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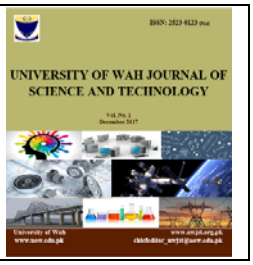

Petro-physical Analysis and Reservoir Characterization of Sara West-01 Well, Southern Indus Basin, Pakistan

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***Abstract*— The purpose of entire study is to evaluate the hydrocarbon potential via petro physical analysis and reservoir characterization by utilizing well log data of Sara West-01, Ghotki, Southern Indus Basin, Pakistan. The mentioned well is exploratory and the Tullow Pakistan is the operator on this well. For the evaluation of the potential of reservoir, different equations have been used for the interpretation of different well logs. Habib Rahi Formation and Sui Main Limestone reservoirs of Cretaceous age of the area have been selected for the evaluation of their respective petrophysical parameters and for more distant computations by retaining the fact that they have favorable ranges for saturation of water, porosities, and volume of shale. Density porosity, Neutron porosity, and resistivity logs do not show any direct identification for the presence of hydrocarbons. Different suits of wireline logs have calculated various petrophysical properties like porosity, resistivity, volume of shale and fluid saturation. Although the formations have clean lithologies with very little shaly content and good effective porosity but the fluid saturation plots depicts Sara West-01 as water wet well.**

***Index Terms*— Petrophysical analysis, Reservoir intervals, Sara West-01, Habib Rahi Formation, Sui Main Limestone, Southern Indus Basin, Pakistan.**

I. INTRODUCTION

WELL SARA WEST-01 lies in southern part of the Ghotki district, in north east of Nawab Shah and in the south of Sukkur. The well under study (exploratory well, operator: Tullow Pakistan) is situated at latitude 27º48'30.75" N and longitude 69º59'23.79" E. The well reaches the T.D of 1258 meters. Southern Indus Basin is very promising in having the potential for exploration of hydrocarbons due to the presence of proven source and reservoir rocks.

Data for this research includes wireline logs of Sara West-01. Reservoir characterization is a process by which the reservoirs are estimated and calculated. There are different methods used for the estimation of reserves which include productive decline curve, volumetric equation, reservoir analogy, and reservoir simulation etc. [1]. A major feature of petro physics is measuring and evaluating of the rock properties by gaining well log measurements [2]. All these properties has been studied with the help of different suits of Logs such as Gamma Ray Log, Density Log, Spontaneous Potential, Neutron Log and Resistivity Log run in the well Sara West-01 to acquire the data for Log interpretation to know the characteristics of the reservoir.

II. GEOLOGY OF SOUTHERN INDUS BASIN

Sukhar Rift present in the west of Southern Indus Basin which is dividing both the Central and Southern Indus Basins. The Southern Indus Basin has considerable potential for hydrocarbon exploration because of the presence of measured/proven source and reservoir rocks. There are five major units of Southern Indus Basin which are Kirthar fold belt, Karachi trough, Thar platform, Kirthar fore deep, and Offshore Indus as shown in *Fig. 1*. It can be noticed that both the Thar platform and Karachi depression developed into offshore Indus. The Indian shield encompasses the Southern Indus Basin to the east and the marginal geographical zone of Indian plate to the west.

Thar platform is managed by basement topography and contemplate as a gentle sloping monocline associated with respect to Punjab platform as shown in *Fig. 1*.

The sedimentary cover of Thar Platform pinches put towards the Indian shield and the availability of surface expressions at Nagar-Parker high. It is different from the Punjab platform as it gives details about the underground

Manuscript received June15, .2017; accepted December 01, 2017.

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structures that are formed due to extensional tectonics and results due to anti-clockwise motion of the Indian plate. Karachi trough is differentiating by Cretaceous sediments (thick early) and also stipulates the last stages of marine sedimentation. It contains a large amount of anticlines in which some of them have gas fields.

