Chapter 4

Petrophysical Evaluation

4.1. Introduction:

The static reservoir modelling involves the integration of core data, log and engineering data which are used in order to understand the behaviour of the reservoir at in situ condition. The goal of this chapter is to incorporate core into log analysis description and analysis data of the key wells (Sharaf-1and Sharaf-2) models of volume of shale, porosity and water saturation for uncored intervals and field study.

4.2. Interactive Petrophysics(IP):

Interactive petrophysics (IP) was developed by a petrophysicist with a view to work as petrophysicists want to work , but never thought possible ! The software is different by design – fast , accurate , versatile and just portable . it is an easy-to-use log analysis tool , ideal for both geologists who may wish to quality check their log data and experienced petrophysicists who are able to carry out multi-zone, multi-well petrophysical field analysis.

IP is truly unique in its approach to petrophysics . For the expert user IP offer some of the most sophisticated interpretation modules in the industry. Using only the histograms and log plots. IP ،mouse, you can pick parameters from cross plots instantaneously recomputes and displays the results when parameters are changed.

The software is also used by universities and is an excellent tool for training geoscientists and engineers Interactive Petrophysics gives rapid results.

The standard deterministic analysis is done using three modules:

- Clay Volume
- Porosity and Water Saturation
- Cutoff and Summation

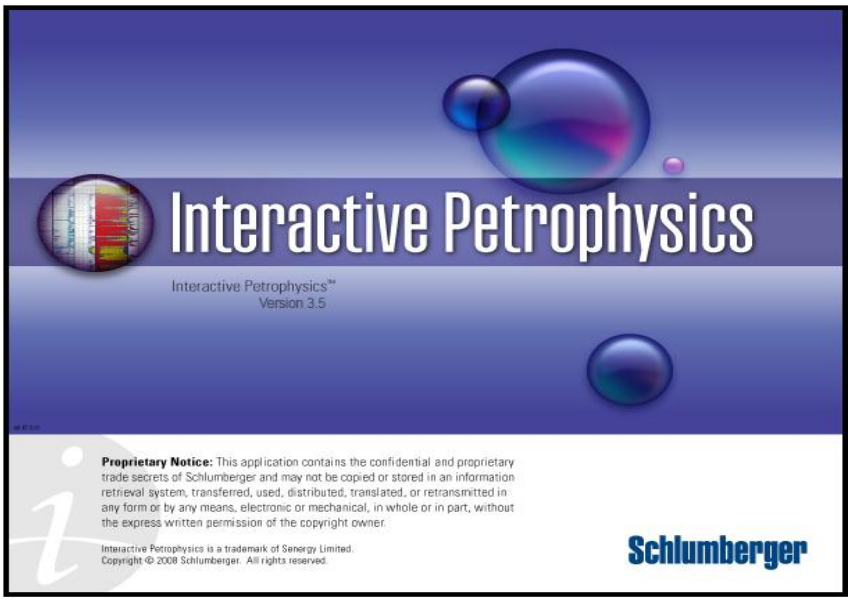


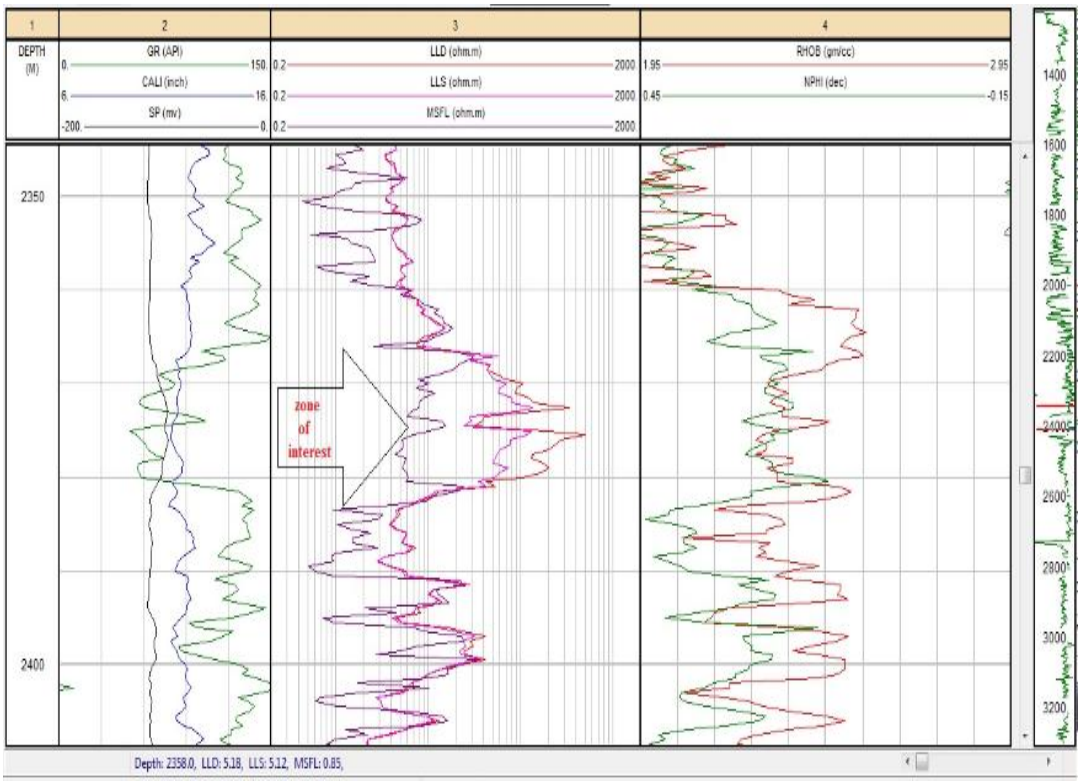
Figure (4.1): Shows the IP window.

