PETROPHYSICAL ANALYSIS OF WELL SHER-01, LOWER INDUS BASIN, PAKISTAN.

By

Mati ur Rehman
Muhammad Sulaman Qazi
Zafaran Zahid

Department of Earth and Environmental Sciences
Bahria University, Islamabad

2016

PETROPHYSICAL ANALYSIS OF WELL SHER-01, LOWER INDUS BASIN, PAKISTAN.

A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of BS in Geology

Mati ur Rehman
Muhammad Sulaman Qazi
Zafaran Zahid

Department of Earth and Environmental Sciences
Bahria University, Islamabad

2016

Department of Earth & Environmental Sciences
Islamabad Campus, Islamabad

Dated: 13/ 01 / 2016

Certificate

This thesis is submitted by **Mr. Matti ur Rehman, Mr. Sulaman Qazi and Mr. Zafran Zahid** and is accepted in the present form by Department of Earth & Environmental Sciences, Bahria University, Islamabad as the partial fulfillment of the requirement for the degree of **Bachelor of Sciences in Geophysics,** 4 years program (Session 2012 – 2016).

Committee Member	Name	Signature
Supervisor	Ms. Urooj Shakir	
External Examiner	Mr. Babar Hussain	
Head of Department (E&ES)	Prof. Dr. Muhammad Zafar	

ABSTRACT

The main purpose of this study is to evaluate the hydrocarbon potential using well log data of Sher-01, Thatta, Southern Indus basin, Pakistan. The above mentioned well was first exploratory but now it is abandoned. Porosity and resistivity logs do not show any direct identification for the presence of hydrocarbons. We have marked two zones in the Lower Guru formation, zone 1 is from 5570 feet to 5700 feet in depth and zone 2 is from 6300 feet to 6500 feet in depth. Various petrophysical properties like porosity, resistivity, volume of shale and fluid saturation have been calculated through different logs. Although both the zones have clean lithologies with very little shaly content and good effective porosity but the graphs of effective porosity and the hydrocarbon potential of zone 2 are showing very high value as compared to zone 1, by which it has been said that zone 2 is more efficient in hydrocarbon as compared to zone 1. By studying all these aspects we came to know that Sher-01 well is oil prone well.

ACKNOWLEDGMENTS

We are quite obliged to Dr Muhammad Zafar, Head of Department, Earth and Environmental Sciences, Bahria University Islamabad, for his respectable guidance throughout the whole study.

Special credit goes to our supervisor, Miss Urooj Muyassar for her supervision and consistent help. Her priceless and enlightening efforts helped all around this venture, to the achievement of this project.

We would also like to thank our parents and siblings because without their prayers, this goal would have been a dream to achieve. We would also like to thank all our friends and colleagues for always being there for help.

CONTENTS

CHAPTER 4

PETROPHYSICAL EVALUATION OF WELL SHER-01

FIGURES

TABLES

CHAPTER 1
INTRODUCTION

1. 1 Location of the study area

Research area for the current study is Sher block, located in Sindh Province. The Sher block lies between the latitudes 24°38'39.2"N; longitudes 68°04'07.4"E. This region present in the southern part of Pakistan and is physiographically known as the "Lower Indus Basin".

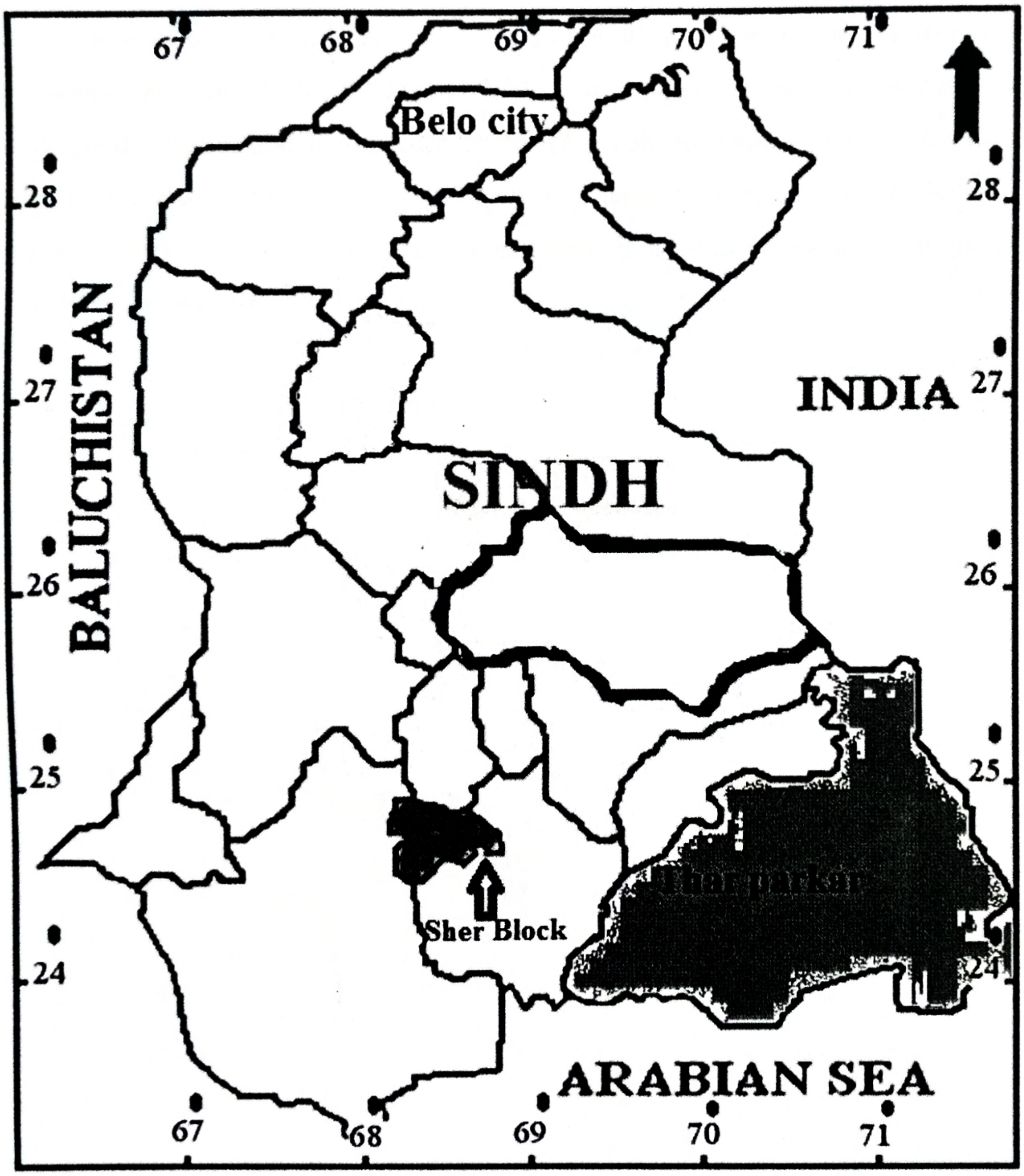

Figure 1.1. Location map of sher block with in Sindh.

1.2 Objectives

Main objectives of the research are to:

(1) Calculate hydrocarbon potential of well Sher-01.

(2) To evaluate reservoir properties.

(3) Indicate lithology and water saturation of productive zones within reservoir formation (Lower Goru).

(4) To evaluate the petrophysical parameters of reservoir zone of sher-01 well.

1.3 Location of selected well for study

Sher-01 is located in sher block at southern indus basin, the well lies between the coordinates 24°38'39.2"N 68°04'07.4"E. The location of the well is geologically very good because the lower guru is the reservoir formation present in this well. Geographically Sher-01 well is present in the Thatta district, having the Belo City in the north, Sujawal City in the east, Nikoti Dhand present in the south and thatta city is present in the west of sher-01 well.

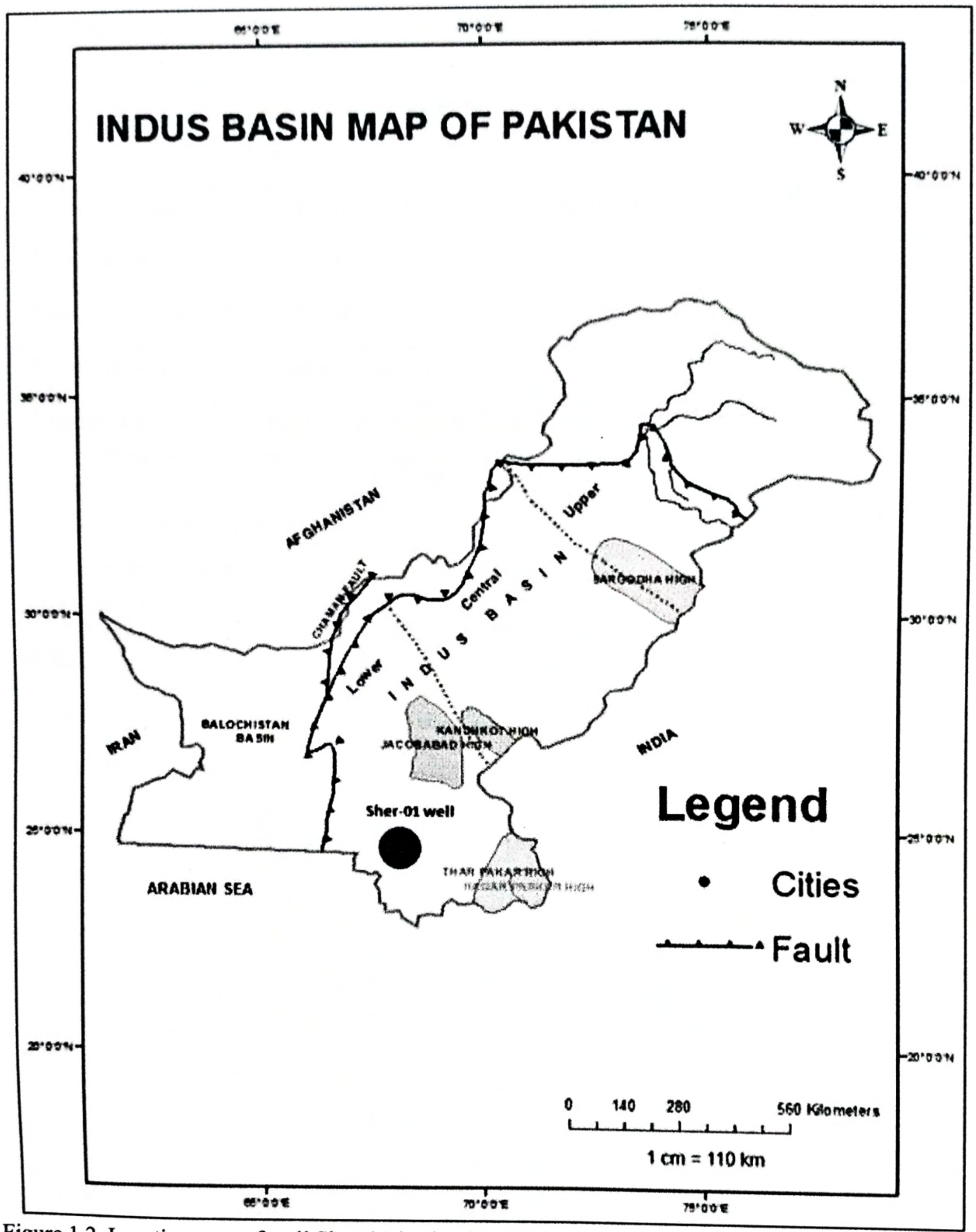

Figure 1.2. Location map of well Sher-01 in sher block (Generated from GIS)

1.4 Well Data

Sher-01 well was drilled by company Philips Petroleum Exploration Ltd in wildcat field in thatta District of Sindh Province. Firstly this well was exploratory then it became abandoned. The well reached T.D of 3677.5 m.

Table 1.2. Selected well for study.

Well Name	Sher-01
Type	Exploratory Abandoned well
Field	Wildcat
Coordinates	Latitude 24.644210 N Longitude 68.068730 E
Total Depth	3677.5
Formation at TD	Sembar
Present Status	Abandoned
Company	Philips Petroleum Exploration Ltd

CHAPTER 2

GEOLOGY AND STRATIGRAPHY OF THE AREA

2.1 Geology of the area

2.1.1 Tectonics

The general tectonics of the region dates back to early Jurassic time when the Indian Plate began to break away from Africa. The timing of this rifting and subsequent divergence is associated with the east African Rift Zones. During early Jurassic to mid Cretaceous time, the Indian Plate began to move NE relative to Africa, resulting in a marine transgression on the western margin of the Indian Plate. The Chiltan is the first known marine unit to be deposited in the area. This break up resulted in ESE –WNW strike slip fault and formed a Pull-Apart Basin. Middle to late Cretaceous time is the important stage in the development of the western continental margin of the Indian Plate. The extensional faulting resulting from the rotation and divergence of the Indian Plate from Africa affected the formation and development of narrow, linear, horst and graben features. This extensional tectonic regime resulted in the development of a passive continental margin on the western part of the Indian Plate (Kadri, 1995).

The province of Sindh is situated in the lower Indus Basin and includes the Sukkur Rift Zone, which comprises of Kandhkot-Mari Horst, Panno Aqil Graben and Jacobabad-Khairpur Horst, Sindh Monocline, a part of Kirthar Depression, Karachi Depression, Mazarani Fold Zone and a part of Kirthar Fold Zone. The Basin mostly fulfils the requirements of generation and accumulation of hydrocarbons. Petroleum prospects of Sindh are described according to its main tectonic zones i.e. the Sukkur Rift Zone, Mazarani Fold Zone, Karachi Depression, and Sindh Monocline (Kadri, 1995).

