PETROPHYSICAL ANALYSIS OF MARI DEEP-06 WELL, MARI GAS FIELD, MIDDLE INDUS BASIN PAKISTAN

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

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ABSTRACT

The aim of this study is to check the reservoir potential of Mari Deep 06 well in Middle Indus Basin. The study concerned with reservoir potential evaluation using petrophysical approach. The approach involves identifying, marking, analyzing, and interpreting the reservoir zones from the well logs and by using different formulas. Several well logs were used such as sonic log, gamma ray log, density log, neutron log and resistivity logs. The petrophysical parameters such as Vsh, total porosity, water saturation, effective porosity, hydrocarbon saturation was accessed from wireline logs.

The best possible reservoir in the well is Habib Rahi Limestone having a good net pay thickness of 279 feet. Based on well log data, this reservoir is classified as excellent reservoirs owing to their high effective porosity and hydrocarbon saturation.

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With the grace of Almighty ALLAH, we have been able to overcome yet another task which was impossible without ALLAH's blessings.

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CHAPTER 1
INTRODUCTION

Mari gas field is in Daharki, District Ghotki, Sindh. It extends in North of Sukkur to about 96 kilometers. This field was discovered by Esso Eastern Inc (EEI) in 1957. One of the first well was also discovered in 1957 named as Mari X-1 with a total depth of 11110 feet (Kadri & I. B, 1995). This well produced gas in the lower Kirthar formation, commonly known as Habib Rahi Limestone. The field area is situated in the Middle Indus Basin, structurally known as Mari-Kandkhot High, which was formed in late cretaceous period as a result of tectonism which was extensional in nature.

1.1 Objective

The main aim of the study was:

(i) To estimate porosity, water saturation, and permeability from the study wells.
(ii) To estimate the volume of shale of the wells.
(iii) To delineate hydrocarbon bearing zones of the reservoir wells.
(iv) To estimate the thickness (pay zone) of hydrocarbon bearing zones.
(v) To estimate reservoir statistics parameters such as gross reservoir thickness, net pay zone.

1.2 Location of study area

The field area (Mari gas) is situated in Daharki, District Ghotki, Sindh. This field extends in North of Sukkur to about 96 kilometers. Mari structure is located in Middle Indus basin. This area is a Thar platform which gently slopes westwards (Ehsan et al., 2018). The study area is having coordinates 27° 56’ 35” N, 69° 44’ 42” E. The location of the well area is shown in figure 1.1.

Figure 1.1 Location map of study area (Survey of Pakistan).

1.3 Climate

As Sindh is a thermal region, so it hot in the summer and cold in the winters. In summers, the districts which are in the northern part of the district are hotter than the other parts of the districts.

1.4 Datasets used in present study

The logs were taken by the approval of DGPC from LMKR. The data was a log data of Mari Deep-06 which was used for petrophysical analysis.

1.4.1 Well data

Directorate General of Petroleum Concession (DGPC) provided the data of Mari Deep 06 well which compromise of the following logs:

Table 1.1. Available well data.

1	**Gamma ray (GR) log**
2	Spontaneous Potential (SP) log
3	Caliper log
4	Resistivity logs (MSFL, LLS, LLD)
5	Density log
6	Neutron log
7	Sonic log

CHAPTER 2

GEOLOGTY AND TECTONICS

2.1 Introduction

Pakistan's Sedimentary basins comprise of 827,000 km^2. This sedimentary area is divided into three basins named as Indus Basin, Baluchistan Basin and Pishin Basin. In the age of Cretaceous and Paleocene an amalgamation of Indus Basin and Baluchistan Basin had occurred. In this process Chaman and Ornach Nal fault were also under influence and got affected (Morton-Thompson et al., 1993). There is also third basin in Pakistan which is known as Khorasan basin or Pishin Basin formed due to the interaction of Indian and Eurasian Plate.

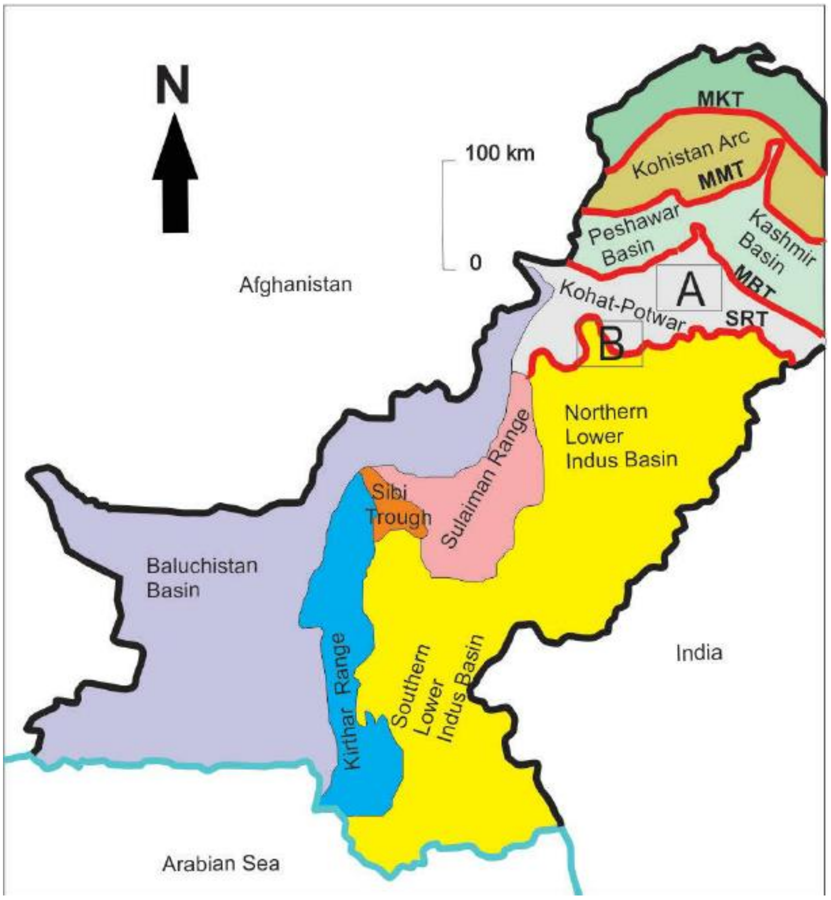

Figure 2.1 Map showing Basins of Pakistan (Niamatullah & Imran, 2012).

2.2 Introduction to Indus Basin

The Indus Basin is largest basin of Pakistan. Its oldest formation is of Precambrian age. The Rocks and formations that have been upraised in Salt Range

Pakistan are generally considered of Precambrian or Permian age. During Indian plate movement different activities occurred like interacratonic activity which results into the formation of Indus basin formation. This basin covers an area of 873,000 (km^2). Indian shield whose topographic high occurs in the form of Nagar Parkar Ridge and Kirana Hills, was controlling sedimentation of Indus Basin till Jurassic. Fold belt regime has southwestern Kohat Plateau along with Northern boundary of Indian Plate. It also has Western Boundary which includes Sulaiman and Kirthar Ranges. This basin is divided into three parts which includes Upper part, Middle part and Lower part of the main basin. Sargodha Highs are separation point in between Upper and Middle while and Mari-Kandhot separates and divides Middle Indus Basin to Lower Indus Basin (Kadri, 1995).

Table 2.1. Stratigraphy of Pakistan (Kadri, 1995).

