PETROPHYSICAL ANALYSIS OF QADIRPUR WELL #17

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List of Abbreviations

DNPL	Development and Production Lease
KUFPEC	Kuwait Foreign Petroleum Exploration Company
LLd	deep Laterolog values
LLs	shallow Laterolog values
LMKR	Landmark Resources
MMSCFD	Million Standard Cubic Feet per Day
MSFL	Micro-Spherically Focused Log values
OGDCL	Oil and Gas Development Company Limited
PKPEL	PKP Exploration Limited
PPL	Pakistan Petroleum Limited
SML	Sui Main limestone
SP	Spontaneous Potential

Abstract

Qadirpur Gas Field is one of the major gas reserves of Pakistan. Qadirpur Well #17 was drilled in Qadirpur Concession field, operated by OGDCL, as a development well in order to utilize hydrocarbon potential of Sui Main Limestone (SML). In this study an effort has been made to analyze petrophysical properties of SML of the Qadirpur Well #17for the depth interval of 1290m to 1390m. The review of stratigraphy and borehole analyses has also been a major objective of the study. Volume of shale has been calculated through the GR log and presented in the histogram. Lithology of the zone has been identified through Density and Neutron Log by marking different values of density and Neutron Log on a Density and Neutron cross plot chart. It is concluded that the reservoir lithology of Qadirpur Well # 17 is Sui Main Limestone. Porosity of formation is calculated from three methods and their average values ranges between 5 to 25%. Resistivity of water has been computed through Archie Equation Method i.e. 0.15 ohmm. Saturation of Hydrocarbon is calculated and resultant values shows that from 1332m to 1341m and from 1355m to 1362m the hydrocarbon saturation is more than 70%. Therefore, both of these zones can be concluded as the hydrocarbon bearing zone.

Chapter # 1

1. INTRODUCTION

This research study is conducted and submitted to Department of Earth & Environmental Sciences, Bahria University Islamabad Campus, for the fulfillment of the degree of Bachelor of Science in Geology. In the present study an attempt has been made to carry out petrophysical analysis of Sui Main Limestone at Qadirpur Well # 17. Qadirpur gas field is one of the major proven gas reserves of Pakistan discovered on March 1990 by a joint venture between operator Oil and Gas Development Company Limited (OGDCL), and joint venture partners Kuwait Foreign Petroleum Exploration Company Pakistan B.V. (KUFPEC), PKP Exploration Limited (PKPEL), a subsidiary of Premier Oil Plc and Pakistan Petroleum Limited (PPL). The field is located at a distance of 8 km from Ghotki in Sindh Province as shown in Fig.1.1. In the tectonic setting of Pakistan, Qadirpur field is situated on Mari Kandhkot High in Middle Indus Basin of Pakistan as shown in Fig.1.2.

A total of 45 wells have so far been drilled in Qadirpur Development and Production Lease (DNPL)out of which 36 are currently producing. The field was developed in three phases, increasing its capacity to 600 Million Standard Cubic Feet per Day (MMSCFD) from an initial 235 MMSCFD (Pakistan Petroleum Limited, 2010).

Qadirpur Well #17 lies 600m South, South East of SP-245 of Seismic Line ′CG-4` and is bounded by Latitude 28˚ - 08′ - 8.49″ N and Longitude 69˚ - 23′ - 6.30″ E (Fig.1.1).

Qadirpur Well #17 was classified as an appraisal/development well. It is classified as vertical well with the maximum hole deviation of 2 degrees.

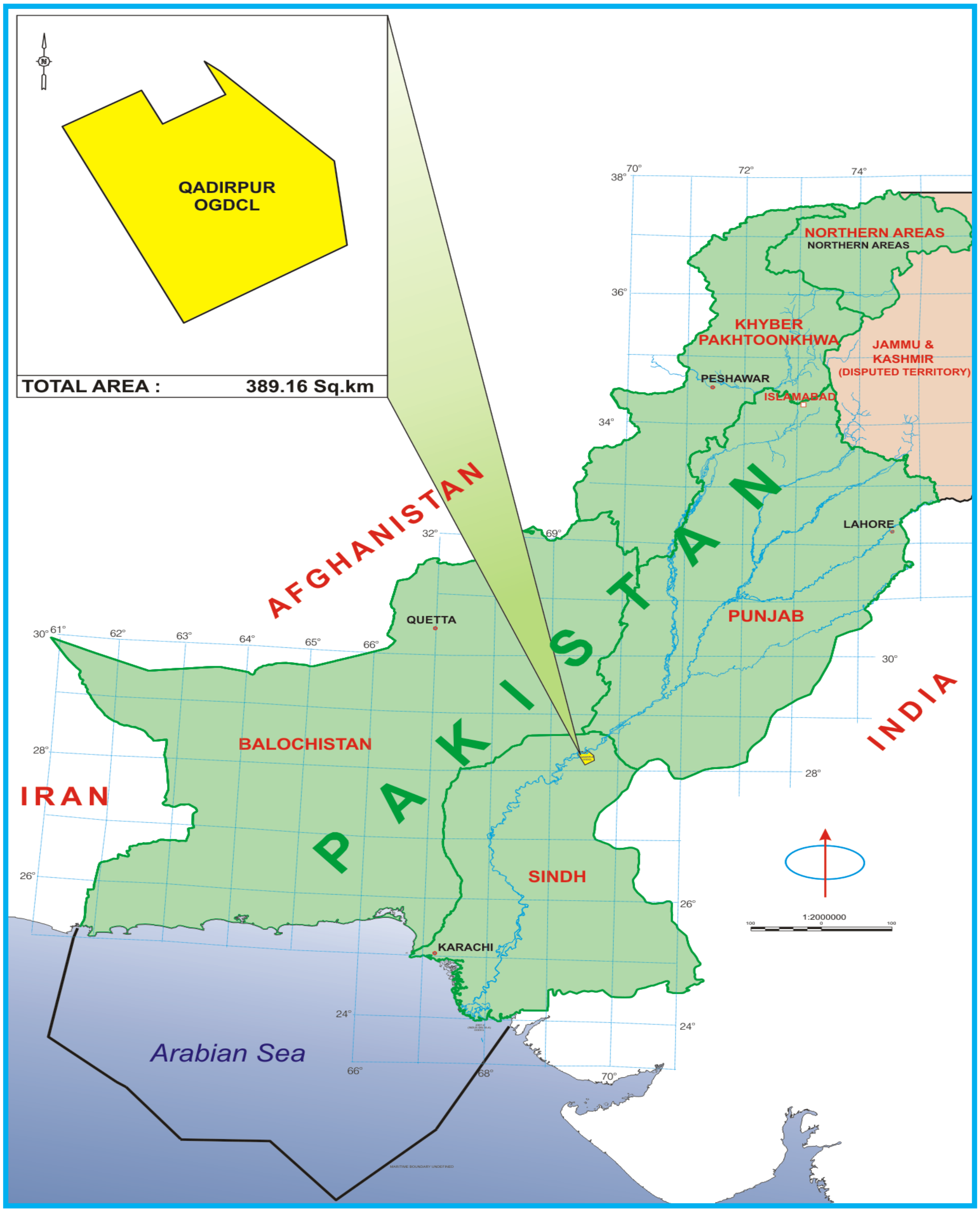

Fig.1.1. Location Map Showing Concession Area of Qadirpur Gasfield. (Pakistan Petroleum Limited, 2010).

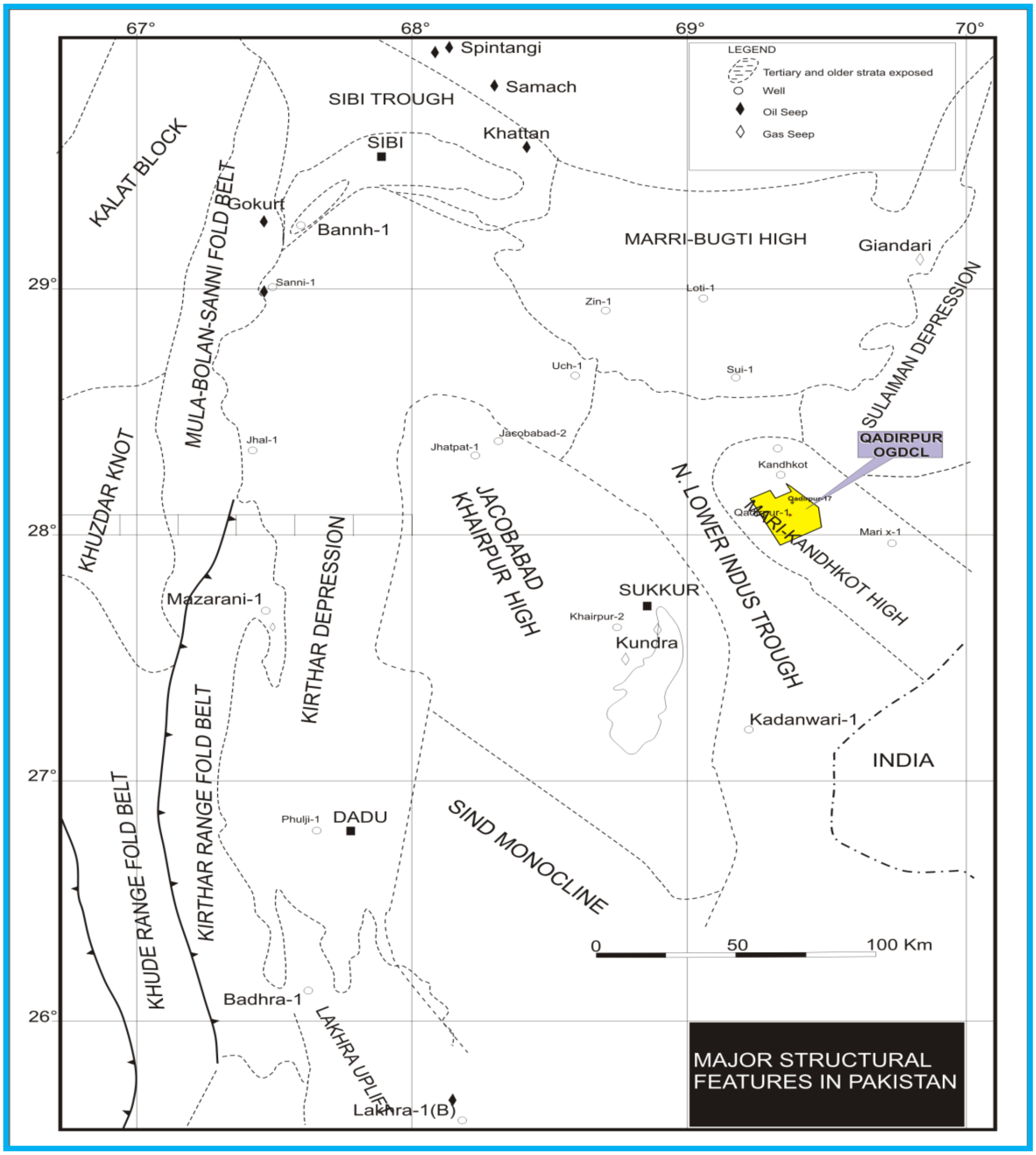

Fig.1.2. Major Structural Features in Pakistan, Eckhoff and Alam (1991).

1.5. Objective of the Study

Objectives of the study are three fold:

i. To define the petroleum system for Middle Indus Basin and review of the Stratigraphy of the Qadirpur Well # 17.
ii. Bore-hole analysis.
iii. To analyze the petro-physical properties of Sui Main Limestone (SML) of Qadirpur Well # 17.

1.6. Structural Geology

Tectonically the Qadirpur Structure occupies a favorable position of Mari- KandhKot High developed on Punjab Platform, a gently west dipping zone flaking the Indian Shield as shown in Fig.1.2. Surface structure is covered by alluvium of flood plain area of river Indus, (Eckhoff and Alam, 1991). Based on seismic data, depth structure maps have been prepared on top of Sui Main Limestone it is a north-south trending anticline, comparatively board in southern half and doubly plunging with an aerial extent of 36 square kilometers with a structural relief of 70 meters as shown in Annexure-A.

1.7. Regional Geology of the Area

Sui Main Limestone (SML) is the main hydrocarbon bearing reservoir of Qadirpur gas-field. The SML is early Eocene to Paleocene in age as shown in Fig.1.3. During the Eocene Period shallow water carbonate represented by Laki Limestone (Equivalent Sui Main Limestone) of Eocene age was deposited over a wide area in the upper and lower Indus basin.