4.3. Petrophysical Properties Evaluation of Sharaf(1):

The well Sharif-1 drilled in 1980 by Chevron company . Significant oil and gas shows started at 2365m to 2381m (zone of interest). Schlumberger conducted the wireline logging, all available logs shown in table(4.1) and in figure(4.2).

Number	Log Type	Beginning at "m"	Ending at "m"
1	GR	1224	3307
2	SP	1220	3310
3	CAL	1224	3307
4	LLD	1224.5	3306.5
5	LLS	1225	3306.5
6	MSFL	1225	3306.5
7	RHOB	1224.5	2725
8	NPHI	1220	3310
9	DT	1224	3307

Table(4.1): shows different available logs type in Sharaf-1.



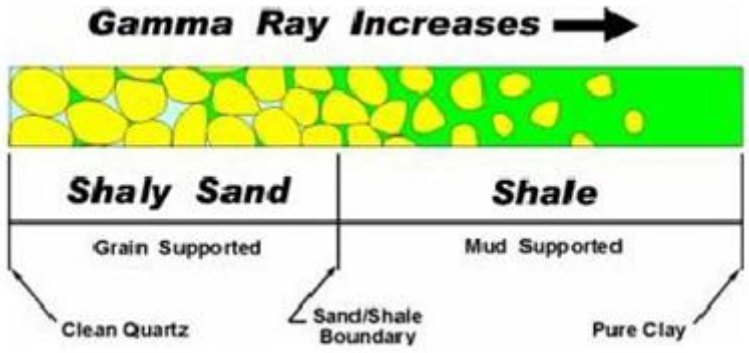
Figure(4.2) shows available logs plot overview around zone of interest.

4.3.1. Volume Of Shale Modeling:

The volume of shale (Vsh) quantity is defined as the volume of wetted shale per unit volume of reservoir rock. Wetted shale is the space occupied by water confined to the shale known as bound water.

Figure (4.3) below shows what happens as clay content is increased from clean sandstones on the left to clay rich shale on the right. Shaly sands are sands with a shale component. These shales are very significant component of shaly sand reservoirs. Increased volumes of shale decrease the effective reservoir capacity and conductive shales reduce the formation resistivity and if not corrected for, give wrong volume of hydrocarbon calculations The volume of shale need to be calculated in petrophysical evaluation.

In order to correct porosity and water saturation results for the effects of shale volume. Shale is considered as an indicator for reservoir quality, In addition to the shale volume, it is important to determine the types of shale for choosing the appropriate shale model.



Figure(4.3): Schematic diagram of variation of sediments with clay mineral contentincreasing from left to right (modified after Heslop, 1972).

The following methods were used to define the shale volume in this study:

- **Single clay indicator:**
  Gamma-Ray (GR) log.
- **Double clay indicators:**
  Neuron/Density method.

4.3.1.1. Gamma-Ray Method:

The gamma ray log is the most common shale volume indicator. The log responds to the changes in natural radiation emitted by formation. In shaly sands the level of gamma radiation emitted is a function of clay volume. The gamma ray log does not measure the volume of silts or other inclusions within the shales. The maximum gamma ray response is taken as the shale point and minimum response as the clean sand point. The Gamma-Ray clay indicator can be calculated using the following methods:

- **Linear Method:**

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad \dots\dots (4.1)$$

Where:

Vsh = shale volume.

GR_{log} = gamma ray reading of formation.

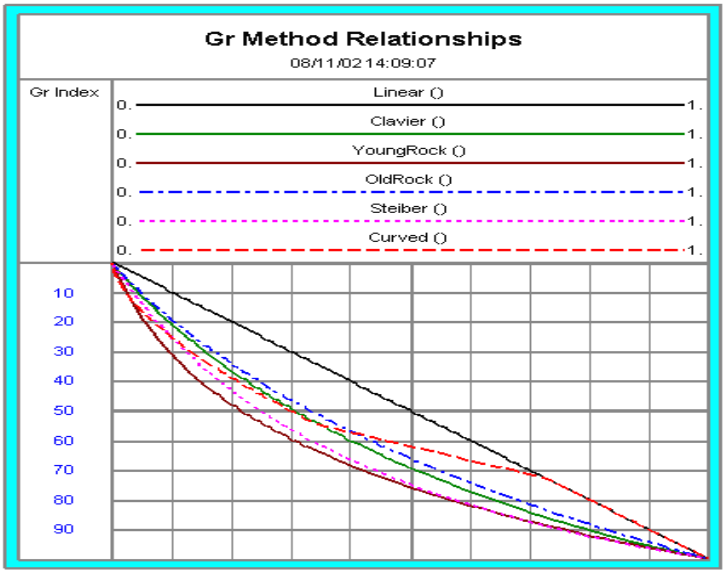
GR_{min} = minimum gamma ray (clean sand or carbonate).