AGE		UPPER INDUS BASIN: SUB BASIN/ FROMATION			SOUTHERN/ CENTRAL BASIN/ FORMATIONS		BALOCHISTAN BASIN BASIN/ FORMATIONS
			POTWAR	KOHAT	KIRTHAR	SULAIMAN	
	PLEISTOCENE		LEI CONGLUMERATE (CONG)		LIE CONGLUMERATE (CONG)		JIWANI; ORMARA; CHATTI
TERTIARY	PLIOCENE	SIWALIKS GROUP	SOAN (Cl,Sst)		SIWALIKS GROUP (Sst)		TALAR
TERTIARY	PLIOCENE	SIWALIKS GROUP	DHOK PATHAN (Cl,Sst)	DHOK PATHAN (Cl,Sst)	SIWALIKS GROUP (Sst)		HINGLAJ
TERTIARY	MIOCENE	SIWALIKS GROUP	NAGRI (Sst)	NAGRI (Sst)	GAJ FORMATION (Sst,Sh,Ls)		PARKINI
TERTIARY	MIOCENE	SIWALIKS GROUP	CHINJI (Sst,Sh)	CHINJI (Sst,Sh)	GAJ FORMATION (Sst,Sh,Ls)		PARKINI
TERTIARY	MIOCENE	RAWALPINDI GROUP	KAMLIAL (Sst)	KAMLIAL (Sst)	GAJ FORMATION (Sst,Sh,Ls)		PANJGUR
TERTIARY	MIOCENE	RAWALPINDI GROUP	MUREE (Sst,Cl)	MUREE (Sst,Cl)	GAJ FORMATION (Sst,Sh,Ls)		PANJGUR
TERTIARY	OLIGOCENE				NARI FORMATION (Ls,Sst)		HOSHAB; SIAHAN; AMALAF
TERTIARY	EOCENE				KIRTHAR FM	DRANZINDA MEMBER (Cl)	SAINDAK; WAHAI MEMBER
TERTIARY	EOCENE				KIRTHAR FM	PIRKOH MEMBER (Ls)	SAINDAK; WAHAI MEMBER
TERTIARY	EOCENE	CHHARAT GROUP		KOHAT FM (Ls)	KIRTHAR FM	DOMANDA MEMBER (Cl)	SAINDAK; WAHAI MEMBER
TERTIARY	EOCENE	CHHARAT GROUP		KULDANA (Cl)	KIRTHAR FM	HABIB RAHI FM (Ls)	SAINDAK; WAHAI MEMBER
TERTIARY	EOCENE	CHHARAT GROUP	CHORGALI	JATTA GYP	KIRTHAR FM	BASKA SHALE	SAINDAK; KHARAN MEMBER
TERTIARY	EOCENE	CHHARAT GROUP	SAKESAR	SHEKHAN (Ls); BAHADUR KHEL SALT	LAKI FM (Ls)	GHAZIJ FM (Sh)	SAINDAK; KHARAN MEMBER
TERTIARY	EOCENE	CHHARAT GROUP	NAMMAL	PANOBA SH; BAHADUR KHEL SALT	SUIMAN LIMESTONE	SUIMAN LIMESTONE	SAINDAK; KHARAN MEMBER
TERTIARY	PALEOCENE	CHHARAT GROUP	PATALA FM (Sh,Ls)	PATALA FM (Sh,Ls)	LAKHRA FM (Ls,Sh)	DUNGHAN FM (Ls)	ISPIKAN MEMBER (CONG)
TERTIARY	PALEOCENE	CHHARAT GROUP	LOCKHART (Ls)	LOCKHART (Ls)	BARA FM	DUNGHAN FM (Ls)	
TERTIARY	PALEOCENE	CHHARAT GROUP	HANGU FM (S.st)	HANGU FM (S.st)	KHADRO FM (Sst)	RANIKOT (Sst,Ls)	RAKHSHANI
CRETACEOUS	LATE				PAB SANDSTONE (Sst)	PAB SANDSTONE (Sst)	HUMAI
CRETACEOUS	LATE			KAWAGARH (Ls)	FORT MUNRO MEMBER (Ls	FORT MUNRO MEMBER (Ls	SINJRANI
CRETACEOUS	LATE				MOGHALKOT Fm (Sst,Ls,Sh)	MOGHALKOT Fm (Sst,Ls,Sh)	SINJRANI
CRETACEOUS	EARLY				PARH FORMATION (Ls)	PARH FORMATION (Ls)	SINJRANI
CRETACEOUS	EARLY		LUMSHIWAL (S.st,Slt.st)	LUMSHIWAL (S.st,Slt.st)	GORU FORMATION (Sst,Sh)	GORU FORMATION (Sst,Sh)	SINJRANI
CRETACEOUS	EARLY		CHICHALI (Slt.st, Cl)	CHICHALI (Slt.st, Cl)	SEMBAR FORMATION	SEMBAR FORMATION	SINJRANI
JURASSIC	LATE						NOT EXPOSED OR DRILLED
JURASSIC	MIDDLE		SAMANA SUK FM (Ls)	SAMANA SUK FM (Ls)	MAZAR DRIK (Sh)	MAZAR DRIK (Sh)	NOT EXPOSED OR DRILLED
JURASSIC	MIDDLE		SHINAWARI FM (Sst,Ls,Sh)	SHINAWARI FM (Sst,Ls,Sh)	CHILTAN FORMATION (Ls)	CHILTAN FORMATION (Ls)	
JURASSIC	EARLY		DATTA FM (Sh)	????	SHIRINAB FORMATION (Sst,Ls)	SHIRINAB FORMATION (Sst,Ls)	
TRIASSIC	LATE		KINGRIALI FM (Dol)	KINGRIALI FM (Dol)	WULGAI FORMATION (Sst,Sh,Ls)	WULGAI FORMATION (Sst,Sh,Ls)	
TRIASSIC	MIDDLE		TRIDIAN FM (Sst,Sh,Dol)	????	WULGAI FORMATION (Sst,Sh,Ls)	WULGAI FORMATION (Sst,Sh,Ls)	
TRIASSIC	EARLY		MIANWALI FM (Sst,Ls,Sh)	????	WULGAI FORMATION (Sst,Sh,Ls)	WULGAI FORMATION (Sst,Sh,Ls)	
PERMIAN	LATE	ZALUCH GROUP	CHHIDRU FM (S.st, L.st)	CHHIDRU FM (S.st, L.st)	NOT EXPOSED OR DRILLED	NOT EXPOSED OR DRILLED	
PERMIAN	LATE	ZALUCH GROUP	WARGAL FM (L.st)	WARGAL FM (L.st)	NOT EXPOSED OR DRILLED	NOT EXPOSED OR DRILLED	
PERMIAN	EARLY	ZALUCH GROUP	AMB FM (S.st, Ls)	AMB FM (S.st, Ls)	NOT EXPOSED OR DRILLED	NOT EXPOSED OR DRILLED	
PERMIAN	EARLY	NILAWAHAN GROUP	SARDHAI FM (Cl)	SARDHAI FM (Cl)	NOT EXPOSED OR DRILLED	NOT EXPOSED OR DRILLED	
PERMIAN	EARLY	NILAWAHAN GROUP	WARCHHA FM (S.st)	WARCHHA FM (S.st)	NOT EXPOSED OR DRILLED	NOT EXPOSED OR DRILLED	
PERMIAN	EARLY	NILAWAHAN GROUP	DANDOT FM (Cl, S.st)	DANDOT FM (Cl, S.st)	NOT EXPOSED OR DRILLED	NOT EXPOSED OR DRILLED	
PERMIAN	EARLY	NILAWAHAN GROUP	TOBRA FM (S.st, Congl)	TOBRA FM (S.st, Congl)	NOT EXPOSED OR DRILLED	NOT EXPOSED OR DRILLED	
CARBONIFEROUS TO ORDOVICIAN							
CAMBRIAN	LATE						
CAMBRIAN	MIDDLE	JHELUM GROUP	BAGHANWALA FM (shl)	KHISOR FM (Dol,gyp,anh,shl)			
CAMBRIAN	MIDDLE	JHELUM GROUP	JUTANA FM (Dol)	KHISOR FM (Dol,gyp,anh,shl)			
CAMBRIAN	MIDDLE	JHELUM GROUP	KUSSAK FM (s.st, slt.st)	KUSSAK FM (s.st, slt.st)			
CAMBRIAN	EARLY	JHELUM GROUP	KHEWRA SANDSTONE	KHEWRA SANDSTONE			
PRE-CAMBRIAN			SALT RANGE FM (salt, gyp,anh) crystalline Basement	????????			

There are three main divisions of Indus Basin which are as under:

(i) Lower Indus Basin

(ii) Middle Indus Basin

(iii) Upper Indus Basin

2.3 Lower Indus Basin

Geographically, It is part of the Sindh province of Pakistan. The basin has four subdivisions. Kirthar Fold Belt, Lower Indus Platform, Kirthar fore deep and Indus offshore. It is considered as a result of crustal feature linked with inferred fossil rift. It is present beneath the sedimentary sediments and sequences. The divergence in

Indo Pakistan subcontinent is the main cause of abovementioned extension. This separation occurs in early Paleozoic. Horst and graben structures are responsible for characterizing features related to fossil rift that is obtained from magnetic anomaly trend. There is also a system of transcurrent faults. Horst blocks are present in Jacobabad, Mari Kandkhot and Lakhra highs. It is mainly thought that the Separation between Indo-Pakistan and Madagascar resulted into the formation of these structures. Indian and Eurasian Plate convergent result in transpression which caused inversion and superimposition of transform style. Examination of the Crustal features belongs to the basement and the different Seismic events suggest that individual units activated third time (Ahmed et al., 2015). The sequence of the Indus basin is the result of deformation occurred due to Rift structures. The proposed geological model suggests potential for environment of deposition of hydrocarbons for thermally matured source rocks, and structures for seal as well as reservoir. The rifting phenomenon from Gondwanaland in the Indian plate are the major happenings of tectonism and certainly controlling source of sedimentation in the Lower part of the Indus basin. In the early cretaceous age these controlling factors starts tilting and uplifting in the Indian plate. It was cretaceous age in which Indian plate separated from the Madagascar plate and it observed different folding, faulting and hotspot activities which raised and eroded the flood basalts in the area. Normal faults are striking in the North to Northwest direction.

Bela-Ophiolites of caused gentle folding. Structural quiescence and carbonate deposition occurred ion Eocene. Sinistral transpression occurred due to Himalayan collision. There are fold thrust structures in the western direction of Lower Portion of Indus Basin. Carbonates and Recent Deposits of Infra Cambrian are at the depth of the discussed tectonic region. It is now considered as a part of suture zone, as it was a passive margin before., separating Indian and Afghan plate. Sedimentation from thinner to thicker side in the west direction increased. At the ending portion of the basin Stratgraphical sequences changes rapidly. Permian-Tertiary age is famous for unconformities identified at the basement. Jurassic sequence in eastern part of the basin has Tertiary contact. Stratigraphy of southern Indus Basin include Kirthar fold belt, Lower Indus Platform, Kirthar foredeep and Indus Offshore (Ahmed et al., 2015).

In the North-South direction there is tectonic feature shows similarities with Sulaiman Fold Belt named as Kirthar Fold Belt. It has similarities both in stratigraphic and tectonic frames. Petroleum systems are well established in clastic rocks that includes Mughal Kot, Pab and Ranikot. While Pub Sandstone has the reputation of big discoveries of hydrocarbon mainly gas. Sari Mehar, Jhal Magsi, etc. are forts of other discoveries. The Lower Indus Platform is considered among the well explored and highest producing areas of Indus Basin. Badin Block is another literature name of this platform. Play type has extensional features which has primary reservoir in upper Goru of cretaceous age, having Goru and Sember shales as source of hydrocarbons. which is sourced by organic rich shales of Sembar and Goru. There are two play types in Offshore Indus Basin. Miocene & Pliocene deltaic sequence has good petroleum system. While Eocene-Oligocene shales are good seal rocks. This basin has very limited exploration history. In past 50 years, nearly 15 wells had been drilled.

Potential Reservoirs in Eocene include Pirkoh members of Kirthar Formation and Habib Rahi Limestone. The main reservoir in Dhodak oil & gas fields is considered to be sandstones of Ranikot. Lower Goru sandstone, Sembar and Chiltan Limestone are of Jurassic age and are commercially very viable during chemical examination and testing. Lumshiwal and Lower portion of Goru formation has protentional reservoirs mostly has shallow marine or deltaic environment of deposition. Limestone of Eocene Ghazij Formation is also a reservoir (Ahmed et al., 2015).