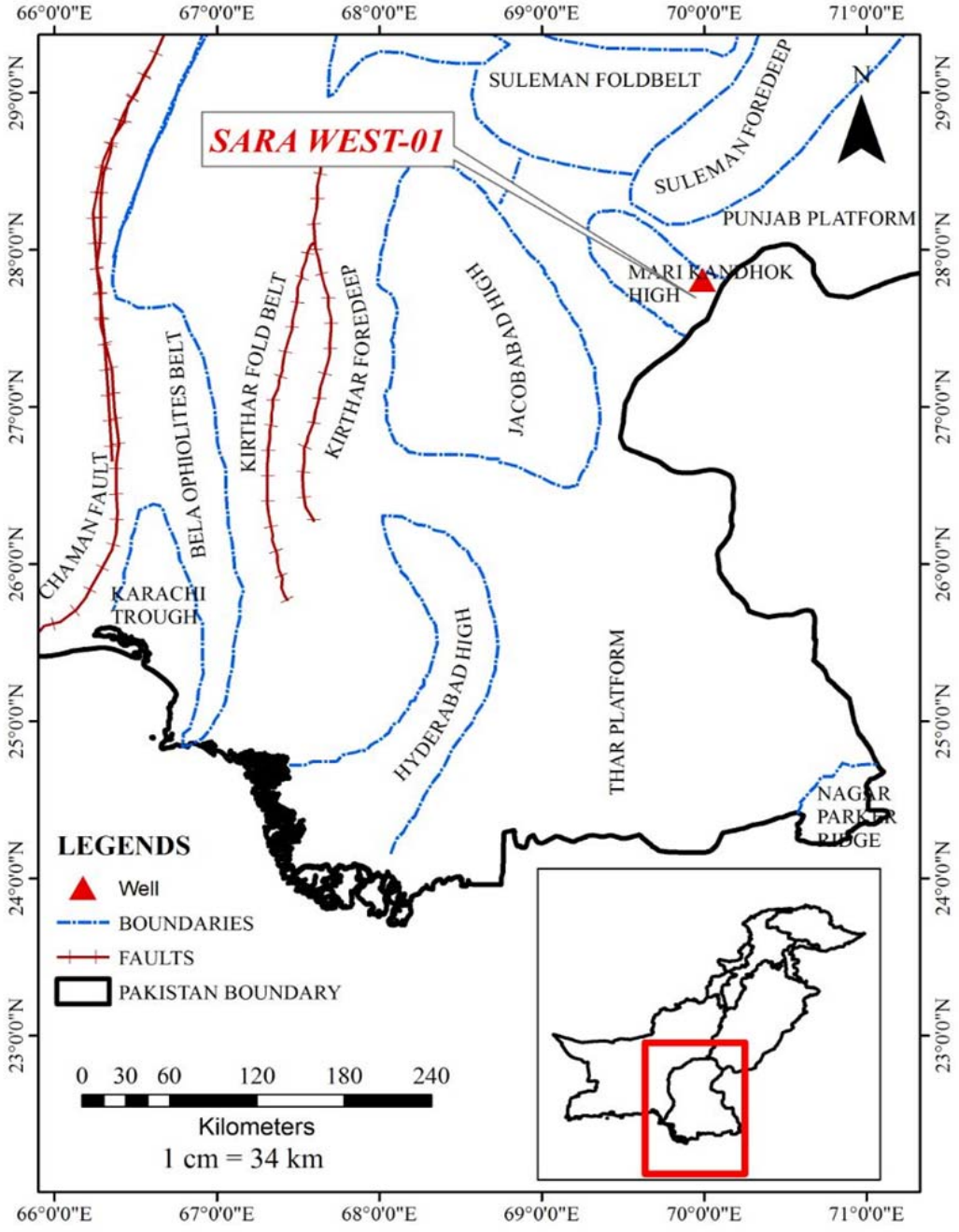

Fig. 1. Tectonic map of Southern Indus Basin with highlighted study area (Shape file from Pakresponse.info. Map generated in ArcGIS).

TABLE I
STRATIGRAPHIC SUCCESSION OF WELL SARA WEST-01

Formation	Age	Formation top (meters)	Thickness (meters)	Description
Siwaliks	Miocene Pleistocene Pliocene	0.00	603.00	Sandstone, shale & conglomerates
Drazinda		603.00	33.00	Shale
Pirkob Limestone		636.00	100.00	Limestone
Sirki Limestone		736.00	50.50	Shale
Habib Rahi Limestone	Eocene	786.50	90.50	Limestone
Ghazij shale		877.00	303.50	Shale & sandstone
Sui Main Limestone		1180.50	77.50	Limestone
Ranikot	Paleocene	1258.00	186.00	Limestone, sandstone, Shale

In this area the late, middle and early cretaceous rocks are preserved [3]. In case of Kirther fore deep, more than 15000 meters of the thickness has been gained to Kirther fore deep by the aggregating sediments and it is trending in the north-south direction as it is having a faulted eastward boundary with the Thar platform. However, this foredeep is having very large proneness for maturation of source rock [3]. Both the Sulaiman and Kirthar fold belt are quite similar to each other in their stratigraphic equivalence and structural style and trending in the north-south direction [3]. Cretaceous-Eocene and Oligocene-Recent are the two different phases of geological history accounted in offshore Indus area and this area forms the part of passive continental margin. The sedimentation started from Cretaceous time in this region [3].