GR_{max} = maximum gamma ray (shale).

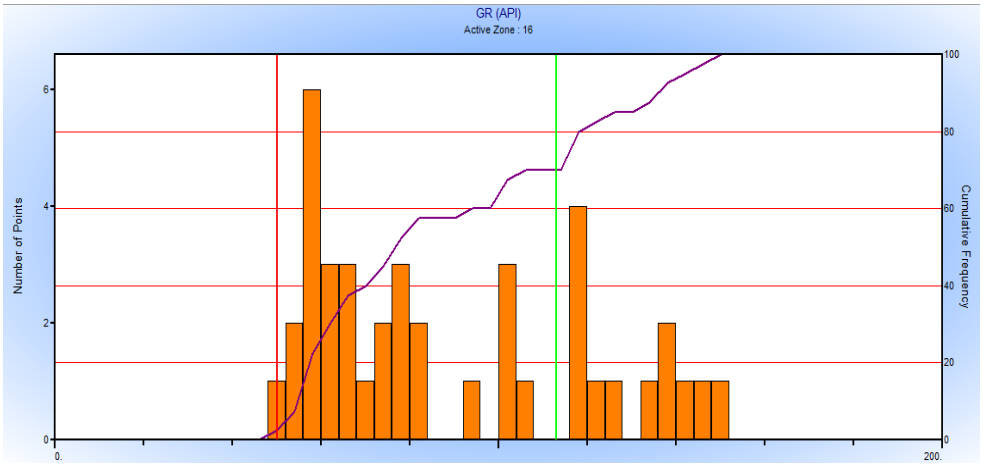
Zone #	Gr Use	Gr Clean	Gr Clay	Gr Method
1	✓	37.	84.	Linear
2	✓	72.	124.	Linear
3	✓	43.	104.	Linear
4	✓	50.	144.	Linear
5	✓	56.	97.	Linear
6	✓	55.	105.	Linear
7	✓	50.	104.	Linear
8	✓	48.	120.	Linear
9	✓	44.	134.	Linear
10	✓	43.	132.	Linear
11	✓	85.	139.	Linear
12	✓	55.	143.	Linear
13	✓	62.	148.	Linear
14	✓	102.	148.	Linear
15	✓	92.	150.	Linear
16	✓	50.	113.	Linear
17	✓	43.	146.	Linear
18	✓	85.	120.	Linear
19	✓	78.	124.	Linear
20	✓	57.	143.	Linear

Table(4.2):shows values of GR used in Linear Method.

The approach used in deciding which of the resulted shale volume model to be used was based on overlaying the resulted shale volumes with that derived from petrography studies. The best match with the petrography volume of shale was choosen .



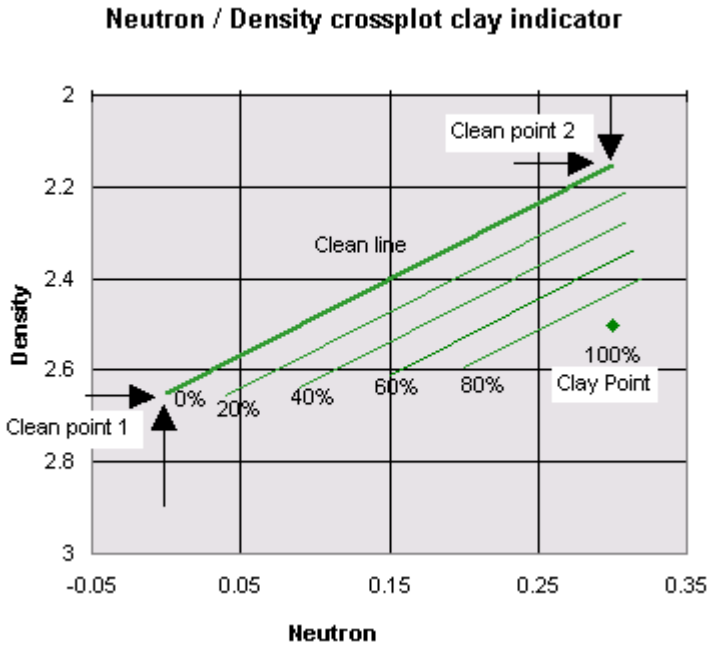
Figure(4.4): shows the different gamma ray Vclay relationships.



Figure(4.5):Shows the GR Histogram a round zone of interest.

4.3.1.2. Neutron-Density Method:

The double clay indicators (neutron-density) utilize the principle of defining a clean line and a clay point. The clay volume is calculated as the distance the input data falls between the clay point and the clean line. An example of double clay indicator is shown in Figure below(4.6).



Figure(4.6): illustrates the principle of neutron-density cross plot as clay indicator.

