An integrated geophysical study to delineate the sub surface hydrocarbon potential of Sinjhoro area, Lower Indus Basin, Pakistan

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(2013-2017)

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Dedication

I dedicate my efforts to my Late Father and Uncle

Raja Khalid Waheed Abbasi & Raja Nawaz Janjua

Who were always with me in every part of life.

ACKNOWLEDGEMENTS

All praises be to Allah, the Sustainer of the world, the Compassionate the Merciful to whom alone, we look for help and who blessed me the potential to complete this research work. All respect for his last Prophet Muhammad (S.A.W) whose existence erased dark nights of ignorance, bestowing immense treasure of knowledge, humanity and eternal guidance. Foremost, I would like to express my sincere gratitude to my Supervisor **Dr. M. Gulraiz Akhter** for his patience, motivation, guidance, valuable suggestions, continuous encouragement, keen interest and immense knowledge throughout the Degree. I am thankful **to Sir Sakib Mehmood** and **Sir Fahad Mehmood** for their valuable time, guidance and help. I sincerely want to thank all my friends for their endless love, care and moral support during my academics. Last but not the least; I feel my proud privilege to mention the feelings of obligation for the outstanding guidance of my mother, relatives, my elder brother **Raja Haseeb Iqbal** and specially to my Guardian **Raja Sarfraz Akram** for their unlimited love, priceless prayers, spiritual and intellectual inspiration, encouraging attitude to carry me at the destination and for their stretching hands of sincerity towards me to achieve outstanding goals of life. I can never reciprocate their love and kindness.

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ABSTRACT

This dissertation contains the interpretation of 2D seismic reflection data of selected seismic lines of Sinjhoro Exploration Lease (E.L.), Southern Indus Basin, Pakistan. The main objective of this Project was delineation of subsurface structure. The data comprised three seismic lines, base map and well tops of well CHAK 66-01. The names of lines obtained are (200 17-SNJ-03 200 17-SNJ-23 and 200 17-SNJ-24).

Three prominent reflectors were marked on the basis of their reflection character. They represent Rani kot, Lower Goru and Basal Sands respectively. Structural analysis of the seismic data shows that this area is characterized by normal faulting. The Lower Goru formation of early to Middle Cretaceous age is the best known reservoir of the area and was of main concern. Time and Depth contour maps of Lower Goru Formation and Basal Sands help us to confirm the presence of horst and graben structure in the given area. This horst and graben structure acts as a trap in the area, which is best for hydrocarbon accumulation. In the Formation Evaluation of Lower Goru the zones were studied on the basis of the different log suites. Porosity, Volume of shale, Resistivity of the Formation water and saturation of formation water was determined in order to assess the Hydrocarbon potential of the Lower Goru. Petrophysical results are particularly valuable in mature field settings where hydrocarbons are known to exist but their exact location, pay, lateral variations and other properties are poorly defined. After all the major work unconventionally Hydrocarbon reserves has been calculated which gives a rough idea about the amount of reserves present in the area and also pressure of overlying rocks on the reservoir.

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Chapter no. 01

INTRODUCTION TO THE STUDY AREA

Introduction to the area

Sanghar District is one of the largest districts in the Sindh province of Pakistan. Bounded by India on the east. The district capital, Sanghar, is itself a small city roughly 56 km south-east of the city of Nawabshah. Sinjhoro is about 2.25 km North-west from Sanghar city, along shah dad-pur road shown in (Fig 1.1).

Sinjhoro is part of Indus basin. The Sinjhoro E.L covering an area of 179.31 Square Km approx.

It is extensional regime and normal faults are present here.

The location of area and its latitude and longitude is given below:-

- Latitude 26° 00' 00N to 26°15' 00 N
- Longitude 68° 48' 00E to 69° 05' 60 E

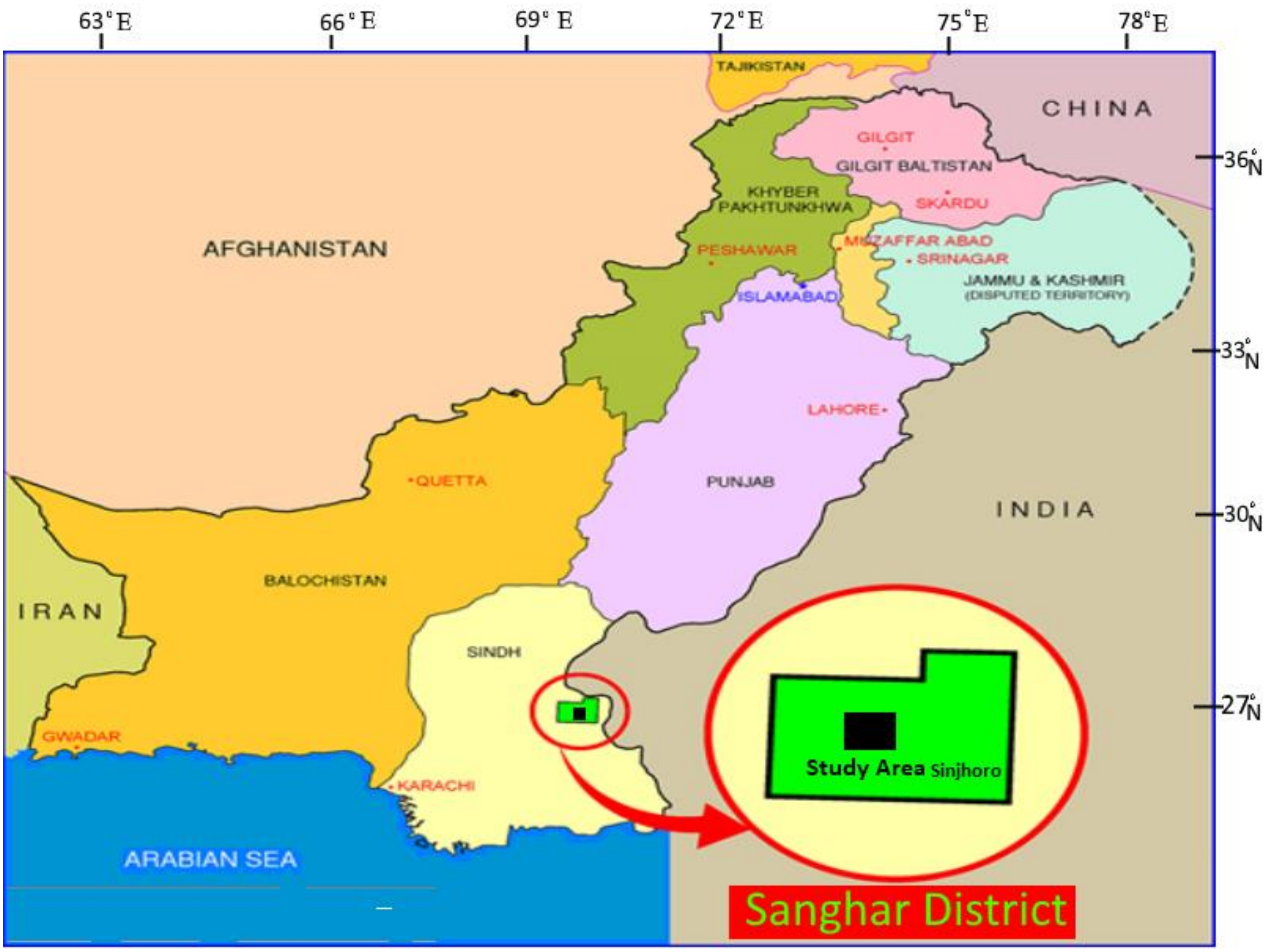


Fig 1.1 Location Map of the Sinjhoro Area (Google Images Edited)

1.1 Seismic Data

The Data set used in the study area consists of three 2D-seismic lines shown in Table(1.1). A Single well is in the study area to understand the subsurface geology. Dip lines are 200-17-SNJ-03 and 200-17-SNJ-23 contain short points while 200-17-SNJ-24 is the strike line along with well chak 66-01.Well data information is given in Table(1.2).

Line direction for Dip line NE-SW, for Strike line NW-SE.
Sampling Interval: 4ms
Range of frequency: 15-7 Hz
Dominant frequency: 30 Hz
The record length of the seismic data was set to 4004ms
Seismic reference datum (SRD) was set to mean sea level (MSL) as the study area is regionally flat and near to the shore

Serial No	Line Number	Type
1	200-17-SNJ-03	Dip
2	200-17-SNJ-23	Dip
3	200-17-SNJ-24	Strike

Table1.1seismic lines used for Base Map

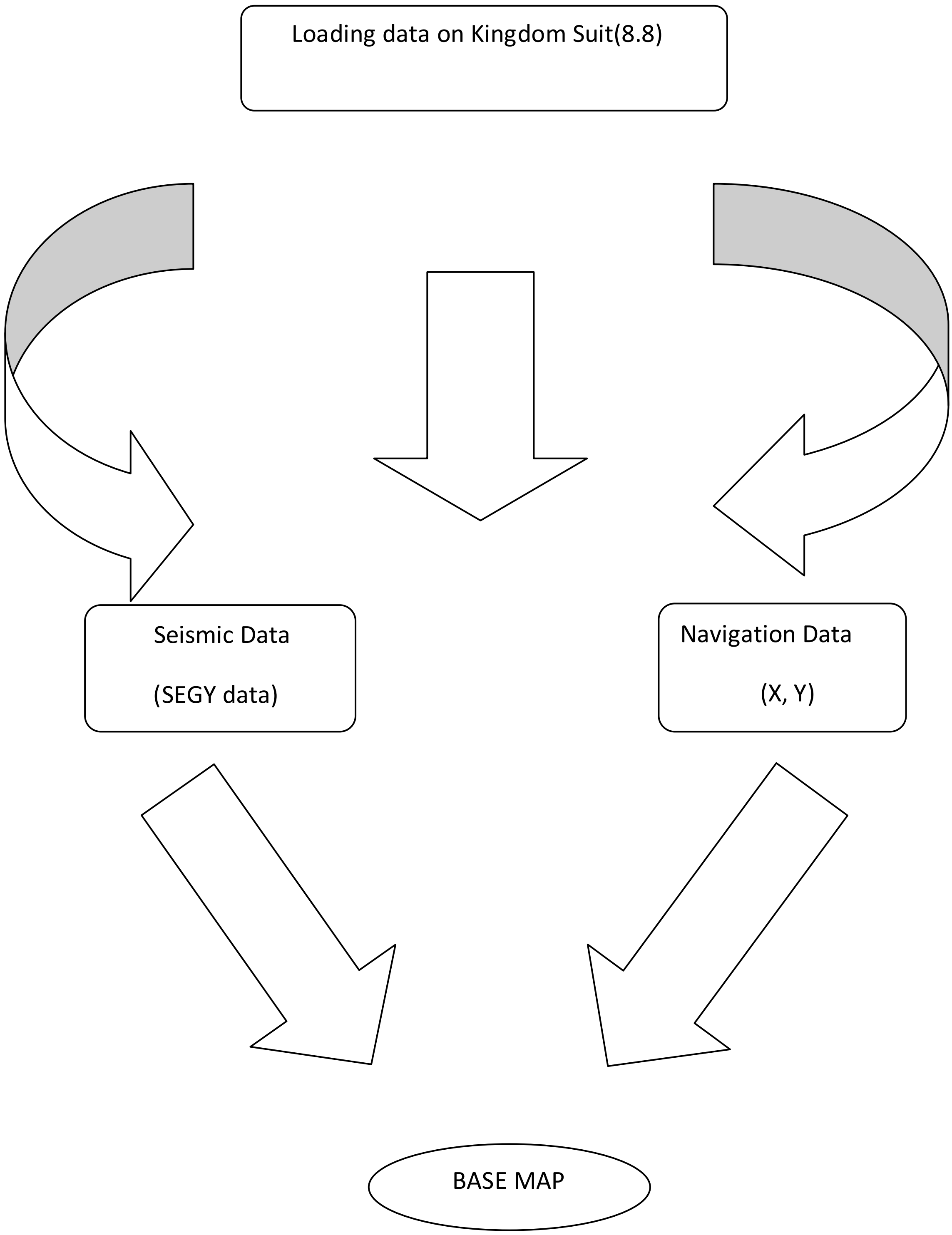
Well Name	Latitude	Longitude	Elevation(m)	Depth Reference	Total Depth(m)	Status
CHAK-66-01	27º9’ 54”N	70º52’34”E	31.93	KB	2999	Oil&Gas

Table 1.2 Information for well Data

1.2 Base Map

A base map is a map on which primary data and interpretations can be plotted.A base map typically includes the locations of concession boundaries, wells, seismic survey points with geographic reference such as latitude and longitude. Geophysicist typically use shot points maps, which show the orientation of seismic lines and the specific points at which seismic data were required to display interpretation of seismic data.The major requirement for the construction of the base map is the Navigation file (DBO format) and SEG-Y files.