The entire Southern Indus Basin divulge extensional tectonics and as an outcome, normal faults are engendered to show horst and graben structure with the previous being of enormous exploratory significance. The source rock in the area of study is Sembar Formation of Jurassic age, while the reservoir rocks are limestone of Habib Rahi Formation and Sui Main Limestone, and seal rock is Ghazij shale.

III. METHODOLOGY

In Sara West-01, two zones were marked. The zones have been selected because the values were relatively low in these regions as compared to other regions in the gamma ray log as well as resistivity values. For determination of porosity, two logs have been used i.e. Neutron log and density log and these values were also holding up other logs that aided marking the intervals in the formations.

Sand packages and shale beds were present in the Habib Rahi Limestone Formation. The values of the gamma ray log were relatively low and the values of later log deep (LLD) were also relatively low. The two main properties for the characterization of reservoir rock are porosity and permeability [4].

The investigation of porosity and permeability with the recognition of the intervals within Sara West-01 well is successfully brought about by calculating Volume of clean, volume of shale, saturation of hydrocarbon, saturation of water and porosities with the help of different wireline logs (i.e.) Gamma-ray log, Neutron log, Density log, resistivity log and Sonic Potential log for the total depth of about 1258 meters.

The values of volume of shale are calculated by picking the readings from the Gamma-ray log. The Volume of shale is calculated, with the help of following formula [5]:

$$V_{sh}=GR_{Log}\text{-}GR_{Min}/GR_{Max}\text{-}GR_{Min} \quad (1)$$

GR_{Log} = log reading acquired from data
GR_{Min} = lowest Gamma-ray log value
GR_{Max} = highest Gamma-ray log value

After calculating the values of the volume of shale, the volume of clean calculated by the help following equation:

$$V_{clean} = (1\text{-}V_{sh}) \quad (2)$$

After the calculation of the volume of Clean, The neutron porosity (φ_N), density porosity (φ_D), average porosity (φ_A) and effective porosity (φ_E) were calculated using the equations (2- 4) [2], [4] and [6].

$$\varphi\_D=(\rho_{ma}-\rho_b)/(\rho_{ma}-\rho_f) \quad (3)$$

$$\varphi\_A=(\text{Density porosity} + \text{Neutron porosity}) / 2 \quad (4)$$

$$\varphi\_E = \varphi\_(A)\times (1\text{-}[V]_{sh}) \quad (5)$$

φ_D = Density porosity
φ_E= Effective porosity
φ_(A)= Total porosity
ρ_{ma} = Density of matrix (2.71 g/cm3)
ρ_b= Bulk Density
ρ_f = Density of fluid (1.1 g/cm3)

The part of pore spacing that accommodates water is termed as water saturation, which is denoted by Sw. During the log analysis of under study well, water saturation is calculated with the help of Archie equation [7].

$$[Sw]_n= (a /\varphi\ m \text{ x } R_w /R_t) \quad (6)$$

By equation (6), saturation of water is calculated. After this, hydrocarbon saturation is calculated by putting the values of Sw in the following equation

$$Sh = (1\text{-}Sw) \quad (7)$$

n = Saturation exponent
Sw = Saturation of water
R_t = Deep zone resistively (LLD)/True resistivity
φ = Effective Porosity
R_w = Formation water resistivity
Sh = Saturation of hydrocarbon,
m = Cementation factor
a = Tortuosity factor

Water saturation and saturation of hydrocarbon are the 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 following cut-offs were used to pinpoint intervals for further detailed petrophysical analysis;
Effective porosity (φ_E) > 7 %
Water saturation (Sw) < 80% and
Volume of shale (V_{sh}) < 35%.

IV. RESULTS AND DISCUSSION

A. Identification of reservoir intervals

The identification of a potential reservoir zone in a borehole is very important and different criteria can be used like low GR log values, high effective porosity values and high neutron porosity values. The petrophysical parameters were determined for the formations drilled within Sara West-01 well, the Habib Rahi Limestone and Sui Main Limestone formations were selected for detailed petrophysical analysis, as they are fulfilling the criteria of cut off factor.