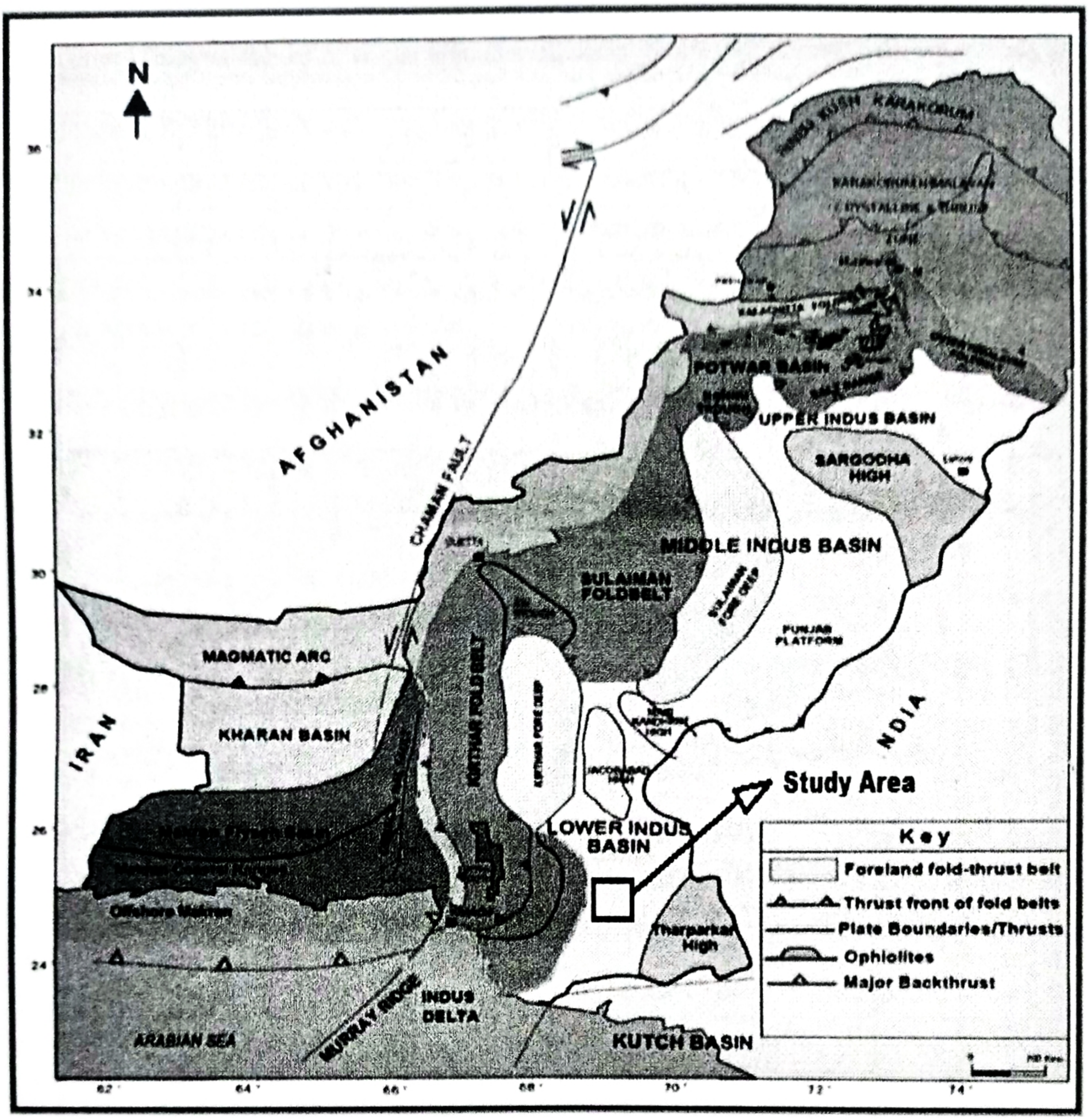

Figure 2.1. Techtonic map of Pakistan showing the study area (Raza et al., 1990).

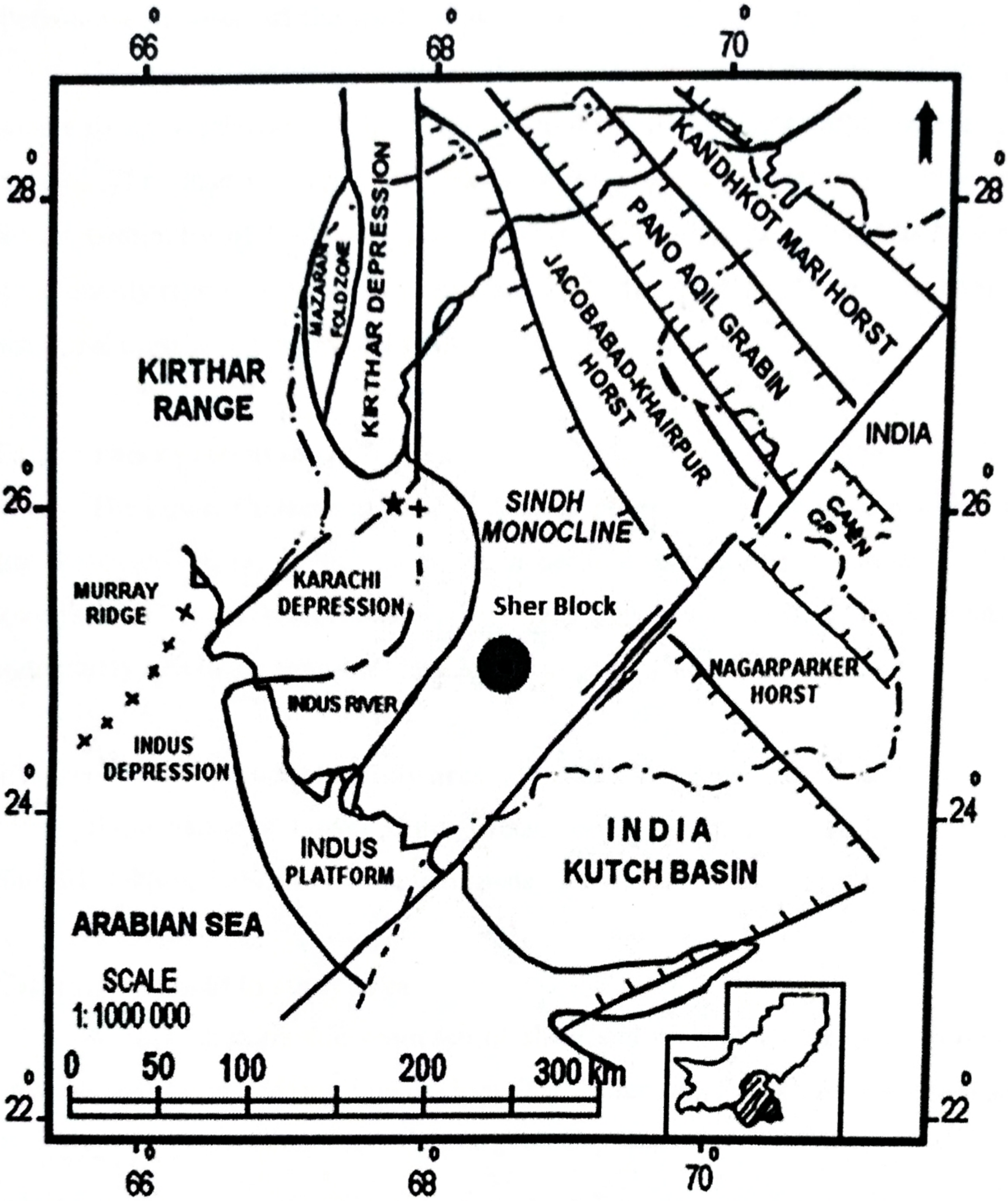

Figure 2.2. Tectonic map of Southern Indus Basin showing Sher block (Raza et al., 1990).

Petroleum prospect of the study area

The Early Cretaceous shale of the Sembar Formation are the well-recognized source rocks which charged the hydrocarbon pools on the Thar Slope and the Karachi Trough. The close vicinity of the Block to the prolific petroleum province and the lateral continuity of Early Cretaceous Lower Goru clastics ensure the presence of good quality reservoir horizons in this basin. The prospective play types comprise the structural traps with the possibility of stratigraphic traps.

Source rocks present in study area

The Lower Cretaceous Shale of Sembar Formation is proven source for oil and gas discovered in the Lower Indus Basin because of its organic richness, oil-prone kerogen type and thermal maturity. The lower part of the Lower Goru Formation is moderately rich in organic shale having fair to good genetic potential.

Reservoir rocks present in study area

Basal Sands of Lower Goru (Cretaceous) Formation are proven producer in Sher-01, Jakhro, Bobi and Kadanwari fileds.

Cap rocks present in study area

A thick stratigraphic sequence of shale and marl of Upper Goru Formation provides seal for underlying Lower Goru Sand Reservoir. The intra-formational shale of Lower Goru Formation also serves as good Cap Rock.

2.2 Stratigraphy

The sedimentary section of Lower Indus Basin in the South Eastern Pakistan consists mainly of Permian through Mesozoic sediments overlying a strong angular unconformity of presumably Late Paleozoic age.

This part represents pro-gradational Mesozoic sequences on a westward inclined gentle slope. In the Thar Slope area, all Mesozoic sediments are regionally plunging to the west and are truncated un-conformably by the volcanic Basalt of Khadro Formation and sediments of the Paleocene age. Permian, Triassic and Lower Jurassic sediments in the Sindh Area consist of inter-bedded sandstone, siltstone and shale of continental to shallow marine origin. Platform carbonates (Chiltan Formation) conformably overly the Jurassic clastics. Cretaceous sediments consist of a series of inter-bedded shale, siltstone, sandstone, marl, limestone and chalk. These are divided into four separate formations termed as Sembar, Lower Goru, Upper Goru and Parh. The Sembar Formation directly overlies the Jurassic carbonates and consists largely of shale with interbedded sands. The Lower Goru consists of sand packages separated by shale and at places marl units; the Upper Goru consists predominantly of marl and shale while Parh comprises limestone and chalk. Tertiary sediments consist of interbedded sands and shale with massive Eocene carbonates (Kazmi and Jan, 1997).

Table 2.1. Generalized stratigraphic sequence of Southern Indus Basin (Raza et al., 1990).

ERA	PERIOD	EPOCH		FORMATION		LITHOLOGY	DESCRIPTION
CENOZOIC	QUATERNARY	HOLOCENE		ALLUVIUM			Sandstone, clay, shale, and conglomerate
CENOZOIC	TERTIARY	PLIOCENE-PLEISTOCENE		SIWALIK			Sandstone, shale, and conglomerate
CENOZOIC	TERTIARY	MIOCENE		GAJ			Shale, sandstone, and limestone
CENOZOIC	TERTIARY	OLIGOCENE		NARI			Shale, limestone, and sandstone
CENOZOIC	TERTIARY	EOCENE	LATE				
CENOZOIC	TERTIARY	EOCENE	MIDDLE	KIRTHAR			Limestone and shale
CENOZOIC	TERTIARY	EOCENE	EARLY	LAKI/GHAZIJ			Laki: Limestone and shale Ghazij: Shale and sandstone
CENOZOIC	TERTIARY	PALEOCENE		BARA-LAKHRA			Limestone shale and sandstone
CENOZOIC	TERTIARY	PALEOCENE		KHADRO			Basalt and shale
MESOZOIC	CRETACEOUS	LATE		PAB			Sandstone and shale
MESOZOIC	CRETACEOUS	LATE		MUGHAL KOT			Limestone shale and minor sand
MESOZOIC	CRETACEOUS	LATE		PARH			Limestone
MESOZOIC	CRETACEOUS	MIDDLE		GORU	UPPER		**MAIN SEAL** Shale and marl
MESOZOIC	CRETACEOUS	MIDDLE		GORU	LOWER		Shale and sandstone
MESOZOIC	CRETACEOUS	EARLY		SEMBAR			**MAIN SOURCE** Shale and sandstone
MESOZOIC	JURASSIC	LATE					
MESOZOIC	JURASSIC	MIDDLE		MAZAR DRIK / CHILTAN			Chiltan: Limestone Drik: Limestone and shale
MESOZOIC	JURASSIC	EARLY		SHIRINAB			Limestone, shale, and sandstone
MESOZOIC	TRIASSIC	EARLY-LATE		WULGAI			Shale and sandstone

LEGEND: ● Oil; ✡ Gas; Sandstone; Clay; Limestone; Shale; Conglomerate; Basalt

The Lower Goru play discoveries are located within the platform part of the Middle and Lower Indus Basin, from near the Mari High all the way down to the Badin area. The stratigraphic interval of interest is comprised of the followings.

(1) Thick basinal (bathyal/ pelagic) shale unit and the overlying interbedded turbidite lobes and progradational wedges of sand and shale conventionally referred to as the Sembar Formation, and

(2) The overlying deltaic and shelfal paralics referred to as the Lower Goru Member.

The lithology and other salient stratigraphic features of different formations penetrated at Chak63-01, after correcting tops and thickness of formations through wireline logs, are described below (Kadri, 1995):

2.2.1 Alluvium

Age	:	Post Paleocene .
Interval	:	Surface – 68.5 m.
Thickness	:	68.5 m.
Contact	:	The lower contact with ranikot formation is Unconformable.
Lithology	:	Sandstone with subordinate clay / claystone and rare conglomerate.

2.2.2 Ranikot Formation

Age	:	Paleocene.
Interval	:	68.6 – 655 m.
Thickness	:	586.6 m.
Contact	:	The lower contact with deccan trap is unconformable.
Environment	:	Continental to shallow marine, mixed facies.
Lithology	:	Sandstone interbedded with shale and thin beds of limestone and clay/claystone.

The formation can be subdivided into the following sections on the basis of relative proportions of different lithlogies.

The upper section from 68 m to 255 m comprises predominantly shale with thin interbeds of sandstone. The middle section, which extends from 256 to 407 m, consists mainly of limestone with thin interbeds of shale and sandstone. The lower middle section from 408 to 470 m comprises sandstone with minor beds of shale. The basal part from 470 to 654 m, comprises sandstone with interbedded clay/claystone and minor beds of shale.