Steps for the construction of the base map are elaborated by the flowing flow charts:



1.3 Base Map of the area

Base Map of three Seismic lines used in project shown in (Fig 1.2) below.

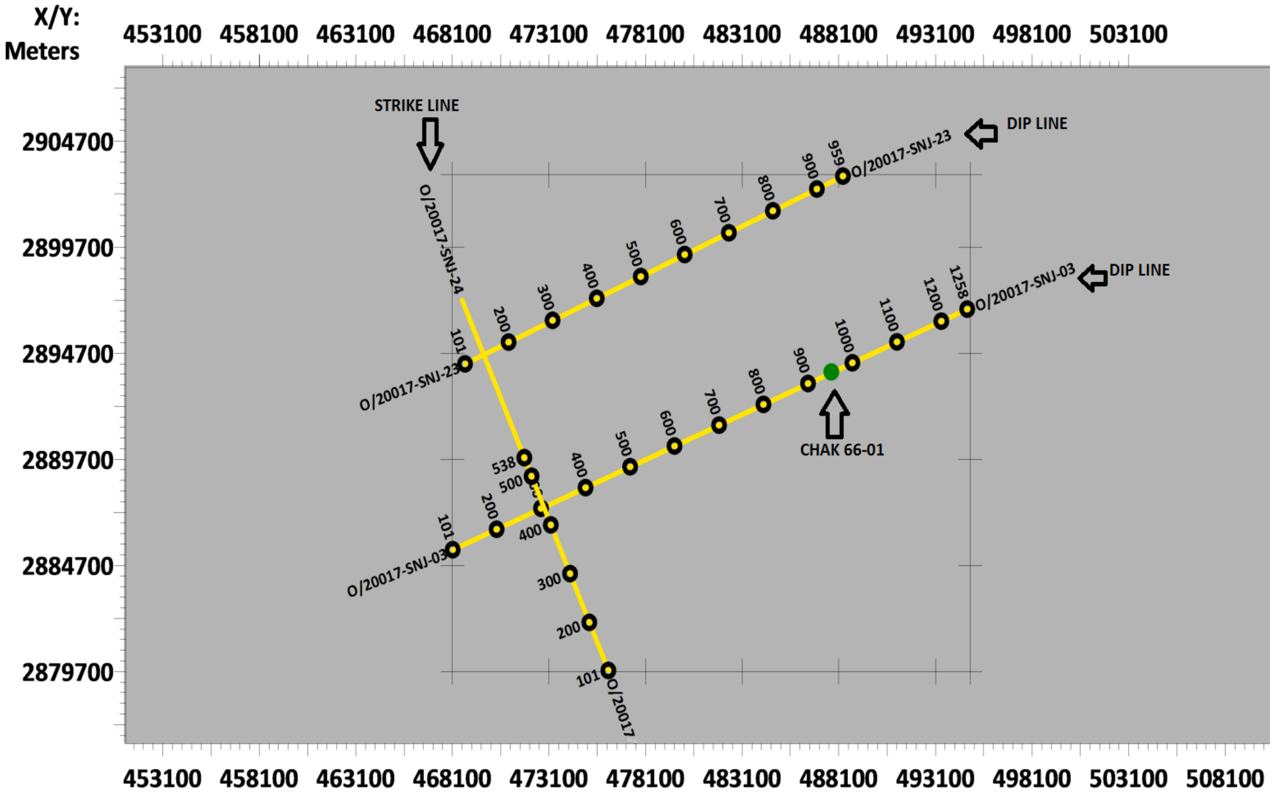


Fig 1.2 Base Map of the study area.

1.4 Objectives

The main objective of this research work is to carry out a comprehensive interpretative study of the available seismic lines. However, a complete and reliable picture of the subsurface could not be obtained on the basis of the three available seismic lines. To have a slight grip over interpretation done, available literature was also taken in to consideration. This study contains the demarcation and delineations of the structural and regional fault trends in the area. This whole research gives an idea about the regional trends of the marked horizons, particularly the reservoirs. Evaluating the reservoir properties of Chak 66-01 along with the suggestion of new well location are also main objectives.

Chapter no. 02

General geology, Stratigraphy and Tectonics of the study area

2.1 General Geology of Sinjhoro

As the project area is located in Sanghar District, the southern part of the Indus basin. So we can define regional geology of Sinjhoro area. The southern Indus is a strain basins characterized by tectonic faults up on the western edge of the Indo Pakistan sub-continent identifies. Several hypotheses have been proposed, the origin of these crusts explain functions, but Keller chains remain enigmatic. Thar platform gently sloping monoclinic banalog Punjab platform controlled topography of the basement, the sedimentary wedge thins towards the Indian plates whose surface expressions in the form of nagarparkar high are available, it differs from the Punjab platform that it shows the buried formed by tectonic extension from the from the current counter clockwise movement of the Indian plate resulting structures. It is in the east of the Indian plate limited goes in Kirthar and Karachi trough in the west and in the north by Mari Bugti inner folded zone.

The platform by thar, Karachi built trough and offshore Indus stratigraphic structure cross-section clearly shows the stratigraphic and structural differences between the two sub-basins. The platform brands very good development of the early / mid-Cretaceous sand Guru, the reservoir for oil and gas (Kadri, 1995)

2.2 Indus Basin

The Greater Indus Basin extends over most of eastern Pakistan and the westernmost parts of India, covering an area of about 873,000 square kilometers (km^2). Given its geological and tectonic evolution, the Indus basin can be divided into three parts: from North to South, the Upper Indus Basin, the Middle Indus basin and the Southern Indus basin.

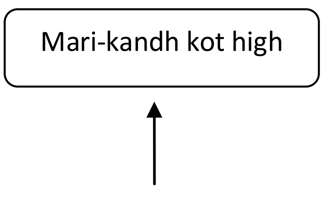
Due to the convergence between Indian and Eurasian plate, it is suggested that Indus Basin is separated into two parts i-e.

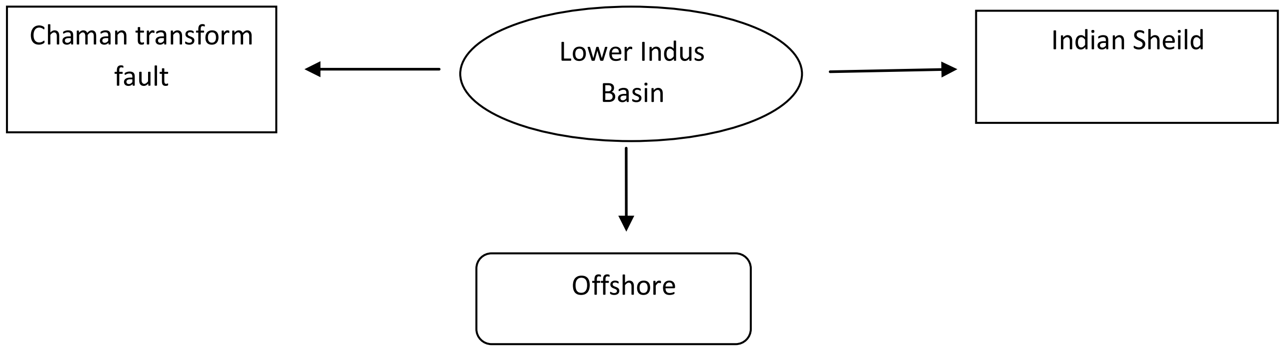
1. Upper Indus Basin
2. Lower Indus Basin

2.3 Stratigraphy and Tectonics Setting

Tectonically Indus Basin is steady area than other zones of Pakistan (Kadri, 1995).

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).





Boundaries of Lower Indus Basin

2.4 <u>Tectonic Zone and Geology of Sinjhoro</u>

Sinjhoro E.L is a part of Thar Slope Platform area of Southern Indus Basin. It is bounded in the east by Indian Shield and in the west by Kirthar and Karachi Trough and in the north by Mari Bugti Inner Folded Zone. During the drift of the Indian plate towards the North-North East, which started in the Triassic, sedimentation took place along the leading edge of the plate in a marginal sag basin. Although several sedimentary cycles can be recognized within this phase, no major tectonic activity occurred until in the Cretaceous. In the lower Indus region, a depositional environment during the Paleocene resembled the pattern of the Mesozoic. However, later during the Eocene, the first orogenic pulse exercised its influence on the sedimentation by that time, the paleo geographic changed completely with the emergence of a volcanic island arc, North West of present day Pakistan. The sediments derived from the arc entered marine environments towards South East and independent decenters developed in various parts of Pakistan. The marine sediments became restricted to a narrow but rapidly subsiding trough in the Kirthar Area. The clastic supply from the rising Himalayas and from the local positive regions of the axial belt was so abundant that a spectacularly thick sequence of molasses sediments reached more than 7000m. Towards the end of the Paleocene, the Indus Basin was filled with sediments and must have resembled a vast flood plain with braided stream, the only elevation being the hills of the folded belts. This part of Lower Indus Basin represents progradational Mesozoic sequences on a westward inclined gentle slope. Every prograding time unit represents lateral facies variations from continental and shallow marine in the east to dominantly basinal in the west. In Thar Slope Area, all Mesozoic sediments are regionally plunging to the west and are truncated by unconformable volcanic (Basalt of Khadro Formation) and sediments of Paleocene age. Two broad geological divisions of this region the Gondwanaland and the Tethyan domains are discussed. In this scenario Pakistan is unique inasmuch as it is located at the junction of these two diverse domains. The southeastern part of the Pakistan belongs to Gondwanaland domain and is sustained by the Indo-Pakistan crustal plate. The northern most and western regions Pakistan fall in tethyan domain and present a complicated geology and complex crustal structure.

On the basis of plate tectonic features, geological structure, orogenic history (age and nature of deformation, magmatism and metamorphism) and litho facies, lower Indus basin may be divided into the following broad tectonic zones shown in (Fig 2.3a).