Potential Reservoirs are thick up to 400m. Sandstone porosities are high up to 30%. Limestone porosity ranges up to 9-16%. Permeability of these reservoirs ranges up to 1 to 2000md. Largest reserves were 625 m thick of Sui Main Limestone Member. Sui Limestone and Habib Rahi Limestone are also productive. In 1999, Pab sandstone begun to produce Gas from Sui field.

As per the collected data and information, there are 55 wells drilled between 1955 and 1984 in the southern part of Indus basin. Multi fold seismic survey was conducted for the 27 wells out abovementioned 55 wells. These wells are well producing, and gas discovery is dominating the oil in the region. There occurred five gas discoveries which indicated the potential and presences of hydrocarbons. Qadri in 1986 mentioned and classified Mesozoic tilted fault blocks, Tertiary reef banks, and drape and compressional anticlines as the main indicator of hydrocarbons.

2.4 Tectonic Setting of Study Area

The middle Indus basin is formed on north western edge of Indian plate during late Jurassic to early cretaceous. Indian Plate acted as passive margin and sedimentary record shows evidence that passive margin mighty has far away from west, near to Afghanistan (Mahar et al., 2010).

This Basin closed during deposition of Ghazij Formation. It has shale. Deltaic deposition system developed that entered basin from north-west. Closure of deposition of Kirthar Formation is in late to early Oligocene time. There is deformation on western edge of basin. It is related to Himalayan Orogeny.

First uplift was happened near K-T Boundary. It is placed as tertiary unconformity. Ranikot clastic thin out, thickened prograde away from highs.

Second event occurred during late Eocene-Oligocene time. There were many episodes of structural changes in west and northwest. Final modification occurred in shaped of traps. Then, secondary migration and reservoir fills during this period (Mahar et al., 2010).

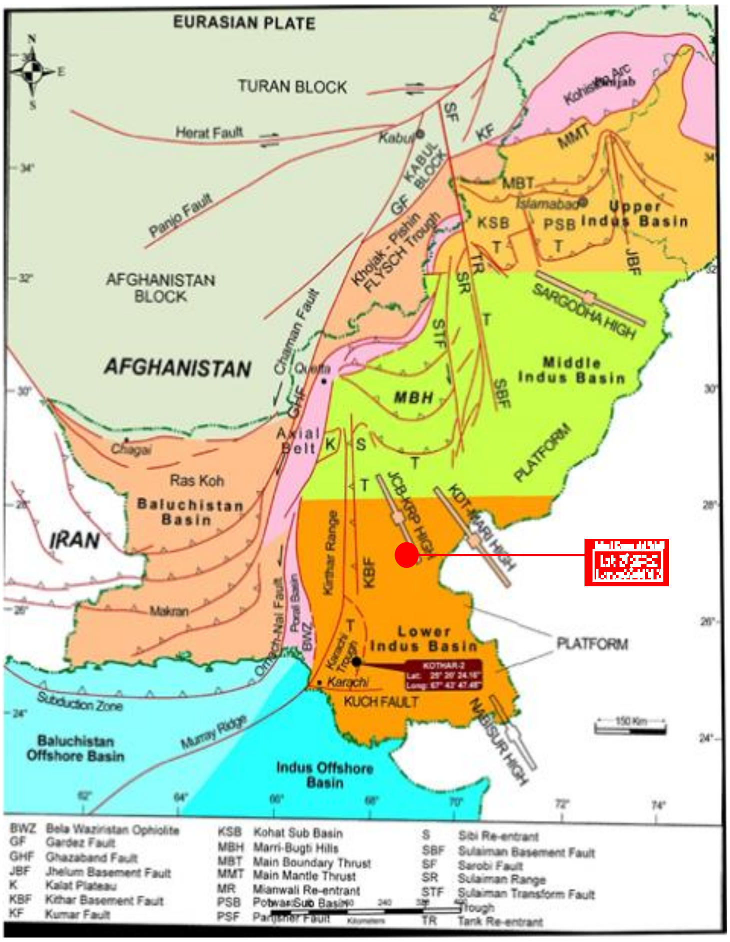

Figure 2.2. Tectonic Map of Pakistan (Iqbal & Khan, 2012).

2.5 Structural Styles of Mari Field

Seismic event shows structural spread of Mari high that are truncated by tertiary unconformity at base. The Mari area has wrench faulting at basement. Mari anticline was formed due to inversion in late Tertiary age. On the basis of development drilling and seismic interpretation Mari structure was delineated. It covers total area of 187,000 acers within gas water contact. 9.7 TCF is gas in place in order (Iqbal & Khan, 2012).

CHAPTER 3
STRATIGRAPHY

3.1 Introduction

The Middle Indus Basin contains formations from Precambrian to Neogene. The groups include in the Middle Indus Basin are Siwalik, Ghazij, Ranikot, Zaluch, Jhelum and Kirana (Khan et al., 2013). The generalize petroleum geology in stratigraphy of Middle Indus Basin is show in Figure 3.1

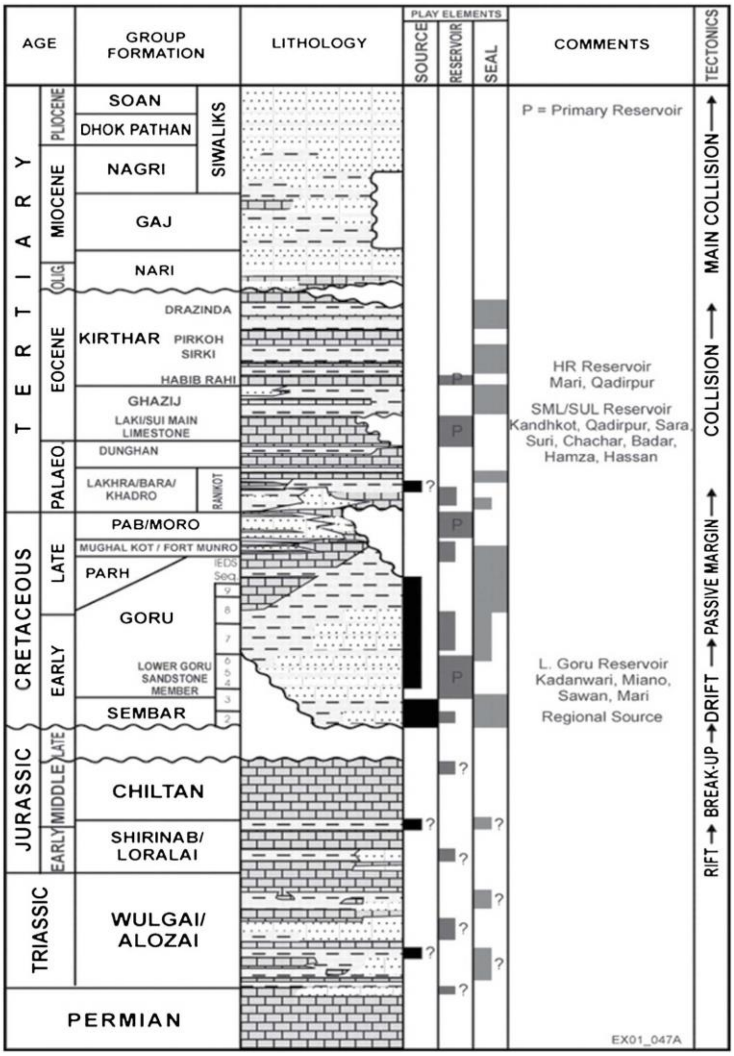

Figure 3.1 Basin fill sedimentary deposits, lithologies of formation group, petroleum contribution of known fields, and major tectonic event of middle Indus basin. (Khan et al., 2013).

3.2 Generalized Stratigraphy

Stratigraphy and petroleum geology for Mari gas field is given in Table 3.1 (Kadri., 1995).

Table 3.1. Stratigraphy of Mari Gas Field (Kadri., 1995).

Age	Formation/ Member/ Unit
Oligocene	Nari Formation (i) Nari Formation (ii) Nal Limestone Member
Middle Eocene	Kirther (i) Pirkoh limestone and Marl (ii) Sirki (Upper Alabaster and Shale unit, inter limestone Marl and Shale unit) (iii)Habib Rahi limestone Member
Lower Eocene	Ghazij (i) Baska Shale (ii) Shale with Nodular Limestone (iii)Ghazij Shale
Upper Paleocene	Dungan Formation
Lower Paleocene	Ranikot Formation (i) Upper Ranikot (ii) Lower Ranikot
Cretaceous	(i) Pab Sandstone (ii) Parh Limestone (iii)Goru Formation (iv)Sember Formation

3.3 Oligocene Succession

3.3.1 Nari Formation

This contains sandstone and shale. The below contact is confirmable to' gradational with Kirthar and Nisai Formation. The color of sandstone is greenish grey, grey, brown and wide colored. The grain size ranges from fine to coarse grain. The color of shale is red to brown, sometimes purple. It belongs to shallow marine environment (Kadri., 1995).

3.3.2 Nal Member

Below part of this formation is brown to grey, nodular shale, massive limestone that has been the name of Nal Member. The below contact of the Nari formation is conformable and gradational with Kirther and Nisai Formation. Shallow marine is environment of deposition for Nal member. Oligocene is its age (Kadri., 1995).

3.4 Middle Eocene Succession

3.4.1 Pirkoh Formation

Its color is grey to white. The limestone is thin bedded with dark grey calcareous claystone. It has high fossil content. Sirki Member is lying below, and the contact is normal. Greenish grey Marl with soft to hard texture with greenish grey shale. This limestone is from shallow marine environment. Its age is Middle Eocene (Kadri., 1995).

3.4.2 Sirki Member

This member is divided into two units. Upper unit has shale with Alabaster and streaks of limestone and marl. It has gradual and normal contact with underline limestone. Shale is fossiliferous, pyritic with greenish grey to brownish grey amorphous to micro crystalline shale. Its EOD (Environment of deposition) is shallow marine and Middle Eocene in age (Kadri., 1995).