2.2.3 Deccan Trap

Age	:	Paleocene.
Interval	:	656– 791 m.
Thickness	:	136 m.
Contact	:	The lower contact with upper guru is unconformable.
Lithology	:	Sandstone with interbedded clay/ claystone and thin beds of basalt.

2.2.4 Upper Goru Formation

Age	:	Cretaceous.
Interval	:	791 – 1641 m.
Thickness	:	850 m.
Contact	:	The contact with lower Goru Formation is conformable.
Environment	:	Marine transitional, occasionally sub littoral.
Lithology	:	Upper Goru Formation consists of marl with minor shale and limestone.

2.2.5 Lower Goru Formation

Age	:	Early cretaceous.
Interval	:	1641– 3505 m
Thickness	:	1865 m
Contact	:	The contact with Sembar formation was not penetrated.
Environment	:	Shallow marine, transitional, sub littoral to littoral.

Lithology : Lower Goru formation consists of dominantly shale with subordinate sandstone, marl, siltstone and rare beds of limestone.

The sand in the Goru is the most important entity in the Lower Indus Basin from petroleum reservoir point of view. The shales of Goru are most widely distributed of post Jurassic formations. It extends from Waziristan to as far south as Cutch in India.

The thickest Goru sedimentation occurs within the Karachi Embayment. Regionally the thickness increases towards the center of the Karachi embayment. One of the wells located west of Badin Platform partially penetrated about 2360 m of Goru section. In the Kirthar fold belt, the Goru formation thins gradually to the north while the large part of the Sulaiman Fold Belt also seems to have relatively thin Goru sediments. At least the part of the Kirthar Fold Belt north of 28° N Latitude and the Sulaiman Fold Belt appear to have been relatively positive areas within Goru time and it appears probable that at this time there was already a restricted high area which divided the Balochistan and the Indus Basins (Blanford, 1878). Between the Duki High and the Axial Belt, east of Quetta, a subsidiary low existed in which thick deposits of of Goru were laid down. These deposits differ from typical Goru, especially in color. The formation was probably not deposited around the northern part of Khairpur-Jacobabad High; the relatively thin deposits towards south are due to Late Cretaceous or Early Paleocene erosion. In the West, along the margin of the Axial belt, the formation is absent mainly because of erosion. In the east, it is not present in cutch and Jaisalmer area mainly due to non-deposition (Kadri, 1995).

The Goru Formation is dominantly shale or mudstone, frequently calcareous. It is thin bedded where bedding is discernible and ranges in color from black to grey and locally maroon. Sand is rare in the upper part with increasing tendency towards base where it has developed into a producing reservoir (Lower Sindh). Only locally does limestone form a significant percentage of the formation. On the basis of its lithological content it has been divided into Lower Goru and Upper Goru. The name Lower Goru has been applied to the lower sandy member, whereas within the same area the upper shale unit is termed as Upper Goru (Kadri, 1995).

Of considerable significance is the appearance of sandstone in the Lower Goru in the Sulaiman Lobe to Badin Platform in the southeast. The wells drilled in the 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. The zone of facies lateral change, from sand to shale, has been an area of major interest to oil companies as it bears all the hydrocarbon potential in Badin area and further northwards at least up to Kandhkot. Within the Kirthar Fold Belt, many sections show an increase in the lime content and red coloration, especially near the top of the section. The causes of these facts are unknown but the former, atleast may be resulted simply to distance from source of clastic sediments.

The petroleum potential of Lower Goru Sand is very good as it contains all the hydrocarbons in Sindh Monocline.

During drilling of Sher-01, a normal succession comprising Alluvium, Ranikot, deccan trap, upper guru, lower guru Formations were penetrated. The top of Lower Goru Sandstone was encountered at 1641 m.

On the basis of wireline logs, the Lower Goru Formation was studied and further split into following standard units.

Upper Sand, Shale and Marl Sequence

Interval	:	1942 – 2827 m.
Thickness	:	885 m.
Lithology	:	Shale with sandstone, siltstone, marl and rare limestone.

Basal Sands (Lower Goru Formation)

Interval	:	2827 – 2860 m.
Thickness	:	33 m.
Lithology	:	Sandstone with subordinate shale.

Talhar Shale (Lower Goru Formation)

Interval	:	2860 – 2936 m.
Thickness	:	76 m.
Lithology	:	Shale with minor traces of siltstone and sandstone.

Massive Sands (Lower Goru Formation)

Interval	:	2936 – 3006.5 m.
Thickness	:	70.5 m.
Lithology	:	Sandstone with subordinate shale.

Table 2.2. Generalized stratigraphic sequence of Southern Indus Basin (reproduced from Raza et al., 1990).

AGE	FORMATION	DESCRIPTION	PLAY ELEMENTS
RECENT	Alluvium	Sandstone, Clay, Shale and Conglomerate	
PLIO-PLIESTOCENE	Siwalik	Sandstone, Shale and Conglomerate	
MIOCENE	Gaj	Sandstone, Shale and Limestone	
OLIGOCENE	Nari	Sandstone, Shale and Limestone	
EOCENE	Kirthar	Limestone and Shale	
	Ghazij	Shale and Sandstone	
	Laki	Limestone and Shale	
PALEOCENE	Bara –Lakhra	Limestone, Shale and Sandstone	
	Khadro	Basalt and Shale	
CRETACEOUS	Pab	Sandstone and Shale	Reservoir
	Mughal Kot	Limestone, Shale and Minor Sand	Reservoir
	Parh	Limestone	
	Upper Goru	Shale	
	Lower Goru	Shale and Sandstone	Reservoir
	Sembar	Shale and Sandstone	Source
JURASSIC	Chiltan	Limestone	

Table 2.3. Borehole Stratigraphy of Sher-01

AGE	FORMATION	FORMATION TOPS (m)	LITHOLOGY
POST PALEOCENE	ALLUVIUM	Surface	Sandstone with subordinate clay/claystone and rare conglomerate.
PALEOCENE	RANIKOT	68.6	Sandstone interbeded with shale and thin beds of Limestone and clay/claystone.
CRETACEOUS	DECCAN TRAP	655.3	Limestone and chalk.
CRETACEOUS	UPPER GORU	791.5	Marl with minor shale and limestone.
CRETACEOUS	LOWER GORU	1641.3	Shale with subordinate sandstone, marl, siltstone and rare limestone.
EARLY CRATECEOUS	SEMBER	3505	Mainly shale with subordinate amounts of siltstone.
TOTAL DEPTH		3505	

CHAPTER 3
WIRELINE LOGGING

Well logging, also known as borehole logging is the practice of making a detailed record (a well log) of the geologic formations penetrated by a borehole. The log may be based either on visual inspection of samples brought to the surface (geological logs) or on physical measurements made by instruments lowered into the borehole (geo physical logs). Some types of geophysical well logs can be done during any phase of a well's history: drilling, completing, producing, or abandoning. Well logging is performed in boreholes drilled for the oil and gas, groundwater, mineral and geothermal exploration, as well as part of environmental and geotechnical studies (Rider, 1986).

3.1 Gama ray log

Gamma ray logging is a method of measuring naturally occurring gamma radiation to characterize the rock or sediment in a borehole or drill hole. It is a wireline logging method used in mining, mineral exploration, water-well drilling, for Formation evaluation in oil and gas well drilling and for other related purposes. Different types of rock emit different amounts and different spectra of natural gamma radiation(Rider,1986).

3.2 Sonic log

Sonic logging is a well logging tool that provides a formation's interval transit time, designated asΔt, which is a measure of a formation's capacity to transmit seismic waves. Geologically, this capacity varies with lithology and rock textures, most notably decreasing with an increasing effective porosity. This means that a sonic log can be used to calculate the porosity of a formation if the seismic velocity of the rock matrix, V_{mat}, and pore fluid, V_l, are known, which is very useful for hydrocarbon exploration (Rider, 1986).

3.3 Spontaneous potential log

The spontaneous potential log, commonly called the self-potential log or SP log, is a passive measurement taken by oil industry well loggers to characterize rock formation properties. The log works by measuring small electric potentials (measured in millivolts) between depths in the borehole and a grounded voltage at the surface. Conductive fluids are necessary in bore hole to create a SP response, so the SP log cannot be used in nonconductive drilling muds (e.g. oil-based mud) or air filled holes (Rider, 1986).

3.4 Resistivity log

Resistivity logging is a method of well logging that works by characterizing the rock or sediment in a borehole by measuring its electrical resistivity. Resistivity is a fundamental material property which represents how strongly a material opposes the flow of electric current. In these logs, resistivity is measured using 4 electrical probes to eliminate the resistance of the contact leads. The log must run in holes containing electrically conductive mud or water. Resistivity logs often are excellent for correlating within shale successions or with clean sandstone with uniform Gamma response(Rider, 1986).

3.5 Induction log

Induction logging is a method used to measure formation resistivity in boreholes containing oil-base muds. It is designed for deep investigation. Induction logging can be focused in order to minimize the influences of the borehole, the surrounding formations, and the invaded zone. One transmitter coil and one receiver coil. A high-frequency alternating current of constant intensity is sent through a transmitter coil. The alternating magnetic field created induces currents in the formation surrounding the borehole. These currents flow in circular ground loops coaxial with the transmitter coil and create, in turn, a magnetic field that induces a voltage in the receiver coil(Rider, 1986).

3.6 Caliper log

The caliper Log is a tool for measuring the diameter and shape of a borehole. It uses a tool which has 2, 4, or more extendable arms. The arms can move in and out as the tool is withdrawn from the borehole, and the movement is converted into an electrical signal. Caliper log is shown in track 1 of the master log together with the bit size for reference. Borehole diameters larger and smaller than the bit size are possible. Many boreholes can attain an oval shape after drilling. This is due to the effect of the pressures in the crust being different in different directions as a result of tectonic forces. In oval holes, the two arm caliper will lock into the long axis of the oval cross section, giving larger values of borehole diameter than expected. In this case tools with more arms are required(Rider, 1986).

3.7 Formation density log

Formation density log measures the bulk density of the formation for determining the total porosity of the formation. It is useful in the detection of gas-bearing formations and in the recognition of evaporates. Radiations are induced to bombard the formation and measures how much radiation returns to a sensor (Rider, 1986).

3.8 Neutron log

Neutron porosity tool provides accurate formation porosity, fluid typing and lithology. Larger tools also feature an acoustic caliper, used to correct the neutron porosity measurement for borehole effects and to provide measurements of borehole size (Rider, 1986).

CHAPTER 4
PETROPHYSICAL EVALUATION OF WELL SHER-01

Well-Logging or Wireline logging is used in oil industry in order to check and record the properties of the sub-surface formations. Wireline logging is carried out by lowering a single logging tool or a set of logging tools by a cable from a winch, which is generally mounted on the logging truck or offshore unit. The logging tools then records the petro-physical properties of the formation. The data is recorded in digital format either on the surface or either it is recorded in the borehole by using a cartridge. Print record or the electronic record known as well log are obtained from data. The well logging operation can be performed during drilling known as logging while drilling or after the drilling of the borehole, reaching the desire depth known as wireline logging.

4.1 Interpretation of Sher-01, Southern Indus Basin

In order to interpret the log we interpret it step wise first we select the zone of interest then pick the values of log from each zone and every log. After picking values then calculate the properties of rock with the help of logs.

4.1.1 Methodology

In the course of evaluating well Sher-01 in the Southern Indus Basin, first marking of zone of interest in the logs, by closely observing the GR, resistivity and porosity log followed by the determination of volume of shale with the aid of GR log and determination of the lithology. Afterwards, with the help of sonic log, porosity was evaluated and then, Rw, saturation of water, saturation of hydrocarbon was determined and finally, net pay thickness were determined by using different techniques.

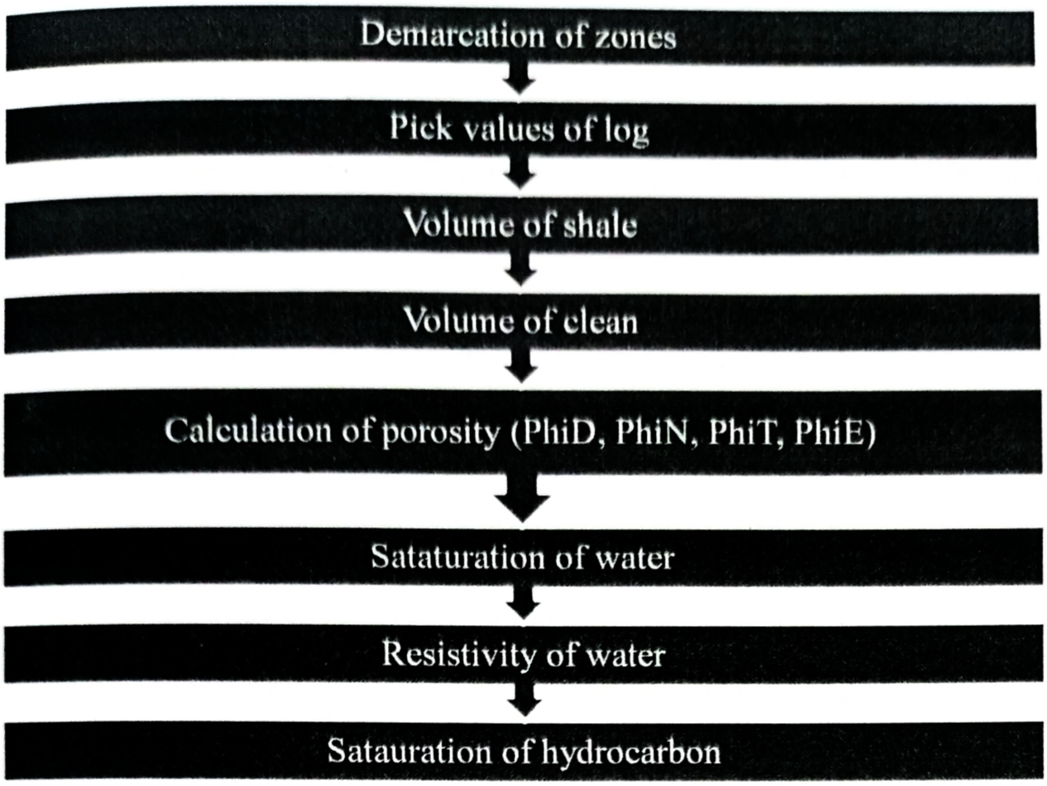

Figure 4.1. Methodology of log interpretation

4.1.2 Demarcation of zone of interest

Petrophysical interpretation starts with marking the zone of interest with respect to different wireline logs curves behavior.