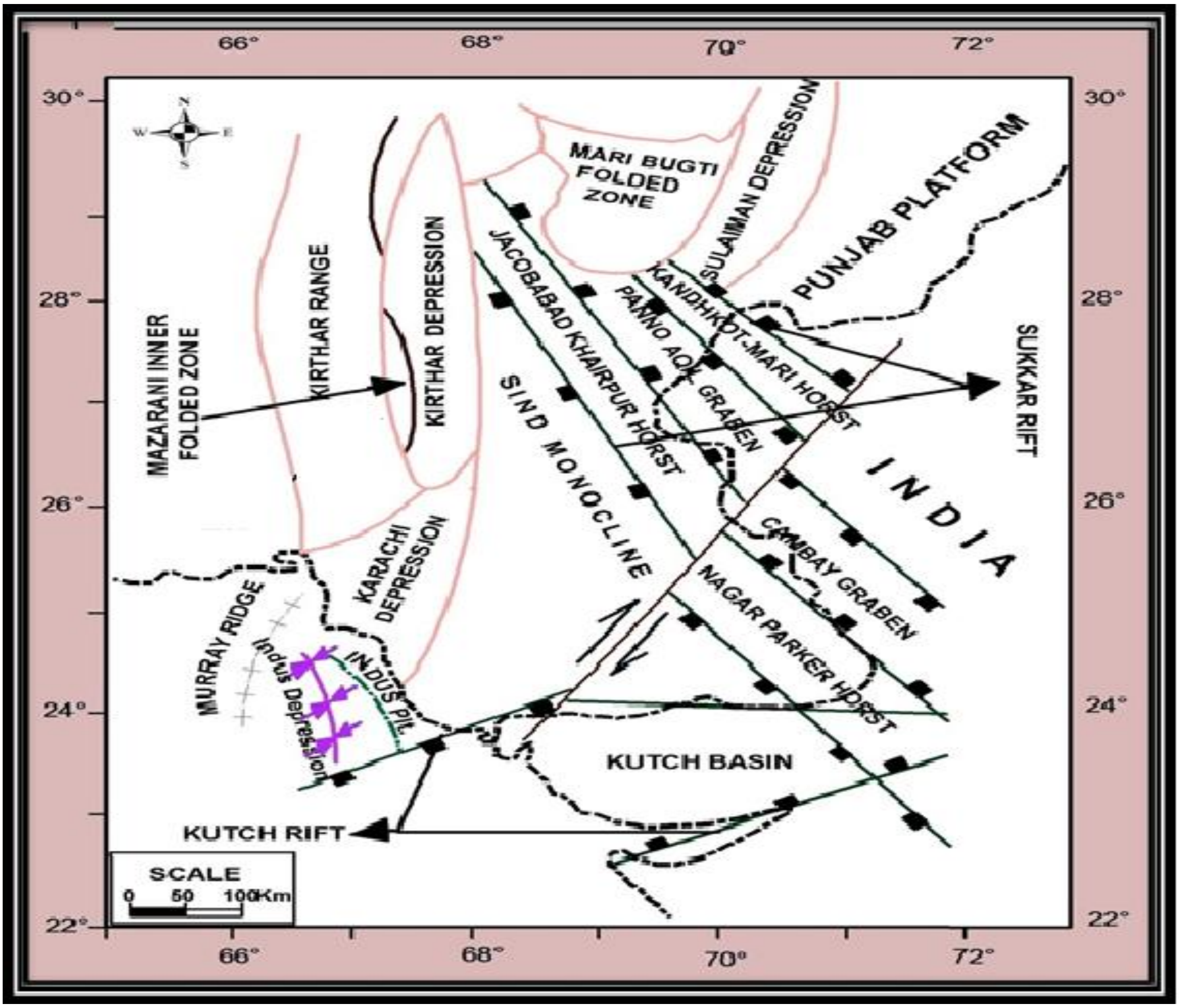
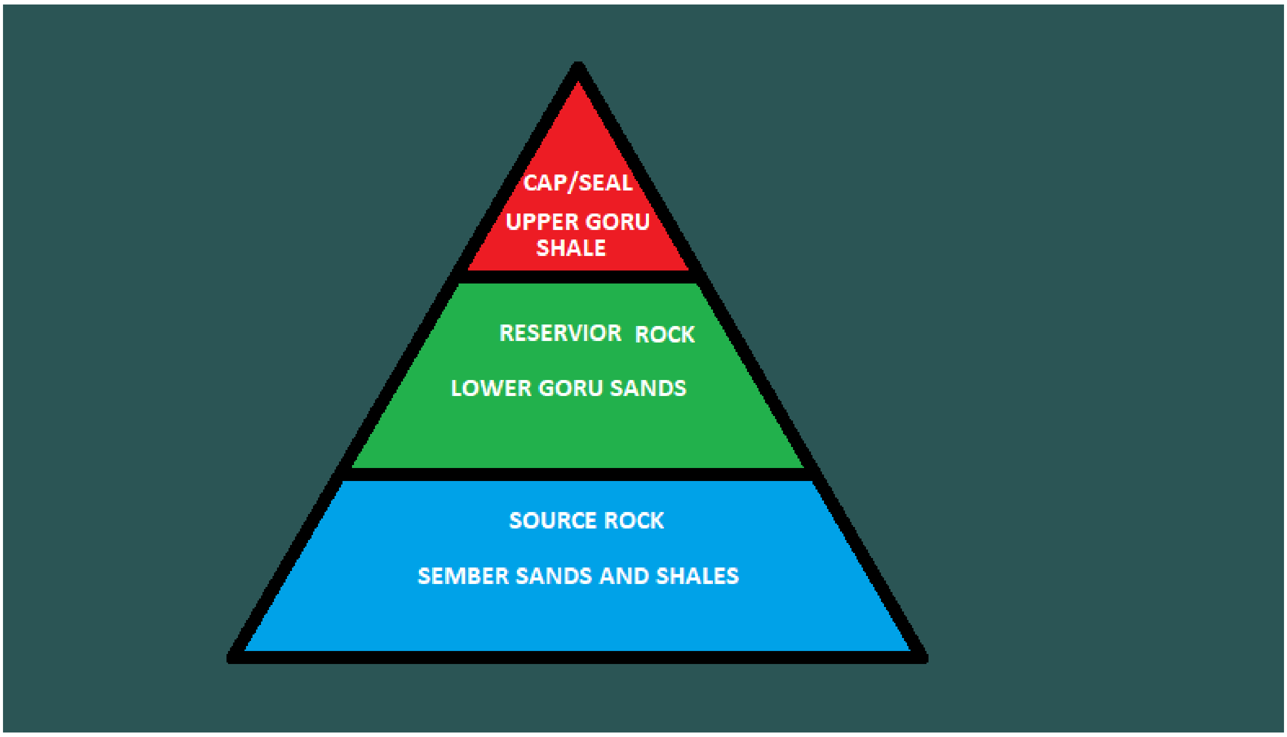


Fig 2.3a Tectonic zones of Lower Indus Basin (Raza et. Al. 1990).

2.5 Petroleum Prospect

Stratigraphic column shows that different rocks act as Source, reservoir and Cap rock.



Reservoir Rocks

The depositional environment of the Lower Guru sands in the Sinjhoro field is interpreted to be a wave dominated, low stand shelf edge delta system with barrier sands and channel fills. The low acoustic impedance together with strong seismic amplitudes indicates the presence of reservoir quality sands. According to Iqbal kadri in Petroleum geology of Pakistan, Reservoir quality sands are only present in the deposition ally up dip, i.e. the shallowest marine part of the low stand wedge, as are found in the Sawan, Miano, Sinjhoro and Kadanwari Fields (Afzal, 1996).

Seal Rocks

The known seals in the system are composed of shales which are interbedded with sands and overlying the reservoirs.. The upper Goru shale and interbedded shales of sui Main limestone are acting as seal in study area.

Source Rocks

Source rock is the productive rocks for hydrocarbon. They also initiated the conversion of organic compound into oil and gas form. The Formations, which act as source rocks in the project area are as follows:

- Sember Formation: Sember Formation is believed to be the source of hydrocarbon in Sinjhoro field and huge gas accumulation in Suleiman province. Potential reservoir occurs within the sandstone of formation.

2.6 General Stratigraphy

Summary of stratigraphic sequence of Southern Indus basin is given below (Kadri 1995).

AGE	GROUP	FORMATION	LITHOLOGY
Miocene		Gaj	Shale
Oligocene		Nari	Shale, sandstone
Eocene	Kirthar Group	Kirthar	Interbeds of limestone, shale
		Laki	Limestone, shale, laterite
		Sui main limestone	Limestone
Paleocene	Ranikot Group	Lakhra	Limestone, sandstone
		Bara	Sandstone, shale
		Khadro	Sandstone, basaltic flows
C R T A C E O U S		Pab sandstone	Sandstone
		Fort Monro	Limestone, shale
		MughalKot	Mudstone, shale
		Parh limestone	Limestone, marl, shale
		Goru	Sandstone, shale
		Sember	Shale, limestone
Jurassic		Mazar Dirk	Interbeds of shale, lst
		Chiltan	Limestone, chert
		Shirinab	Interbeds of shale, lst
Triassic		Wulgai	Shale, limestone

2.7 Stratigraphy of the Area

The area comprises a full range of formation with oldest rock in the area from Pre-Mesozoic till most recent formation of Eocene age. But major focus in the area due to petroleum play is on Lower Guru Formation which is of Cretaceous age which is acting as reservoir in the entire basin. See (Fig 2.6a).

Goru formation

The sands of Goru are the most important entity in the southern Indus basin from the petroleum reservoir point of view. The thickest Goru sedimentation occurs within the Karachi Embayment. On the wells west of Badin platform, Goru is partially penetrated about 2,360 meters (Kadri, 1995).Based on its lithological content, Goru Formation has been divided into upper and lower portions, with sand being rarer in upper portion. Upper portion is predominantly shale while the lower portion is the sandy member. This lower portion (lower Goru) is the most important reservoir in southern Indus basin. It contains all the hydrocarbons in Sindh Monocline (Kadri, 1995).The wells drilled in Badin area exhibit a lateral facies change from east to west, from producible sand/shale sequence in Lower Goru to non-reservoir sand/shale facies, which in turn is entirely represented by shales further west (Kadri, 1995).

Parh limestone

Although Parh limestone occurs widely throughout the Indus Basin, erosional truncation has limited the Formation distribution to an area lesser than Goru and Sember Formations (Kadri, 1995). Like in Badin platform area it is only present in southern portion and that too in the form of thin layer. No oil or gas shows have been found in the Parh limestone in the subsurface and no surface seeps are known.

Pab sandstone

It is light grey to light tan to brown, quartose, fine to coarse grained, hard to soft sandstone. It is occasionally conglomeratic and generally cross-bedded. It is considered to be deposited under shallow water environment characteristic of the Mughal Kot deposition. In the Mughal Kot seepage area, most of oil seeps are from Pab. It also forms petroleum reservoirs at Pirkoh, Loti, Dhodak and Rodho fields. It is considered to have no source potential (Kadri, 1995).

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. 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.

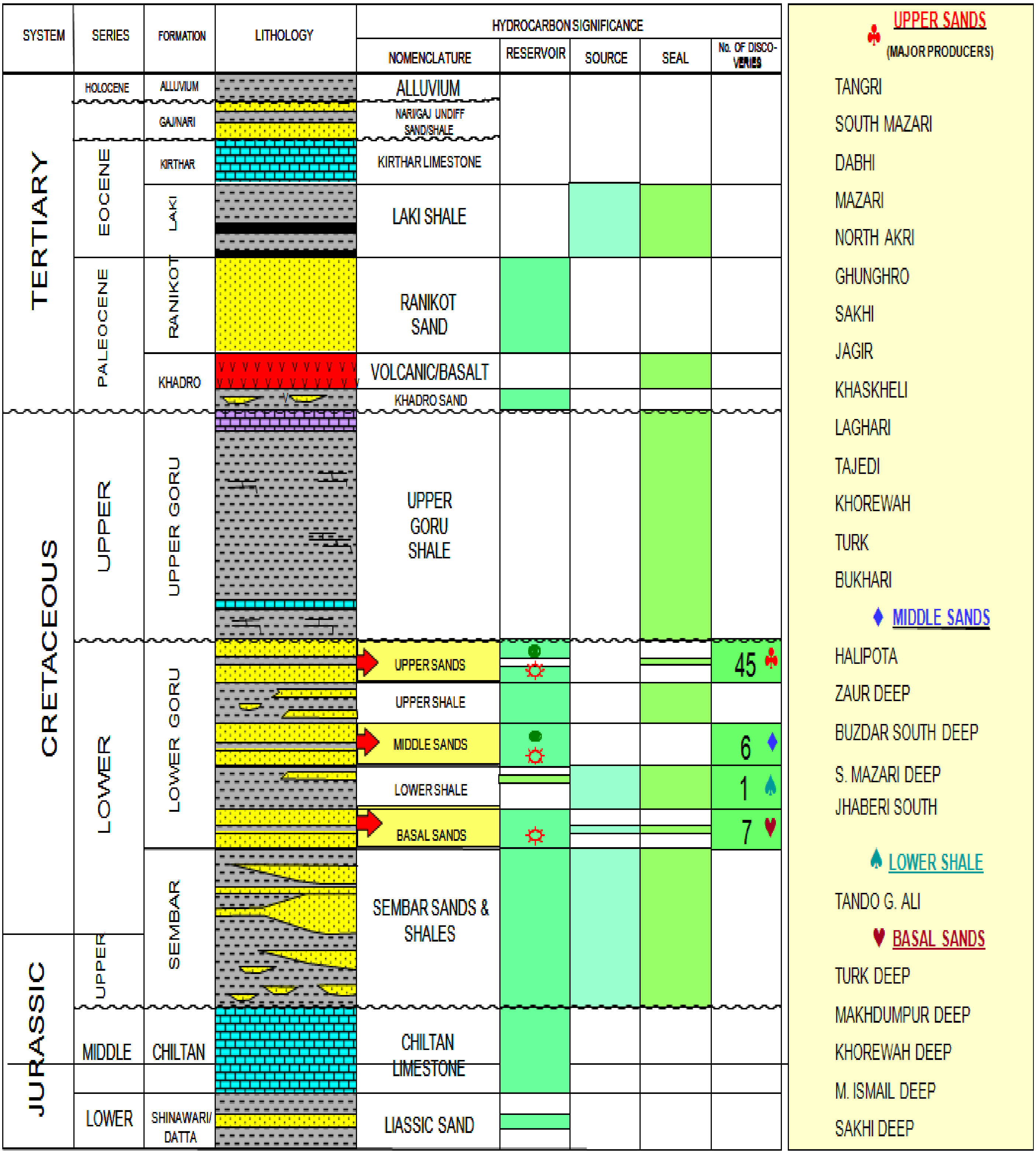


Fig 2.6a Stratigraphy of the Area.