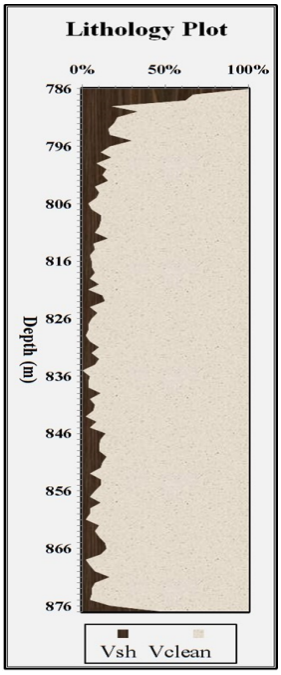

Fig. 2. Lithology plot showing the variation of volume of shale and volume of clean with respect to depth.

B. Petrophysical interpretation of Habib Rahi Limestone

The Habib Rahi Limestone is 90 m thick with a depth range of 786m-877m. Different log curve statistics were calculated in order to determine its reservoir potential. In general sand has been dominant. The volume of shale is very high from 786m to 790m. After 790 m, there is relative decrease in volume of shale as shown in *Fig. 2*. Average value of volume of shale in this zone is 11.95% and average value of volume of clean is 88.05%. Both volume of clean and volume of shale have inverse relation to each other as shown in *Fig. 2*. The lithology determines from NPHI and RHOB is prominently limestone as shown in *Fig. 3*.

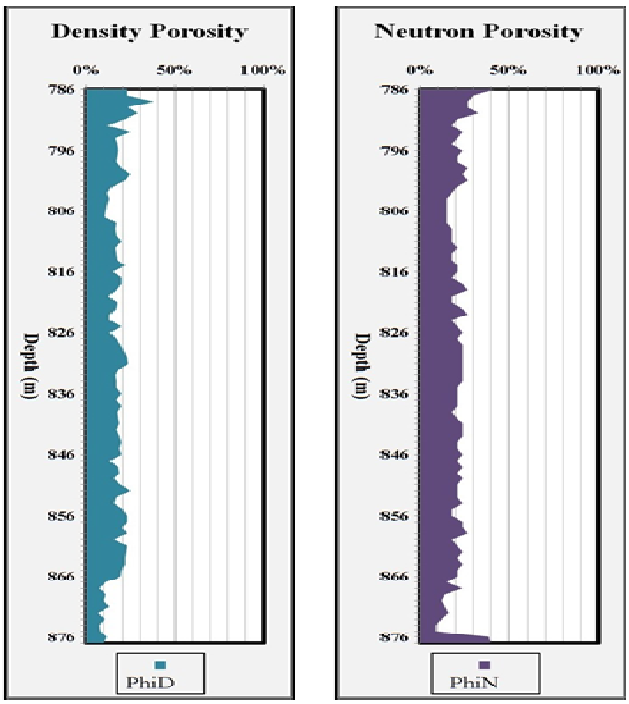

Fig. 3. Density and neutron porosity plot of Habib Rahi Formation, Sara west-01 well.

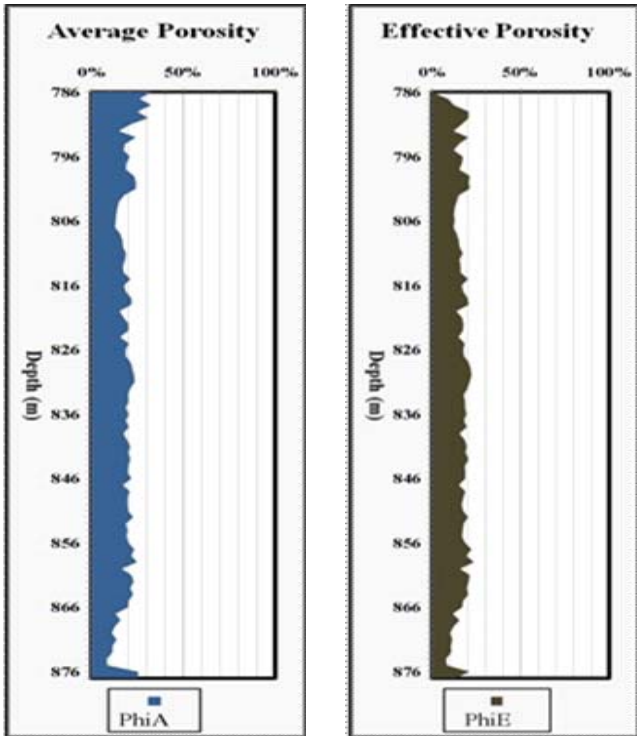

Fig. 4. Average and effective porosity plot of Habib Rahi Formation Sara west-01 well.