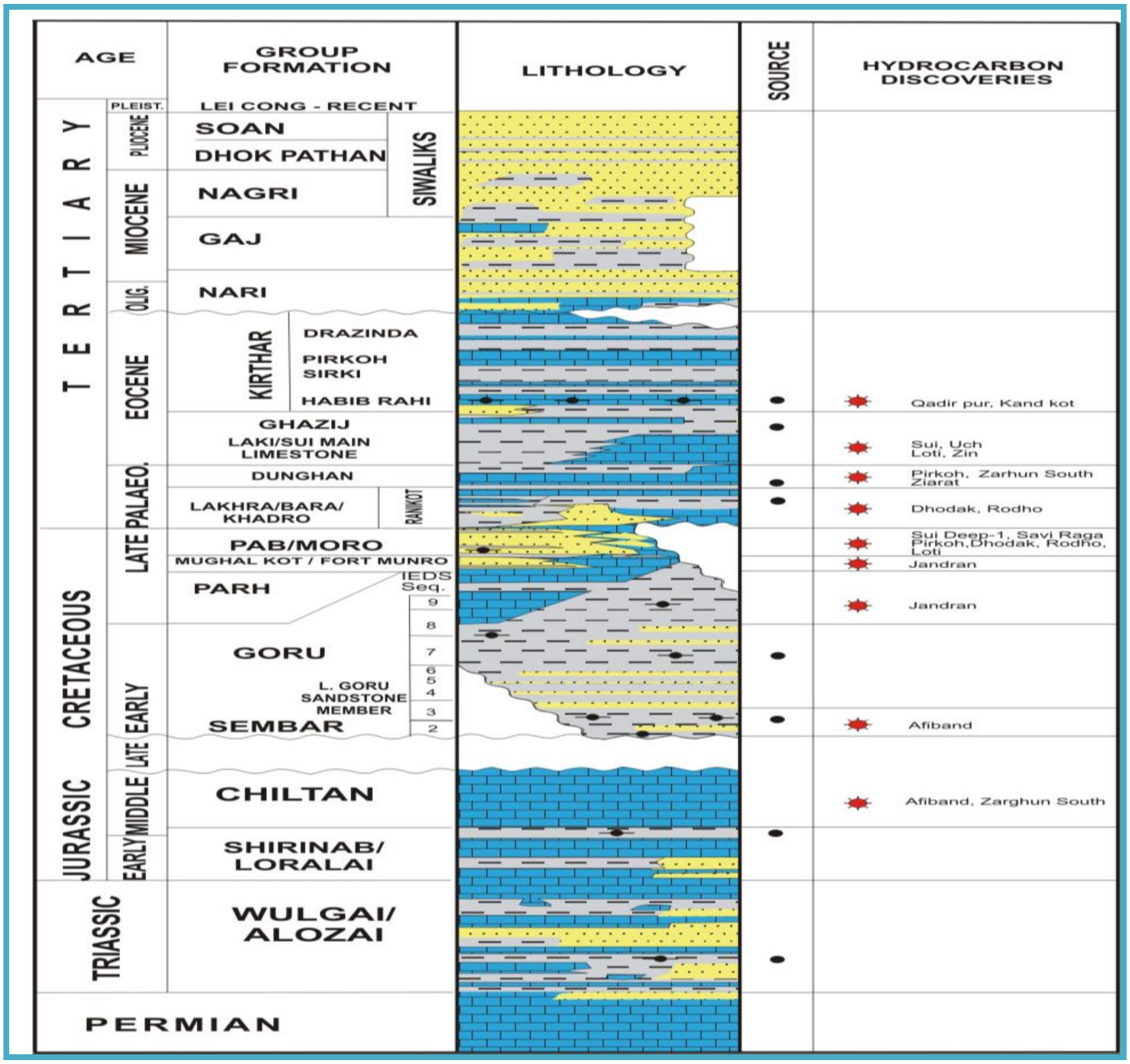

Fig. 1.3. Stratigraphy and Hydrcarbon System of Middle Indus Basin. (Qadri, 1995).

It appeared that a broad northeast-southwest trending shelf ramp/shoal system was established in the Eocene, running from Kothar and Hundi near Karachi the southwest through Sui, Mari, Qadirpur in the central province and extending to northeast upto Badhuana and Kamiab on the Punjab Platform as shown in Fig.1.4. The Limit of carbonate Sedimentation to the west was marked by Western Boundary Thrust Fault and to the east; it was marked by the presence of land mass. The existence of this broad shelf ramp/shoal was strongly suggested on the basis that the numerous wells drilled within this region encountered carbonate rocks of Eocene age (Siddiqui, 2004).

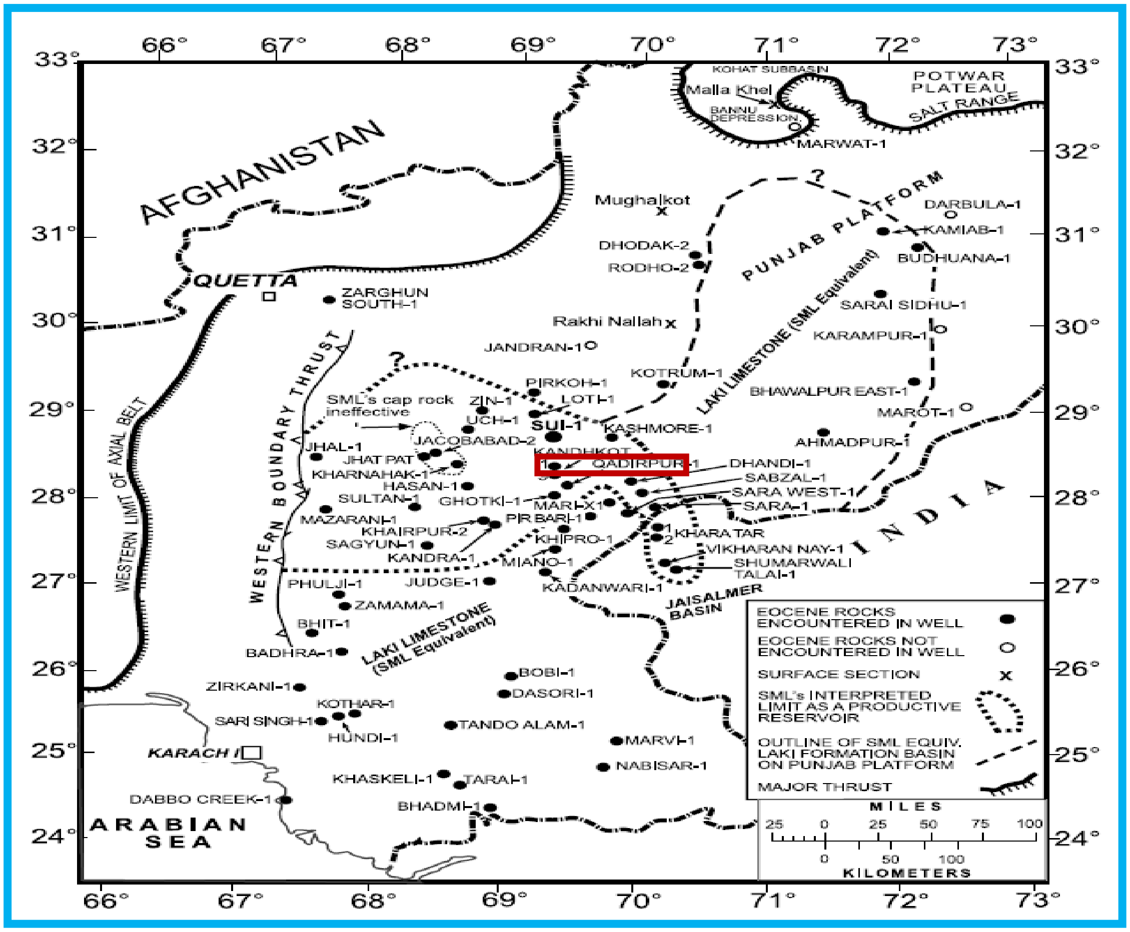

Fig. 1.4. The Tectonic Elements and Laki Limestone (SML equivalent) Limits (Siddiqui, 2004).

The carbonate rocks included Sui Main Limestone and its equivalent Laki Limestone, both Sui Main and Laki Formation is represented by thick succession of clean foraminiferal shoals, deposited on a shallow, high energy, open marine carbonate platform. Laki Limestone was massive and cherty and lacked porosity, and was largely unproductive. Sui Main Limestone however represented the productive facies of Laki Limestone. The development of Sui Main Limestone, the productive facies of Laki Limestone, was limited to the central part of the province comprised of Mari, Kandhkot, Sui, Uch and Zin, and Mazarani field as shown in Fig.1.5 (Siddiqui, 2004).

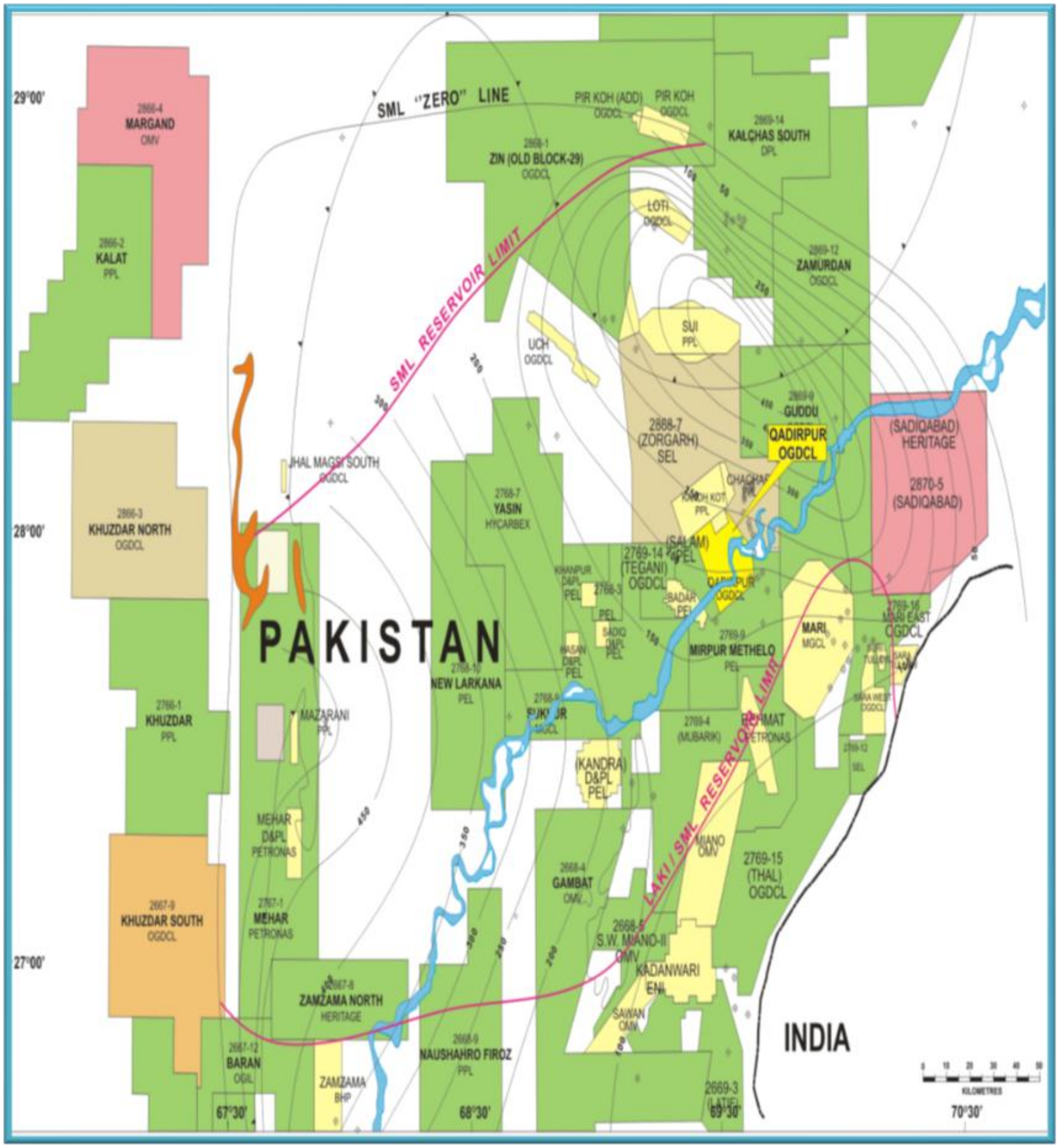

Fig.1.5. Isopach Map of Laki-Sui Main Limestone Showing Reservoir Limit,(after Siddiqui, 2004).

1.8. Hydrocarbon System of Qadirpur Gasfield

The Hydrocarbon system of Qadirpur Gasfield is shown in Fig.1.3.

1.8.1. Source Rocks

Middle Indus basin is a proven basin for gas having major gas fields of Pakistan i.e. Sui, Mari,Uch, Loti, Zin, Qadirpur etc. In Middle Indus basin there are multiple stacked sources as shown in Fig.1.3, with fault systems that allow mixing of hydrocarbons from more than one source. However, Sembar Formation is widely regarded as the major prolific source for gas accumulation in Middle Indus basin (Qadri, 1995).

1.8.2. Cap Rocks

For the whole stacked reservoir column in Middle Indus basin overlying younger thick shales provide cap rocks, as shown in Fig.1.3. Ghazij Shale and shale within the Sui Upper and Sui Main Limestone act as cap rock for Sui Main and Sui Upper Limestone (Qadri, 1995).