Chapter no. 03

SEISMIC INTERPRETATION

A tool to transform the whole seismic information into structural or stratigraphic model of the earth is interpretation. It is rare that correctness or incorrectness of an interpretation is ascertained, because the actual geology is rarely known in well manner. Good interpretation is tested by consistency rather than correctness. Not only a good interpretation be consistent with all the seismic data, it also important to know all about the area, including gravity and magnetic data, well information, surface geology as well as geologic and geo-physical concept (Telford, 1999).

Seismic data has been interpreted in two modes.

- The first mode is in areas of substantial well control, in which the well information is first tied to the seismic information, and the seismic then supplies the continuity between the well for the zone of interest.
- The second mode is in areas of no well control (frontier areas) in which the seismic data provide both definition of structure and estimates of depositional environments.

The main purpose is to make reflection as clear as possible to study structure and stratigraphy of subsurface. Geologic meaning of the reflection is the indication of the boundaries where there is change in the acoustic impedance. Seismic data has been interpreted with well control and the well information is used to tie with the seismic data.

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

- Stratigraphic Interpretation
- Structural Interpretation

3.1 Structural Interpretation

It is the study of reflector geometry on the basis of the reflection time. The main application of the structural Interpretation of seismic section is in the search for structural traps containing hydrocarbons. Most structural interpretation uses two way reflection times rather than depth. Time structural maps are constructed to display the geometry of selected reflection events. Seismic sections are analyzed to delineate the structural traps like folds, faults and anticlines. In this modern era of science and technology, software suits provide a great help in analyzing the seismic data both structurally and stratigraphically. Software helps the interpreter by automatically detecting the fault zones and then marking them on the whole project area. But for this the seismic data should be high resolution.

For this particular project, we emphasized more on the structural interpretation. Since we did not have digital copies of the seismic lines, horizon-marking and time-reading was done manually.

3.2 Stratigraphic Interpretation

Stratigraphic interpretation involves the subdivision of seismic sections into sequence of reflections that are interpreted as a seismic expression of genetically related sedimentary sequences. According to Dobbin&Savit, throughout the history of reflection method, its performance in locating hydrocarbons in stratigraphic traps has been much less favorable then in finding structurally entrapped oil and gas. Stratigraphic oil traps can result from reefs, pinch outs or other features associated with erosional truncations, facies, transition and sand lenses associated with buried channel, lacks are similar sources. Different software provide help in stratigraphic analysis as well by overlaying different seismic attributes on seismic sections to detect pinch outs, truncations etc.

3.3 Techniques for Structural Interpretation

Seismic sections give images of reflection arrival times. Variation along profile is called as time scanning. Structural Interpretation is done by:

1. Time Section
2. Depth Section

Time Section

It is basically the reproduction of seismic section, Time section have two scales one is vertical scale consisting of time while the second is horizontal scale that consists on SP's.

Depth Section

In seismic data interpretation and processing the important is the accurate measurements of seismic velocities. Following method listed below is used to determine the average velocity in order to construct the depth section

$$Depth = \frac{V * T}{2}$$

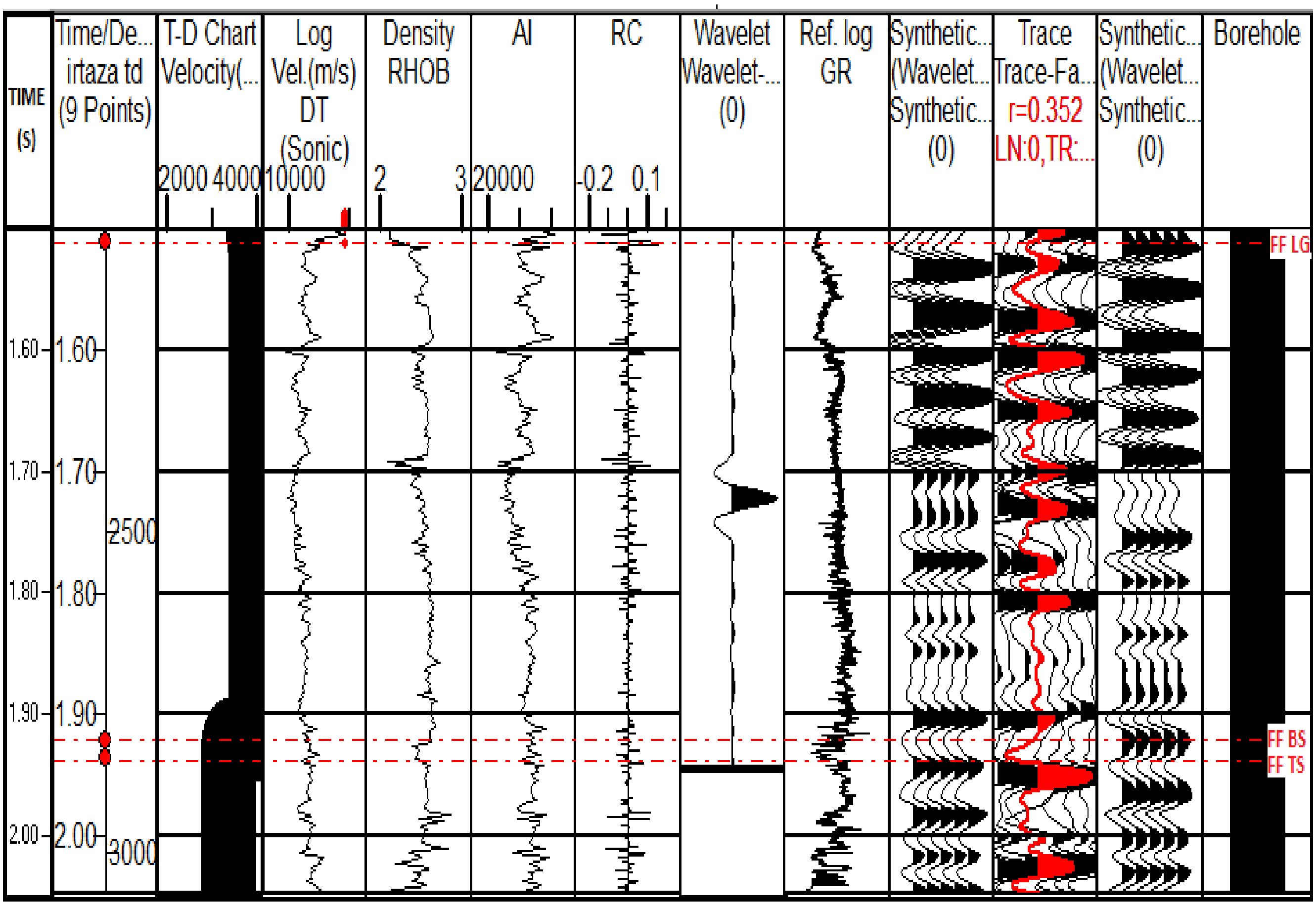
Where, T= Two way travel time of each reflector in seconds
V= Velocity of respective reflectors

3.4 Structural Interpretation of Seismic Data

Brief stepwise methodology is given below which is used for interpretation:

Generation of Synthetic Seismogram

Synthetic seismogram was generated by Ricker wavelet. Horizon marking is the main purpose of synthetic seismogram. Well CHAK66-01 which is on the line 200-17-SNJ-03 (Fig 3.4). Well tops were also imposed on the respective synthetic seismogram showing. Ideally, if high impedance rocks lie below the low impedance rocks, then there would be positive phase at sequence boundary. And if there is low impendence rocks lying below the high impedance rocks, then there would be negative phase at the sequence boundary. Synthetic seismogram was correlated with the line 200-17-SNJ-03 shot point 960 where well CHAK66-01 was located.



FORMATION	DEPTH (Elev.	DEPTH Re(fTVDSeis)	AVG VEL	TIME TO TOP	TIME THICKNESS	INT VEL	THICKNESS
FF ALLUVIUM	0.0	0.0	-0.0	-0.03374	0.64678	1892.5	612.0
FF LAKI	612.0	612.0	1996.6	0.61304	0.39831	2756.6	549.0
FF RANIKOT	1161.0	1161.0	2295.9	1.01135	0.30075	3125.5	470.0
FF PARH	1631.0	1631.0	2486.1	1.31210	0.07228	3929.2	142.0
FF UPPER GORU	1773.0	1773.0	2561.4	1.38438	0.12727	3928.7	250.0
FF LOWER GORU	2023.0	2023.0	2676.5	1.51155	0.40908	4004.1	819.0
FF BASAL SAND	2842.0	2842.0	2959.3	1.92073	0.01655	3382.7	28.0
FF TALAR	2870.0	2870.0	2962.9	1.93728			

Fig 3.4 Synthetic Seismogram of CHAK 66-01

Picking Horizons

After tying Synthetic Seismogram the respective reflectors has been marked on the section. On the basis of prominent coherency of reflections visible on seismic section from the subsurface interface the reflectors are marked. Then this information is shifted to other seismic lines by tying seismic sections. The reflection of all the prominent reflectors was recognized on the basis of the synthetic seismogram and their lateral continuity. Lower Goru and Basal Sand were marked on the basis of synthetic seismogram while Ranikot Formation was marked on well top base.

Identification of Faults

On the basis of discontinuity on the reflections, faults are marked. On strike line no fault has been marked whereas faults has been marked on dip lines which clearly indicates the discontinuity and as the hanging wall moves down so on this base these faults can said to be normal faults. As the seismic sections were of fair quality it was not difficult to identify the faults on the basis of break in the continuity of reflector. The Middle Indus basin is characterized by normal faulting with strike slip component structures. As our interested formation was Lower Goru, it has normal faults. Many faults were marked on the basis of clear breaks in the continuity. All faults make horst and graben structure in the area.

3.5 Interpreted Seismic Sections

As each seismic line demonstrates different type of information so each interpreted seismic section is discussed.

Line 200-17SNJ-03

It is a dip line which has series of normal faults and showing series of horst and graben structures. Three reflectors marked on this line starting from Ranikot formation to Basal sand (Fig 3.5a). All these reflectors marked on the basis of continuous reflection while 6 faults are marked on this line. As discussed CHAK 66-01 well lie on this line and synthetic has generated from this well data and reflectors marked on this section after tying synthetic. All marked faults can be seen in this section. In this section Ranikot formation is at 1.006 second time, Lower Goru formation is at 1.509 sec, Basal Sand formation is at 1.922 sec.

Line 200-017-SNJ-23

It’s a dip line and has 4 extending faults (Fig 3.5b). This line is same as 200-017-SNJ-03. In this section Ranikot formation is at 1.027 sec time, Lower Goru formation is at 1.508 sec, Basal Sand is at 1.861 sec.