Bottom unit has limestone marl with shale. It has lower normal contact with Habib Rahi Limestone. Limestone is crystalline, compacted, fossiliferous showing light grey to creamy yellow color. Marl is massively compacted, pyritic and dolomitic with soft to medium hard texture. It has same age and depositional environment like that of first unit.

3.4.3 Habib Rahi Limestone Member

It comprises of limestone with streaks of marl and shale. It has lower normal contact with Baska shale. Limestone is very rigid, compacted and high in fossil content Marl is light grayish in color and it contains chert, soft while shale is olive green. It has same age and depositional environment like that of Sirki member (Kadri., 1995).

3.5 Lower Eocene Succession

3.5.1 Ghazij Formation

It comprises of shale and has bands of limestone and marl in it. It has underline normal contact with Dunghaln Limestone. Shale is olive green, mordantly laminated fossiliferous splintery and slightly carbonaceous. Marl is grey, soft to hard with pyritic texture. It is deposited in shallow marine environment, and lower Eocene in age (Kadri., 1995).

3.6 Upper Paleocene Succession

3.6.1 Dungan Formation

It comprises of shale and has bands of limestones in it. It has underline gradual and normal contact with Ranikot formation. Limestone is grey to brownish grey hardly compacted crystalline and contain fossils. It is upper Paleocene in age and deposited in shallow marine environment (Kadri., 1995).

3.7 Lower Paleocene Succession

3.7.1 Upper Ranikot Formation

It consists of shale and have bands like that of upper formation. It has lower gradual and normal contact with Ranikot Formation. Shale is greenish grey, splintery, laminated, fossiliferous and slightly calcareous. Limestone is greenish grey hard crystalline and argillaceous. Marl is greyish, brown to medium hard. It also has same depositional environment and age like that of Dungan formation (Kadri., 1995).

3.7.2 Lower Ranikot Formation

It consists of shale and sandstone with bands of siltstone. It has unconfirmable lower contact with Pab sandstone. Shale is greenish grey, arenaceous, silty, slightly calcareous. Sandstone is fine grain subangular, subrounded, fairly sorted. It is hardly compacted and compose of corals and shells. It also has same age and depositional environment like that of upper formation (Kadri., 1995).

3.8 Cretaceous Succession

3.8.1 Pab sandstone

Sandstone is white to dirty white hard compacted fine to medium grain. It shows angular to subangular, well sorted and slightly calcareous composition. Lithologically it is identified with siltstone, shale and sandstone. Its age is cretaceous while Environment of deposition is deltaic (Kadri., 1995).

3.8.2 Parh Formation

It, mostly, contains limestone as main lithology. Pab sandstone overlain and conformably contacted with it. Argillaceous Limestone is present with hard compactness. Marl and poor-quality shale are also a part of this formation. Pelagic Environment of deposition is observed while age of the formation dates to cretaceous. It is conformably contacted with Goru Formation (Kadri., 1995).

3.8.3 Goru Formation

It is well producing Formation of the area and has great petroleum prospect. It has lithology consisted of siltstone, Limestone with interbedded shale. It is transitionally contacted with Sember Formation. Limestone, present here, is thin bedded while shale is of maroon color. It has pelagic Environment of deposition. The age of the Goru Formation is founded early cretaceous (Kadri., 1995).

3.8.4 Sember Formation

It comprises of silty shale and argillaceous limestone. It is conformably contacted with Goru Formation while in the lower side it is observed disconformable. In the lithology, Black colored Shale and nodularity in limestone is present mainly argillaceous in nature. It is of Lower cretaceous age while pelagic is its Environment of deposition (Kadri., 1995).

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CHAPTER 4

PETROPHYSICAL ANALYSIS

4.1 Introduction

Petrophysics is the branch of geology that deals with study of chemical and physical rock properties and their interactions (Quadri & Shuaib., 1986). We can also use petrophysics because we can find the properties of oil/gas reservoirs. These properties include porosity, resistivity, volume of shale, permeability etc. These following parameters are required for determination of fluid saturation, permeability and effective porosity. The given information is used for marking hydrocarbon bearing zone. It also estimates the recoverable hydrocarbons. The basic purpose of well logs study can also have refurbished through well information/data. Due to this data oil and gas can be found and it estimates the quantity of water.

4.2 Petrophysical Analysis

To evaluate rock properties within the study area, petrophysical analysis has been done. The main aim of petrophysical analysis is to differentiate between hydrocarbon and non-hydrocarbon bearing zone. It also identifies lithology which gave hydrocarbon potential. It also highlights different characteristics of hydrocarbon bearing zones like saturation, porosity, and resistivity (Quadri & Shuaib., 1986).

The steps taken four petrophysical analysis are given below:

(i) Shale volume (Vsh)

(ii) Porosity of Reservoir (Φ)

(iii) Water resistivity (Rw)

(iv) Water saturation (Sw)

Saturation of hydrocarbons (Sh)

4.3 Well Statistics

The statistics of well Mari deep-06 are shown in the table below

Table 4.1. Well Statics.

Well Name	**Mari Deep-06**
Company	Schlumberger and Mari Petroleum Company Limited
Field	Mari
Province	Sindh
Location	Daharki
Type	Exploratory
Total Depth	4678 ft
Logging Date	21 February 2001
Well Status	**Appraisal**

4.4 Methodology

The following methodology has been implemented to compute the parameters required for performing petrophysical analysis

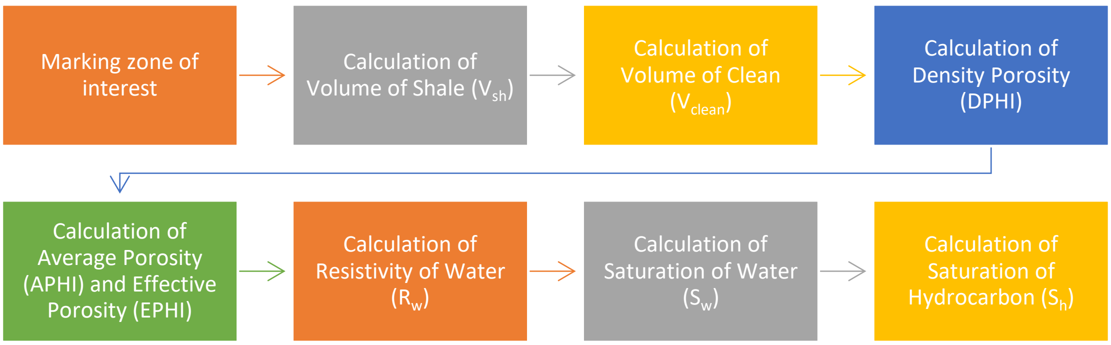


Figure 4.1 Methodological chart to carry out Petrophysical analysis.

4.5 Marking Zone of Interest

The part of the formation which is acting as prospect reservoir is called as zone of interest. It can vary from few feet to meters. This zone is marked based on gamma ray, neutron, density, caliper and resistivity logs.

Criteria to mark zone of interest are (Ehsan et al., 2018).

(i) Caliper should be stable i.e. it should be less or greater than bit size.

(ii) Gamma ray should be low. Low gamma ray indicates clean lithology.

(iii) Resistivity logs should be in the following order MSFL < LLS < LLD

(iv) There should be neutron density cross over which means that both indicate low values

(v) SP should be negatively deflected which marks/shows the zone of permeability.

4.6 Marked Zones of Interest

The well log data shows Habib Rahi limestone as a reservoir. According to the criteria the caliper and resistivity logs are stable, but caliper was not stable throughout the well. There is a separation between MSFL, LLS and LLD and there is also a cross over between neutron and density. Their values are so reliable. The average value of neutron porosity (NPHI) was 0.186 v/v and the average value of bulk density (RHOB) is 0.2394 g/cm^3

The resistivity logs values are low to intermediate throughout the well but the separation between MSFL and LLD was clear and observable. Water based drilling mud was used. The rest of the log behavior was according to the criteria.

Table 4.2. Zones of Interests in well data.

Zone 1	
Formation	Habib Rahi Limestone
Starting Depth	2237 ft
Ending Depth	2516 ft
Thickness	279 ft

4.7 Petrophysical interpretation

On the basis of Conditions mentioned in the section 4.5, four zones of interests have been marked, which are discussed below.

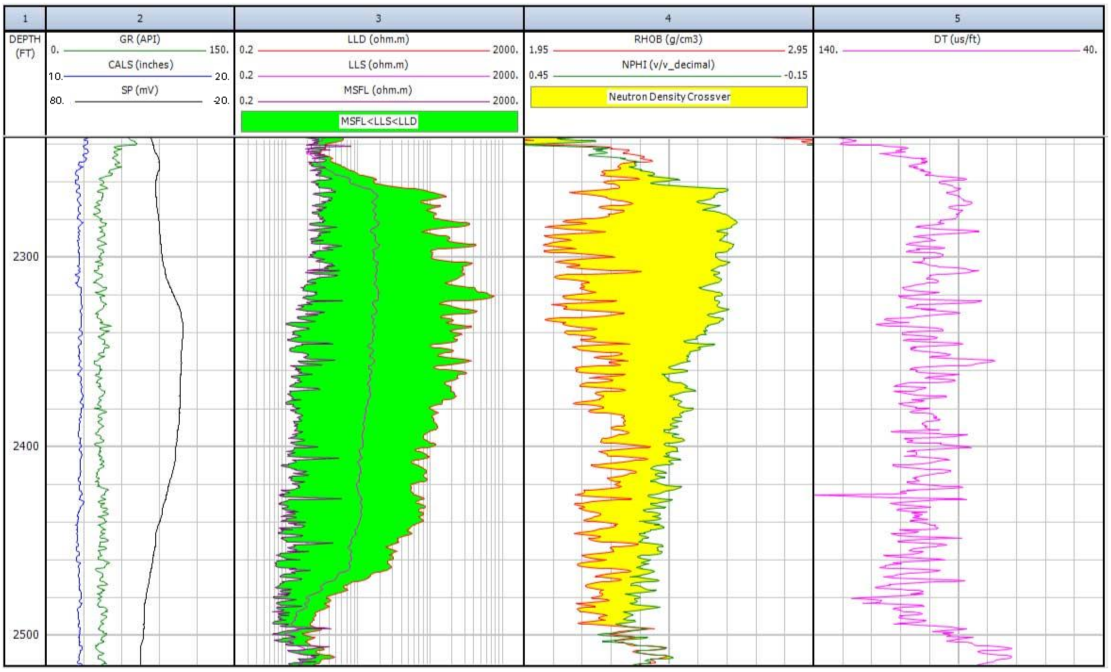


Figure 4.2. Zone 1 Habib Rahi Limestone (2237-2516).