Average and effective porosity is approximately 20% and 16.75 % respectively as shown in *Fig. 4*, which shows that there is no sufficient porosity for the accumulation of hydrocarbon.

Average Saturation of water in this formation is 88 % as shown in *Fig. 5*; vuggy or crystalline type porosity is present in Habib Rahi Formation and the formation is water wet, further property readings are shown in Table II.

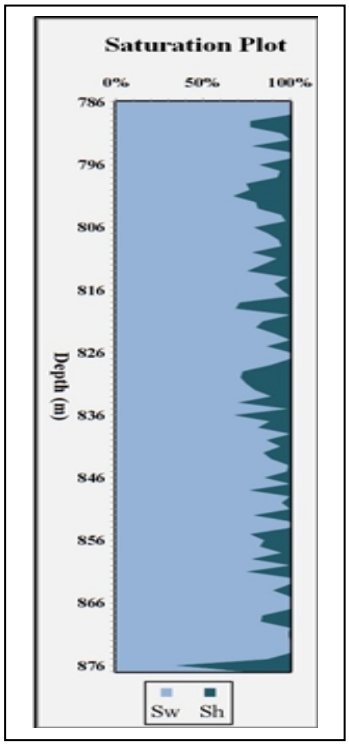

Fig. 5. Fluid saturation plot of Habib Rahi Formation showing the variation of water saturation and hydrocarbon saturation.

TABLE II
SUMMATION TABLE OF PETRO PHYSICAL PARAMETERS CALCULATED FOR HABIB RAHI FORMATION.

Property Readings	Average
Volume of Shale	12%
Vclean	81%
Effective Porosity	16.75%
Saturation of Water	88%
Saturation of Hydrocarbon	12%

C. Petrophysical interpretation of Sui Main Limestone

The Sui Main Limestone is 77.50m thick having a depth range from 1180.50m to 1257m. In general sand has been dominant. The volume of shale is almost constant but at 1223m there is relative decrease in volume of shale. Average volume of shale in this zone is 30.44% and average volume of clean is 69.56%. Both volume of clean and volume of shale have inverse relation as in *Fig. 6*. Prominent lithology is Limestone based on the neutron and density porosity plots. This formation interval has quite promising effective porosity 9.38 as shown in *Fig. 8*, and the saturation of water is 98% as shown in *Fig. 9*, property readings are shown in Table III.

TABLE III
SUMMATION TABLE OF PETRO PHYSICAL PARAMETERS CALCULATED FOR SUI MAIN LIMESTONE.

Property Readings	Average
Volume of Shale	30.44% %
Volume of Clean	69.56%
Effective Porosity	9.38%
Saturation of Water	98%
Saturation of Hydrocarbon	2%

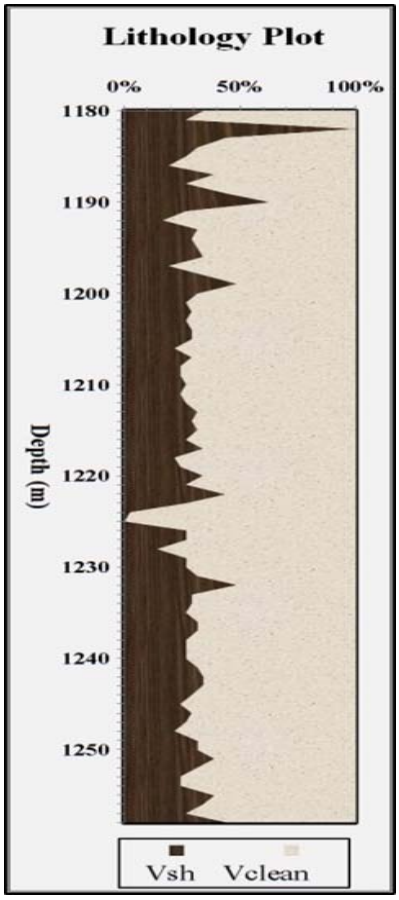

Fig. 6. Lithology plot of Sui Main Limestone showing the variation of volume of shale and volume of clean with respect to depth.