1.8.3. Reservoir Rocks

The Middle Indus basin has proven multiple gas reservoirs column which includes carbonates as well as clastics stacked between Middle Jurassic Chiltan Limestone to Eocene HabibRahi member of Kirthar Formation of Eocene age as shown in Fig.1.3. Sui Main Limestone is the primary reservoir at Qadirpur gas field with a average porosity range of 20 to 30%, with secondary porosity (fractures) contributing important role in enhancing the reservoir quality (Ali *et al*, 2005).

1.8.4. Trap

The trap mechanism of Mari Kandhkot High and adjoining area is controlled by folds as well as a combination of fault and fold geometry. The Jacobabad High and the Mari-Kandhkot High were inverted in response to rifting of Madagascar and India in the Late Cretaceous, thermal doming during the base Paleocene Deccan event and emplacement of a series of ophiolites along the western margin of the Indian plate in the late Paleocene / earliest Eocene. The Mari-Kandhkot High ceased to become active in the Middle Ypresian although the Jacobabad High continued to exert an important influence on the location of the carbonate platform margin during the deposition of the Sui Upper Limestone. The Jacobabad High and Mari-Kandhkot High were inverted during the Oligocene and Neogene as part of the Kirthar foredeep bulge, which resulted in the generation anticlinal traps. Trap formation may have post-dated peak oil generation, as reflected by the dominance of Gas Fields around the study area (Qadri, 1995).

Chapter # 2

GENERALIZED STRATIGRAPHY OF WELL QADIRPUR # 17

2. Introduction

The encountered formations and their lithofacies are illustrated in Fig.2.1. Initially 90 meters of Alluvium was drilled before penetrating into Pliocene rocks top of Sui Main Limestone encountered at 1290 m. Lithological and other salient features of the encountered formations are as under.

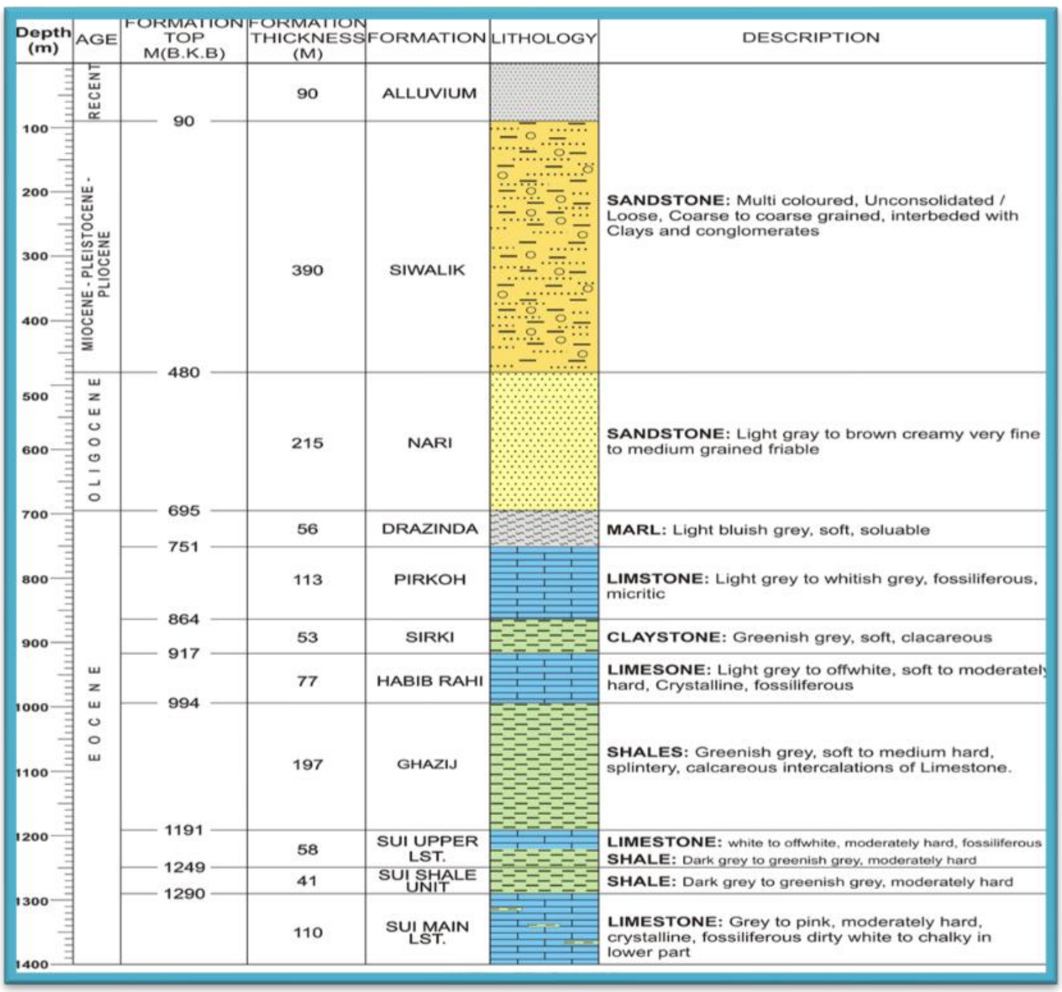

Fig.2.1. Stratigraphic Column of Qadirpur Well# 17, (After Qadri, 1995).

2.1. Alluvium

a.	Age	Recent
b.	Interval	0-90 m
c.	Thickness	90 m
d.	Contact	The lower contact with Siwalik Group is unconformable
e.	Environment	Fluviatile

f. Lithology Alluvium is the youngest deposit. It is mainly composed of sandstone with subordinate clay/claystone. Sandstone is light grey, multicolored, transparent, loose, sugary, fine to medium grained, fairly calcareous and highly micaceous. Clay/claystone is generally light brown, earthy, soft, sticky, hydrophyllic and slightly calcareous (Ahmed *et al*, 1977).

2.2. Siwalik Group

a.	Age	Early Pleistocene
b.	Interval	90 – 480 m
c.	Thickness	390 m
d.	Contact	The lower contact with Nari Formation is unconformable
e.	Environment	Fresh Water

f. Lithology Siwaliks Group consists of sandstone with interclations of siltstone, streaks of clay/claystone and limestone. Sandstone is light grey, brownish grey, yellowish grey, light brown, fine to medium grained, at places coarse grained, at places coarse grained, sub angular to sub rounded, loose to friable, sugary, at places consolidated, silty, highly micaceous and fairly calcareous. Siltstone is light grey light brown, earthy, medium hard, occasionally grading to very fine grained sandstone and calcareous. Clay/Claystone is khaki, reddish brown, earthy, yellow, soft to moderately indurated, hydrophyllic, sticky and slightly calcareous. Limestone is yellow to yellowish brown, light brown, orange, medium hard to hard, compact massive crystalline and fossiliferous (Ahmed *et al*, 1977).

2.3. Nari Formation

a. Age Oligocene

b. Interval 480-695 m

c. Thickness 215 m

d. Contact Contact with underlying Kirthar Formation is unconformable

e. Lithology Nari Formation Consists of sandstone with interclations of clay/claystone. Sandstone is white, off white, light grey, brownish grey, yellowish grey, loose, friable to medium hard, fine to medium grained, sub angular to sub rounded, fairly sorted, poor to fairly cemented and calcareous. Clay/Claystone is light grey, yellowish white, brownish grey, soft, sticky, hydrophyllic and calcareous (Ahmed *et al*, 1977).

2.4. Kirthar Formation

The Kirthar Formation is divisible into four easily distinguishable members.

2.4.1. Drazinda Member

a. Age Middle Eocene

b. Interval 695-751 m

c. Thickness 56 m

d. Contact Lower contact with Pirkoh Limestone is conformable

e. Environment Shallow Marine shelf deposit

f. Lithology Darazinda Formation mainly comprises of marl with streaks of shale and rare traces of limestone. Marl is light grey, white, off white, soft to firm, pasty, sticky, pyritic and hydrophyllic. Shale is light grey, greenish grey, soft to moderately intruded, sub fissile, silty and calcareous (Ahmed *et al*, 1977).

2.4.2. Pirkoh Limestone Member

a. Age Middle Eocene

b. Interval 751-864 m

c. Thickness 113 m

d. Contact The lower contact with Sikri Member is conformable

e. Environment Shallow marine inner to outer shelf

f. Lithology Pirkoh Limestone is dominantly limestone with streaks of marl. Limestone is white to off white, dirty white, creamy, chalky, medium hard to hard, crystalline, at places micro crystalline, argillaceous, dense, compact and fossiliferrous. Marl is off white, light grey, soft, pasty, sticky, and hydrophyllic. On the basis of lithology this formation can be further subdivided into two sections (Ahmed *et al*, 1977).

2.4.3. Sikri Member

a.	Age	Middle Eocene
b.	Interval	864-917 m
c.	Thickness	53 m
d.	Contact	The lower contact with Habib Rahi member is conformable
e.	Environment	Shallow Marine inner to outer shelf
f.	Lithology	Sikri Member consists of shale with streaks of marl and traces

of limestone shale is greenish grey, bluish grey. light grey, at places brown soft to moderately intruded, blocky, sub fissile, pyritic, pasty hydrophillic, splintery and calcareous .Marl is light grey, off white, soft pasty, sticky and hydrophyllic. Limestone is off white, light grey, medium hard, dense and fossiliferrous (Ahmed *et al*, 1977).

2.4.4. Habib Rahi Limestone Member

a.	Age	Middle Eocene
b.	Interval	917-994 m
c.	Thickness	77 m
d.	Contact	The lower contact with Gazij Formation is conformable
e.	Environment	Shallow marine inner to outer shelf,

f. Lithology Habib Rahi Formation at this well consists of limestone with traces of marl. Limestone is off white, creamy, dirty white, medium hard to hard, micro crystalline, dense, biogenic, compact at places brittle, occasionally chalky, mega and micro fossils are common, micro fractured, micritic and pyritic. Marl is generally dirty white, light grey, soft, sticky, pasty and hydrophyllic (Ahmed *et al*, 1977).

2.5. Ghazij Formation

a. Age Lower Eocene

b. Interval 994-1191 m

c. Thickness 197 m

d. Contact The lower contact with Sui upper Limestone is conformable

e. Environment Shallow marine outer shelf

f. Lithology Ghazij Formation consists of shale with thin bands of limestone and marl. Shale is greenish grey, soft fissile to sub fissile splintery, blocky, pyritic fossiliferous, and slightly calcareous to calcareous. Marl is greenish grey, bluish grey, soft, sticky, pasty and hydrophyllic. Limestone is brownish grey, medium hard to hard, compact, microcrystalline, at places dolomitic, and fossiliferous (Ahmed *et al*, 1977).

2.5.1. Sui Upper Limestone

a. Age Lower Eocene

b. Interval 1191-1249 m

c. Thickness 58 m

d. Contact Lower contact with Sui Shale Unit is conformable

e. Environment Shallow marine

f. Lithology Sui Upper Limestone consists of limestone with thin bands shale and traces of marl. Limestone (wackstone to packstone) is off white, grey, creamy, dirty white, at places light brown, hard to very hard compact, micro crystalline, biogenic, micritic, dense argillaceous and fossiliferous. Shale is greenish grey, light grey, soft to medium hard, moderately indurated, fissile, laminated and slightly calcareous. Marl is dirty white, light grey, soft, pasty, sticky and hydrophyllic (Qadri, 1995).

2.5.2. Sui Shale

a. Age Lower Eocene

b. Interval 1249-1290 m

c. Thickness 41 m

d. Contact Lower contact with Sui Main Limestone is conformable

e. Environment Shallow Marine outer shelf

f. Lithology Sui Shale Unit comprised of shale with thin bands of marl and limestone. Shale is greenish grey, light grey, bluish grey, soft to moderately indurated, fissile, laminated, splintery, pyritic, and slightly calcareous. Marl is off white, white grey, soft, sticky, pasty and hydrophyllic. Limestone is off white, light brownish grey, microcrystalline, compact, dense at places argillaceous and fossiliferous (Qadri, 1995).

2.5.3. Sui Main Limestone

a. Age Lower Eocene

b. Interval 1290-1400 m

c. Thickness 110+ m

d. Contact Stratigraphic contact with underlying formation was not drilled.

e. Environment Shallow Marine inner shelf

f. Lithology Sui Main Limestone is dominated by limestone with subordinate beds of shale. Limestone (wackstone) is off white, whitish grey, light grey, dirty white, medium hard to hard, microcrystalline to crystalline, dense, compact, miritic, bioclastic, fractured at places fractures are filled with carbonaceous/ argillaceous material, rarely vugy, moldic, pyritic, mega and microfossils are common. Visual porosity is 10-12% (Qadri, 1995).

Chapter # 3

PETROPHYSICAL ANALYSIS

3. Introduction

Conventional (or reservoir) petrophysical properties generally include lithology, porosity, density, water resistivity and water saturation. In this part of study an effort has been made to analyze the petrophysical properties of Qadirpur Well #17. Analysis has been carried out on a digitized log data.