The total thickness of the zone is 279 ft. In this zone Gamma Ray shows low values indicating clean lithology as shown in Fig. 4.13. Crossover between N-D is wide and clear which shows the presence of gas in the formation. According to the Figure 4.6 Gamma ray log and Caliper log are almost stable, while there is a clear separation between MSFL, LLS and LLD according to the criteria mentioned in section 4.6.

4.8 Well Logging

Methodology that was adopted is given in figure 4.1. Calculations was done manually by using well logs that is by the use of gamma ray logs. Reservoir logs was identified to which the shale volume can also identified, formation porosity was determined, hydrocarbon bearing zone detected due to neutron density logs.

4.8.1 Volume of Shale (Vsh)

Gamma Ray is used to find the shale content present ion formation. The higher will be gamma ray value more will be shale, and which indicates dirty lithology, while formation having low gamma ray value indicates low amount of shale and lithology will be clean lithology.

Shale content indicate high gamma ray value as compared to sandstone and limestone.

$$I_{GR} = \frac{(\mathbf{GRlog - GRmin})}{(\mathbf{GRmax - GRmin})} \qquad \text{eq. 4.1}$$

Where:

I_{GR} = Index of Gamma Ray
GRlog = Value of Gamma Ray at the depth of interest
GR_{min} = Gamma Ray Minimum value
GR_{max} = Gamma Ray Maximum value

4.9 Calculation of Vclean

This formula which is given below is to be used to the calculate volume of clean (Schlumberger, 1974).

$$\mathbf{V_{clean} = 1 - V_{sh}} \qquad \text{eq. 4.2}$$

V_{sh} = Shale Volume (IGR)

4.10 Porosity Calculation

Porosity can define as total number of empty spaces present in rock body. There are 2 types of porosities, primary and secondary. It is developed during the time of deposition while secondary porosity is develop after deposition due to fracturing or dissolution (Ehsan et al., 2018).

4.10.1 Calculation of Density Porosity

Using bulk density log, density values are picked, and following formula is used to calculate the porosity:

$$\mathbf{\Phi} = \frac{(\mathbf{\rho ma - \rho b})}{(\mathbf{\rho ma - \rho f})} \qquad \text{eq. 4.3}$$

Where:

Pma = Density of matrix for limestone/sandstone=2.71/2.65 g/cm^3
Pb= Formation Bulk Density
Pf = Fluid density (For saline water = 1.1g/cm^3
Φ = Porosity density of rock

4.10.2 Calculation of Neutron Porosity

The NΦ is indicated by neutron log. The values indicate porosity of a formation.

4.10.3 Calculation of Sonic Porosity

The matrix of the lithology and transit time is needed to calculate the sonic porosity, where the following relation is used

$$\mathbf{SPHI} = \frac{(\boldsymbol{\Delta t - \Delta tma})}{(\boldsymbol{\Delta tf - \Delta tma})} \quad \text{eq. 4.4}$$

Where:

Δt = time from sonic log (µs/feet)

Δt_{ma} = traveling time through the matrix (µs/feet) (for limestone= 47.6 µs/feet) (for Sandstone= 55.5 µs/feet)

Δt_f = traveling time through the fluid (µs/feet) (for saline water= 185 µs/feet)

4.10.4 Calculation of Average Porosity

It can be calculated by the average of the neutron and density porosity.

$$\mathbf{APHI} = \frac{(\mathbf{Nphi} + \mathbf{Dphi})}{\mathbf{2}} \qquad \text{eq. 4.5}$$

4.10.5 Calculation of Effective Porosity

It can be calculated by multiplying the average porosity and volume of clean lithology in case of no caving.

$$\mathbf{EPHI = EPHI * V_{clean}} \qquad \text{eq. 4.6}$$

And in case of no caving

$$\mathbf{EPHI = APHI * V_{clean}} \qquad \text{eq. 4.7}$$

4.11 Resistivity of water (Rw) Calculation

The resistivity of water is required for the calculation of saturation of water. Following are the steps through which resistivity is calculated:

Step 1

The first is to calculate the Geothermal Gradient and it can be determined by the below given formula

$$\textbf{Geothermal Gradient} = \frac{\textbf{Borehole Temprature} - \textbf{Surface Temprature}}{\textbf{Total Depth}}$$

Step 2

The next step is to calculate formation temperature (FT) which can be calculated by using the following formula

$$\textbf{F T} = (\textbf{Formation Top} * \textbf{Geothermal Gradient}\ ) + \textbf{Surface Temprature}$$

Step 3

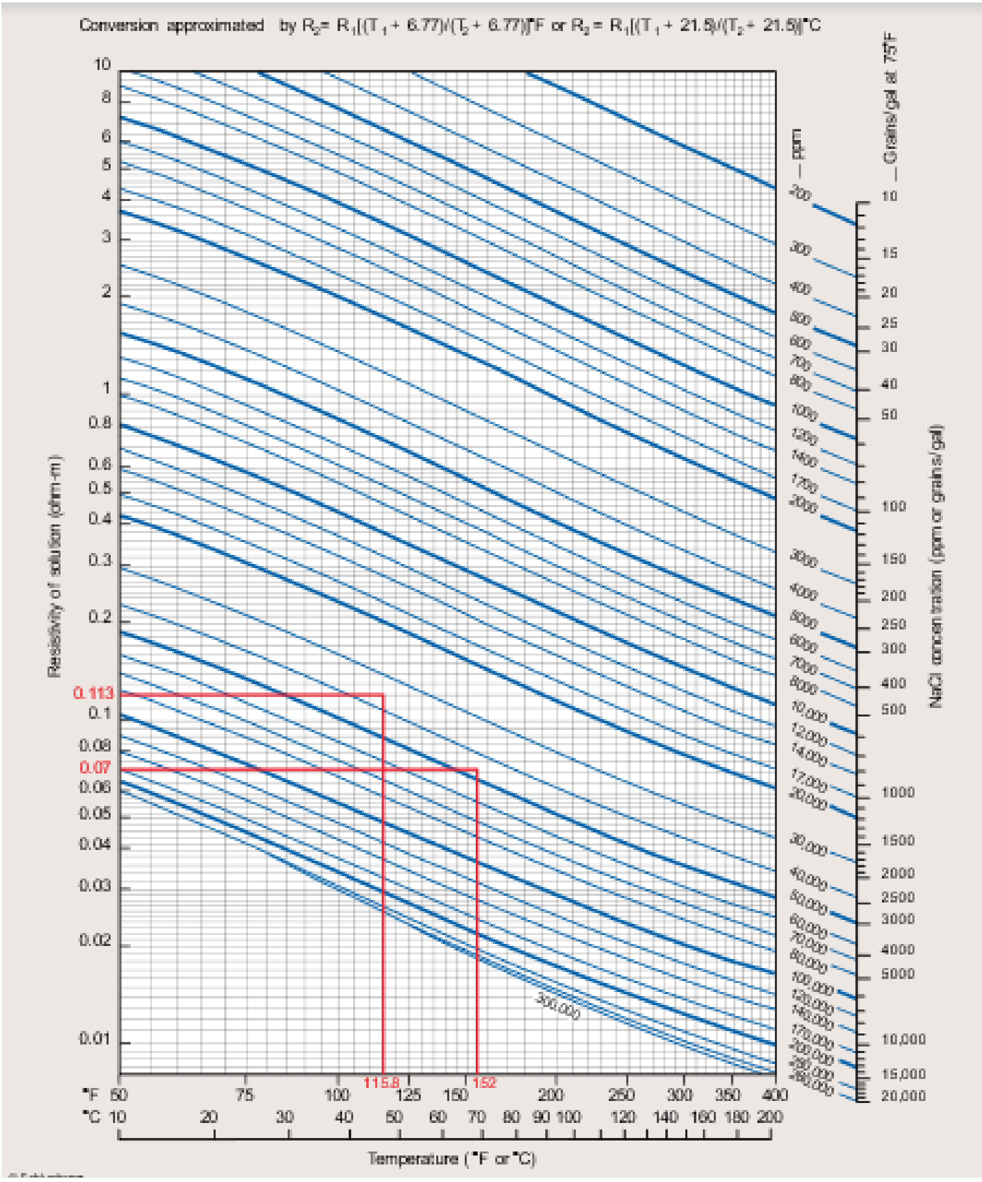


Figure 4.3. GEN-09 for Mari Deep 06 Formation.

R_{mf} @ Surface Temperature is noted from log header and is converted to R_{mf} @ Formation temperature by using the Schlumberger GEN-9 chart. The calculated value for the given formation is given in figure 4.2.

Step 4

R_{mf} at formation temperature which was calculated by using GEN-9 chart is converted to R_{mf} eq by using SP-2 chart.