In Sher-01, two zones was marked. The zones have been selected because the gamma ray values were relatively low in these regions as compared to other regions in the log as well as resistivity values. Neutron and density log were available so they have been used to determine the porosity and these values were also supporting other logs that helped marking the zones of interest.

Sand packages and shale beds were present in the Lower Guru Formation. The values of the gamma ray log were relatively low and the values of laterolog deep (LLD) were also relatively low.

Table 4.1. Target Zones of Lower Guru formation in Sher-01 well.

Formation	Starting depth (feet)	Ending depth (feet)	Thickness (feet)
Lower Guru zone 1	5570	5700	130
Lower Guru zone 2	6300	6500	200

4.2 Interpretation of Lower Guru Formation

4.2.1 Calculation of volume of shale

Volume of shale is calculated using Gamma Ray log. This value is calculated by taking the readings from the log and determining the shale volume with the help of following formula:

$$Vsh = \frac{GR_{Log} - GR_{Min.}}{GR_{Max.} - GR_{Min.}}$$

Where,

GR_{log} = log reading obtained from data

GR_{min} = lowest log reading i.e. representing clean beds

GR_{max} = highest log reading i.e. shale bed

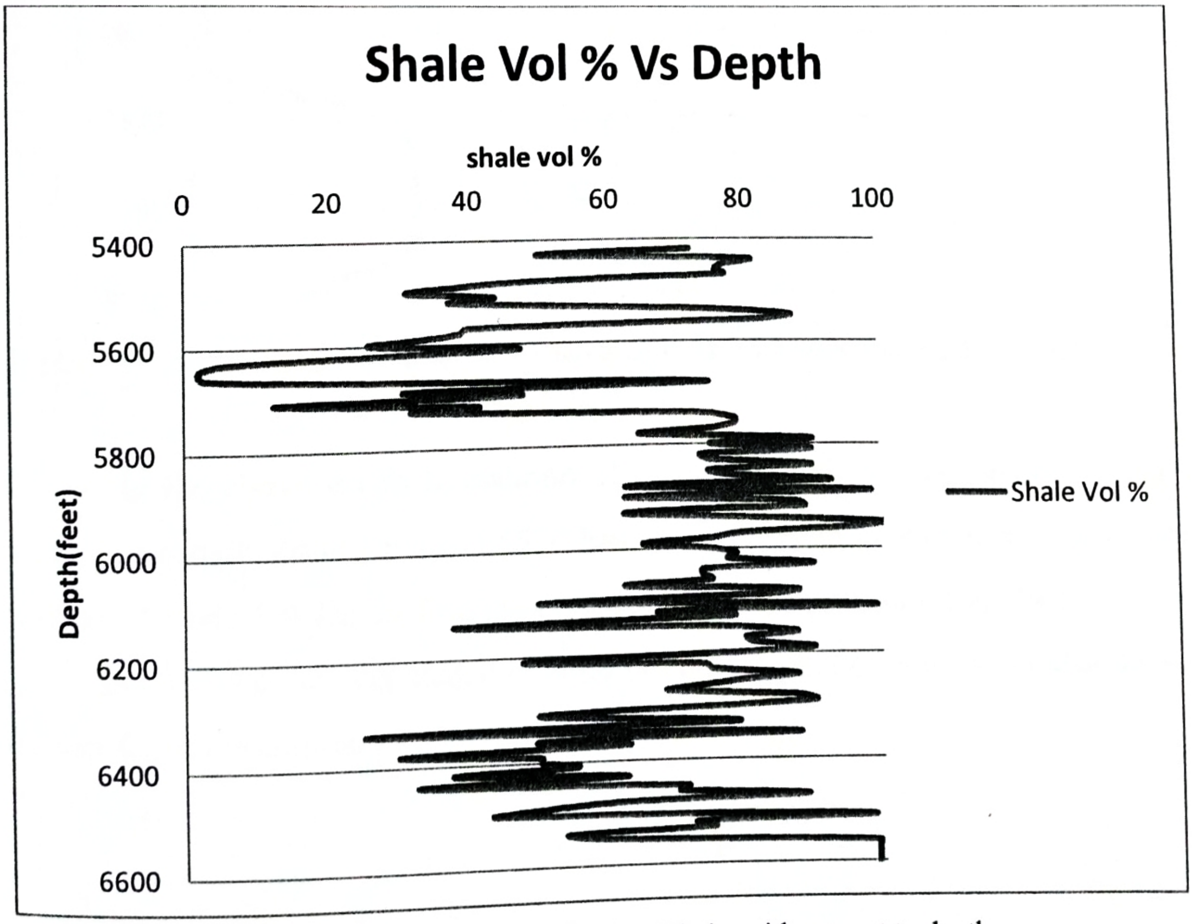

Figure 4.2 Graph showing the variation of volume of shale with respect to depth.

4.2.2 Demonstration of volume of shale on the basis of Zones

We have marked two zones in the Lower Guru formation and we will study both the zones separately to understand their behavior clearly i.e. how the values are fluctuating against the depth at these two zones.

4.2.2.1 Zone 1

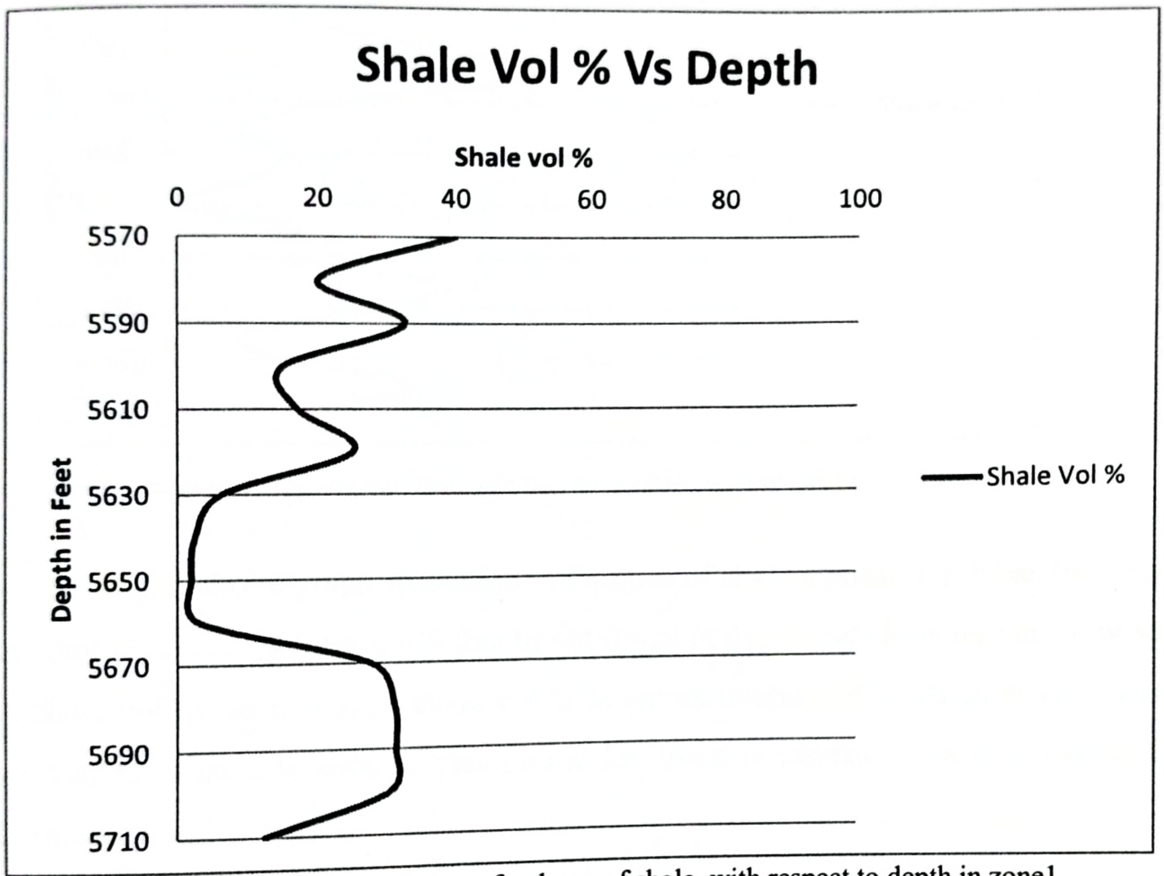

Figure 4.3 Graph showing the variation of volume of shale with respect to depth in zone1

In the above graph fluctuation of values of shale vol against depth has been shown in zone 1. Zone 1 is from 5570 feet to 5710 feet in depth and showing very low values of shale vol i.e. in this zone shale vol % is approximately 20.24% which is very less and we can say that this zone is clean zone i.e. there is sandstone as it is Lower Guru Formation.

4.2.2.1 Zone 2

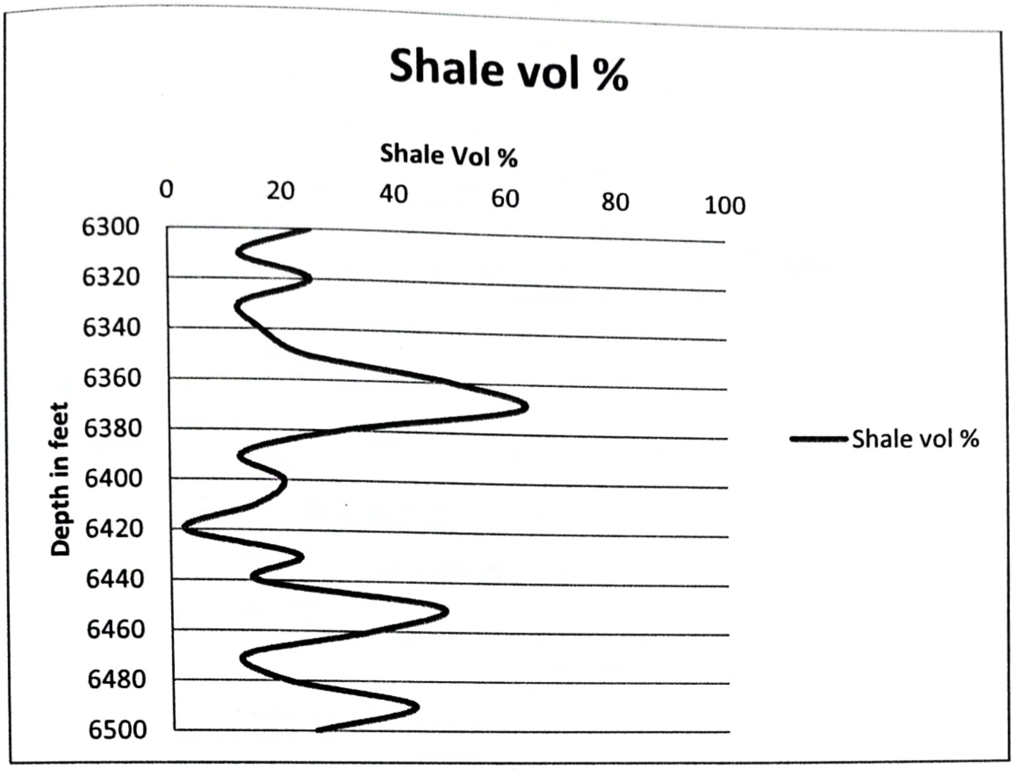

Figure 4.4 Graph showing the variation of volume of shale with respect to depth in zone2

In the above graph fluctuation of values of shale against depth has been shown in zone 2. Zone 2 is from 6300 feet to 6500 feet in depth and showing very low values of shale vol i.e. in this zone shale vol % is approximately 24% which is very less and we can say that this zone is clean zone i.e. there is sandstone as it is Lower Guru Formation.