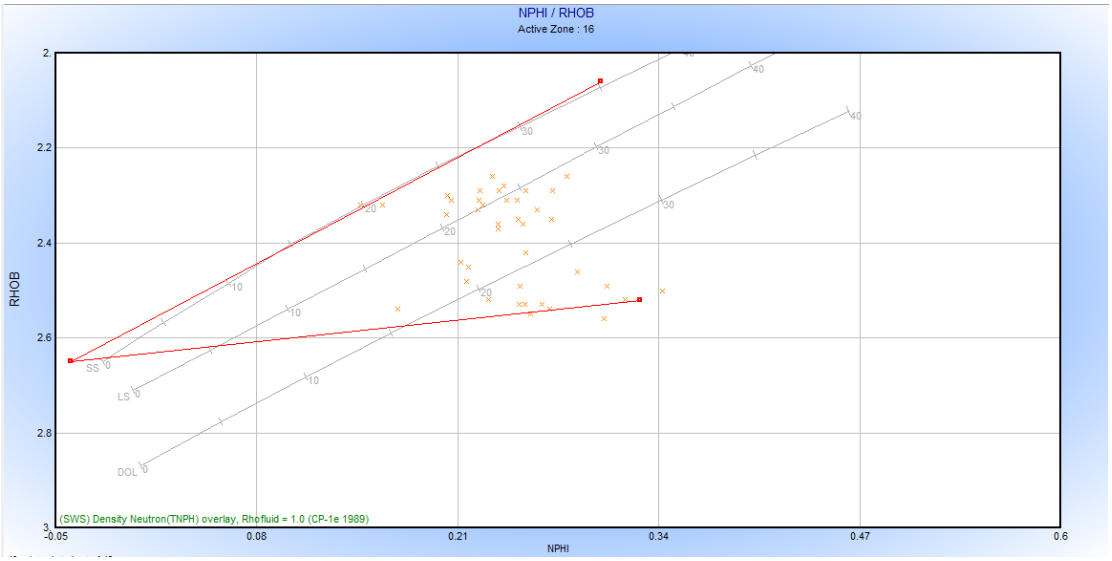
The Neutron-Density double clay indicator relationship:

$$V_{sh} = \frac{(\mathbf{DenCl2} - \mathbf{DenCl1}) \times (\mathbf{Neu} - \mathbf{NeuCl1}) - (\mathbf{Den} - \mathbf{DenCl1}) \times (\mathbf{NeuCl2} - \mathbf{NeuCl1})}{(\mathbf{DenCl2} - \mathbf{DenCl1}) \times (\mathbf{Neuclay} - \mathbf{NeuCl1}) - (\mathrm{DenClay} - \mathrm{DenCl1}) \times (\mathrm{NeuCl2} - \mathrm{NeuCl1})}$$

…..(4.2)

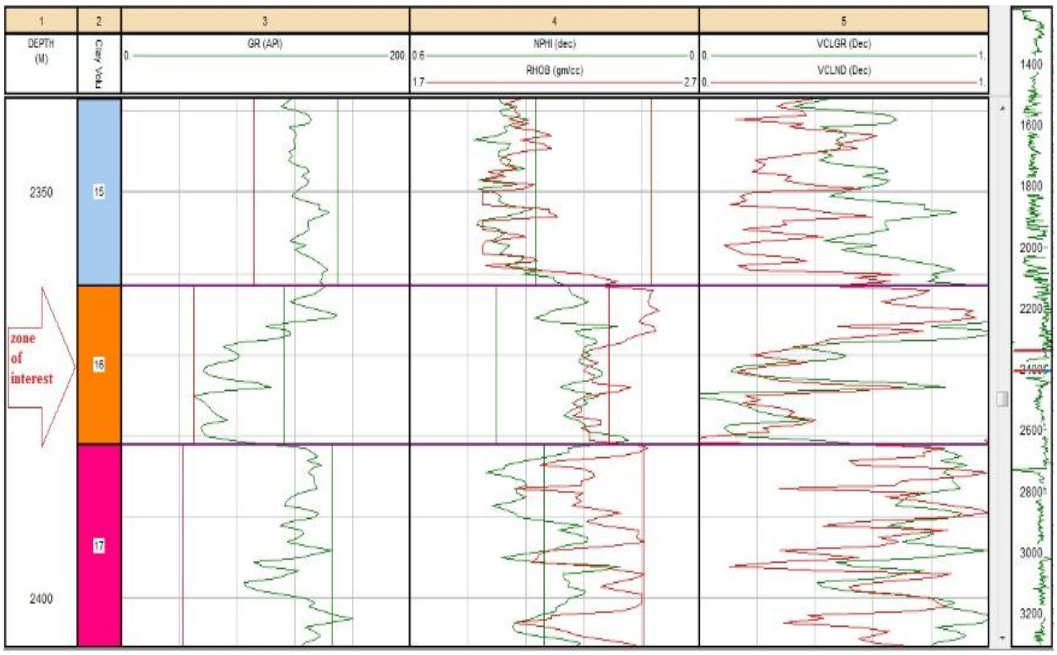
Where:

$DenCl1$, $NeuCl1$, DenCl2 and $NeuCl2$ are the density and neutron values for the two ends of the clean line.