3.2. Log Data

The data for the analysis of Qadirpur Well #17 is taken from Landmark Resources (LMKR). In this study first step was to digitize the data as it was available in raw form. Data included the GRlog values in API unit, Resistivity Logs (Micro-Spherically Focused Log values(MSFL) in Ohmm unit, shallow Laterolog values (LLs) in Ohmm unit, deep Laterolog values (LLd) in Ohmm unit, Spontaneous Potential log values in MV unit, Neutron log values in V/V unit, Density Logs in G/C3 unit. No data quality problem was observed in any of the logs provided by LMKR.

3.2.1. Borehole Analysis

Borehole analysis describes the borehole sections and its lengths, casing sizes and shoe depths, deviation recorded etc. Six inches is the standard minimum hole size for correct and safe operation of normal logging tools. A limited number of slim-line, small-diameter tools are available for smaller holes. The borehole analysis is given in Table 3.1.

Table 3.1. Analysis of Borehole for Qadirpur Well #17

Depth (m)	Hole size (inches)	Formation	Deviation (degree)	Casing (inches)	Shoe at (m)
Surface - 408	17 ½	Alluvium and Siwaliks	1½	13 3/8 "	405.5
409-1300	12 ¼	Siwaliks, Nari, Drazinda, Pirkoh, Sikri, HabibRahi, Ghazij, Sui Upper Limestone, Sui Shale Unit and Sui Main Limestone	1½	9 5/8"	1289.50
1301- 1400	8 ½	Sui Main Limestone	1 - 1½	7"	1379.5

3.2.2. Drilling/ Mud Logging Parameters for Qadirpur Well #17

While drilling in Qadirpur Wel#17 different types of mud was used in different hole sections. Tables 3.2 describe drilling section and mud used for teach section together with drilling mud and mud cake properties:

Table 3.2.Drilling/ Mud Logging Parameters for Qadirpur Well #17

Title	**405.5 to 1298 m** **12x1/4" Drilling Section**	**1298.5 to 1400 m** **8x1/2" Drilling section**
Mud Type	KCL Mud	CLS, CL, LCM Treated, &KCl Mud
Density	1.23 G/cm^3	1.1 G/cm^3
Viscosity	60 S	51 S
Fluid Loss	7.5cm^3	6.5cm^3
Ph	9.5	9.5
Source of Sample	Flow Line	Flow Line
Mud Resistivity (Rm)	0.4 ohmm at 77^o F	0.6 ohmm at 75^o F
Mud Filtrate Resistivity (Rmf)	0.393 ohmm at 76^o F	0.6 ohmm at 75^o F
Mud Cake Resistivity (Rmc)	0.894 ohmm at 77^o F	1.082 ohmm at 76^o F
Maximum Temperature	150 ^{o} F	142^o F

3.3. Methodology and Results

By utilizing the available data following petrophysical analysis has been conducted in this study. For log interpretation, different types of standard graphs and mathematical charts have been used. The important reservoir parameters which were calculated are volume of shale, porosity of the formation, resistivity of the formation water, water and hydrocarbon saturation. The calculated values are plotted against depth for each particular formation encountered in Qadirpur Well#17.

3.3.1. Determination of Volume of Shale from Gamma Ray Log

The Gamma Ray logs records the natural radioactivity of formations. Radioactive log provide information on the lithology of the formation. In sedimentary rocks the log normally reflects the clay content of the formation, as the radioactive elements tends to concentrate in clay. Applications of GR Logs include the determination of shale beds and lithology indicator. The non-radioactive minerals e.g. coal beds may be detected by their characteristically low GR value. It can be used formations between wells and estimation of shale. Shale exhibit relatively high GR count rates due to the presence of potassium ions in the lattice structure of the clay minerals as shown in the Table 3.3. The most common reservoir rock minerals (quartz, calcite and dolomite) in a pure state do not contain radioactive isotopes and yield low GR readings (Asquith and Krygowski, 2004).

Gamma Ray Log can be used to calculate volume of shale in porous reservoirs. The volume of shale expressed as a decimal fraction or percentage is called Vshale. Calculation of the gamma ray index is the first step needed to determine the volume of shale from gamma ray log. The gamma ray log has several nonlinear empirical responses as well linear responses. The nonlinear responses are based on geographic area or formation age. All nonlinear relationships are more optimistic that is they produce a shale volume value lower than that

Table 3.3. Typical GR levels for Common Minerals and Formation Materials

Lithology	**Gamma Ray Values (in API units)**
Sandstone	15-30 (rarely to 200)
Limestone	10-40
Dolomite	15-40 (rarely to 200)
Shale	60-150
Organic-rich Shale	100-250
Anhydrite, halite	8-15
Sylvite (KCI)	350-500
Coal	15-150 (any value possible)

from the linear equation (Asquith and Krygowski, 2004).

Volume of Shale is calculated with the following equation:

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

V_{sh} = Volume of Shale (%)

GR_{log} = Gamma Ray Log (API Unit)

GR_{max} = Gamma Ray Maximum (API Unit)

GR_{min} = Gamma Ray Minimum (API Unit)

Minimum and maximum value of Gamma ray log is calculated from the available data for GR_{log}. Therefore, GR_{max} = 95 and GR_{min} = 16.5.

As a general rule-of-thumb, a value of 60 API units is a satisfactory boundary to differentiate Limestone i.e. below 60 and Shale i.e. above 60 (Crain, 1986). The Fig.3.1 shows a graph made for the values of Volume of Shale for after five meters depth of Qadirpur Well #17. The resulted values of Volume of Shale from the above mention equation presented through Histogram in Fig.3.2. The results for every meter are presented in the Table 1-A of Appendix. Result shows that the maximum volume of shale 86% is encountered at the depth of 1310m, while the minimum volume of shale 27% is present at the depth of 1346m, of Qadirpur Well #17.

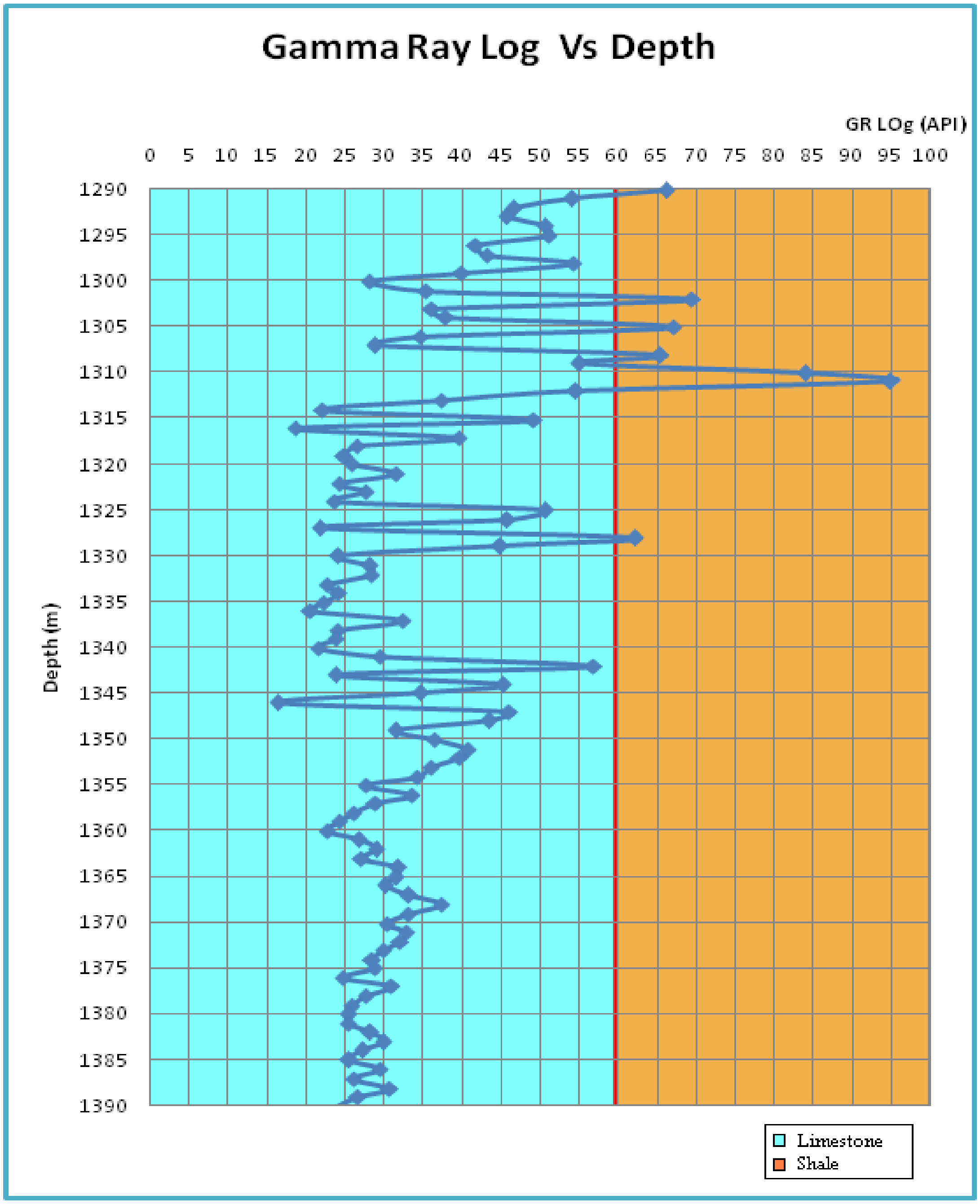

Fig.3.1. Gamma Ray Log Vs Depth of Qadirpur Well # 17

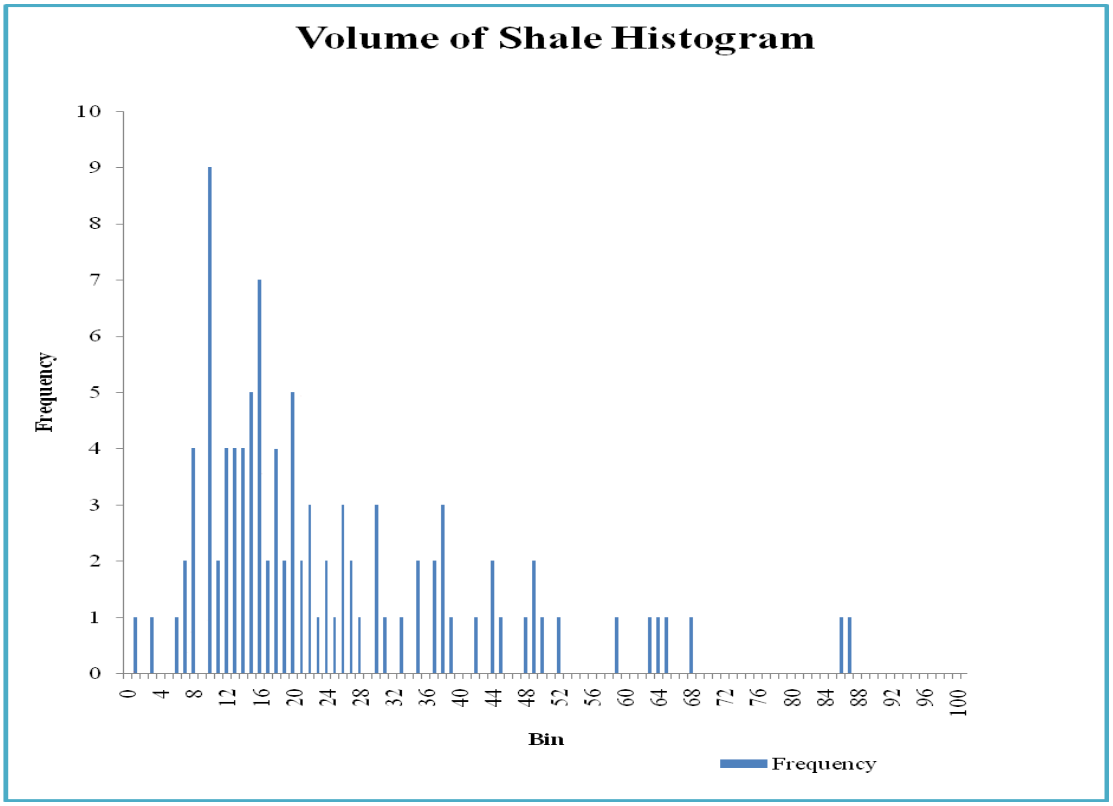

Fig.3.2. Volume of Shale Histogram of Qadirpur Well # 17

3.3.2. Determination Lithology from Density and Neutron Log

The density-Neutron log is probably the best tool to help the Petrophysicists to identify the type of formation or lithologies of a given zone. Lithology for Qadirpur Well # 17 is identified by marking different values of density and Neutron Log on a Density-Neutron crossplot chart,(Crain, 1986), as shown in the Fig 3.3. In the cross plot below some of the values of Porosity from Neutron log and bulk density are marked at random depth of the well. At the depth of 1300m of Qadirpur Well #17 Porosity from Neutron Log is at 19.69% while Bulk Density of 2.36 gm/cc crosses each other in the zone of Limestone (see Table

3.4). Therefore, it can be concluded and hence confirmed that the lithology at this interval i.e. 1290m to 1400m of Qadirpur Well # 17 is Sui Main Limestone.