4.2.3 Calculation of volume of clean

Volume of clean sand is calculated from volume of Shale which we calculated earlier. Volume of clean sand is calculated by using following formula:

$$Vclean = (1 - V_{sh})$$

Where

Vclean = Volume of clean

Vsh = Volume of Shale

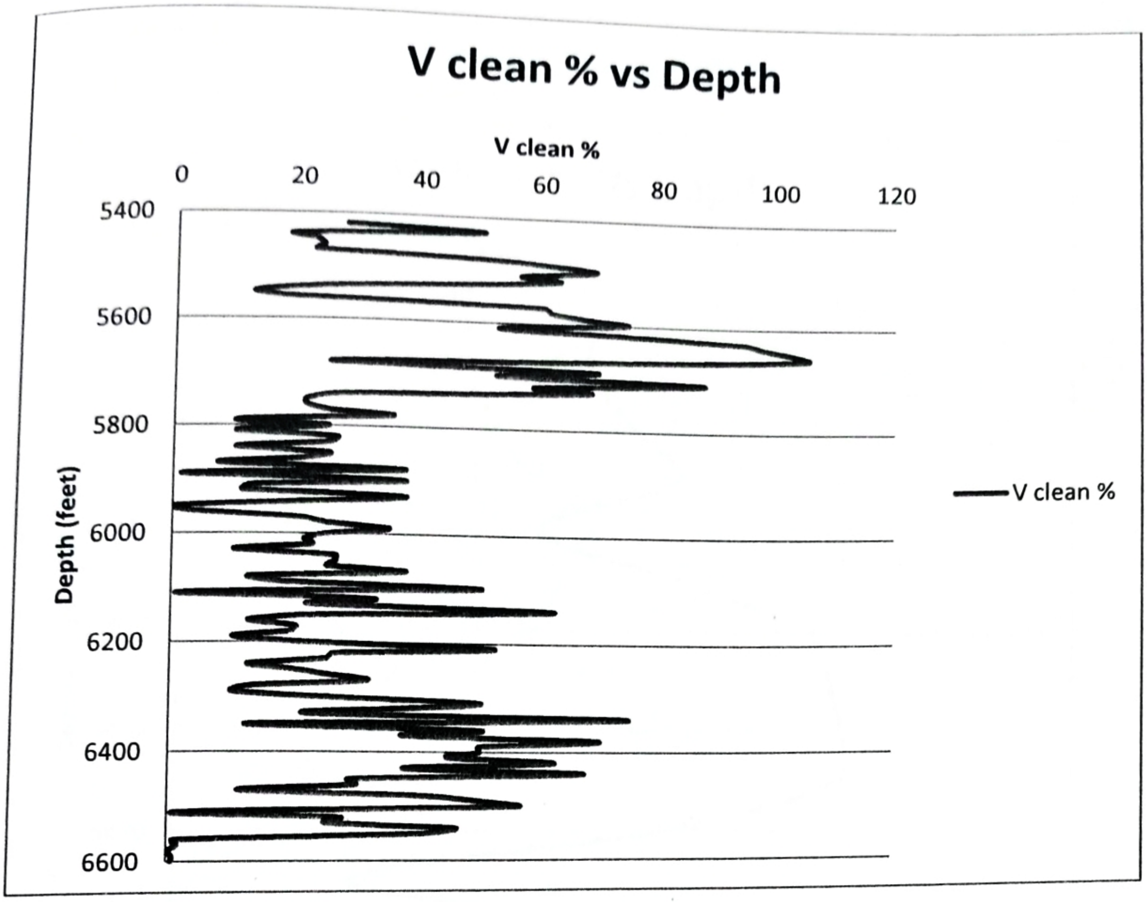

Figure 4.5. Showing the variation of and volume of clean with respect to depth.

4.2.4 Demonstration of V Clean on the basis of Zones

We have marked two zones in the Lower Guru formation and we will study both the zones separately to understand their behavior clearly i.e. how the values are fluctuating against the depth at these two zones.

4.2.4.1 Zone 1

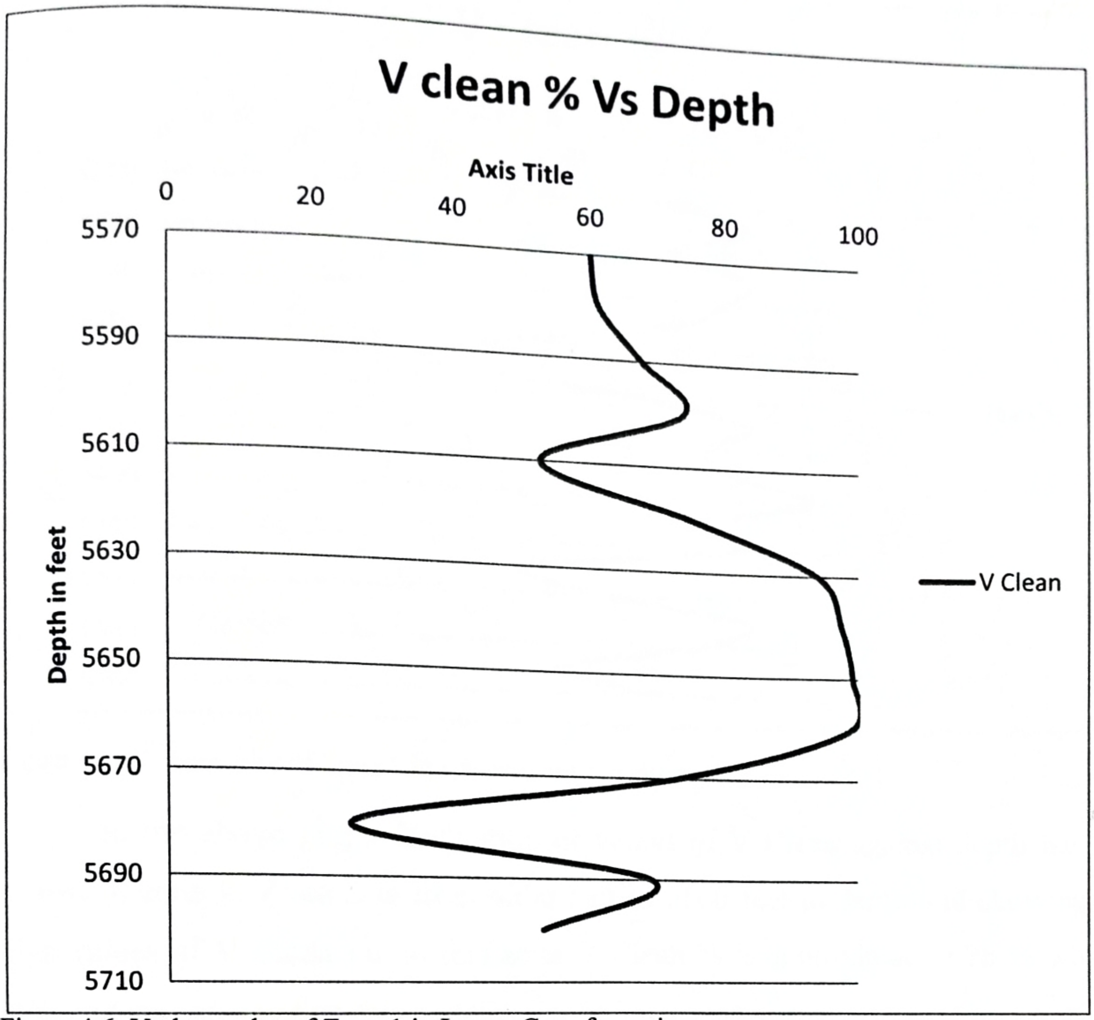

Figure 4.6. V clean plot of Zone 1 in Lower Guru formation

In the above graph fluctuation of values of V Clean against depth has been shown in zone 1. Zone 1 is from 5570 feet to 5710 feet in depth and showing very high values of V Clean i.e. in this zone V Clean % is approximately 80 % which is very high and we can say that this zone is very rich in sandstone.

4.2.4.2 Zone 2

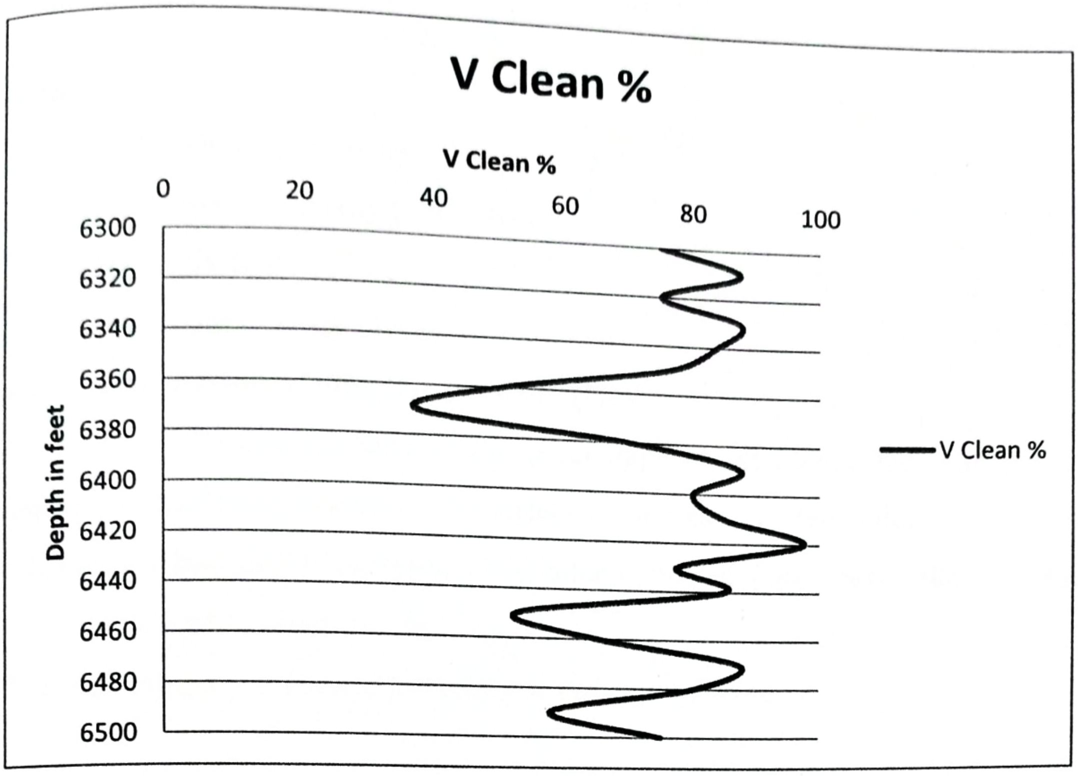

Figure 4.7. V clean plot of Zone 1 in Lower Guru formation

In the above graph fluctuation of values of V Clean against depth has been shown in zone 2. Zone 2 is from 6300 feet to 6500 feet in depth and showing very high values of V Clean i.e. in this zone V Clean % is approximately 76 % which is high and we can say that this zone is rich in sandstone.

4.2.5 Calculation of porosity

After calculating volume of shale, porosity was calculated with the help of density and neutron logs.

4.2.5.1 Density porosity

Density porosity is calculated with the help of density log. Two separate values are used, the bulk density and the matrix density. The bulk density is the density of the entire formation whereas; the matrix density is the density of the solid framework of the rock. It has a relatively shallow depth of investigation, for calculating density porosity the values of the bulk density are taken from log while the fluid density can be read from the log header as 1.2 g/cm^3. Density porosity was then calculated with the help of following formula:

$$\Phi D = (\rho_{ma} - \rho_b) / (\rho_{ma} - \rho_f)$$

Where;

ΦD = Density porosity

ρ_{ma} = Matrix density (2.65 g/cm^3)

ρ_b= Bulk Density

ρ_f = Fluid Density (1.2 g/cm^3)

4.2.6 Calculation of effective porosity (□e)

The effective porosity is the percentage of interconnected pore space with respect to the bulk volume. The effective porosity is the value that is used in calculations because it represents the interconnected pore spaces that contains the recoverable hydrocarbon fluids.

Effective Porosity = $(sonic\ porosity \times volume\ of\ Clean)$

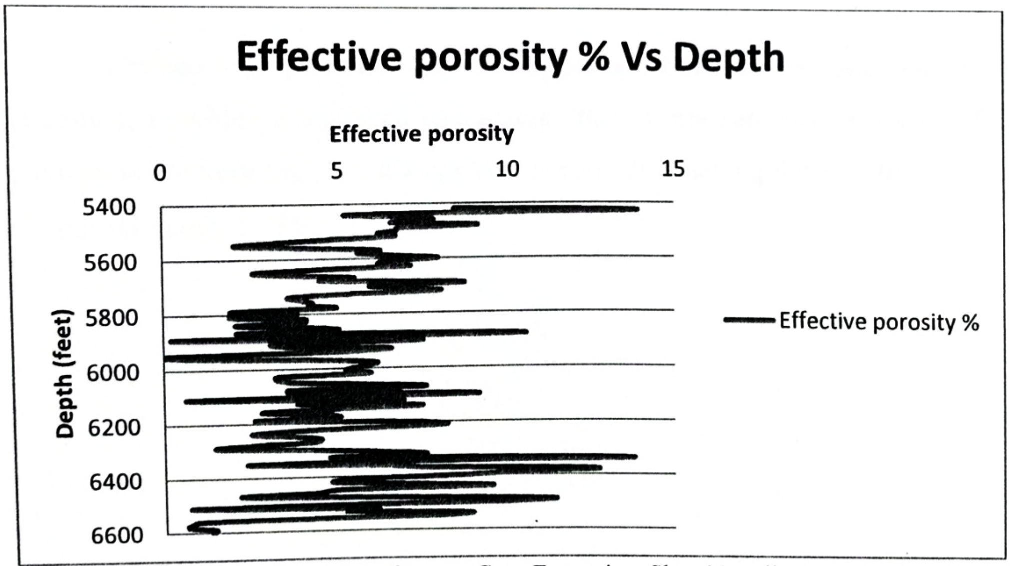

Figure 4.8. Effective porosity plot of Lower Guru Formation, Sher-01 well.

4.2.7 Demonstration of Effective porosity % on the basis of Zones

We have marked two zones in the Lower Guru formation and we will study both the zones separately to understand their behavior clearly i.e. how the values are fluctuating against the depth at these two zones.

