behavior of the structure. There are small anticlinal structures bounded by two normal faults which is clue towards either horst and graben structures to some extent.
- Interested zone is marked which indicates hydrocarbon potential zone where hydrocarbon saturation is 57% and water saturation is 43%.
- Rock properties calculated helped to study the nature and type of lithologies.Elastic Modulus decreases in zone which indicates that it is resistive rock with hydrocarbon saturated.
- Seismic attribute analysis confirmed about all the interpreted horizons and faults on different seismic sections.

REFERENCE

- Asquith, G. B, Krygowski, D, & Gibson, C. R. (2004). *Basic well log analysis* (Vol. 16). Tulsa.
- Coffeen, J.A., 1986, Seismic Exploration Fundamentals, PennWell Publishing Co.
- Croizé, Ehrenberg, S. N, Bjorlykke, K Renard, F, & Jahren, J. (2010). Petrophysical properties of bioclastic platform carbonates: implications for porosity controls during burial. *Marine and Petroleum Geology*, *27*(8), 1765-1774.
- Dobrin, M.B. & Savit C.H., 1976, "Introduction to Geo-Physical Prospecting":2_n Edition, McGraw Hill Company.210-300, 450-510p.
- Kadri I. B, 1995, Petroleum Geology of Pakistan, Published by Pakistan Petroleum Limited, Feroz sons (pvt) limited; 275 p.
- Kazmi A. H. & Jan, M.Q, 1989, Geology & Tectonics of Pakistan", Graphic Publishers, Karachi, Pakistan. 540-560.
- Kearey, P & Brooks M.1984, Introduction to Geophysical Exploration", Blackwell Scientific Publications, Oxford, 1-98p..
- Rider M. H.(1996).The Geological Interpretation of Well Logs
- Mavko, G, Mukerji, T, & Dvorkin, J. (2009). *The rock physics handbook: Tools for seismic analysis of porous media*. Cambridge university press.
- Oil and Gas Development Company Limited, 2014, Sinjhoro (Gas/ Condensate Field), Online Available: http://www.ogdcl.com/ about-us/Fields.html#Sinjhoro.
- Robinson ES, & Coruh, c, 1988, "Basic Exploration Geophysics", John Wiley & Sons, New York, 25-70p
- Raza, H. A, R. Ahmed, S. M. Ali, and J. Ahmad, (1989), Petroleum prospects Sulaiman Sub Basin, Pakistan Journal of Hydrocarbon, Res. 1(2): 21-56.
- Sheriff, R.E, (1999), "Encyclopedia Dictionary of Exploration Geophysics", Society of Exploration geophysists, Tulsa, Oklahoma.
- Shah, M.T**,** 1997. Mineralogy, Chemistry and genesis of the Proterozoic base metal deposits at the northern margin of the Indian plate in Besham area, northern Pakistan.

- Subrahmanyam, D, & Rao, P. H. (2008). Seismic attributes—A review. In *7th International Conference & Exposition of Petroleum Geophysics* (p. 398).
- Telford e, 2004 "Applied Geophysics", Cambridge University Press, London, 860p.
- Tarbuck, E.D & Lutgens,F. K "Earth Science" (Eight edition) 1997, Prentice Hall, New Jersey.
- Taner, M. T, Koehler, F, & Sheriff, R. E. (1994). Complex seismic trace analysis. *Geophysics*, *44*(6), 1041-1063
- Wyllie MRJ, Gregory AR & Gardner LW. (1956). Elastic wave velocities in heterogeneous and porous media.