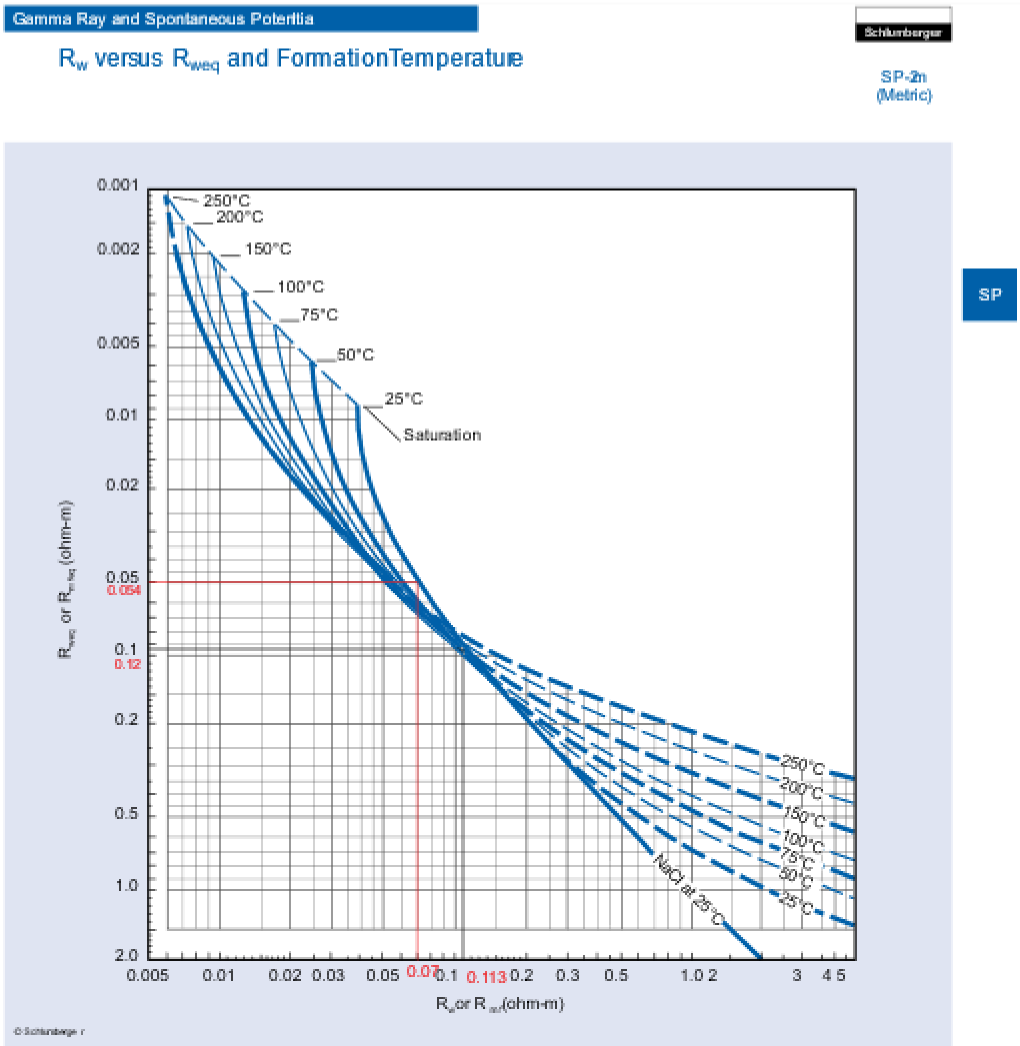


Figure 4.4. SP-2 Chart for Mari Deep 06 Formation.

Step 5

This step involves the calculation of SSP by using SP log which is required to calculate Rweq. Then by using the SSP, Formation Temperature and the Rmfeq value in SP-1 chart a straight line is drawn passing through the Rmfeq which gives the value of Rweq. The step 5 calculated for formation is given in figure.

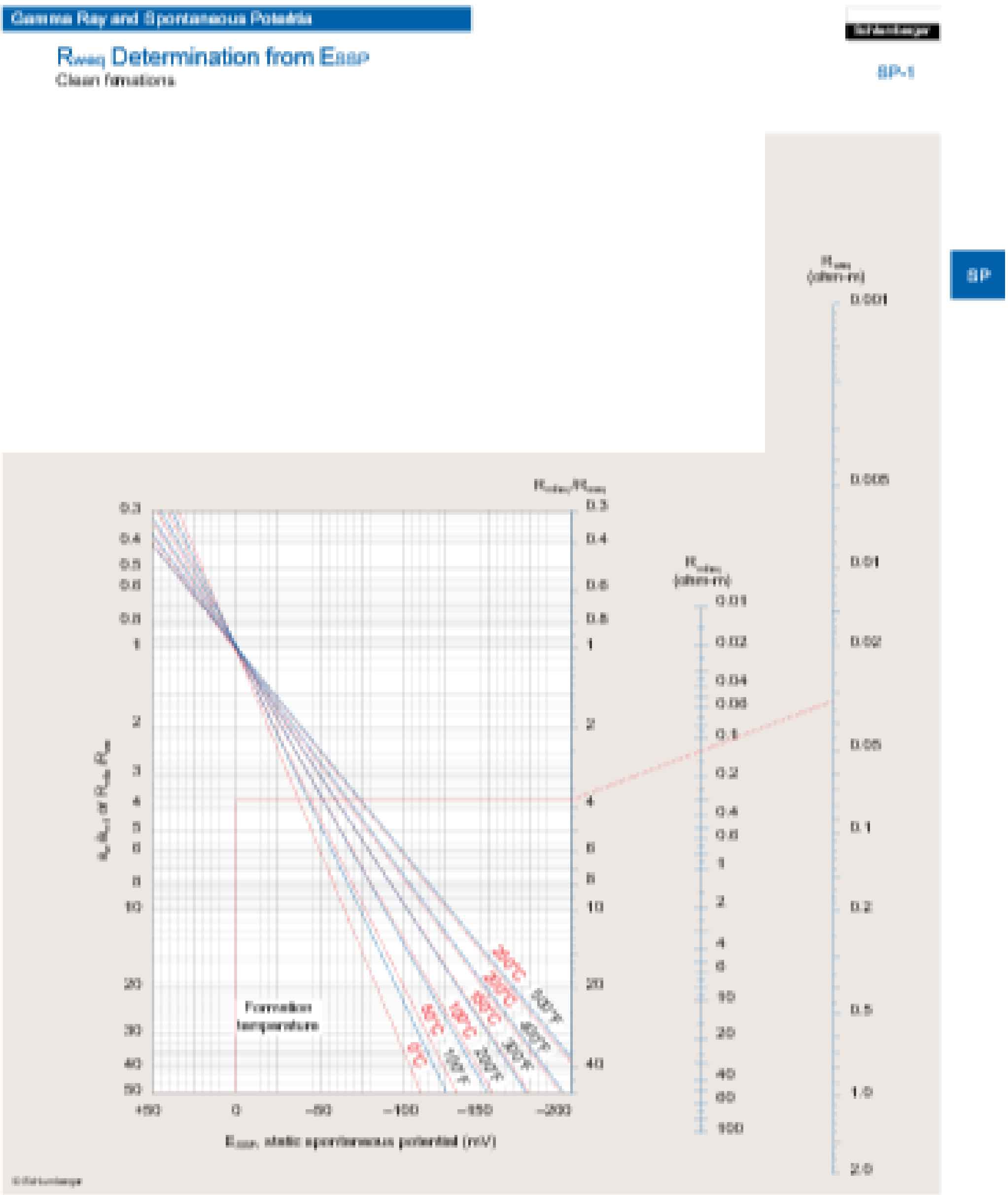


Figure 4.5. SP Chart for Mari Deep 06 Formation.

Step 6

This is the last step where the resistivity of water is calculated using the SP-2 chart. Here the value of Rweq is used for the calculation of Rw. For Mari Deep 06 the value of Rw is 0. The calculated value of Rw is shown in the figure 4.6.

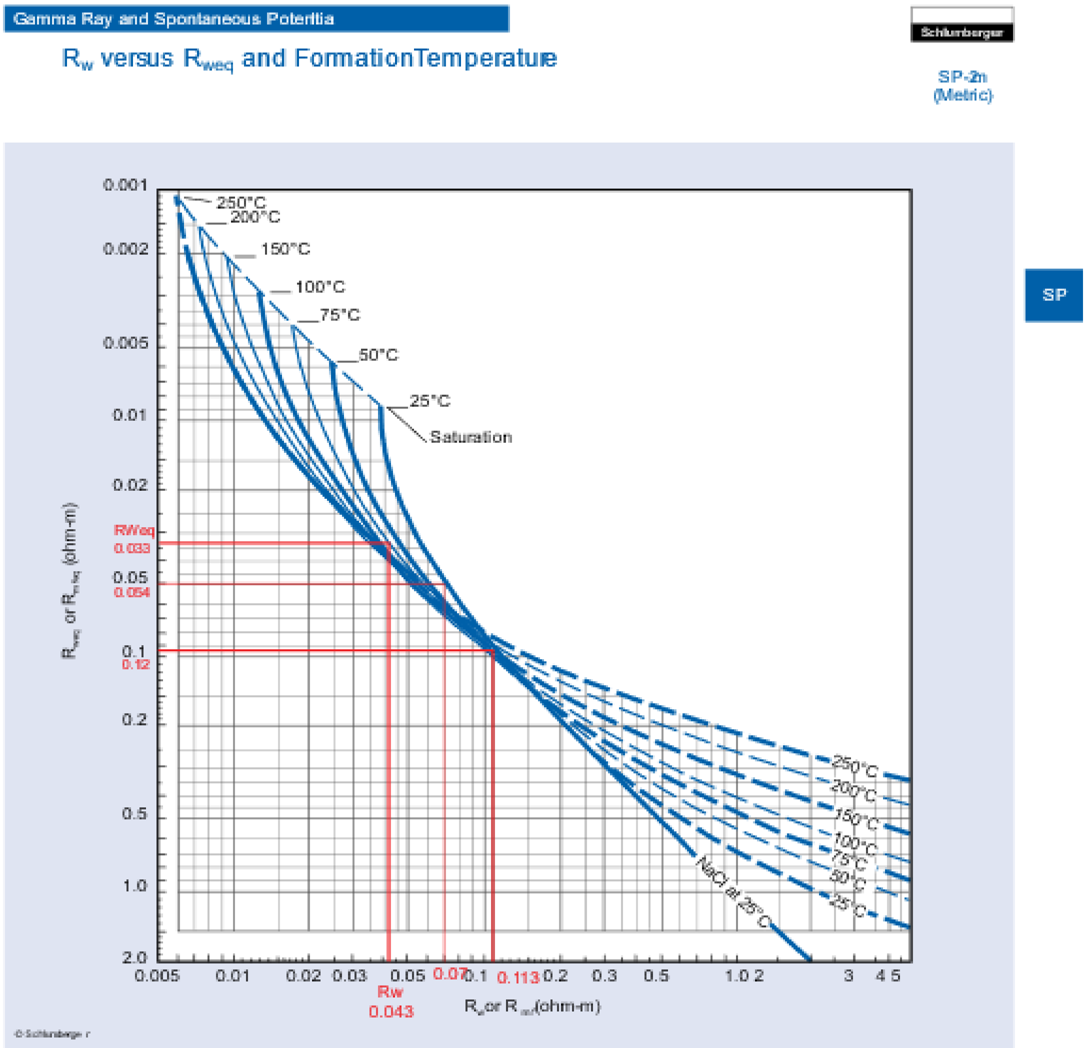


Figure 4.6. SP-2 Chart for Mari Deep 06 Formation.