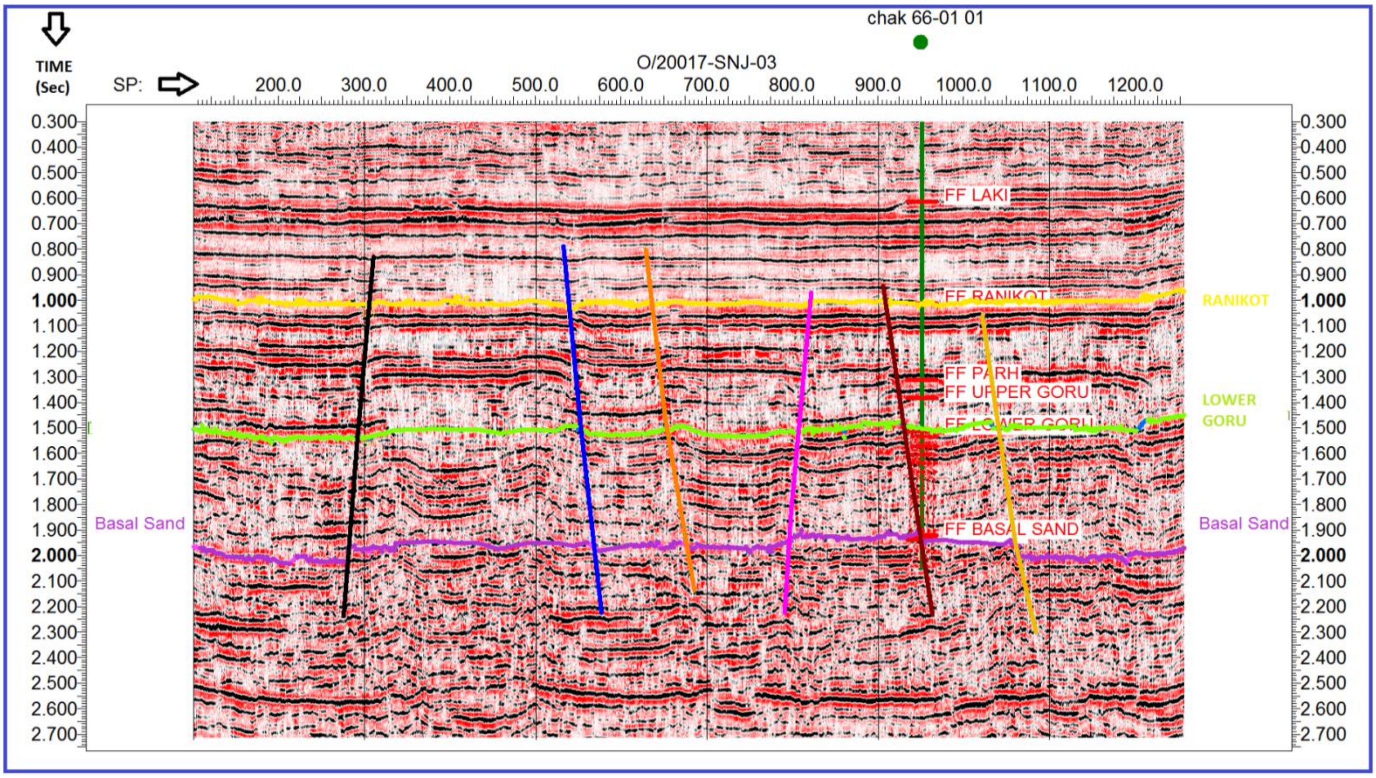


Fig 3.5a Marked Horizons and Faults are shown on seismic Dip line 20017-SNJ-03

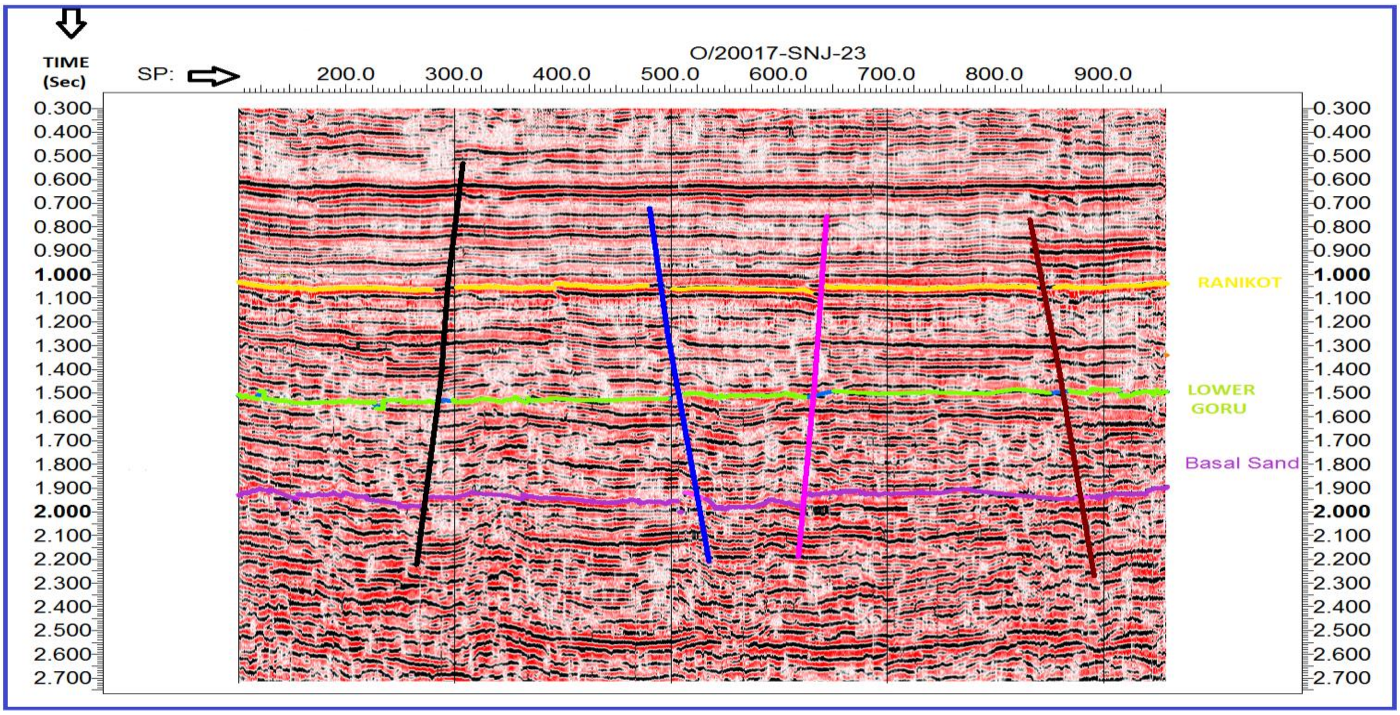


Fig 3.5b Marked Horizons and Faults are shown on seismic Dip line 20017-SNJ-23

Line 200-017-SNJ-24

It is a strike line and it gives straight reflectors and three reflectors marked on this line starting from Ranikot formation to Basal sand formation (Fig 3.5c). In this section Ranikot formation is at 1.031 sec, Lower Goru formation is at 1.462 sec, Basal Sand formation is at 2.013 sec.

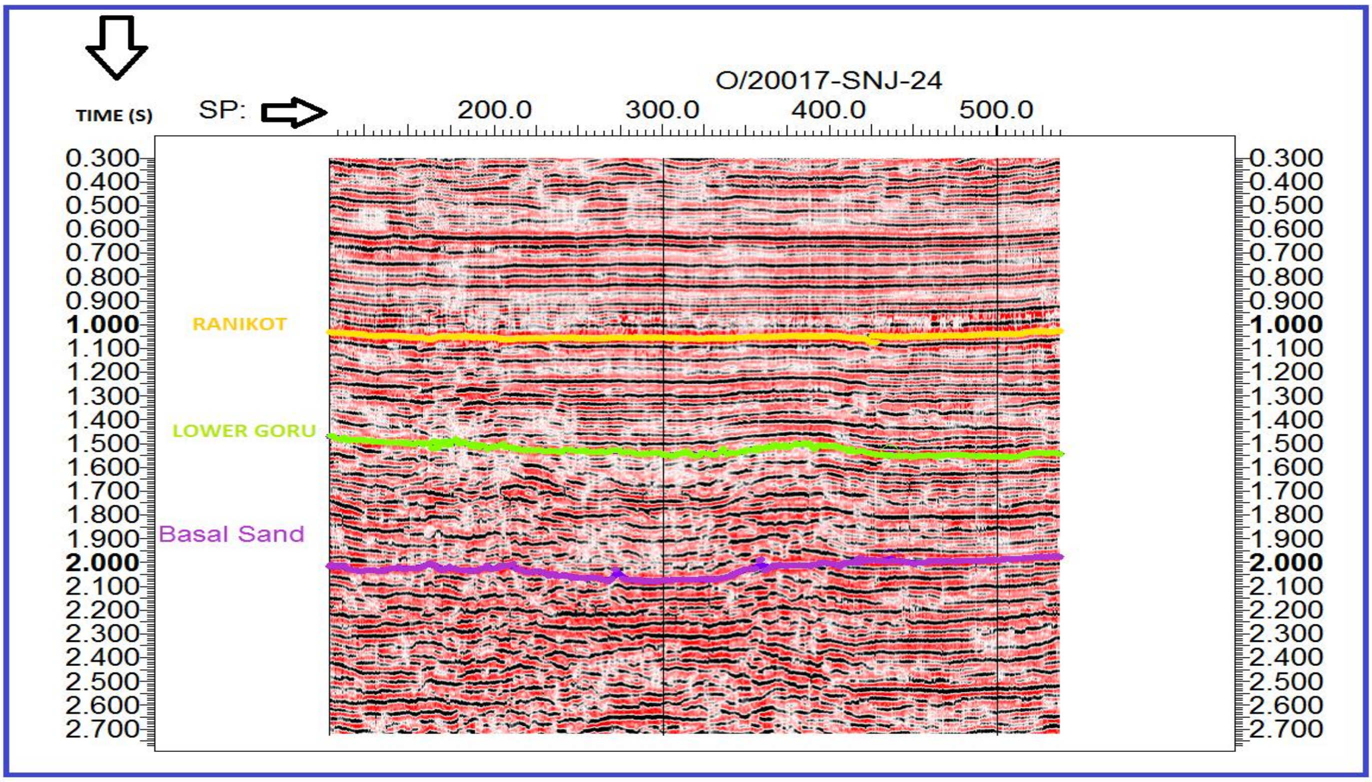


Fig3.5c Horizons can be seenon seismic strike line 20017-SNJ-24

3.6 Contour maps

Contour lines are representative of the same events. Proficiency in contouring is the quest for a two dimensional representation of a three-dimensional surface is a basic skill that should be in the armory of every exploration. The coordinates (X and Y) time and velocity (converted to average velocity) values are picked against each shot point from seismic section i.e. used for the preparation of contour maps. Time and depth contour maps of Lower Goru and Basal Sand Formations are prepared in this study. For depth contour maps Average Velocity is used but it was not given so we used constant velocity and this constant velocity is calculated by using relation s = v t. The surface maps represent the lateral and vertical distribution of the formation. Time and depth contour maps of Lower Goru Formation (Fig 3.6a, 3.6b) indicate that the whole area is based on series of horst and graben structure which confirms that the area is in extensional regime. Well is drilled in half Graben structure. Likewise Lower Goru Formation, Basal Sand also indicates the same result. Its contour maps also indicate the horst and graben structure (Fig 3.6c, 3.6d). As the whole area is based on series of horst and graben structure so we should explain that horst is the elevated block which is the main target in hydrocarbon exploration while graben is the depressed block which may act as kitchen for hydrocarbon generation. The fault cuts are dipping in east and west direction while they are trending in North and south direction.