Figure(4.7): illustrates neutron-density crossplot around zone of intrest.

The figure(4.7) below shows the output curves of Clay volume evaluated from single clay indicator (GR method) and double clay indicators (neutron-density method) around zones (15, 16 and 17).



Figure(4.8): shows the output curves.

4.3.2. Porosity Model :

The porosity of a rock is the volume of the non-solid portion of the rock that is filled with fluids divided by the total volume of the rock(Crain, 1986). In general, porosities tend to be lower in deeper and older rocks due to cementation and overburden pressure stress on the rock. The porosity from logs can be estimated from sonic) or a combination of porosity logs. The ،a single porosity log (density, neutron porosity derived directly from logs without correction for clay content is regarded as total porosity.

Effective porosity is the resultant porosity determined after removal of the effect of clay. However, in an interval of no shale, the total porosity equals the effective Estimation of porosity. The porosity from log can be determined in both .porosity clean and shaly zones as presented below.

4.3.2.1. Porosity Determination from Density Log:

The porosity derived from the density log ($Ø_D$) is defined by the following relationships (Wyllie, 1963).

$$\emptyset_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \dots \dots (4.3)$$

Where:

ρ_{ma} = matrix desity

ρ_b= log density

ρ_f= formation fluid density.

$Ø_D$= porosity from density

For:

Fresh water mud, ρ_f = 1.0 g/cc

Salt water mud, ρ_f = 1.1 g/cc

Gas mud, ρ_f = 0.70 g/cc

According to Dresser Atlas 1979, density porosity in a shaly formation is calculated using the following equation:

$$Ø_{Dcorr} = \frac{(\rho ma - \rho b) - Vsh\ (\rho ma - \rho sh)}{(\rho_{ma} - \rho_f)\ (\rho_{ma} - \rho_{sh})} \dots\dots (4.4)$$

Where:

$Ø_{D\ corr}$ = Corrected density for shale effect.

V_{sh} = Volume of shale.

ρ_{sh} = Density value of adjacent shale formation.

4.3.2.2. Porosity Determination from Neutron Log:

Neutron log porosity is calculated by the acquisition software and is displayed directly on the log. The logs must be interpreted from a specific chart because they are not calibrated in physical units. A convenient standard for the neutron log is the neutron porosity index given in limestone. In a shaly formation, the neutron log will appear to be more porous.

The effect of shale on the neutron log can be corrected by the following equation:

$$\emptyset N_{corr} = \emptyset N_{log} - V_{sh} \times \emptyset N_{sh} \ldots\ldots (4.5)$$

Where:

$\emptyset N_{corr}$ = Corrected Neutron porosity.

$\emptyset N_{log}$ = Neutron log reading of the interval.

$\emptyset N_{sh}$= Volume of shale.

ØNsh = neutron log of the adjacent shale formation.

4.3.2.3. Neutron-Density porosity Model:

Using the input 'Mineral Model' parameter, the program calculates the porosity for each mineral from the neutron and density logs. For the Sand/Limestone/Dolomite Model , the program first decides , based on the matrix density , whether the Sand/Limestone or Limestone/Dolomite Model should be used. Once the four porosities (density porosity for 2 minerals and neutron porosity for 2 minerals) have been calculated, using the equation of density porosity model and neutron porosity model , the crossplot is calculated as follows:

$$\emptyset = \emptyset_{D1} + \frac{\emptyset_{N1} - \emptyset_{D1}}{1 - (\emptyset_{N1} - \emptyset_{N2})/(\emptyset_{D1} - \emptyset_{D2})} \ldots\ldots (4.6)$$

Where:

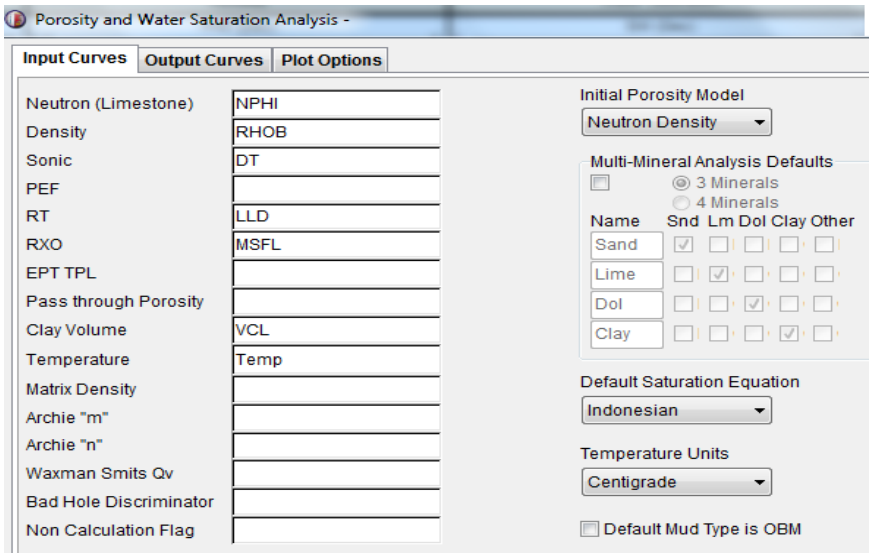
$\emptyset_{N1}$ = Neutron corrected porosity for matrix1.