Table.3.4. Determination of Lithology from Density & Neutron Log of Qadirpur Well #17

Depth (m)	Bulk Density gm/cc	Porosity From Neutron Log	Lithology Identified
1300	2.36	19.69	Limestone
1307	2.42	10.45	Limestone
1314	2.45	13.1	Limestone
1333	2.44	18.26	Limestone
1344	2.49	13.5	Limestone
1377	2.27	20.92	Limestone
1390	2.29	19.87	Limestone

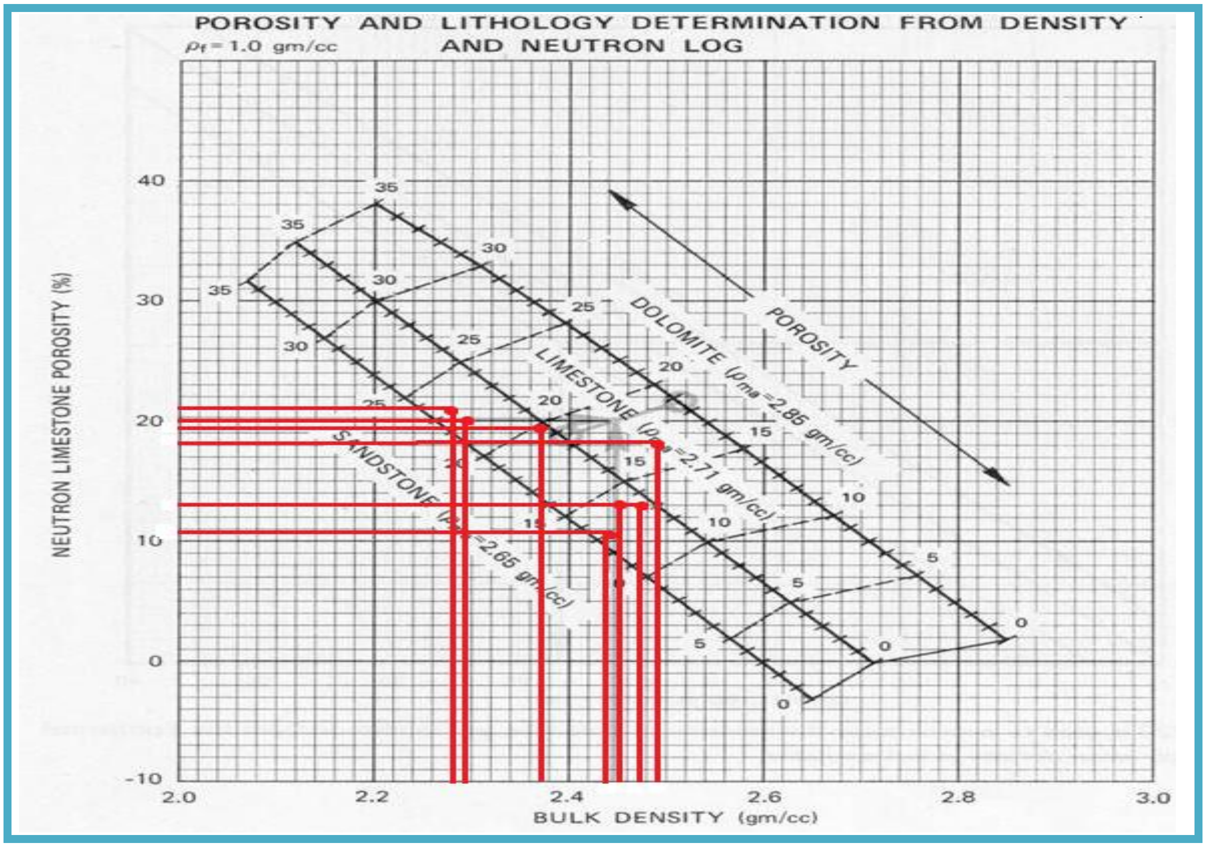

Fig.3.3. Determination of Lithology from Density and Neutron Log for Qadirpur Well # 17

3.3.3. Determination of Porosity

Porosity determines reservoir storage capacity. It is defined as the ratio of void space, commonly called pore volume, to bulk volume and is reported either as a fraction or percentage. Almost all hydrocarbon reservoirs are composed of sedimentary rocks in which porosity values generally vary from 10 to 40% in sandstone and from 5 to 25% in carbonates (Thompson and Woods, 1992). This part of the study presents the determination of porosity through various different log analyses. Subsection-1 includes determination of porosity from Density Log. Subsection-2 presents the determination of porosity from Neutron Log. Average porosity from Density and Neutron has been calculated and presented in subsection-3. Porosity from Sonic log is determined in subsection-4 while average porosity from neutron and sonic log is present in subsection-5.

3.3.3.1. Calculation of Porosity from Density Log

Density log is well log that records formation density. The logging tool consists of a gamma-ray source and a detector shielded from the source so that it records backscattered gamma rays from the formation. The backscattering depends on the electron density of the formation, which is roughly proportional to the bulk density. The source and detector usually are mounted on a skid which is pressed against the borehole wall. The compensated density logging tool includes a secondary detector which responds more to the mud cake and small, borehole irregularities. The response of the second detector is used to correct the measurements of the primary detector. The density log applies primarily to uncased holes

(Bateman, 1985). The Table 3.5 lists the densities (in g/cc) of a number of common formation minerals and fluids.

Table 3.5. Densities of a Number of Common Formation Minerals and Fluids

Matrix	**Density(g/mm)**	**Pore Fluid**	**Density(g/mm)**
Quartz	2.65	Fresh Water	1.00
Calcite	2.71	Salt water (200g/l)	1.13
Dolomite	2.87	F. Water+ 30% Oil	0.9-0.94
Rock Salt	2.03	F. Water+ 30% Oil	0.73-0.78

Shale often has matrix density similar to quartz so the porosity expression above can be used in shaly sands without knowledge of the relative volumes of shale and sand. As density tools investigate formation within 6 inches of the borehole wall the pore fluid (in reservoir intervals) is predominantly invading mud filtrate.

In a hydrocarbon bearing zone, the fluid in the invaded zone will be a mixture of mud filtrate, residual hydrocarbons and connate water. Density is a good method for determining either total or effective porosity in a single or multiple mineral, fluid-filled reservoirs (Thompson and Woods, 1992). The density log reading (ρ_b) is interpreted in terms of porosity (ø) of the formation using the following expression:

$$ø = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

ρ_{ma} = Density of the Matrix Material

ρ_f = Pore Fluid Density

Density of Matrix Material has been calculated and the resultant value is 2.71. Value of Pore fluid density is 1. Porosity plays an important role in production of the well. If the porosity (Ø) is greater than 6%, formation is regarded as productive formation (Ali *et al*, 2005). The resulted values of Porosity from the above mention equation are graphically presented in Fig.3.4. The graph is made for the values of Porosity for after every five meters depth of Qadirpur Well #17. The results for every meter are presented in the Table 1-A of Appendix.

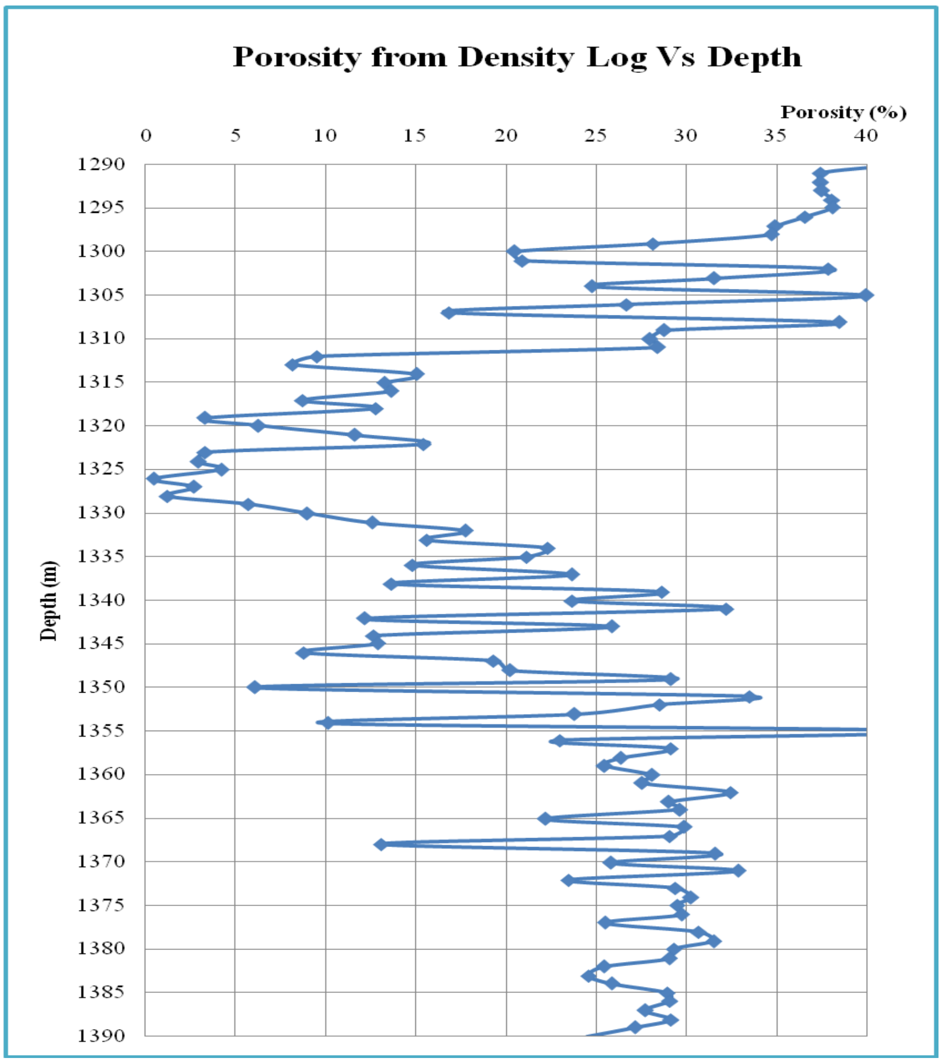

Fig.3.4. Porosity from Density Log vs Depth of Qadirpur Well # 17

3.3.3.2. Calculation of Porosity from Neutron Log

Neutron log is a log of a response primarily related to hydrogen concentration but also affected by mineralogy and borehole effects. The neutron log does not distinguish between the hydrogen in the pore fluids (i.e., water, oil, gas), or water bound to solid surfaces. In clean oil-filled or water-filled formations the apparent porosity reading of the neutron log reflects the amount of liquid-filled pore volume. Neutron log is useful to ascertain the presence of gas and determine mineralogy and shaliness (Bateman, 1985). The log porosity output is based on a sample limestone/freshwater model and is scaled in limestone porosity units. Accurate porosity values can be read from the log over water bearing zone limestone intervals. Gas and shale have particular marked effects on the log reading. Gas filled formation has a low hydrogen population (relative to water and oil) which the tool records as low apparent porosity (Thompson and Woods, 1992). The resulted values of Porosity from the Neutron Log are graphically presented in Fig.3.5. The graph is made for the percentage values of Porosity for after every five meters depth of Qadirpur Well #17, showing the distribution of porosity against the different depth values of zone of interest. The results for every meter are presented in the Table 1-A of Appendix.