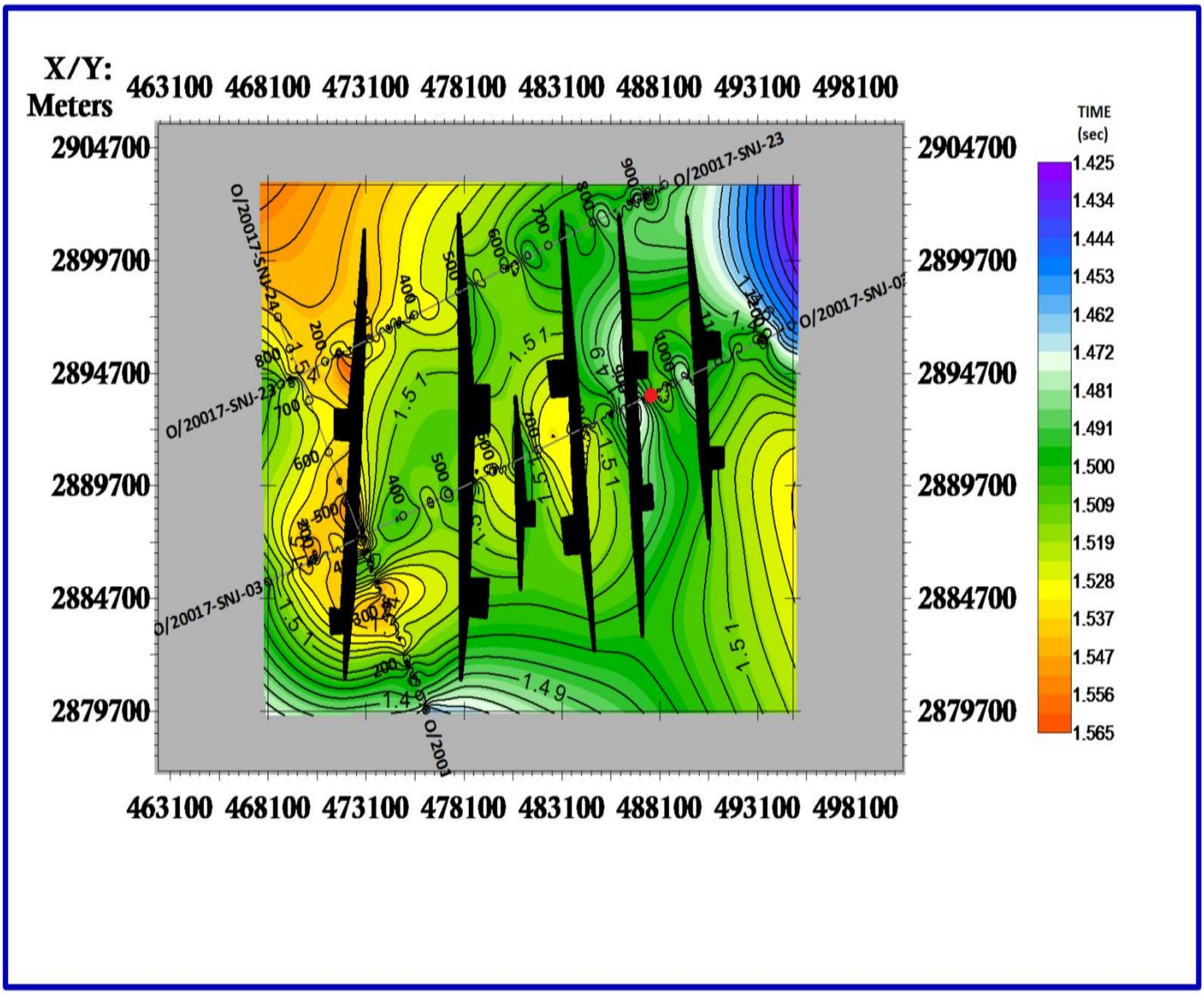


Fig: 3.6a Time Contour Map of Lower Goru

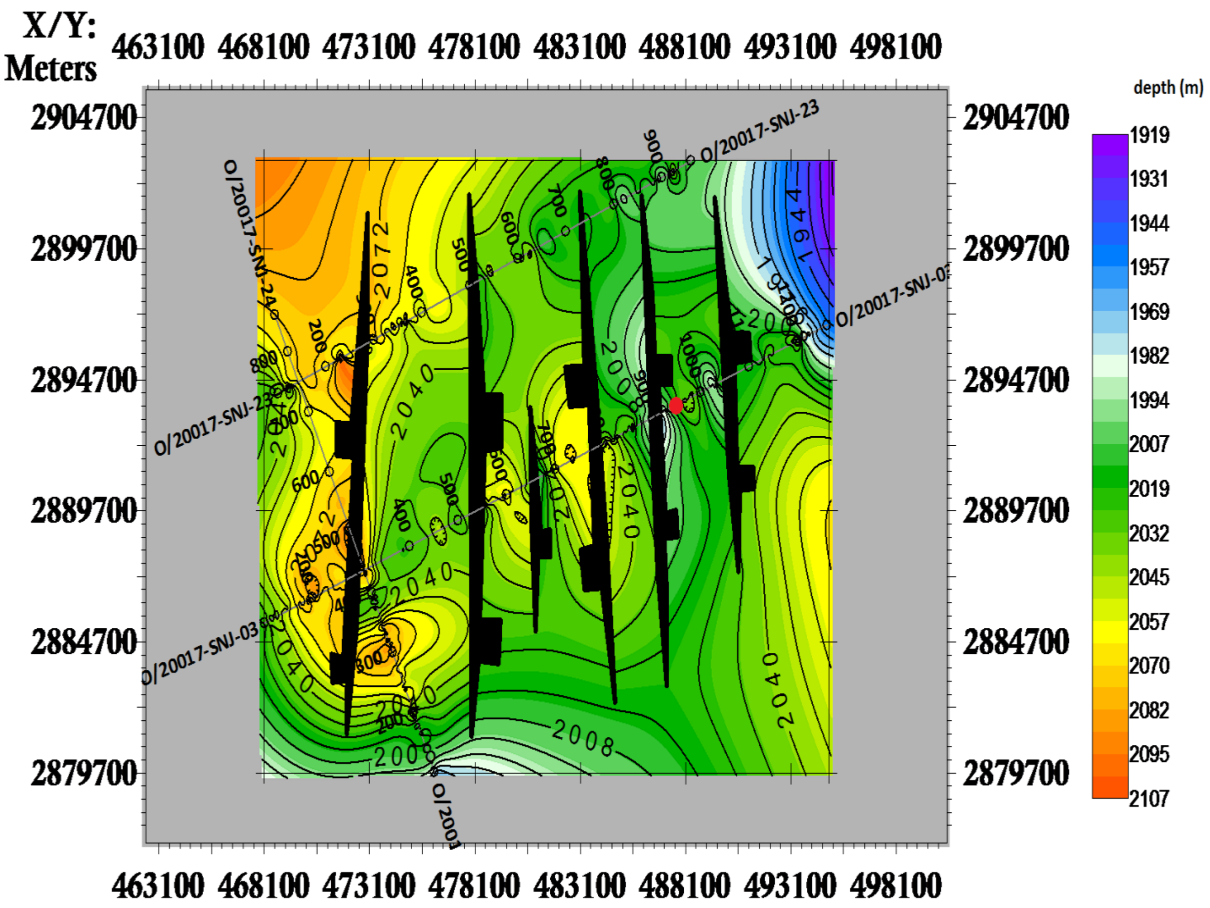


Fig 3.6b Depth Contour Map for the Lower Goru

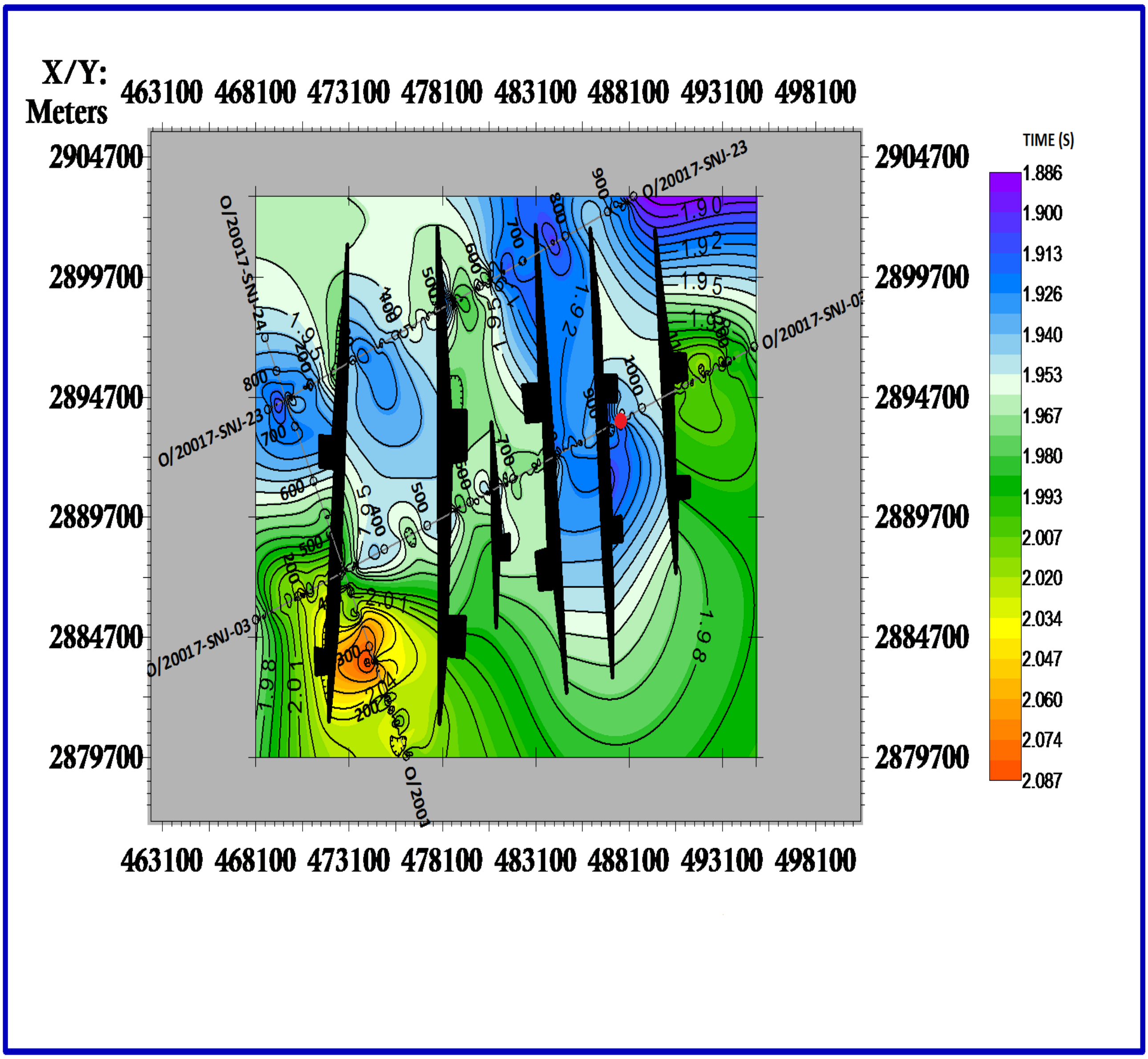


Fig 3.6c Time Contour Map for the Basal Sand.