$\emptyset_{N2}$ = Neutron corrected porosity for matrix2.

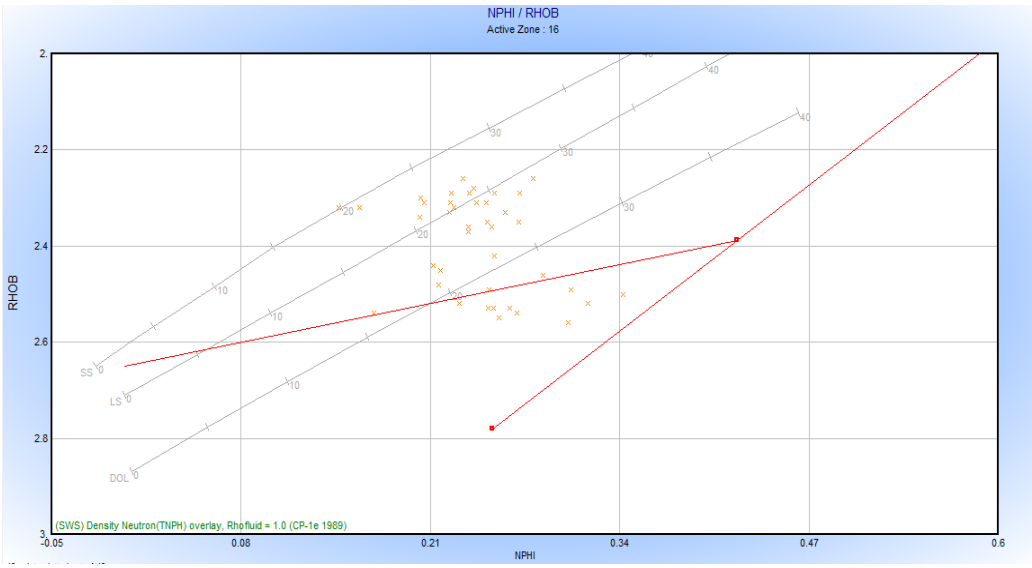
$\emptyset_{D1}$= Density corrected porosity for matrix1.

$\emptyset_{D2}$= Density corrected porosity for matrix2.

The program solves the same equation as for the variable hydrocarbon density logic described above , except for porosity and clay volume . the hydrocarbon density being known .



Figure(4.9): shows the input curves for porosity and water saturation analysis.



Figure(4.10): illustrates the Neutron-Density porosity crossplot.

4.3.3. Effective Porosity Determination (∅e) :

Effective porosity(∅e) excludes all the bound water associated with clays but involves all the connected pores in the pore system that can contribute to flow has been determined from the density log as follows:

$$\emptyset e = \frac{\rho_m - \rho_{\log} - V_{clay} * \rho_m - \rho_{clay}}{\rho_m - \rho_f} \ldots\ldots (4.7)$$

Where:

∅e = Effective porosity from density log (v/v).

ρ_m= Matrix density (g/cc) = 2.67g/cc from core grain density.

ρ_{log} = Log bulk formation density (g/cc).

4.3.4. Water Saturation Model:

The saturation of fluid of a reservoir rock is referred to as the percentage of the pore space filled with a particular fluid, and the sum of all the fluids in the pore spaces equals one hundred percent. The saturation of water is always part of the fluids that occupy the pore spaces of reservoir rock.

Connate water usually is in the range of 10 % to 40 % in most rocks which means that it only occupies about 10to 40 percent of the pore volume of the rock and other fluids (hydrocarbon) occupy the rest. Free water is water that resides within the macro-porosity region of the interconnected pore space of a reservoir and is able to flow under an applied pressure gradient(Newman, 1987).

Determination of water saturation from logs can be grouped into two, namely the Clean Sand (Shale free) and Shaly-Sand models. The Clean Sand or shale free group is determined from the Archie‟ s relationship while the Shaly-Sand models can further be sub-divided into two main equation groups according to Petrolog (2006) as follows:

Group 1: The volume of Shale or Resistivity model:

- Simandoux.
- Modified Simandoux.
- Poupon Leveaux.
- Fertl and Hammack.
- **Indonesia.**

This particular group uses the effective porosity as the input porosity in the water saturation equation.

Group 2: Cation Exchange or Conductivity model:

- Waxman-Smits.
- Modified Waxman-Smits.
- Dual –Water.
- Juhasz.

The group 2 as listed above uses the total porosity values in the water saturation equation. Before discussing in details the water saturation models, some of the basic input parameters to these models such as the formation temperature and resistivity of water at formation temperature will be estimated and verified in as many ways aspossible. Other basic parameters like cementation and saturation exponents (m and n) earlier determined from special core analysis will be used for the evaluations of water saturations.