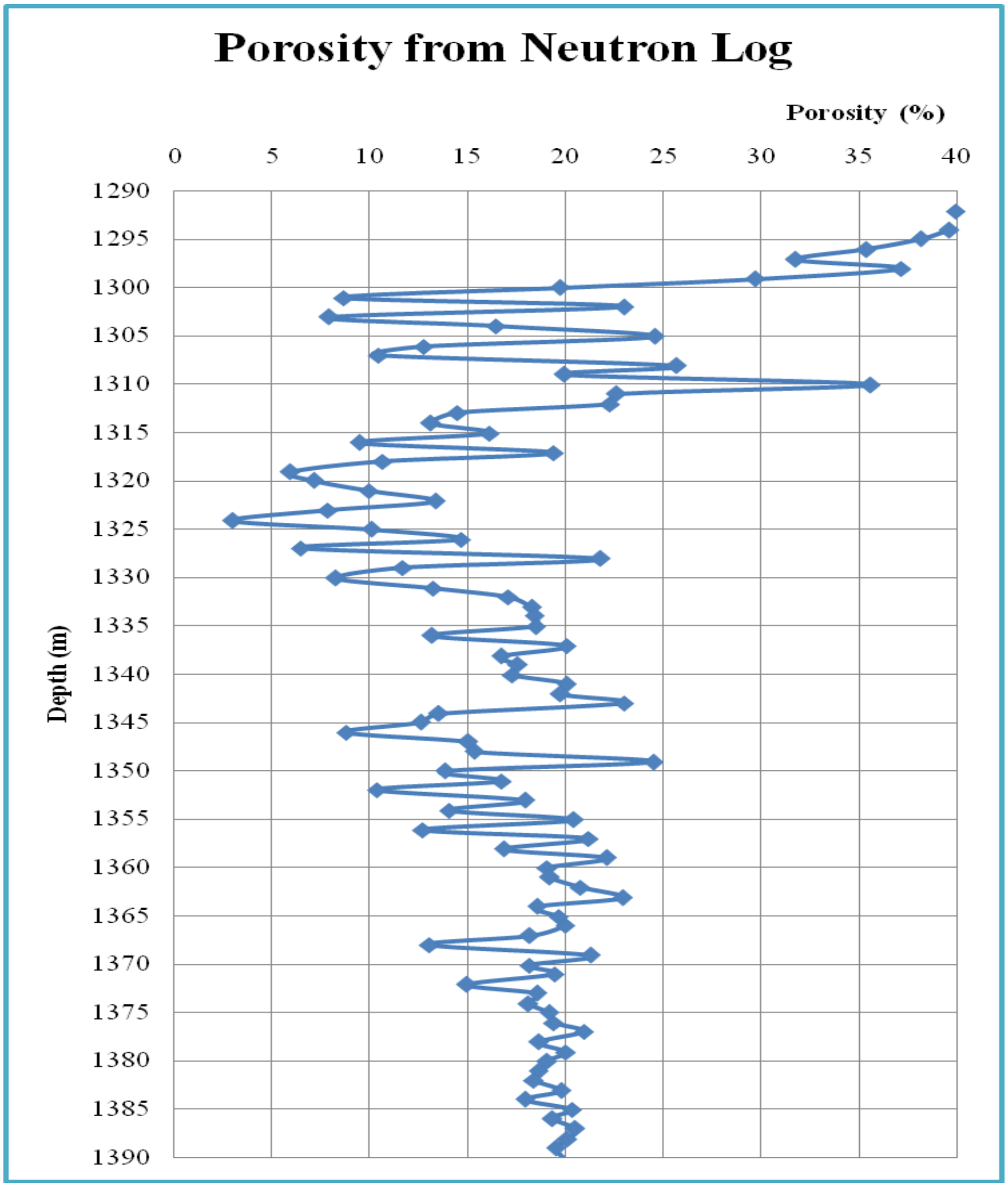

Fig.3.5. Porosity from Neutron Log Vs Depth of Qadirpur Well # 17

3.3.3.3. Calculation of Average Porosity from Neutron and Density Log

The combination of density and neutron logs is now used commonly as a means to determine porosity that is largely free of lithology effects. Each individual log records an apparent porosity that is only true when the zone lithology matches that used by the logging engineer to scale the log. A limestone-equivalent porosity is a good choice for both neutron and density logs, because calcite has properties that are intermediate between dolomite and quartz. By averaging the apparent neutron and density porosities of a zone, effects of dolomite and quartz tend to cancel out (Doveton, 1999). The true porosity may be estimated either by taking an average of the two log readings or by applying the equation:

$$\emptyset = \sqrt{\frac{\emptyset_n^2 + \emptyset_d^2}{2}}$$

Where $\emptyset_n^2$ and $\emptyset_d^2$ are neutron and density porosities. In the present study average of two log readings have been taken and the resultant values are graphically presented in Fig.3.6. The graph is made for the percentage values of Average of Porosity from Density and Neutron Log for every five meters depth of Qadirpur Well #17, showing the distribution of porosity against the different depth values of zone of interest. The results for every meter are presented in the Table 1-A of Appendix.

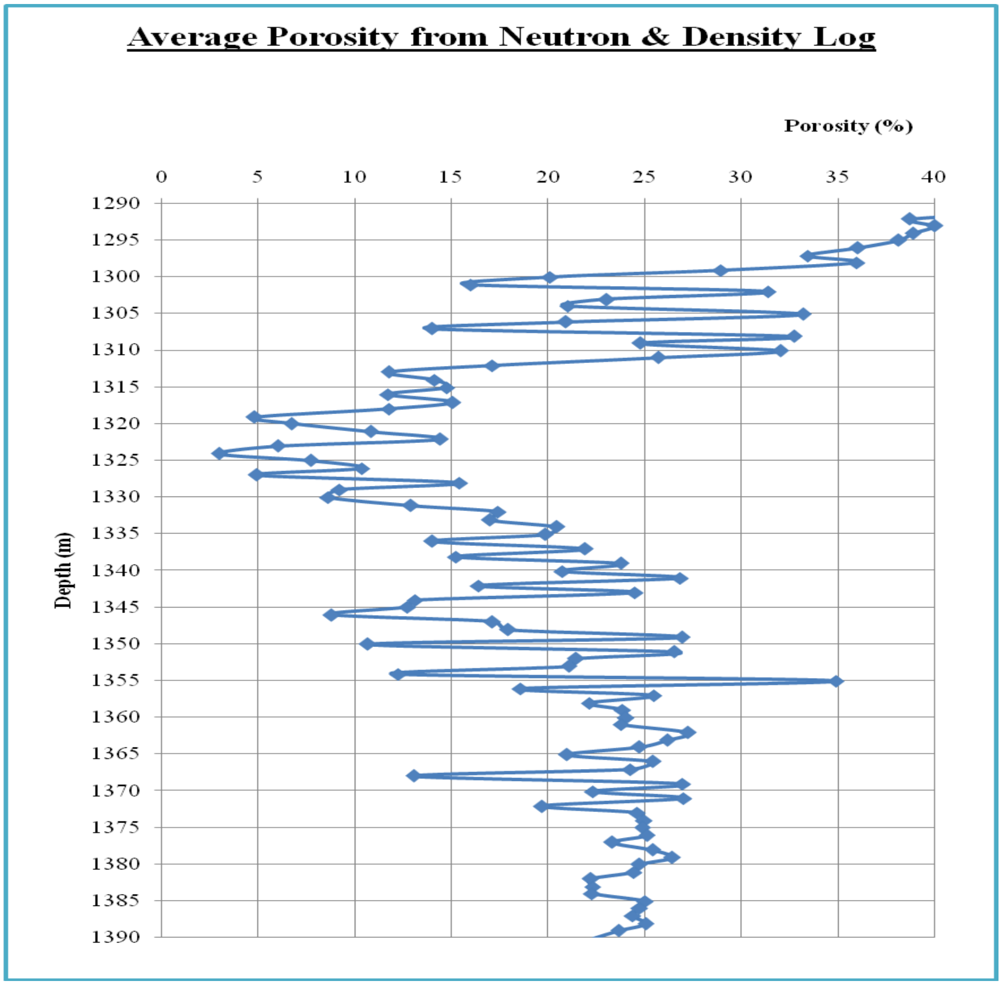

Fig. 3.6.Average Porosity from Neutron and Density Log Vs Depth of Qadirpur Well # 17

3.3.3.4. Calculation of Porosity from Sonic Log

A sonic log is a recording against the depth of the travel time of high frequency acoustic pulses through formation close to the borehole. This is done by measuring the pulse arrival time at two receivers spaced at different distances from an acoustic transmitter. By subtracting the transit time to the near receiver from that of the far receiver the acoustic velocity of the formation is defined over the interval between the receivers. The formation travel time measurement Δt can be interpreted in terms of the porosity of the formation according to Wyllie or time average equation (Wyllie *et al*, 1958), such that:

$$\phi = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_{fl} - \Delta t_{ma}}$$

Where, Δt is the zone transit time, $\emptyset$ is the porosity, Δt_{ma} is the matrix transit time, and Δt_{fl} is the pore fluid transit time. The computation of porosity requires the stipulation of a matrix mineral transit time.

Table 3.6. Travel Times for Formation Minerals and Fluids

Material	**Travel Time (μsec/ft)**
Sandstone Matrix	51-55.5 (Quartz:56)
Limestone Matrix	43.5-48 (Calcite:49)
Dolomite Matrix	38.5-43.5 (Dolomite:44)
Fresh water/Salt water	218/189
Oil	238
Casing	57

In the present study main focus is on Limestone and value of matrix transit time is 48 and pore fluid time is 189 as for salt water mud systems a fluid travel time Δt = 189 μ sec/ft can be used which assumes the formation investigated is entirely flushed with mud filtrate. This approach works well in consolidated water or oil bearing reservoirs, but is not suitable in unconsolidated water or oil bearing reservoirs, where the time average relationship breaks down. In unconsolidated formations poor grain contact increase transit times and corrections (compaction factor) must be applied to porosity calculations. This model assumes that the formation is made up of a homogenous mix of a rock matrix and pore fluid and that transit time is related to the proportion of each. Matrix and fluid travel times represents 0% to

100% porosity respectively and values between these extremes can be interpolated assuming a linear relationship, providing the acoustic properties of each medium is known (Thompson and Woods, 1992). The resulted values of Porosity from the Sonic Log are graphically presented in Fig.3.7. The results for every meter are presented in the Table 1-A of Appendix.

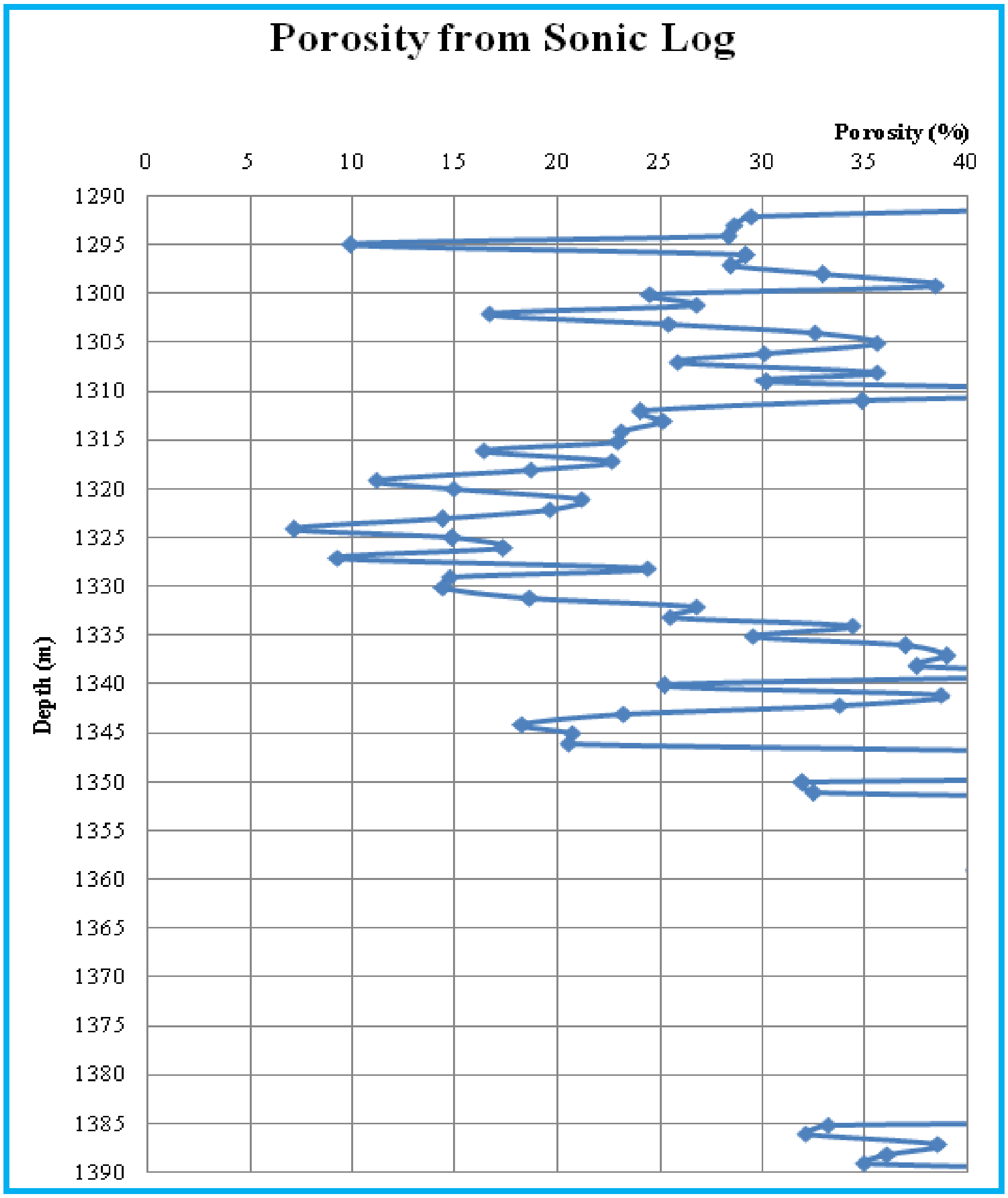

Fig.3.7. Porosity from Sonic Log Vs Depth of Qadirpur Well # 17

3.3.3.5. Calculation of Average Porosity from Neutron and Sonic log

The average of Porosity from Neutron and Sonic Log has been calculated and the results of calculation for every meter are presented in the Table 1-A of Appendix.