4.2.7.1 Zone 1

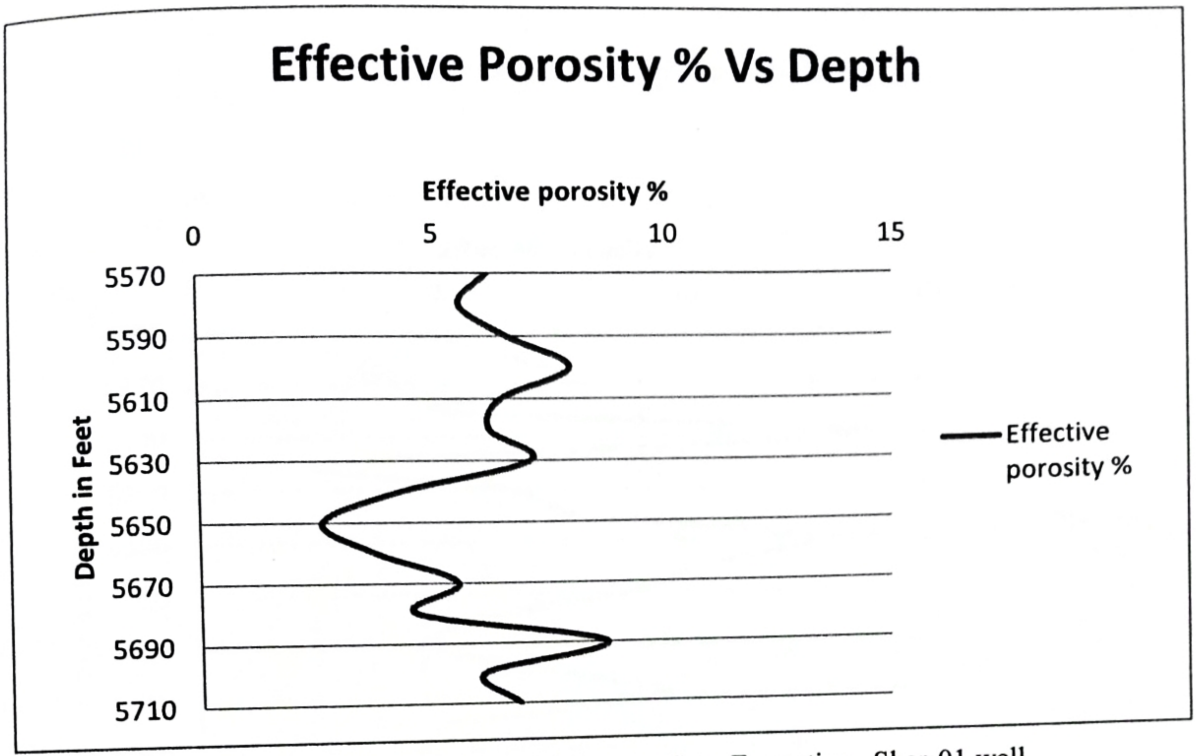

Figure 4.9. Effective porosity plot of Zone 1 in Lower Guru Formation , Sher-01 well.

The above graph is showing the percentage of effective porosity against Depth in zone 1, in which it has been encountered that in this zone percentage of effective porosity is not very high i.e. it's not very porous. It Is having the effective porosity % of approximately 5.78%.

4.2.7.2 Zone 2

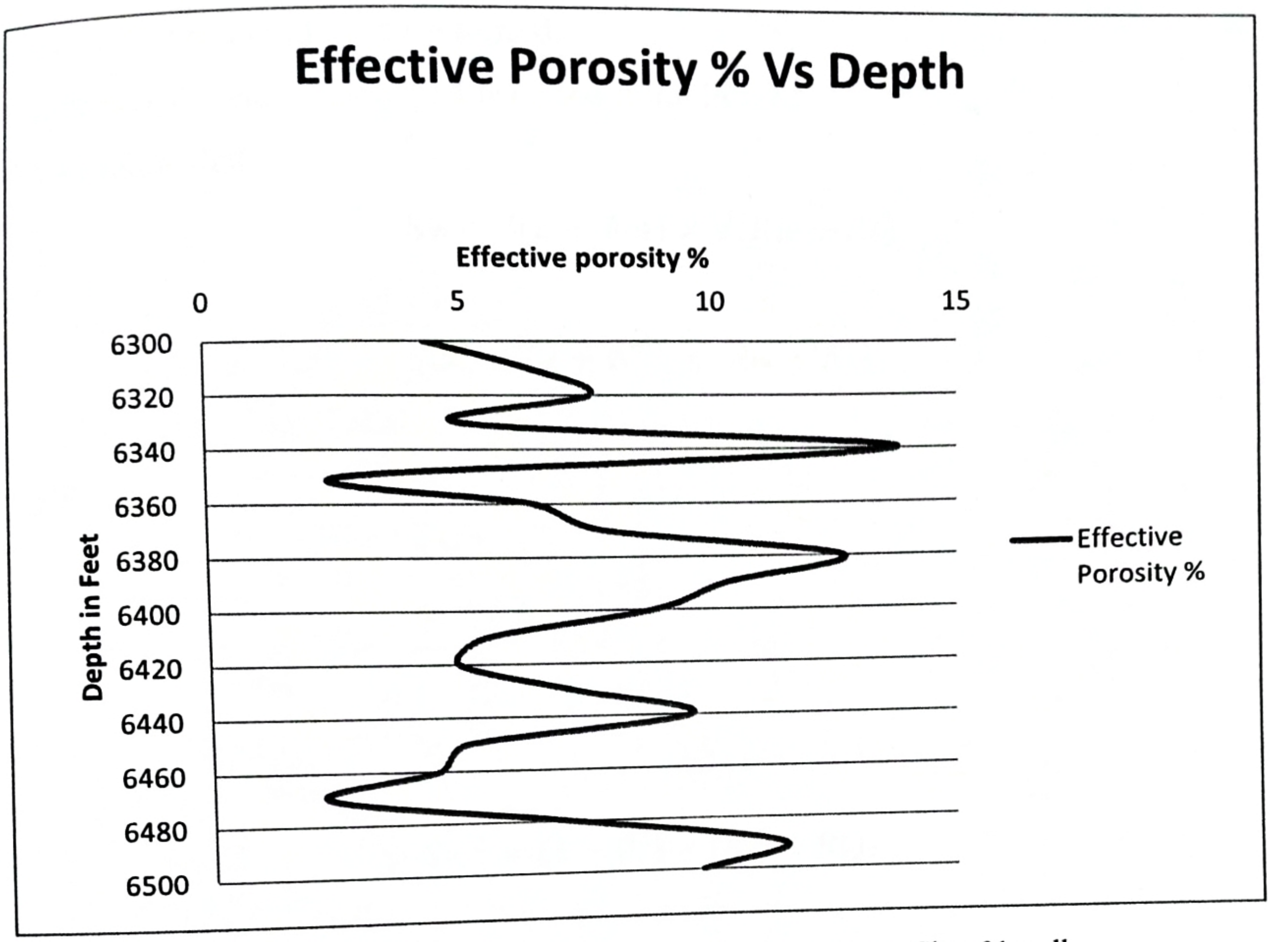

Figure 4.10. Effective porosity plot of Zone 2 in Lower Guru Formation , Sher-01 well.

The above graph is showing the percentage of effective porosity against Depth in zone 2, in which it has been encountered that in this zone percentage of effective porosity is higher than zone 1 i.e. it's porous medium than zone 1. It Is having the effective porosity % of approximately 7.23%.

4.2.8 Resistivity of Water (Rw)

There are many methods to obtain water resistivity (Rw) and this is the most sensitive parameter in the computation of water saturation. In the countries where oil industry is advanced, Rw catalogues are available. Therefore, Rw catalogues are available from oil companies and/or professional societies of well analysts for different formations. Such catalogues are available in well-explored areas like Alberta (Canada), Texas (USA), etc. In developed fields water samples can be obtained and got analyzed from laboratories. In case of wildcat wells, usually water-bearing strata are not present on logs; therefore it is necessary to compute it by indirect methods. Water samples recovered from the Repeat Formation Tester (RFT) or Drill Stem tests

(DST) have to be analyzed for their chemical compositions and measurements of resistivity at different temperatures, this is the most reliable method. In less explored areas such information is hard to find.

However Rw can be obtained from the formula

As we know that

$$Sw = \sqrt{(a \div \emptyset m)} \times \sqrt{(Rw \div Rt)}$$

$$Sw^2 = (a \div \emptyset^m) \times (Rw \div Rt)$$

Here

a = 1

m = 2

So

$$Sw^2 = (1 \div \emptyset^2) \times (Rw \div Rt)$$

For water saturation here is 100% water so

Sw=1

Then

$$1^2 = (1 \div \emptyset^2) \times (Rw \div Rt)$$

$$\emptyset^2 = (Rw \div Rt)$$

$$Rw = Rt \times \emptyset^2$$

By this formula we get the value of Rw

Rw=0.0017

4.2.9 Saturation of water and saturation of hydrocarbon

The fraction of pore spacing that contains water is termed as water saturation which is denoted by Sw. Water saturation gives information about the presence of hydrocarbon in reservoir. If saturation of water is less, then saturation of hydrocarbon will be high, but if Sw is 100% than it indicates that hydrocarbon is absent in that zone.

During the log analysis of study well water saturation is calculated with the help of Archie equation.

$$(S_w)^n = (a / \Phi^m \times R_w / R_t)$$

Where:

S_w = Water saturation

R_t = Deep zone resistively (LLD)

R_w = Formation water resistivity

n = Saturation exponent

m = Cementation factor

a = Tortuosity factor

Φ = Effective Porosity

The determination of saturation of hydrocarbon is very important because it will depict the reservoir potential to produce hydrocarbons. If the saturation of hydrocarbon is very high then the next step begins but if the saturation of hydrocarbon is very small or less then well is considered to be dry because less saturated reservoir will not compensate for the drilling expenditures of the company. The formula for the calculation of hydrocarbon saturation is as follows:-

$$Sh = 1 - Sw$$

Where,

Sh = Saturation of hydrocarbon,

Sw= Saturation of water

Figures 4.11 and 4.14, reveal that water saturation and hydrocarbon saturation are mirror image of each other, the regions where hydrocarbon saturation is maximum the water saturation is minimum and where hydrocarbon saturation is minimum where water saturation is maximum. The average hydrocarbon saturation is 58%.

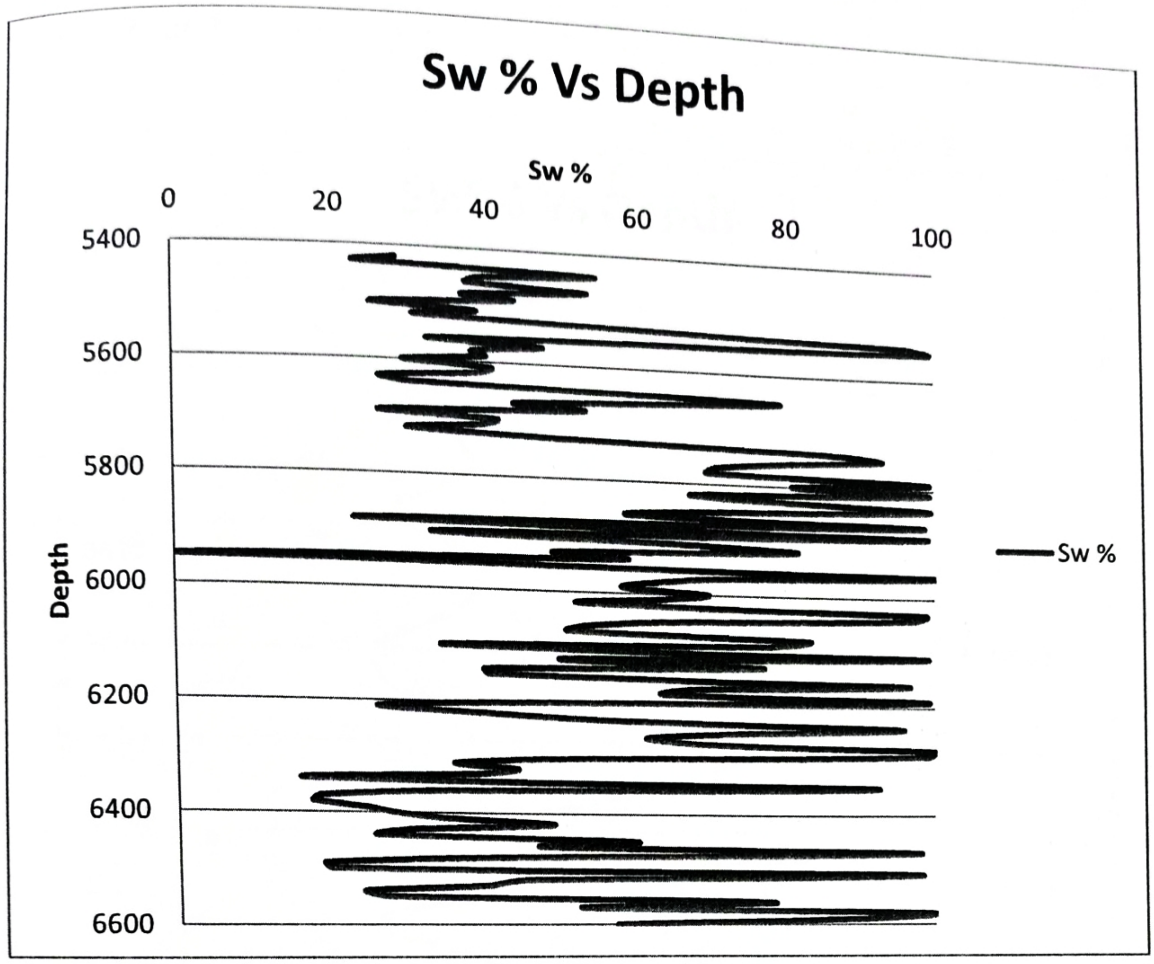

Figure 4.11 Plot of Lower Guru Formation showing the variation of water saturation.

4.2.10 Demonstration of SW on the basis of Zones

We have marked two zones in the Lower Guru formation and we will study both the zones separately to understand their behavior clearly i.e. how the values are fluctuating against the depth at these two zones.