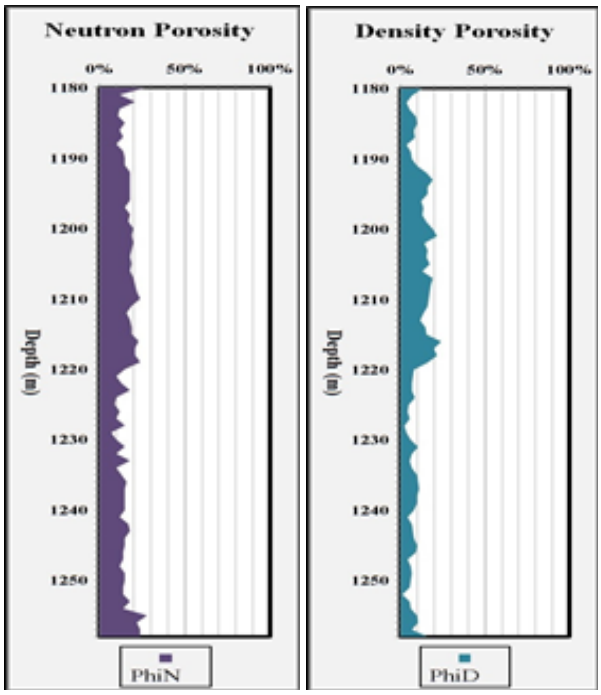

Fig. 7. Density and neutron porosity plot of Sui Main Formation, Sara west-01 well.

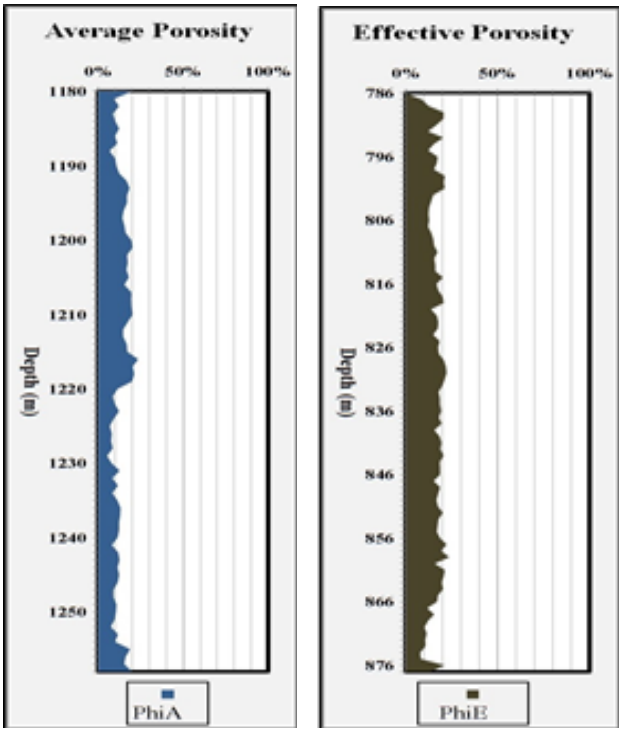

Fig. 8. Average and effective plot of Sui of Main Formation, Sara west-01 well.

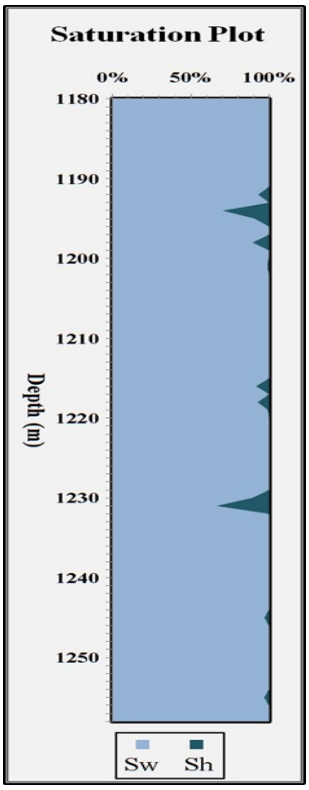

Fig. 9. Fluid saturation plot of Sui Main Limestone showing the variation of water saturation and hydrocarbon.

V. CONCLUSIONS

Both Habib Rahi limestone and Sui main Limestome formations has been analyzed on the basis of different suits of logs, analysis shows that 90 meter thick Habib Rahi Limestone formation is comprised up of dominantly sandstone as the log curve statistics shows that shale has been drastically decreasing as one moves down with depth but the porosity is not showing as much fluctuations with the high amount of water saturation. On the other hand 77.5 meter thick Sui Main limestone is not much promising in accumulating hydrocarbons due to low PHIE values and high volume of shale. However due to fine grain size of sandstone, high water saturation and low PHIE values in both the formations depicts it a water wet well.

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