Calculation of porosity from various methods allowed us to have a comparative analysis. Analysis shows that method of calculating Average Porosity from Neutron and Density Log gives us the best results as it provides the more sensitivity to lithology, porosity, hydrocarbons and shaliness. Uncertain values of porosities indicated in the results are because of the fractured zone of the Sui Main Limestone (SML).

3.3.4.Calculation of Water Resistivity (by Archie Equation)

Marking a transition zone is a first step for the calculation of resistivity of water. From the available log data the transition zone begins from 1380 to 1390m and the gas water contact is at 1390m at the depth of 1390m value of Neutron Porosity is 0.20 (NPHI). If a clean, water-bearing zone is present or can be assumed, R_w can be calculated by using Archie equation. The zone of permeable bed in which water resistivity is determined is selected on log. This zone must be 100% water saturated and must not contain any clay or shale (Thompson and Woods, 1992).The bed must be thick so that the deep investigation resistivity device is not affected by the shoulders beds.

$$(S_w)^n = \frac{aR_w}{\emptyset^m R_t}$$

Lets assume for a, m, and n, the usual initial values of 1, 2, and 2, respectively. We have

$$(S_w)^2 = \frac{R_w}{\emptyset^2 R_t}$$

Therefore,

$$\mathbf{R_w = (S_w)^2 \emptyset R_t}$$

In water zone, $S_w = 1$, thus above equation becomes

$$\mathbf{R_w = \emptyset^2 R_t}$$

Where the value of $\emptyset$ is 0.2 and the value of true resistivity (R_t) of formation is taken from a deep Laterolog (LLD) is 3.78 at the depth of 1390m then the above mentioned equation becomes

$$\mathbf{R_w = (0.2)^2 x\ (3.78)}$$

$$\mathbf{R_w = 0.15}\ \text{Ohmm}$$

3.3.5.Calculation of Water Saturation (by Archie Equation)

Water saturation is an important factor in the quality of Reservoir. Generally if the water saturation is greater than 30% then it will not be a productive formation (Ali *et al*, 2005). Archie (1942) combined three measurable observations into one equation. By saturating a rock sample with the salt solutions of different salinities he found that the resistivity of the wet (water saturated) rock (R_0) was related to the resistivity of the saturating water (R_w) by the relation.

$$\mathbf{R_0 = F.R_w}$$

Where, 'F' is called a formation factor. This formation factor was found to vary predictably as the rock porosity changed, according to

$$\mathbf{F = a/ \Phi^m}$$

Where 'a' is constant, Φ is the porosity of the rock[1] and m is known as the cementation exponent. Therefore R_0 becomes:

$$\mathbf{R_0 = \frac{a\,Rw}{\Phi m}}$$

Lastly, Archie found that rocks at less than 100% water saturation with resistivity R_t obey the rule:

$$S_w^n = \frac{R_0}{R_t}$$

Where n is the saturation exponent. A combination of these relationships given Archie Equation:

$$S_w^n = \frac{aR_w}{\emptyset^m R_t}$$

The values of a, m and n, when they are unknown, can be set to the following general accepted value

Carbonates: a = 1 m = 2 n = 2

Thus final form of the water saturation Archie equation takes the following form:

$$\mathbf{S_w = \sqrt{\frac{R_w}{\emptyset^2\,R_t}}}$$

The resulted values of saturation of Water from the above mentioned equation are graphically presented in Fig.3.8. The graph is made for the percentage values of Water

[1] In the present study, Average Porosity from Neutron and Density Log has been taken for the determination of Saturation of water.

Saturation for after every five meters depth of Qadirpur Well #17, showing the saturation of water against the different depth values of the zone of interest. The results for every meter are presented in the Table 1-A of Appendix.

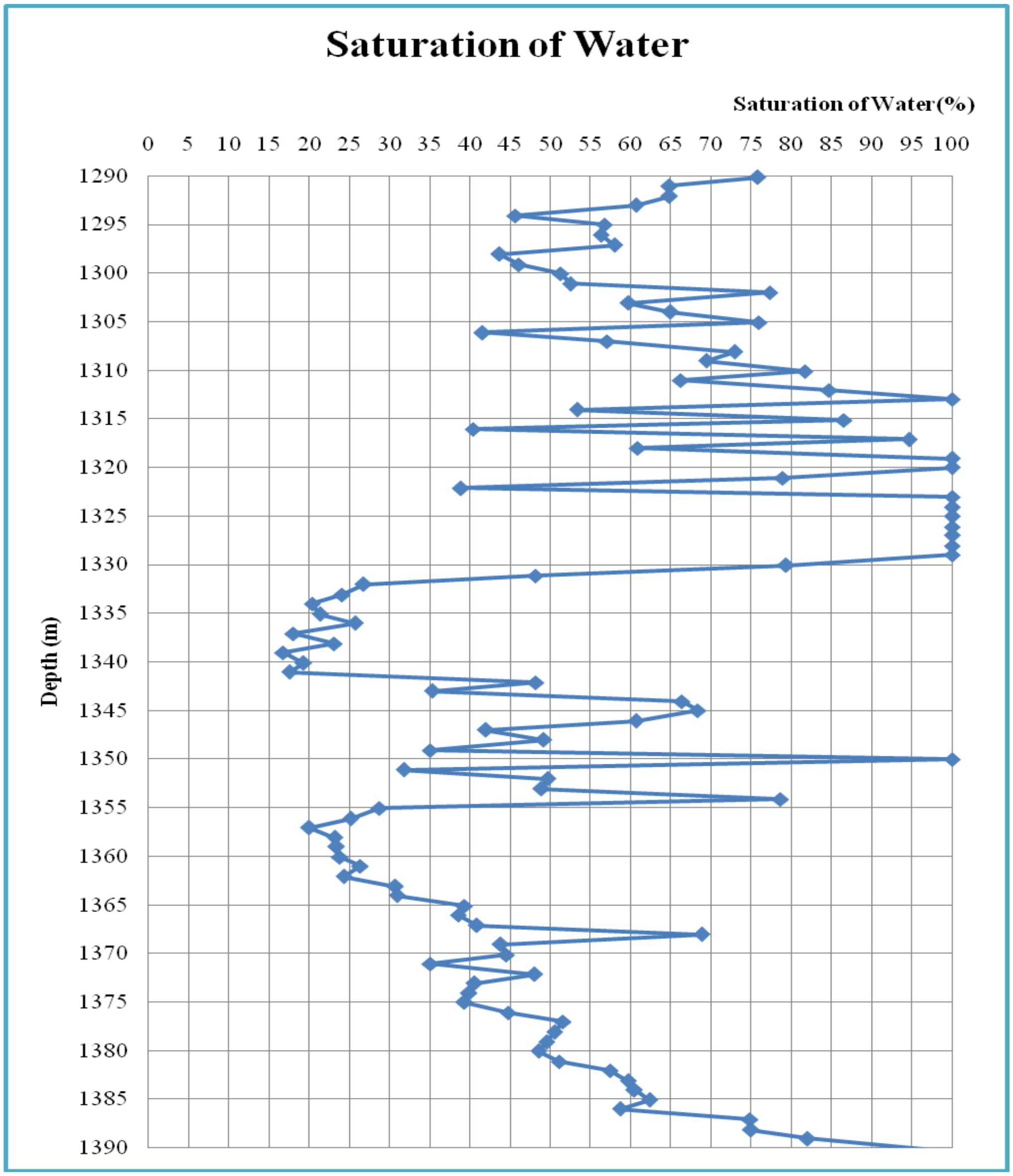

Fig.3.8.Saturation of Water Vs Depth of Qadirpur Well # 17

3.3.6.Calculation of Hydrocarbon Saturation

Hydrocarbon Saturation is calculated by following equation:

$$\text{Total fluid} = \text{Hydrocarbon} + \text{Water}$$

$$SH + Sw = 1$$

$$SH = 1 - Sw$$

The resulted values of saturation of Hydrocarbon from the above mentioned equation are graphically presented in Fig.3.9. The graph is made for the percentage values of Hydrocarbon Saturation for after every five meters depth of Qadirpur Well #17. Result shows that the maximum Saturation of Hydrocarbon is present between the depth intervals of 1332-1341m. In this interval maximum saturation of Hydrocarbon is 83.27% at the depth of 1339m and the minimum Saturation of Hydrocarbon 73.27% is present at depth of 1332m, for the interval between 1355-1364m maximum saturation of Hydrocarbon 80.02% is present at the depth of 1357m, while minimum Saturation of Hydrocarbon 69.08% is present at the depth of 1364m. The results for every meter are presented in the Table 1-A of Appendix.

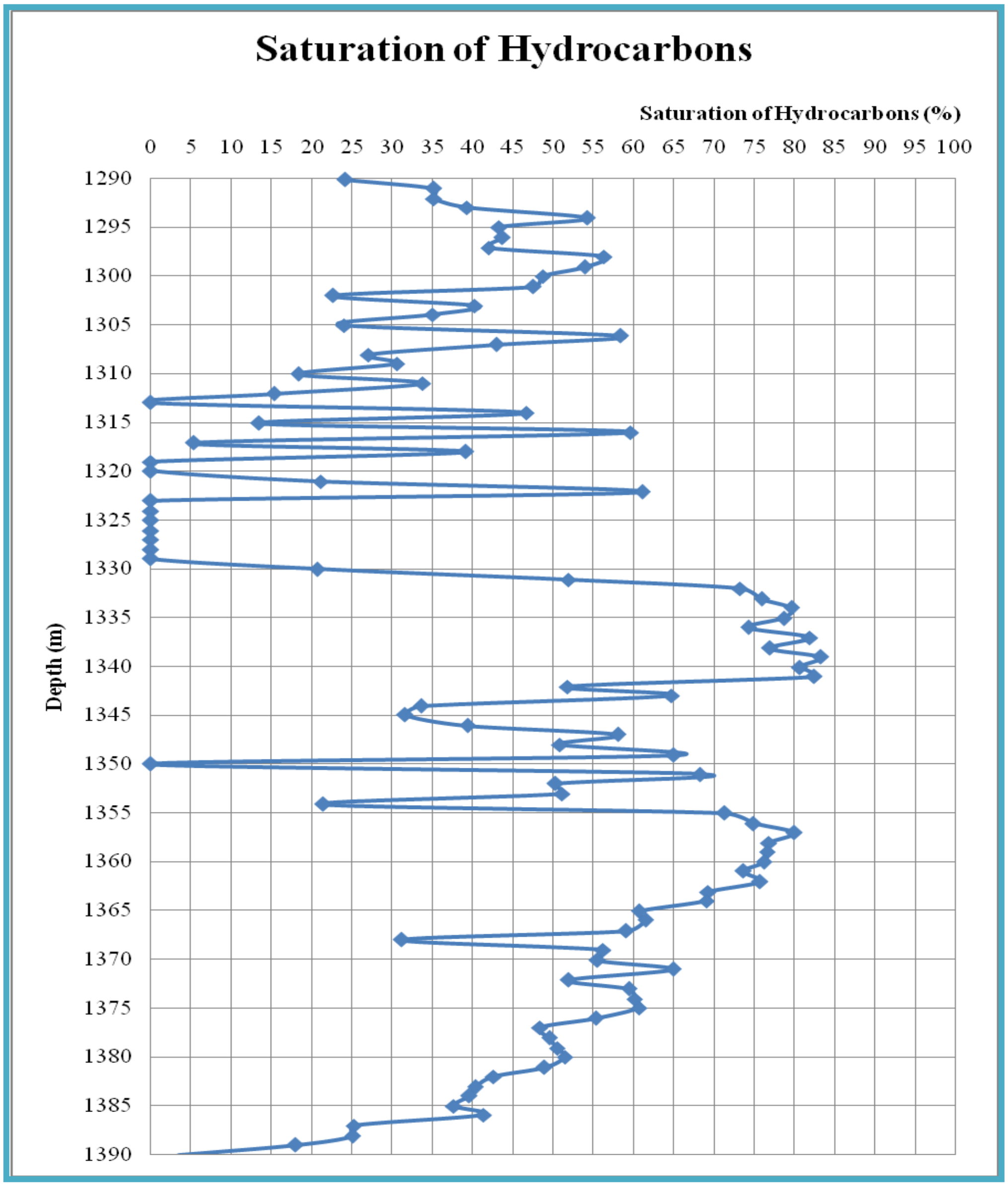

Fig. 3.9. Saturation of Hydrocarbons Vs Depth of Qadirpur Well #17

Conclusion

Petrophysical properties of reservoir generally include lithology, porosity, density, water resistivity, water saturation, and saturation of Hydrocarbons. In this study an effort has been made to review the stratigraphy of the Qadirpur Gas field Well #17. The analysis of petrophysical properties of Qadirpur Well #17 have also been a major objective of the study. The log data has been taken from Landmark Resources (LMKR). Initially raw data was available which has been digitized subsequently. Interval of 1290 to 1390m is the zone of interest of present study. Borehole analysis has been carried out for three different depth intervals.