4.2.10.1 Zone 1

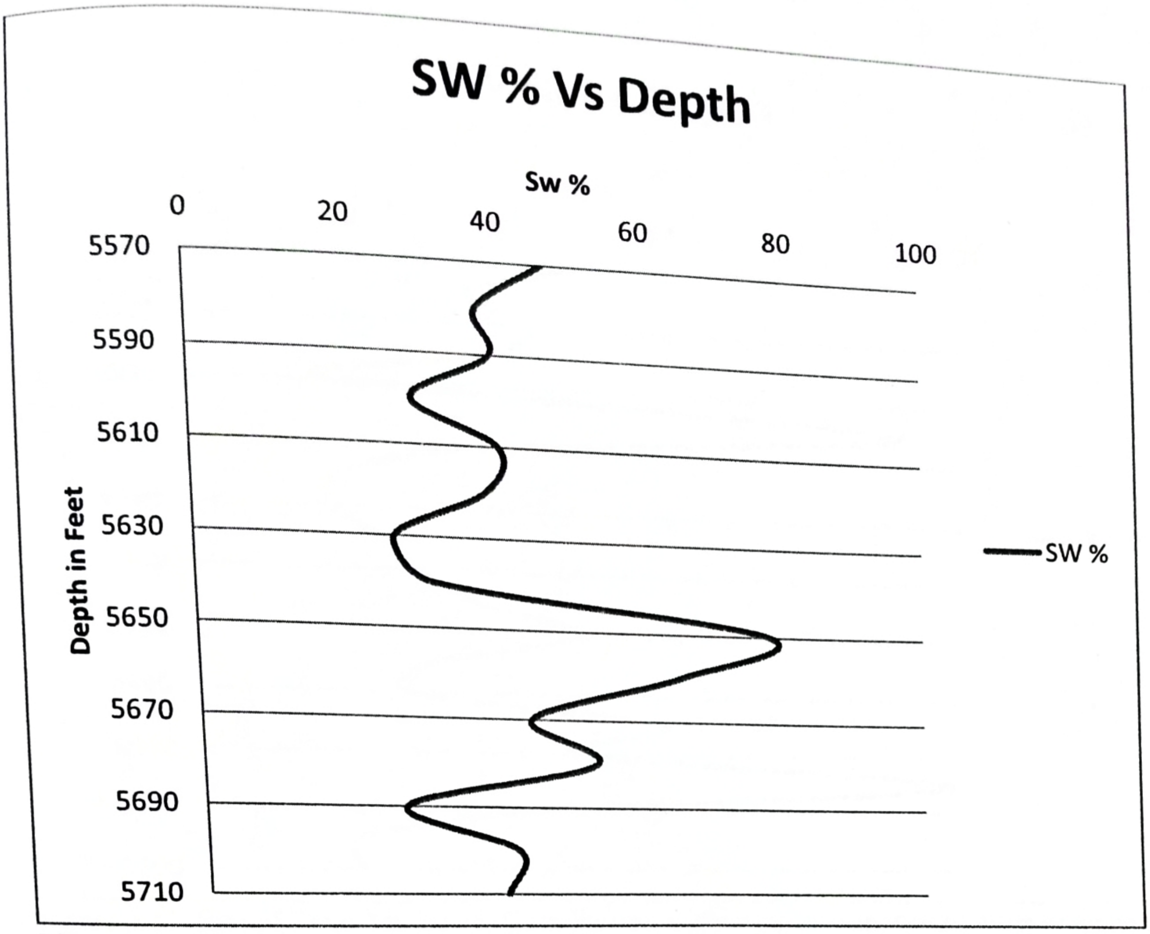

Figure 4.12. Plot of Zone 1 in Lower Guru Formation showing the variation of water saturation.

In the above graph of zone 1 in Lower Guru formation which is showing the variation of saturation of water against depth, in which we can see that Sw % is less in this zone, which is approximately 42.54%

4.2.10.2 Zone 2

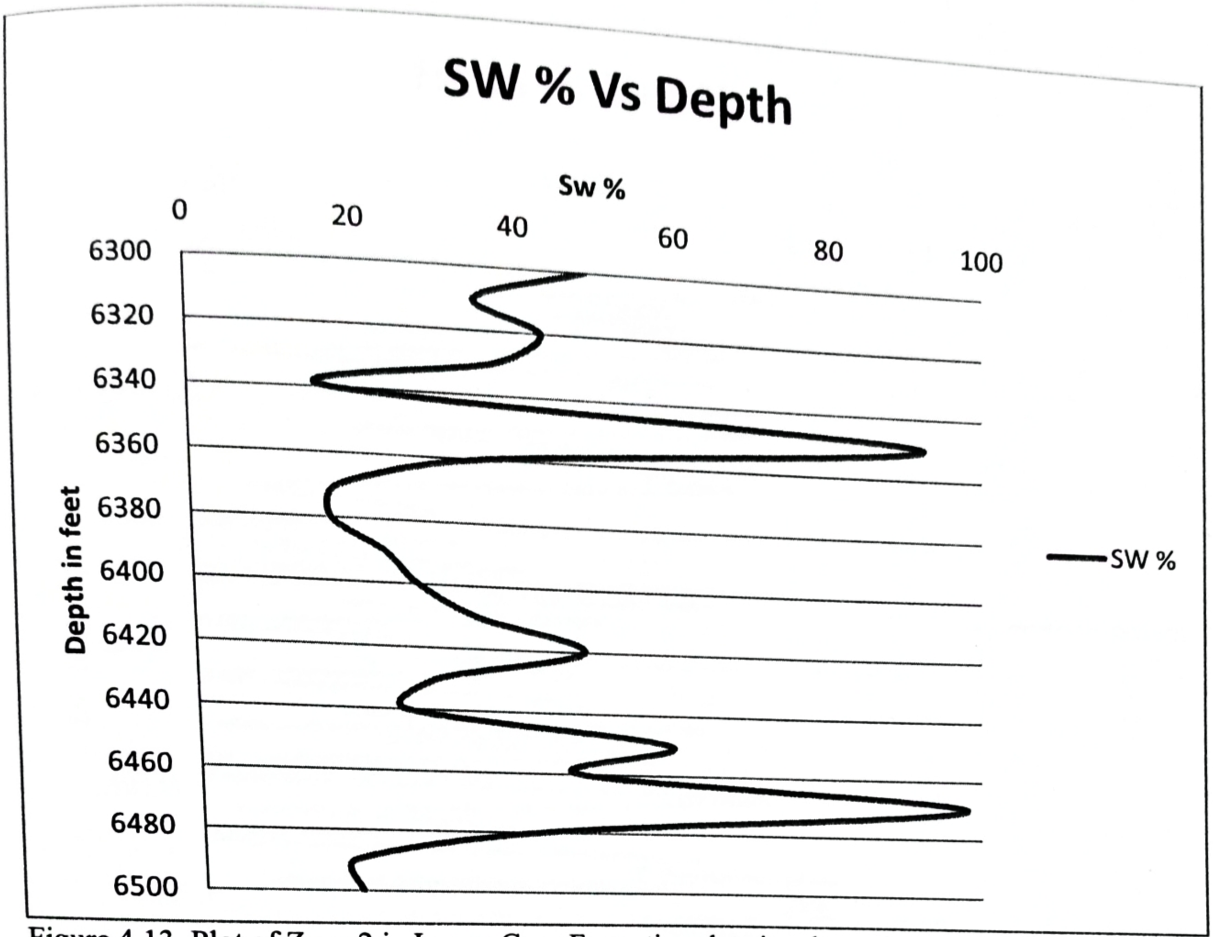

Figure 4.13. Plot of Zone 2 in Lower Guru Formation showing the variation of water saturation.

In the above graph of zone 2 in Lower Guru formation which is showing the variation of saturation of water against depth, in which we can see that Sw % is less in this zone, which is approximately 38.63%

4.2.11 Saturation of Hydrocarbon

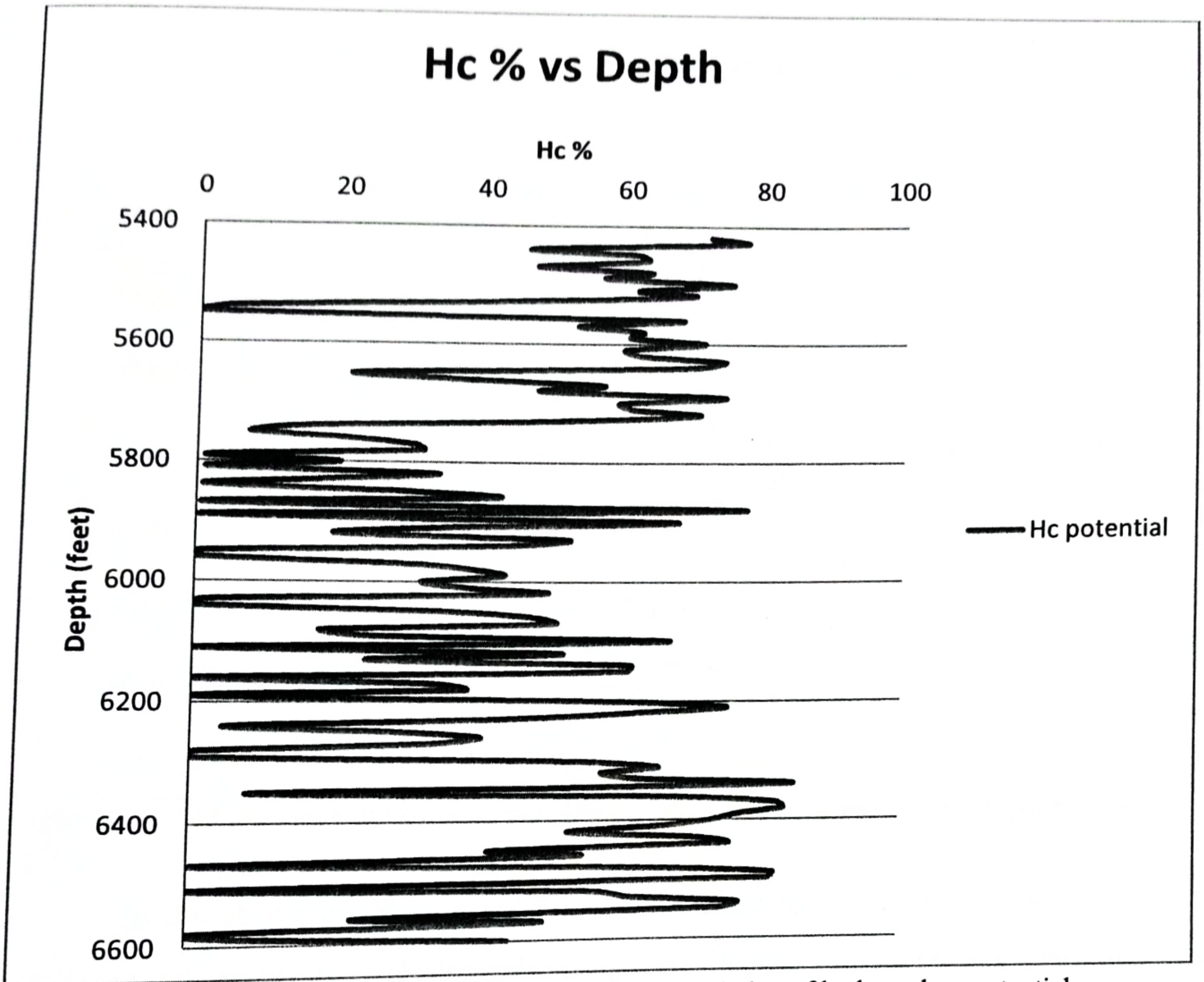

Figure 4.14. Plot of Lower Guru Formation showing the variation of hydrocarbon potential.

4.2.12 Demonstration of HC % on the basis of Zones

We have marked two zones in the Lower Guru formation and we will study both the zones separately to understand their behavior clearly i.e. how the values are fluctuating against the depth at these two zones.

4.2.12.1 Zone 1

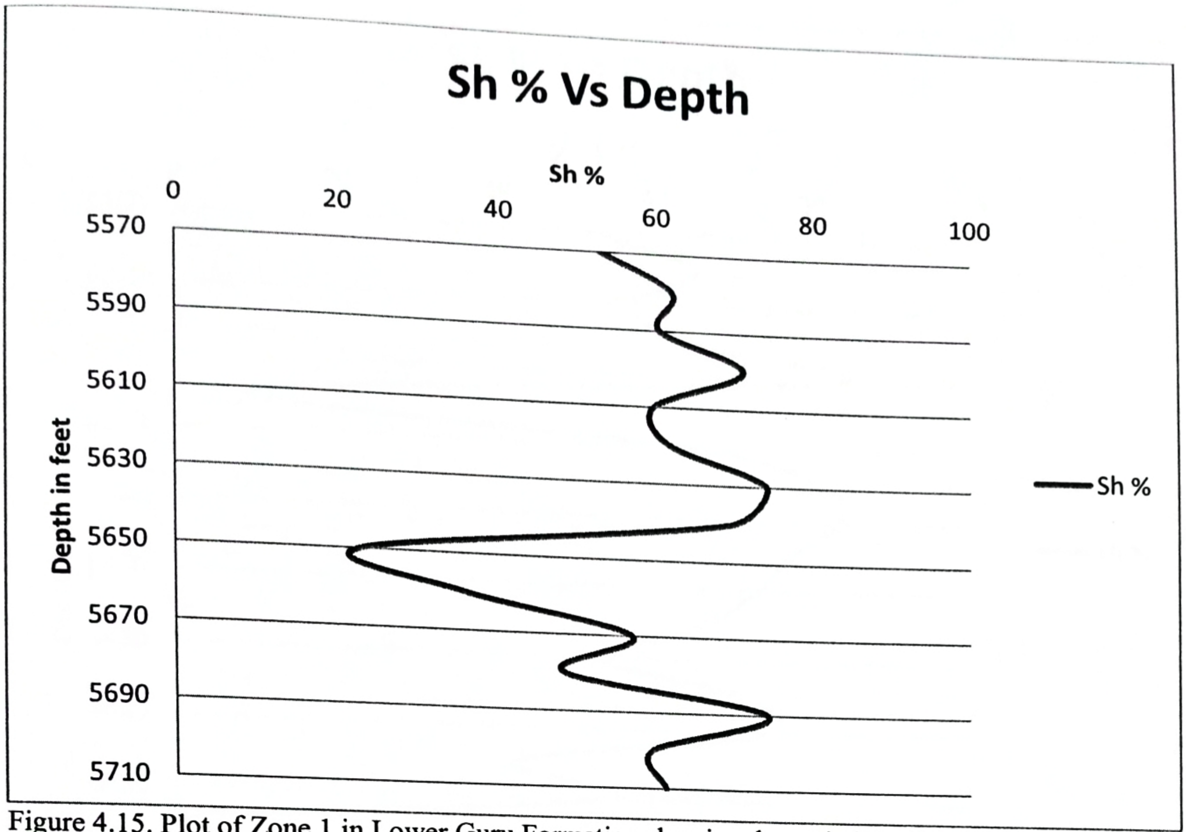

Figure 4.15. Plot of Zone 1 in Lower Guru Formation showing the variation of hydrocarbon potential

In the above graph of zone 1 in Lower Guru formation which is showing the variation of saturation Hydrocarbon against depth, in which we can see that hydrocarbon potential is high that is approximately 57.45% in this zone.