4.3.4.1. Formation Temperature Determination:

The following equation was used for formation temperature determination.

$$\mathbf{T_2 = D\left(\frac{BHT - T_1}{TD}\right) + T_1} \ldots\ldots (\mathbf{4.8})$$

Where:

T_2= Formation Température

D = Log depth

BHT = Bottom hole temperature

T_1= Surface temperature

TD = Total depth

Well Number	Surface Temp °C	Bottum hole Temp °C	Depth in m	ΔT (°C □ Ft)
Sharaf # 1	29.40	96.10	2725.80	0.024
Sharaf #2	29.40	100.30	2868.17	0.024

Table (4.3):illustrates Temperature values on sharaf(1 and 2).

The resistivity of mud filtrate (Rmf) at formation temperature can also be determined using the following equation:

$$R_{mf2} = R_{mf1}\left(\frac{T_1+6.77}{T_2+6.77}\right) \ldots . (4.9)$$

Where:

R_{mf2} = Resistivity of mud filtrate at formation temperature (ohm-m in °F)

R_{mf1} = Known resistivity of mud filtrate at surface temperature (in °F)

4.3.4.2. Formation Water Resistivity Determination (Rw):

Formation water resistivity represents the resistivity value of the water which is uncontaminated by drilling mud that saturates the porous formation.

The relationship for formation water resistivity obtained from water bearing formation is given below:

$$R_w = \frac{R_{mf} * R_t}{R_{xo}} \ldots . . (4.10)$$

Where :

Rw = Water resistivity in uninvaded zone.

Rmf= Resistivity of mud filtrate

Rt = True resistivity from deep resistivity log reading

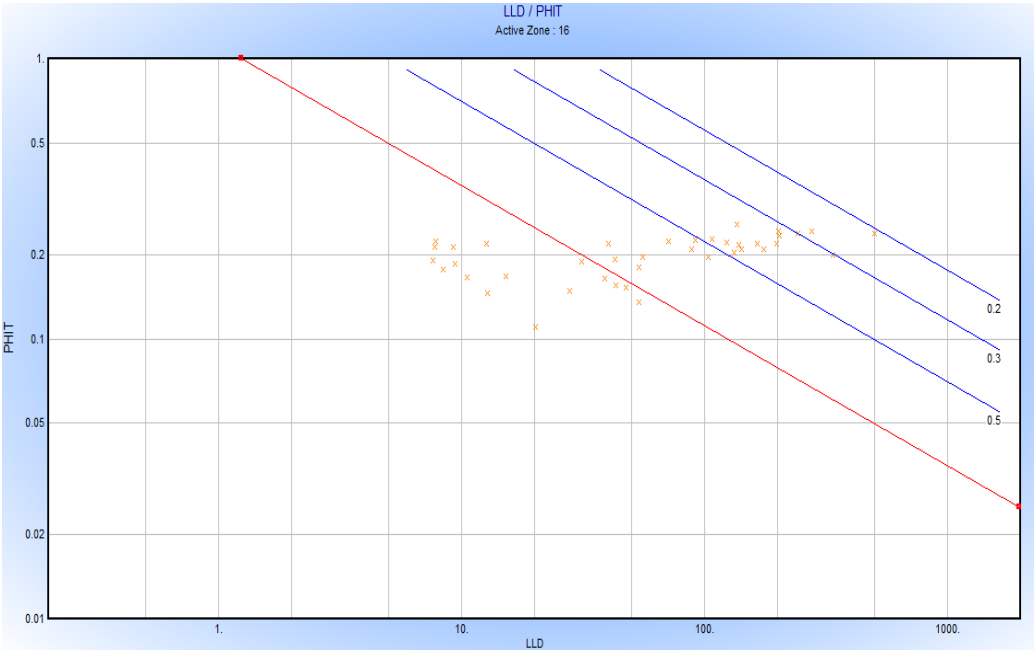
Rxo = Water resistivity from the flushed zone (shallow resistivity reading)

The formation water resistivity estimated from Pickett cross plots are discussed below.

- **Pickett Plot method For Formation Water Resistivity Estimation:**

The concept of the Pickett plot is based on double logarithm plot of a resistivity measurement on the x-axis versus porosity measurement on the y –axis.

After the points are plotted, the one hundred percent water saturation is fixed by drawing it through the lowest resistivity points corresponding to different porosities. Points of constant water saturation will be plotted on straight line and the water resistivity (R_W) can be determined from point on the straight line.



Figure(4.11): shows the pickett plot around zone of interest(16).

The estimates of water saturation are needed when evaluating the potential of a reservoir.

Water saturations of the invaded and un-invaded zones (Sxo and Sw) of a formation can be calculated for clean sands and Shaly-Sand models by using one of the Sw equations below:

4.3.4.3. Indonesian Model:

In 1971, Poupon and Leveaux proposed an empirical model called Indonesia.

The equation was based on characteristic of fresh waters and high degrees formula of shaliness that were present in many oil reservoirs in Indonesia.

The empirical relationship can be written as follows:

$$\frac{1}{\sqrt{R_t}} = \left[\sqrt{\frac{\emptyset^m}{a \times R_W}} + \frac{V_{cl}{}^{((1-V_{cl})/2)}}{\sqrt{R_{cl}}}\right] \times S_w{}^{n/2} \ldots\ldots (4.11)$$

Where:

Rt = Resistivity curve from deep log reading

Rcl = Resistivity of wet clay.