Volume of shale has been calculated through the GR log. A general rule-of-thumb to differentiate the boundary for Limestone and shale has been adopted. Volume of shale is presented in the histogram. Result shows that the maximum volume of shale 86% is encountered at the depth of 1310m, while the minimum volume of shale 27% is present at the depth of 1346m. Formation or Lithology of the zone has been identified through Density-Neutron Log by marking different values of density and Neutron Log on a Density-Neutron cross plot chart. It is concluded that the reservoir lithology of Qadirpur Well # 17 is Sui Main Limestone.

Porosity of formation is calculated through three methods i.e. density, sonic and neutron log separately. Most of the resultant values of Porosity from Density log lie between the ranges of 5 to 35% with average porosity of 23%. Most of the values of Porosity from Neutron Log lie between the ranges of 5 to 25% with average porosity of 19%. Most Porosity values from

Sonic Log lies 10 to 40% with average porosity of 45%. Average of neutron and density log values has also been calculated i.e. 22%. Resistivity of water has been computed through Archie Equation Method i.e. 0.15 ohmm. Saturation of Hydrocarbon is calculated and resultant values shows that from 1332m to 1341m and from 1355m to 1362m the hydrocarbon saturation is more than 70%. Therefore, both of these zones can be concluded as the hydrocarbon bearing zone.

Appendix

Table 1-A. Results: Petrophysical Analysis of Qadirpur Well #17

Depth (m)	Vshale (%)	PHID (%)	NPHI (%)	PHIND (%)	PHIS (%)	PHISN (%)	SW (%)	SHC (%)
1290	63.37	41.73	55.28	48.98	119.08	87.18	75.84	24.16
1291	47.94	37.46	54.31	46.65	53.40	53.86	64.81	35.19
1292	38.35	37.44	39.91	38.70	29.50	34.71	64.80	35.20
1293	37.21	37.53	42.27	39.97	28.65	35.46	60.68	39.32
1294	43.58	38.06	39.60	38.84	28.37	33.98	45.68	54.32
1295	44.22	38.10	38.13	38.11	9.89	24.01	56.70	43.30
1296	32.25	36.60	35.37	35.99	29.22	32.29	56.30	43.70
1297	34.03	34.95	31.76	33.39	28.44	30.10	58.00	42.00
1298	48.23	34.71	37.15	35.95	32.91	35.03	43.66	56.34
1299	29.96	28.14	29.67	28.92	38.44	34.05	46.05	53.95
1300	14.92	20.47	19.69	20.08	24.54	22.11	51.31	48.69
1301	24.17	20.91	8.66	16.00	26.81	17.73	52.47	47.53
1302	67.59	37.90	22.98	31.34	16.67	19.82	77.32	22.68
1303	25.06	31.55	7.90	23.00	25.46	16.68	59.71	40.29
1304	27.34	24.75	16.40	20.99	32.55	24.48	64.93	35.07
1305	64.50	39.99	24.53	33.18	35.60	30.07	76.00	24.00
1306	23.19	26.67	12.71	20.89	30.07	21.39	41.58	58.42
1307	15.82	16.84	10.45	14.01	25.89	18.17	57.04	42.96
1308	62.42	38.46	25.67	32.70	35.60	30.64	72.93	27.07
1309	49.10	28.77	19.94	24.75	30.18	25.06	69.42	30.58
1310	86.11	27.98	35.57	32.00	49.01	42.29	81.69	18.31
1311	85.53	28.42	22.59	25.67	34.86	28.72	66.22	33.78
1312	48.63	9.49	22.25	17.10	24.04	23.15	84.69	15.31
1313	26.60	8.13	14.47	11.74	25.18	19.82	100.00	0.00
1314	7.23	15.04	13.10	14.10	23.12	18.11	53.35	46.65
1315	41.74	13.26	16.09	14.74	22.98	19.53	86.57	13.43
1316	2.80	13.61	9.45	11.72	16.38	12.92	40.35	59.65
1317	29.42	8.73	19.40	15.04	22.62	21.01	94.67	5.33
1318	12.83	12.75	10.62	11.74	18.72	14.67	60.85	39.15
1319	10.67	3.30	5.93	4.80	11.21	8.57	100.00	0.00
1320	12.02	6.25	7.12	6.70	14.96	11.04	100.00	0.00
1321	19.29	11.61	9.93	10.80	21.21	15.57	78.90	21.10
1322	9.92	15.40	13.34	14.41	19.65	16.49	38.89	61.11
1323	14.29	3.30	7.85	6.02	14.36	11.11	100.00	0.00
1324	9.11	2.92	2.99	2.96	7.16	5.08	100.00	0.00
1325	43.53	4.19	10.06	7.71	14.89	12.48	100.00	0.00

Depth (m)	Vshale (%)	PHID (%)	NPHI (%)	PHIND (%)	PHIS (%)	PHISN (%)	SW (%)	SHC (%)
1326	37.36	0.44	14.62	10.34	17.38	16.00	100.00	0.00
1327	6.87	2.68	6.43	4.93	9.29	7.86	100.00	0.00
1328	58.24	1.22	21.76	15.41	24.40	23.08	100.00	0.00
1329	36.23	5.70	11.68	9.19	14.75	13.22	100.00	0.00
1330	9.85	8.96	8.24	8.61	14.43	11.34	79.32	20.68
1331	14.89	12.56	13.20	12.88	18.65	15.93	48.10	51.90
1332	15.14	17.74	17.04	17.39	26.81	21.92	26.73	73.27
1333	7.98	15.58	18.26	16.98	25.50	21.88	24.04	75.96
1334	9.80	22.28	18.38	20.42	34.40	26.39	20.34	79.66
1335	7.39	21.13	18.47	19.84	29.54	24.00	21.31	78.69
1336	5.23	14.81	13.15	14.01	36.95	25.05	25.69	74.31
1337	20.23	23.63	20.02	21.90	39.01	29.51	18.05	81.95
1338	9.74	13.64	16.69	15.24	37.52	27.10	23.06	76.94
1339	9.37	28.63	17.54	23.74	46.24	31.89	16.73	83.27
1340	6.63	23.68	17.26	20.72	25.25	21.25	19.28	80.72
1341	16.65	32.19	20.03	26.81	38.72	29.38	17.51	82.49
1342	51.45	12.18	19.71	16.38	33.76	26.73	48.20	51.80
1343	9.38	25.87	22.97	24.46	23.26	23.12	35.28	64.72
1344	36.61	12.65	13.50	13.08	18.30	15.90	66.39	33.61
1345	23.13	12.87	12.58	12.73	20.71	16.64	68.38	31.62
1346	0.28	8.80	8.76	8.78	20.57	14.66	60.65	39.35
1347	37.73	19.30	15.00	17.12	48.19	31.60	41.94	58.06
1348	34.38	20.22	15.31	17.94	72.55	43.93	49.18	50.82
1349	19.22	29.14	24.46	26.90	80.89	52.67	34.98	65.02
1350	25.49	6.06	13.82	10.67	31.99	22.90	100.00	0.00
1351	30.93	33.53	16.71	26.49	32.48	24.60	31.75	68.25
1352	29.62	28.51	10.33	21.44	59.08	34.70	49.67	50.33
1353	25.01	23.80	17.90	21.06	60.99	39.45	48.85	51.15
1354	22.55	10.12	14.03	12.23	52.41	33.22	78.60	21.40
1355	14.28	44.88	20.42	34.86	73.33	46.88	28.71	71.29
1356	21.69	22.99	12.68	18.57	65.18	38.93	25.11	74.89
1357	15.89	29.12	21.16	25.45	43.69	32.42	19.98	80.02
1358	12.30	26.35	16.83	22.11	64.18	40.51	23.18	76.82
1359	9.93	25.46	22.09	23.83	40.14	31.12	23.40	76.60
1360	7.95	28.11	19.02	24.00	74.18	46.60	23.78	76.22
1361	13.14	27.57	19.18	23.75	112.91	66.04	26.35	73.65
1362	16.00	32.44	20.75	27.23	113.33	67.04	24.31	75.69
1363	13.58	29.04	22.90	26.15	183.97	103.44	30.70	69.30

Depth (m)	Vshale (%)	PHID (%)	NPHI (%)	PHIND (%)	PHIS (%)	PHISN (%)	SW (%)	SHC (%)
1364	19.65	29.65	18.52	24.72	180.21	99.37	30.91	69.09
1365	19.14	22.20	19.62	20.95	128.09	73.85	39.30	60.70
1366	17.47	29.89	19.97	25.42	102.34	61.16	38.51	61.49
1367	21.35	29.07	18.14	24.23	145.11	81.62	40.88	59.12
1368	26.58	13.06	13.01	13.04	86.88	49.94	68.84	31.16
1369	21.16	31.57	21.27	26.92	142.34	81.81	43.79	56.21
1370	17.71	25.82	18.13	22.31	175.82	96.97	44.51	55.49
1371	20.98	32.88	19.42	27.00	149.08	84.25	35.08	64.92
1372	19.86	23.46	14.96	19.67	127.30	71.13	48.07	51.93
1373	17.17	29.42	18.54	24.59	91.91	55.23	40.55	59.45
1374	15.28	30.27	18.08	24.93	97.94	58.01	39.85	60.15
1375	15.78	29.49	19.13	24.86	132.80	75.97	39.30	60.70
1376	10.58	29.73	19.39	25.10	116.24	67.82	44.71	55.29
1377	18.48	25.50	20.92	23.32	110.92	65.92	51.60	48.40
1378	14.34	30.70	18.62	25.39	64.61	41.61	50.49	49.51
1379	11.91	31.53	20.01	26.41	74.47	47.24	49.51	50.49
1380	11.38	29.32	19.04	24.72	117.23	68.14	48.54	51.46
1381	11.38	29.07	18.60	24.40	56.74	37.67	51.05	48.95
1382	15.02	25.42	18.37	22.18	116.45	67.41	57.40	42.60
1383	17.18	24.56	19.76	22.29	101.77	60.77	59.69	40.31
1384	13.80	25.86	17.90	22.24	87.09	52.50	60.43	39.57
1385	11.58	28.94	20.29	24.99	33.19	26.74	62.34	37.66
1386	16.64	29.10	19.32	24.70	32.13	25.72	58.68	41.32
1387	12.26	27.72	20.49	24.37	38.58	29.54	74.81	25.19
1388	18.13	29.16	20.07	25.03	36.10	28.08	74.95	25.05
1389	13.03	27.15	19.48	23.63	34.96	27.22	82.04	17.96
1390	9.41	24.49	19.87	22.30	54.96	37.42	96.53	3.47

References:

Ahmed H., Cheema M.R., Fatmi A.N., Iqbal M.W.A., Raza H.A., Raza S. M., and Shah S.M.I. (1977), 'Memoirs of Geological Survey of Pakistan', Geological Survey of Pakistan, Vol. 12.

Ali A.,Ahmad Z., and Akhtar G. (2005), 'Structural Interpretation of Seismic Profiles Integrated with Reservoir Characteristics of Qadirpur Area', Pakistan Journal of Hydrocarbon Research, Vol.15, pp.25-34.

Archie, G.E. (1942), 'The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics', Petroleum Transactions of AIME, Vol. 146.

Asquith G. and Krygowski D. (2004), 'Basic Well Log Analysis and AAPG Methods in Exploration', Vol. 16, Chapter 3: Gamma Ray, pp. 31 – 35.

Bateman R.M (1985), 'Open Hole Log Analysis and Formation Evaluation', International Human Resources Development Corporation, Newberry Street Boston USA, pp. 439-450.

Crain E.R. (1986), 'Log Analysis Handbook', Penn Well Books, Penn Well Publishing, Tulsa Oklahoma USA, Vol. 1, pp. 250 – 300.

Doveton J. H. (1999), 'Basics of Oil and Gas Log Analysis', Kansas Geological Survey Vol. 2, pp. 8-9.

Eckhoff G. and Alam S. (1991), 'Project report "On the petroleum geology and prospectivity of Kirthar Range, Kirthar Depression and Sibi Trough, Southern Indus Basin, Pakistan.

Pakistan Petroleum Limited (2010), http://www.ppl.com.pk.

Qadri I. B. (1995), 'Petroleum Geology of Pakistan', published by Pakistan Petroleum Limited,pp. 250.

Siddique, N.U. (2004), 'Sui Main Limestone: Regional Geology and Analysis of Original Pressures of a Close-system Reservoir in Central Pakistan' AAPG Bulletin, Vol. 88, No. 7, pp. 1015.

Thompson M.D. and Woods A.M. (1992), 'Standard Interpretations Development Geology Reference Manual', the American Association of Petroleum Geologists Vol. 4, pp.181.

Wyllie M.R.J., Gregory A.R., and Gardner G.H.F.(1958), 'An Experimental Investigation of Factors Affecting Elastic Wave Velocities in Porous Media', Geophysics, Vol. 23, pp. 459-493.