4.2.12.2 Zone 2

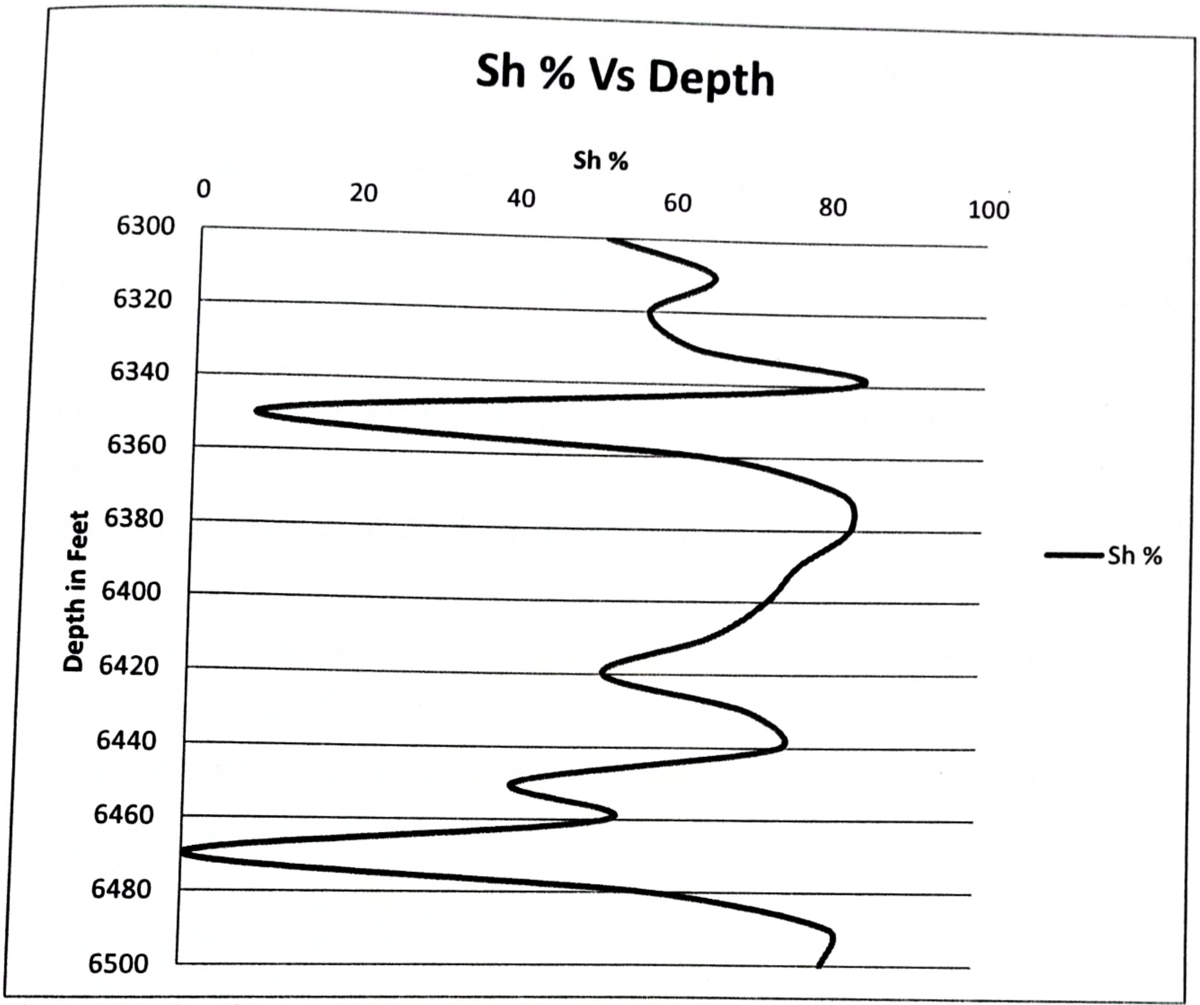

Figure 4.16. Plot of Zone 2 in Lower Guru Formation showing the variation of hydrocarbon potential

In the above graph of zone 2 in Lower Guru formation which is showing the variation of saturation Hydrocarbon against depth, in which we can see that hydrocarbon potential is high that is approximately 61.27% in this zone, zone 2 has more hydrocarbon potential than zone 1.

Table 4.2. Summation table of petrophysical parameters calculated for lower Guru sandstone.

Property Readings	Average in Zone 1 (%)	Average in Zone 2 (%)
Volume of Shale	20.24	24
V clean	79.66	76
Effective Porosity	5.78	7.23
Saturation of Water	42.54	38.63
Saturation of Hydrocarbon	57.45	61.27

RESULTS AND CONCLUSIONS

Volume of shale of Zone 1 is approximately 20.24% and shale volume in Zone 2 is 42.7%.

V Clean % in Zone 1 is approximately 79.66% and V Clean % in Zone 2 is about 58.1%.

But the effective porosity % in Zone 1 is about 5.78% and in Zone 2 effective porosity % is approximately 7.23%.

Saturation of water in Zone 1 is approximately 42.54% and in Zone 2 it is about 38.63%.

Hydrocarbon potential in Zone 1 is approximately 57.45% and in Zone 2 it is about 61.27%.

From the above data we have concluded that zone 2 is more efficient in hydrocarbon potential as compared to zone 1. Though both the zones have less shale and also less amount of water but the percentage of hydrocarbon potential is more in zone 2 as compared to zone 1.

REFERENCES

Blanford, W. T., 1876. On the Geology of Sindh, India, Geology Survey Resources, vol. 9, 8-22.

Kadri, I. B., 1995. Petroleum Geology of Pakistan, Karachi. Pakistan Petroleum Limited. 33, 95-99, 139, 141.

Kazmi, A.H. and Jan, M.Q., 1997. Geology and Tectonic of Pakistan, Graphic Publishers, Pakistan, Karachi. 560p.

Raza, H.A. and Ahmad, R., 1990. Hydrocarbon Potential of Pakistan. Journal of Canada-Pakistan Cooperation, Ottawa, vol. 2, 9-27.

Raza, H. A., Ahmed, R. and Ali, S. M., 1990. Pakistan offshore, an Attractive Frontier, Pakistan, Journal of Hydrocarbon Research, vol. 2, 1-42.

Rider, M.H., 1986. The Geological Interpretation of Well Logs, Whittles Publishing, 280p.

Shah, S.M.I. 1977. Stratigraphy of Pakistan, Memoir Geological Survey of Pakistan, vol 12, 138p.

Huff, K. F., 1980, Frontiers of World Exploration, in: Facts and Principles of World Petroleum Geology, Miall, A. D. (ed) , Canadian Society of Petroleum Geology, Memoir # 6 , Calgary , Alberta , Canada , P.343 – 362.

Pennock, S.,&little, J.(1989). Structural Interpretation Seismic Reflection Data from the Eastern Saltrange and Potwar Plateau. The American Association of Petroleum Geologist Bulletin , 73(70, 841-857.

Siddiqui, Haseeb et al, 2003, ATC. Geology of the Potwar Plateau and the application of 3-D attribute Geovolume Visualization Interpretation Techniques to Enhance the structural and Reservoir Information.

Hussain, M., Rashid, .M.A and Sethi, U.B., 1975, Geology of Parachinar Quadrangle, Pakistan. United States Geological Survey Professional Paper 716-F.7

Archie, G. E., 1942, The electrical resistivity log asan aid in determining some reservoir characteristics: Petroleum Technology, V.S, P.54-62.

Shami, B., &Baig. (2002). Geomodeling for the enhancement of Hydrocarbon Potential of Dhulian oil Field. PAGP-SPE, Annual Techniques sonference.

Steaphan, M.(1988), Basic Method of Structural Geology.

Asquith, G and Gibson. C., 1982, Basic Well Log Analysis for geologists: A.A.P.G Publ., Tulsa, P.216.

Coward, M.P. and Buttler, R.W.H., 1985, "Thrust Tectonics and the Deep Structure of the Pakistan Himalaya", Geology, v.13. P.417-442.

Lillie, R. Jaswal., and Lawrence, R. D., 1997, Structure and Evolution of the Northern Potwar Deformed Zone, Pakistan. AAPG Bulletin, 81: 308 – 328.

Shah, S.M., 1977, Stratigraphy of Pakistan: Mem.Geological survey of Pakistan, v.12, p.34-43.

APPENDICES

Depth	GR log	GR min	GR max	vshale %	vclean %	LLD	N(Φ)	ρB	DPHI %	APHI %	EPHI %	Rw	Sw %	Sh %
ZONE 1														
[illegible]	130	60	140	87.5	12.5	3	0.25	2.54	7.58	16.2931	2.036	0.0017	116.8	16.88
[illegible]	124	60	140	80	20	10	0.25	2.45	13.79	19.39655	3.875	0.0017	33.61	66.39
5570	92	60	140	40	60	2	0.13	2.54	7.58	10.2931	6.175	0.0017	47.20	52.80
5580	91	60	140	38.75	61.25	3.8	0.14	2.59	4.13	9.068966	5.554	0.0017	38.07	61.92
5590	86	60	140	32.5	67.5	2.5	0.16	2.6	3.44	9.724138	6.563	0.0017	39.72	60.27
5600	81	60	140	26.25	73.75	3.2	0.16	2.57	5.51	10.75862	7.934	0.0017	29.04	70.95
[illegible]	98	60	140	47.5	52.5	2.5	0.19	2.57	5.51	12.25862	6.435	0.0017	40.51	59.48
[illegible]	80	60	140	25	75	3	0.13	2.6	3.44	8.224138	6.168	0.0017	38.59	61.40
[illegible]	65	60	140	6.25	93.75	5	0.13	2.62	2.06	7.534483	7.063	0.0017	26.10	73.89
[illegible]	62	60	140	2.5	97.5	10	0.08	2.64	0.68	4.344828	4.236	0.0017	30.77	69.22
5650	58	60	140	2.5	102.5	4.3	0.05	2.65	0	2.5	2.562	0.0017	77.59	22.40
[illegible]	56	60	140	5	105	3	0.07	2.65	0	3.5	3.675	0.0017	64.77	35.22
[illegible]	82	60	140	27.5	72.5	3	0.13	2.62	2.06	7.534483	5.462	0.0017	43.57	56.42
[illegible]	120	60	140	75	25	3	0.26	2.5	10.34	18.17241	4.543	0.0017	52.39	47.60
[illegible]	85	60	140	31.25	68.75	3.3	0.17	2.53	8.27	12.63793	8.688	0.0017	26.12	73.87
5700	98	60	140	47.5	52.5	2.8	0.18	2.58	4.82	11.41379	5.992	0.0017	41.12	58.87
ZONE 2														
6300	80	60	140	25	75	3.9	0.26	2.53	8.27	17.13793	12.853	0.0017	16.24	83.75
6310	70	60	140	12.5	87.5	3.5	0.17	2.53	8.27	12.63793	11.058	0.0017	19.92	80.07
[illegible]	80	60	140	25	75	1.6	0.21	2.37	19.31	20.15517	15.116	0.0017	21.56	78.43
[illegible]	70	60	140	12.5	87.5	5	0.24	2.36	20	22	19.25	0.0017	9.57	90.42
[illegible]	73	60	140	16.25	83.75	3	0.14	2.32	22.75	18.37931	15.39	0.0017	15.46	84.53
[illegible]	79	60	140	23.75	76.25	3	0.22	2.37	19.31	20.65517	15.74	0.0017	15.11	84.88
[illegible]	100	60	140	50	50	3.4	0.13	2.47	12.41	12.7069	6.353	0.0017	35.19	64.80
[illegible]	110	60	140	62.5	37.5	9	0.22	2.37	19.31	20.65517	7.745	0.0017	17.74	82.25
[illegible]	84	60	140	30	70	3.8	0.1	2.27	26.20	18.10345	12.67	0.0017	16.69	83.30
[illegible]	70	60	140	12.5	87.5	3	0.15	2.27	26.20	20.60345	18.02	0.0017	13.20	86.79
[illegible]	76	60	140	20	80	3	0.2	2.43	15.17	17.58621	14.06	0.0017	16.92	83.07
[illegible]	72	60	140	15	85	5	0.17	2.55	6.89	11.94828	10.15	0.0017	18.15	81.84
[illegible]	62	60	140	2.5	97.5	3.2	0.12	2.6	3.44	7.724138	7.531	0.0017	30.60	69.39
[illegible]	78	60	140	22.5	77.5	4	0.24	2.45	13.79	18.89655	14.64	0.0017	14.077	85.92
[illegible]	72	60	140	15	85	3	0.11	2.4	17.24	14.12069	12.00	0.0017	19.83	80.16
6450	98	60	140	47.5	52.5	2	0.2	2.44	14.48	17.24138	9.051	0.0017	32.20	67.79
[illegible]	88	60	140	35	65	4	0.17	2.47	12.41	14.7069	9.559	0.0017	21.56	78.43
[illegible]	70	60	140	12.5	87.5	2.2	0.18	2.34	21.37	19.68966	17.22	0.0017	16.13	83.86
[illegible]	76	60	140	20	80	2	0.18	2.4	17.24	17.62069	14.09	0.0017	20.68	79.31
[illegible]	94	60	140	42.5	57.5	4	0.25	2.35	20.68	22.84483	13.13	0.0017	15.69	84.30
[illegible]	80	60	140	25	75	5	0.16	2.38	18.62	17.31034	12.98	0.0017	14.20	85.79