4.12 Saturation of Water (Sw)

It can also be defined as ratio of water-pore volume and represents the amount of wet zone in the formation. Archie's equation is to be used to calculate water saturation for limestone of Habib Rahi limestone formation. The equation for saturation of water is given below.

$$Sw = [\frac{(a/\ \Phi m)}{(Rw\ /\ Rt)}]^{1/n} \qquad \text{eq. 4.8}$$

Where

R_w = Resistivity of Water

R_t = True resistivity of rock formation

Φ = porosity

a= Factor of Tortuosity 1.0 for carbonates

m= Exponent of Cementation 2.0 for carbonates

n= Saturation exponent (2.0) (Alimoradi et al, 2011)

$$Sw == [SQRT\left(\left(\frac{Rw}{Rt}\right) * \left(\frac{1}{\Phi e^2}\right)\right)] \qquad \text{eq. 4.9}$$

4.13 Saturation of Hydrocarbons (Sh)

Saturation of water is required to calculate saturation of hydrocarbons. The equation used to calculate the saturation of hydrocarbon is given below.

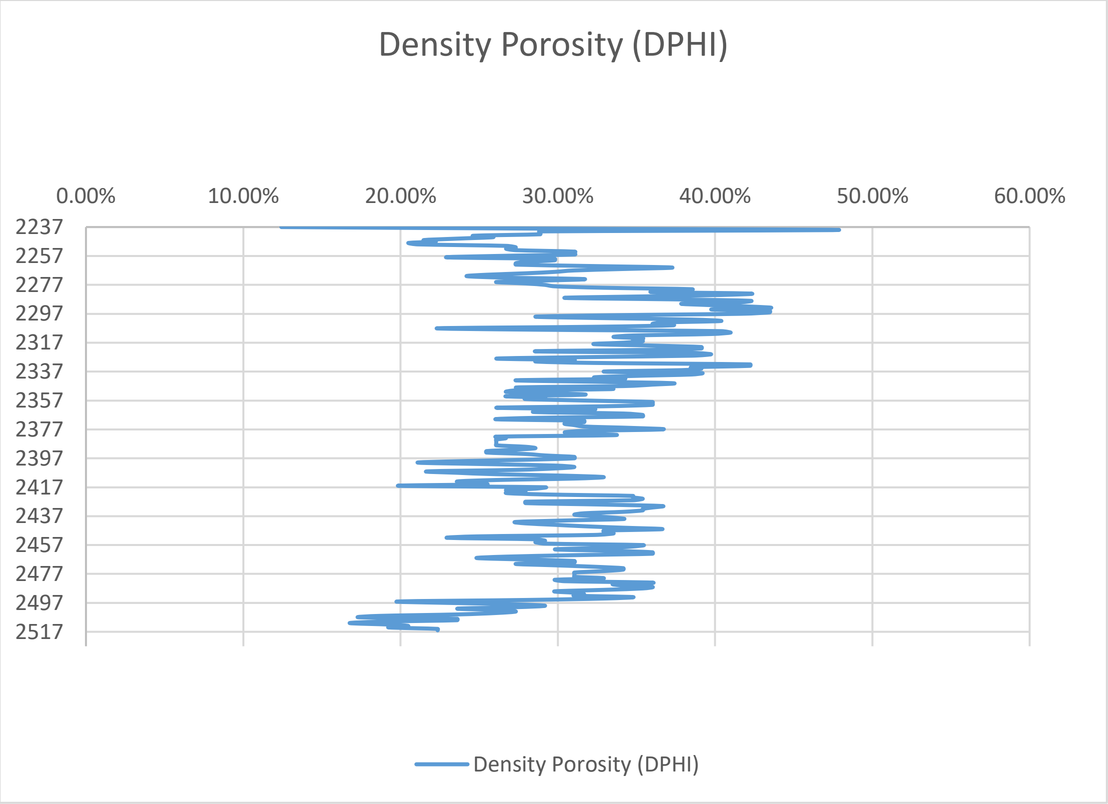
$$\mathbf{S_h = 1 - S_w} \qquad \text{eq. 4.10}$$

Where;

Sh= Saturation of hydrocarbons

Sw= Saturation of Water

4.14 Results



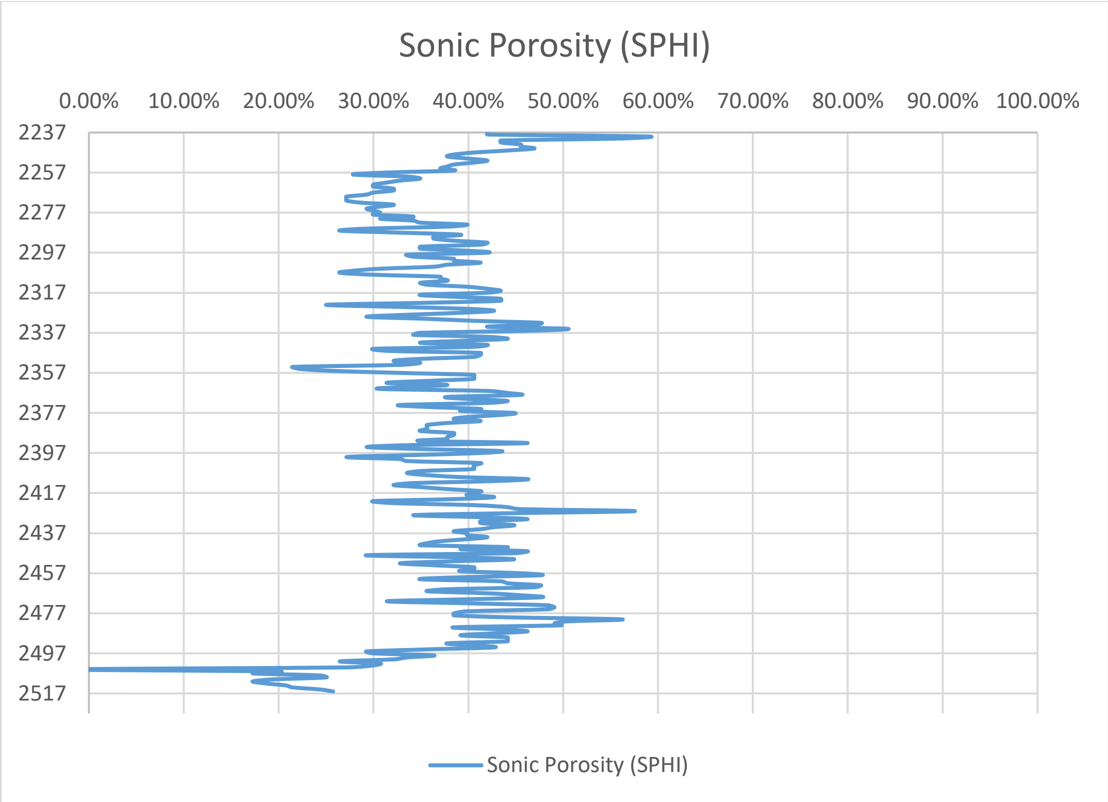
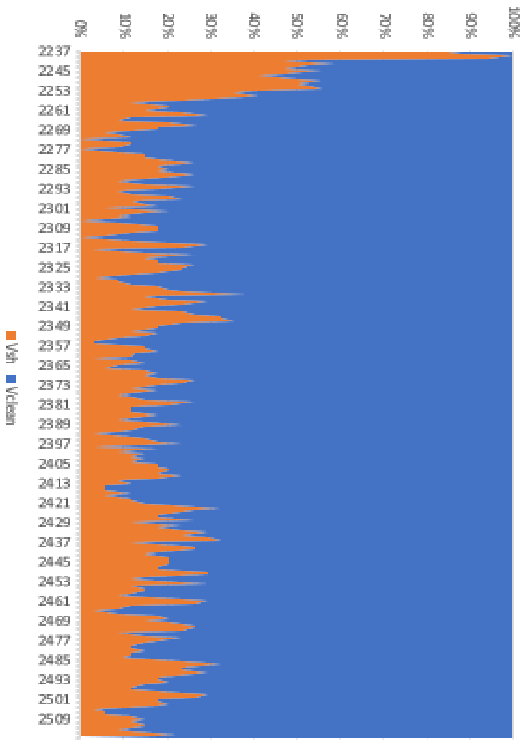


Figure 4.7. DPHI and SPHI Curves of Zone.

The variation in SPHI and DPHI with respect to depth is shown in the graph above. The values of density porosity lie between 31 %, while value of sonic porosity lies between 37 %.