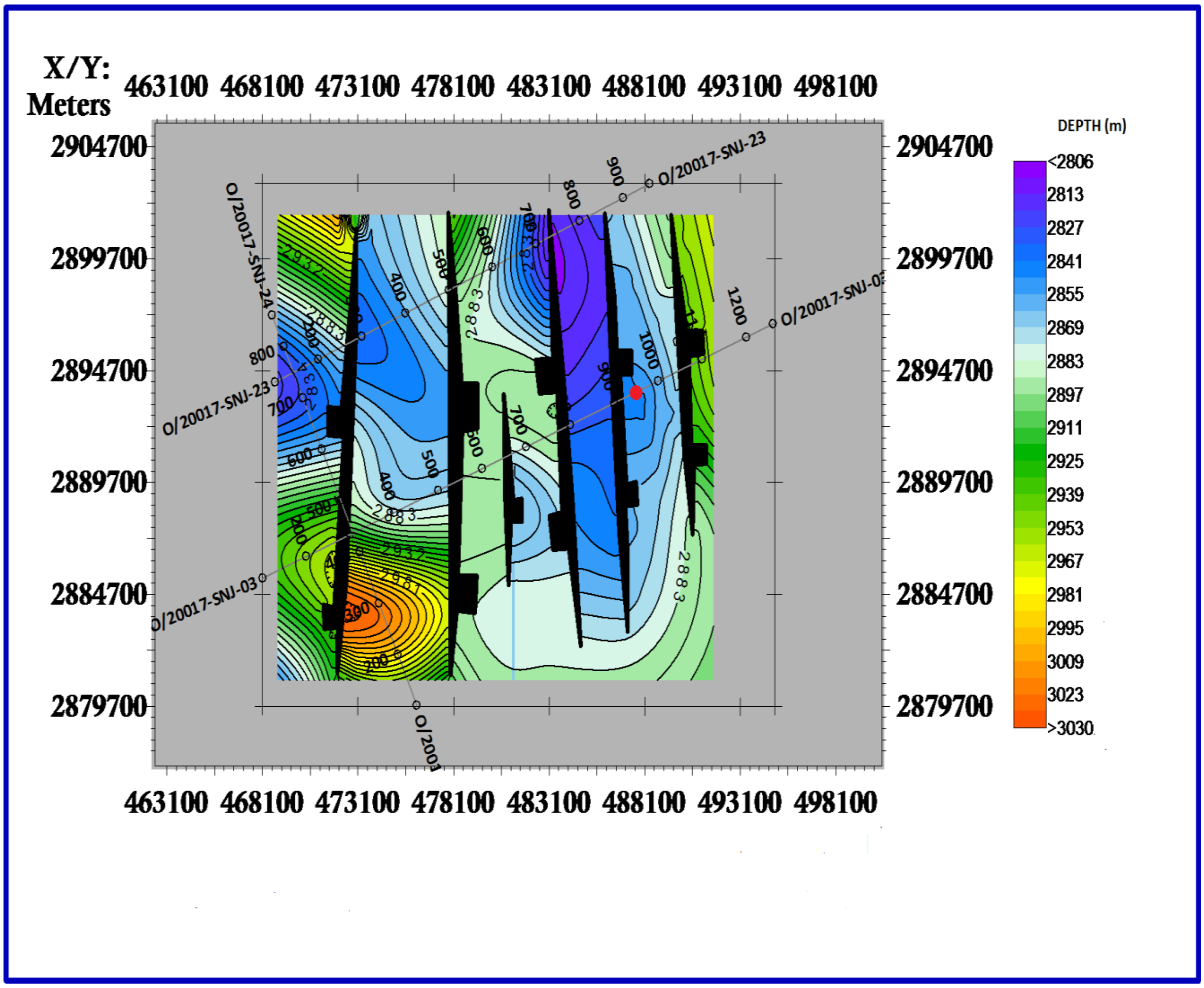


Fig 3.6d Depth Contour Map for the Basal sand

Chapter no. 04

Petrophysics

Petrophysics is the study of the physical and chemical properties that describes the occurrence and behavior of the rocks, soils and fluids. To accurately characterize an oil or gas reservoirs, measurements such as resistivity and density are made, from which effective porosity, saturations and permeability can be quantified.

Types of Logs

- Gamma Ray
- Spontaneous Potential
- Caliper
- Resistivity
- Sonic
- Density
- Neutron

4.1 Well logging techniques

Propose of well logging is to determine various properties of different lithology and also to determine the actual depth, thickness, two way travel time and interval velocities of these lithology. In well logging the cutting of different lithology which come up with mud filtrate give information about type of material, type of fossil in it and also give us the information about depositional history of that material. In well logging different types of logs recorded in the well with the help of a sonde. In early ages different sonde are used to do different type of logging in the well but now a day only one sonde is used which do all type of logging both cased or uncased logging. These logs are then interpreted for the petrophysical study (Table 4.1). The method of well log interpretation is shown in flow chart Figure 4.1.

Table 4.1 Logs used in Petrophysical Analysis

NAME OF LOG	SHORT FORM	UNIT
Neutron Log Porosity	NPHI	p.u
Sonic Log	DT	µsec/ft
Gamma-Ray Log	GR	GAPI
Deep Resistivity Log	LLD	Ohm-m

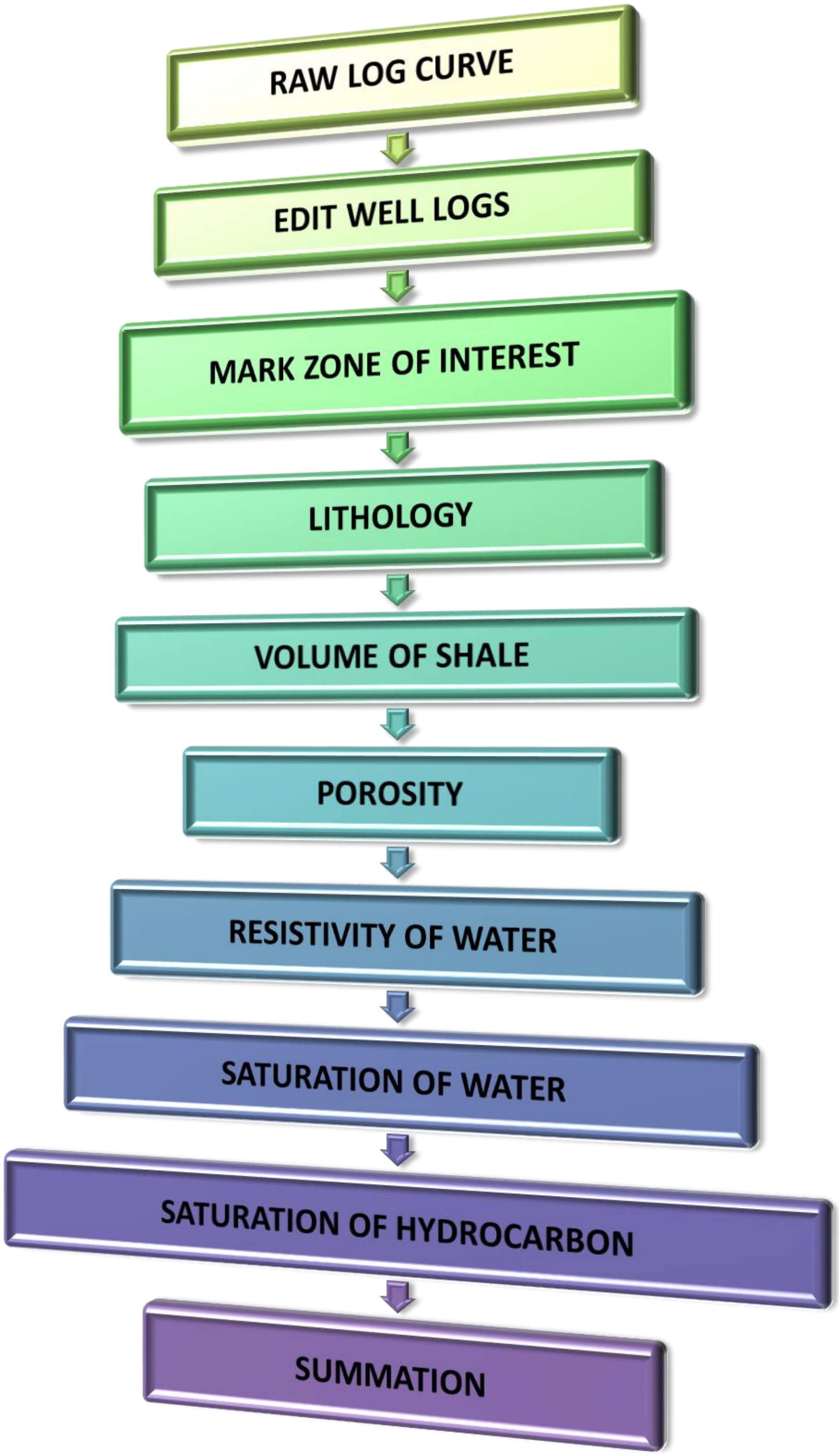


Fig 4.1 Work flow chart of well log interpretation

4.2 Calculation of Petrophysical Parameters

Petrophysics is the study of physical and chemical rock properties and their interactions with fluids. A major application of Petrophysics is in studying reservoirs for the hydrocarbon industry. In this study volume of Shale, Porosity, Water Saturation and Hydrocarbon Saturation has been calculated. The theory of this calculation is as follow:

4.2.1 GR log and volume of shale:

Shale volume is the extant of shale or fine grains present in the reservoir. The increase in shale volume depicts less permeability as the fine grains choke the path of fluid flow in the reservoir. While, low shale volume enhances fluid flow. Volume of shale less than 35% is considered as good for reservoir, so the cutoff of 35% for shale volume is applied to evaluate reservoir. Low value of GR show sand and high value show shale.

Shale volume in our zone of interest marked on the petro physical log index is 31% at the depth (2118-2142) meters.

Because shale is more radioactive than carbonate or sand, gamma ray logs can be used to calculate volume of shale in porous reservoirs. The volume of shale can then be applied for analysis of shaly sands. Calculation of the gamma ray index is the first step to determine the shale volume from a gamma ray log (Schlumberger, 1974).

$$IGR = [GR\ log - GRmin] / [GRmax - GRmin]$$

Where:

IGR = gamma ray index

GR_{log}= gamma ray reading of formation

GR_{min} = minimum gamma ray (carbonate or clean sand)

GR_{max}= maximum gamma ray (shale)

4.2.2 Porosity from logs

Sonic Porosity (φs)

We easily calculate porosity with the help of sonic log this porosity is almost near or equal to actual porosity. Sonic porosity has been calculated with help of the following the formula (Schlumberger,1974).

$$\Phi_S = \Delta T - \Delta t_{mat} / \Delta T_f - \Delta t_{mat}$$

Where

Φ_S=Sonic porosity µs/ft

ΔT =Log response

Δt_{mat} = transit time in matrix

ΔT_{fluid}= transit time in fluids

4.2.3 Water Saturation (S_w) Determination

Water saturation has been calculated with help of the following formula (Archie, 1952)

$$Sw = \sqrt{(a/\Phi^m) \times (Rw/Rt)}$$

Where

S_w= water saturation

R_w=water resistivity (formation)

Φ^m= effective porosity

m =2(cementation factor)

a =1(constant)

R_t=log response (LLd)

R_w has been calculated with help of the following formula:

$R_w = \Phi^2 \times R_t$

where

Φ=porosity in clean zone

R_t=Observed LLd curve in clean zone

Saturation of Hydrocarbon

It is denoted as S_{hc}. Saturation of hydrocarbon is calculated by given formula below;

$\mathbf{S_{hc}} = 1 - S_w$

Where

$S_{w} =$ Saturation or water

4.2.4 Results of Well CHAK 66-01

The well log of the CHAK 66-01 well has been interpreted by using the KINGDOM software (Fig 4.1). Lower goru is our reservoir which has A, B and C type of sands. Reservoir has Various Zones in the well which have been observed on the basis of logs interpretation. Due to the fact that log data only recorded in depth starting from 2000m to 3000 m but we croped the zone of interest only from 2118m to 2142m. This has done due to fact that there is no major anomaly or difference identified in other logs and behavior of logs is another reason which restrict us from marking other zones. The results shows that also there are clean sand in Zone of interest because of low shale value and high matrix value indicated but water saturation increases in this zone and hydrocarbon is less in this zone (Fig 4.1), but it has good effective porosity with few amount of hydrocarbons are also present which may be recovered. From all this we can conclude that CHAK 66-01 may be a hydrocarbon producing well. Zone depth ranges from (2118-2142) Meters Lower Goru reservoir. (Table 4.2)

Table 4.2	**Calculation of Parameters of well CHAK 66-01**	
Serial No	**Parameters**	**Percentage %**
1	Average Shale volume(VSH)	31
2	Average Porosity from Density log(RHOB)	16
3	Average Porosity in(PHIT)	17
4	Average Effective Porosity(PHIE)	11.5
5	Average Water saturation(SWo)	43
6	Average Hydrocarbon(Sh)	57

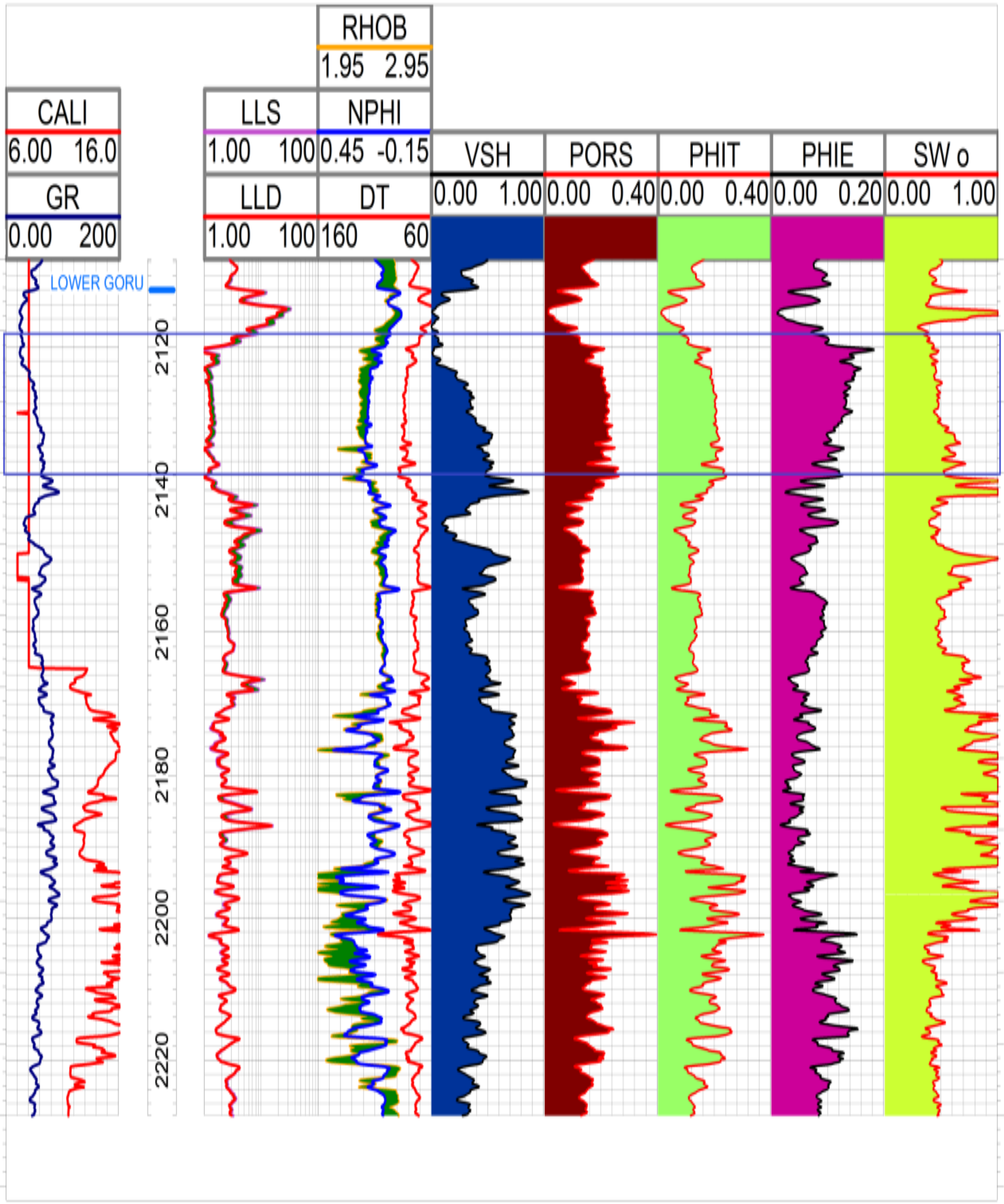


Fig 4.1 Pertophysical behavior of potential hydrocarbon zone of Lower Goru in Chak 66-01

Chapter no 5

Rock Physics

Rock Physics describes a reservoir rock by physical properties such as porosity, rigidity, compressibility, properties that will affect how seismic waves physically travel through the rocks. The Rock Physicist seeks to establish relations between these material properties and the observed seismic response, and to develop a predictive theory so that these properties may be detected seismically.

Rock Physics / Petrophysics: What's the difference?

Rock Physics	**Petrophysics**
a) Rock physics uses sonic logs, Density logs and also dipole logs if available.	a) Petrophysics uses all kind of logs, core data and production data and integrates all pertinent information.
b) Rock physics aim to establish P-wave velocity (Vp) , S-wave velocity (Vs) and their relationship to elastic moduli κ (bulk modulus) and μ (rigidity modulus), porosity, pore fluid, temperature, pressure for given lithologies and fluid types.	b) Petrophysics is generally less concerned with seismic, and more concerned with well bore.

Following rock parameters and engineering properties are calculated using well Data:-

- Density
- Bulk modulus
- Shear modulus
- Young's modulus
- Porosity
- Volume of shale

5.1 DENSITY

Density is a major property of the rock which describes the amount of solid part of the rock body per unit volume. Simply mass per unit volume is called density. Higher denser rocks make the seismic velocity to drop down.
Density is used in various reflectivity and moduli calculation. In seismic methods density and velocity are most important parameters. The geologist determine the rock type and compaction, age, digenesis and burial history while the engineer the porosity, saturation, temperature and pressure gradient. The density of hydrocarbon is much low, so the zone of low density may indicate hydrocarbon or other less dense material.

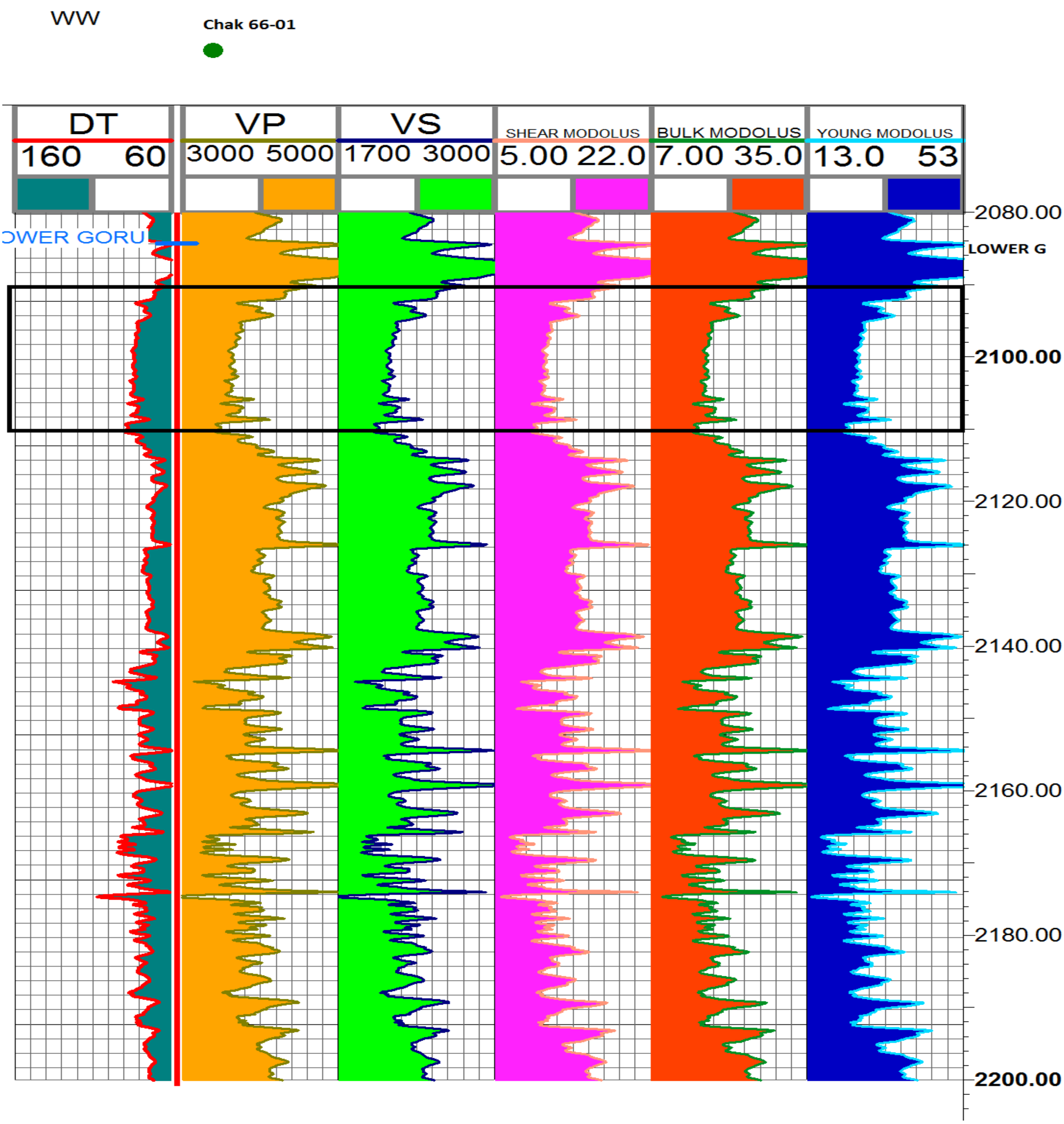


Fig 5.1 Velocity and elastic modulus relationship with depth

5.2 BULK MODULUS

The bulk modulus (K) of a substance measures the substance's resistance to uniform compression. It is the ratio of volume stress to volume strain. It is defined as the pressure increase needed to affect a given relative decrease in volume. It describes the material's response to uniform pressure.

For a fluid, only the bulk modulus is meaningful.

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 from depth 2118m to 2142m of well chak 66-01.
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.

5.3 Shear modulus

Shear modulus is defined as the ratio of the shear stress to the shear strain. This mostly concern with the deformation of a solid as it experiences 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. (Fig 5.1) shows decrease in shear stress in the reservoir zone marked which confirms that is our hydrocarbon bearing zone which is from 2118m to 2142m in well chak 66-01.

5.4 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 uniaxial stress over the uniaxial strain in the range of stress in which hook's law holds. The young modulus behavior, from depth 2118m to 2142m of well chak 66-01, indicates that the stiffness of the subsurface strata reflects the fluctuation (Fig. 5.1).

Chapter no.6

Conclusion

Research work was carried out using data of three seismic lines and single well. It is not sufficient data to accurately approve a zone as potential zone for hydrocarbon. The main purpose of this research was to find the structural trap and zones of the reservoir of Sinjhoro field i.e. Lower Goru that has intercalations of shale and siltstone by using seismic and well log data and to propose a new well location on the basis of seismic data interpretation.
Geologically the study area is located in extensional regime. The rifting occurred during geological past is responsible for extensional features. Three geological formations have been marked on seismic section, namely Ranikot, Lower Goru and basal sands. Now dew to the extensional regime horst and graben structures are present in the area. The seismic line is showing series of horst and graben structures. The fault cuts are dipping in east and west direction while they are trending in North and south direction. Normal faults have very less throw of approx 5ms. Most of the faulting can be observed at cretaceous level, while the faults die out as we move towards younger formation.

Firstly, these faults are deep-rooted into the Sember source shale, and therefore they can act as conduits to primary hydrocarbon migration.

Secondly, these faults can act as a barrier and thus provide a lateral seal to trap the hydrocarbons within the structure. The southern limits of these faults are not obvious due to a lack of seismic data in the study region.

It is concluded from surface Geology of the area that horst and graben structure prevail the whole area. Extension of the structure is in the North-South direction. And clues of horst and graben structure are clear from the normal faulting in the interpreted seismic sections and time, depth sections of Lower Goru Formation and Basal Sands. These structures are largely oriented in a NNW to SSE direction and are a part of the regional rift system of the Lower Indus Basin. Following conclusions has been deduced:

1. Three horizons on all the sections have been marked along with the major and minor faults.
2. Six major faults prevail in the area. These all faults are normal faults. .
3. The generalized structural trend of the faults and intervening blocks is NW - SE direction. Throw of these faults is prominent.
4. Time and depth contour maps were prepared to analyze the overall behavior of the structure. There are small anticlinal structures bounded shown by these maps bounded by two normal faults which is clue towards either Horst or Graben or negative flower structures to some extent.
5. Petrophysical portion of thesis includes the interpretation of well CHAK66-01. From all the results it is concluded that water saturation is decreasing as we move towards the reservoir zone.
6. Volume of shale also decreases in the reservoir zone as compared to other lithologies. From petrophysical analysis it has also seen that some lithologies (from Gamma ray log and other characteristics interpreted as sands) have good saturation of hydrocarbons and have good

porosity. From this result it can be concluded that these lithologies are may be the part of oil reservoirs.

7. Rock physics confirms the results obtained from petrophysics on the basis of Elastic modulae behavior as in the marked 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 and in young's modulus the stiffness of the subsurface strata reflects the fluctuation while decrease in shear stress indicates the Zone of intrest is present.

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