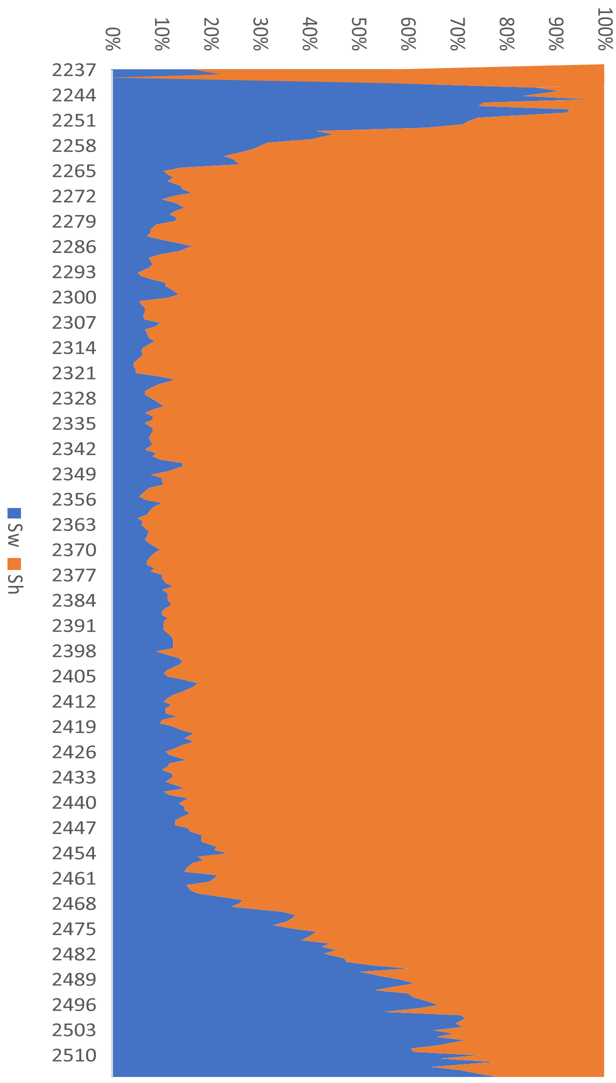
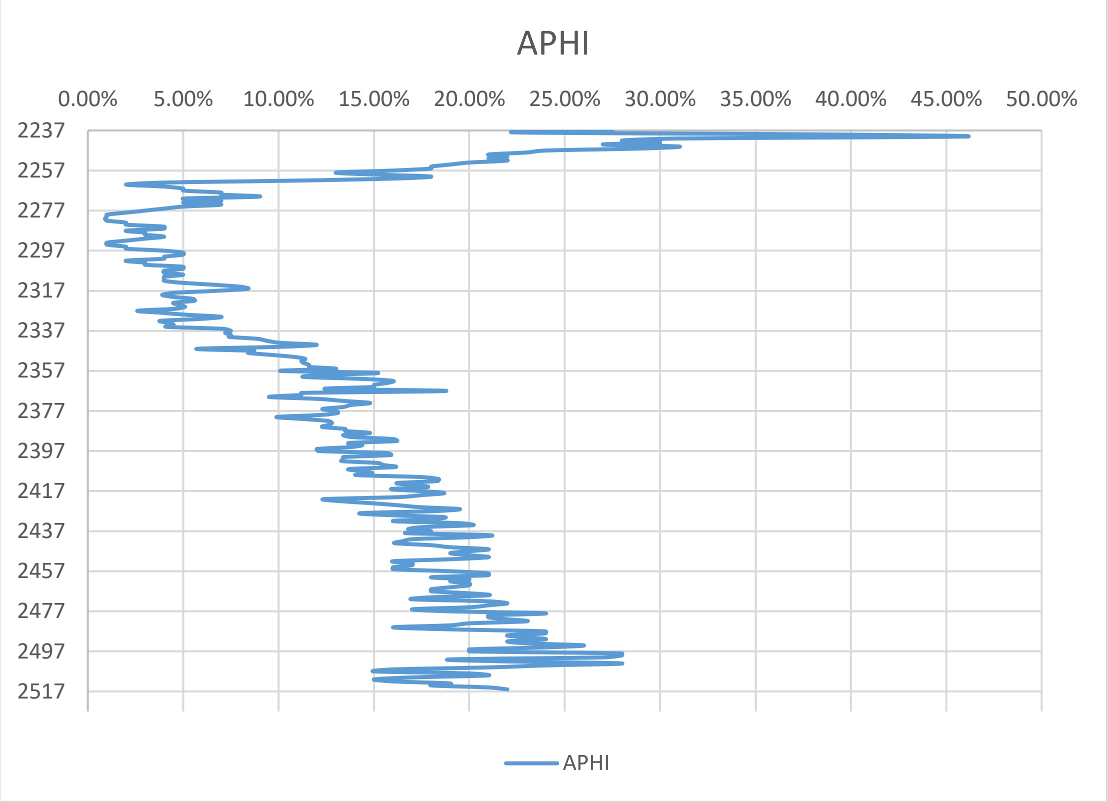


Figure 4.8. (a) Saturation of hydrocarbon and saturation of Water of Zone (b) Volume of Shale and Volume of Clean w.r.t to Zone.

Figure 4.8 (a) shows saturation of hydrocarbons and saturation of water, we can observe that in this zone the saturation of water is less than the saturation of hydrocarbons. The average value of saturation of water is 27% whereas the average value of saturation of hydrocarbons 73%. The Figure 4.8 (b) shows the relation of Vclean to Vsh with respect to depth. Overall, it can be observed that the Vclean is greater than the Vsh. The graph shows that the value of Vsh is increasing with increasing depth. The average value of Vclean is 80% and that of Vsh is 20%.



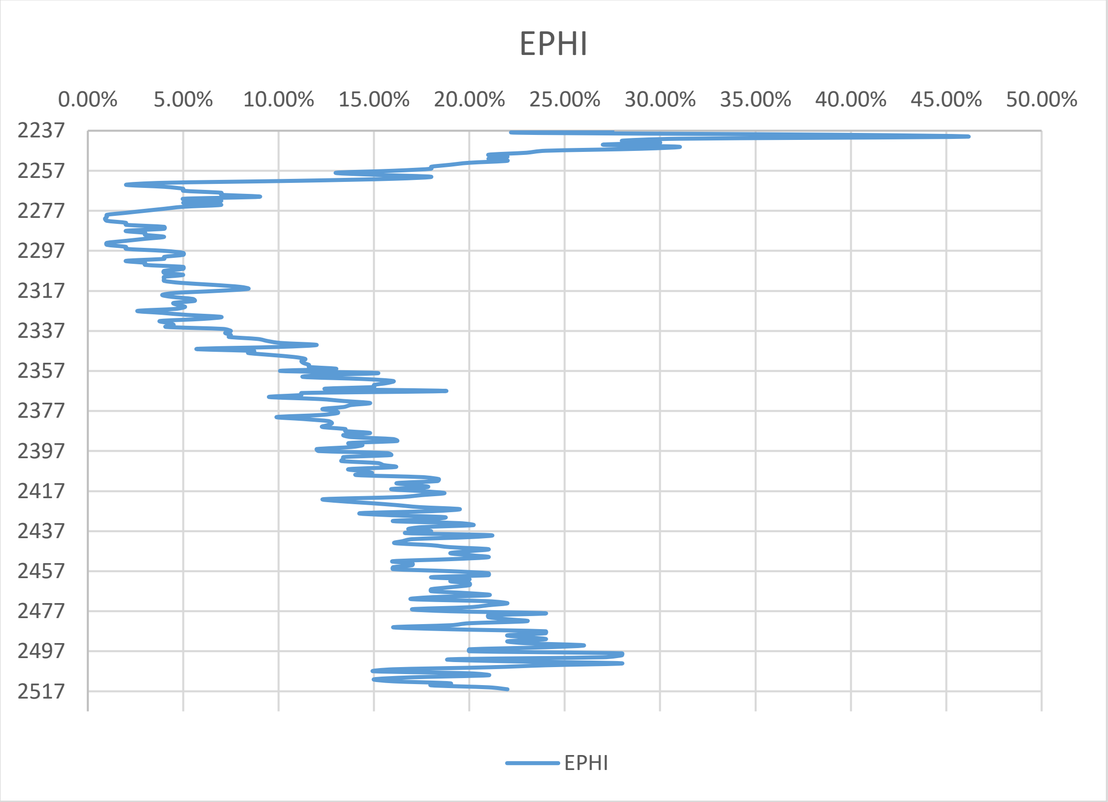


Figure 4.9. Relationship of neutron porosity, average porosity, density porosity and effective porosity of zone.

The figure above is showing variation of porosities with respect to depth. The average value of EPHI is 18%, APHI is 22%.

4.14 Summarized Results of Mari Deep-06 well

Calculated parameters of zone of Mari Deep Formation and for the zones of Ranikot Formation are given below.

Table 4.3. Petrophysical interpretation of zone Mari Deep-06.

	Zone
Formation	Habib Rahi Limestone (Kirther Formation)
Depth (ft)	2237 to 2516
Thickness (ft)	279
Average Vsh (%)	20
Average Vclean (%)	80
APHI (%)	22
EPHI (%)	18
Sw (%)	27
Sh (%)	73

CONCLUSIONS

Following conclusion can be drawn from the work done in this thesis:

(1) Petrophysical analysis of Mari Deep 06 has shown Habib Rahi Limestone as Gas reservoir. Habib Rahi is the main reservoir rock in this well.

(2) The petrophysical analysis of Habib Rahi Limestone of Mari Deep 06 well, The APHI is 22%, EPHI is 17% $Sw_{avg}$is 33% and $Vsh_{avg}$is 24%

(3) The net reservoir and net pay thickness of this zone is calculated. The average thickness of this zone is 279 ft.

(4) The average Vsh_{avg} is 24% and average V_{clean} is 76%

(5) The study and the work done of the available data shows that Habib Rahi Limestone is a good reservoir in this area.

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