Øe = Effective porosity calculated from equation (4.7) above.

Sw= Water saturation, fraction.

Vcl = Volume of shale, fraction.

Rw= Formation water resistivity.

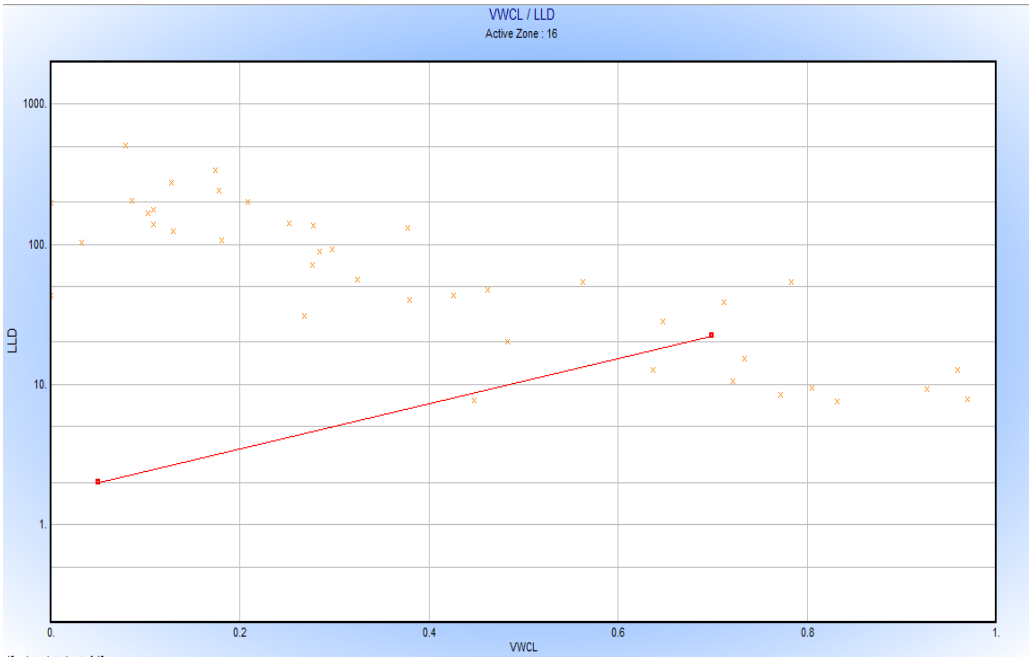
m=Cementation exponent.

a=Tortuosity factor.

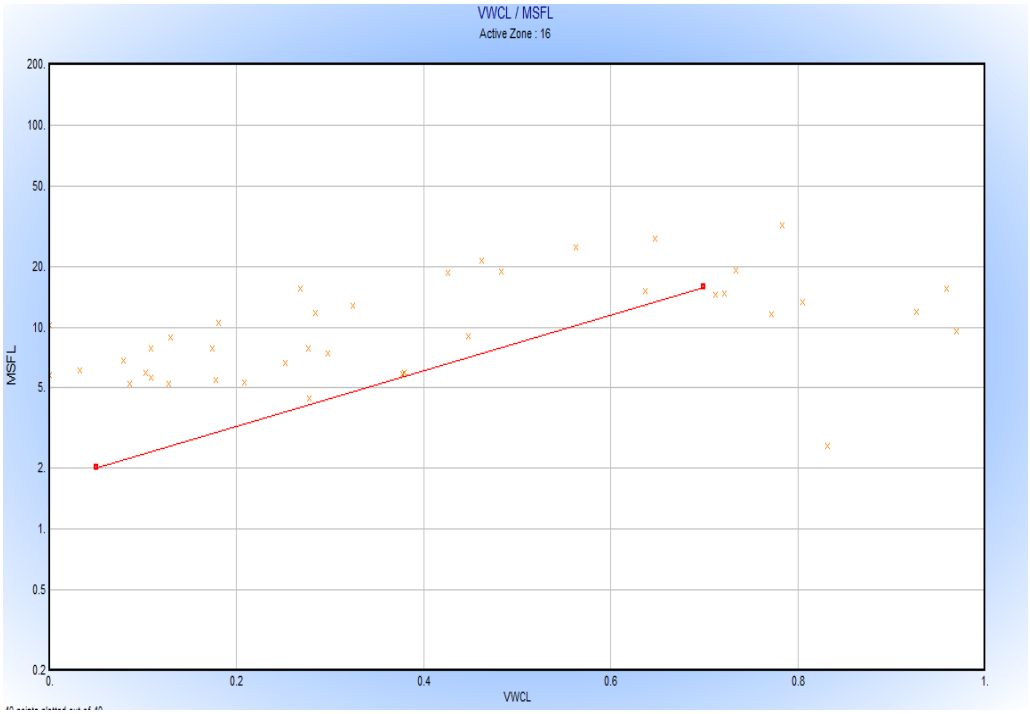
n= Saturation exponent.

In this study we used (m=2, n=2 and a=1) as a constants.

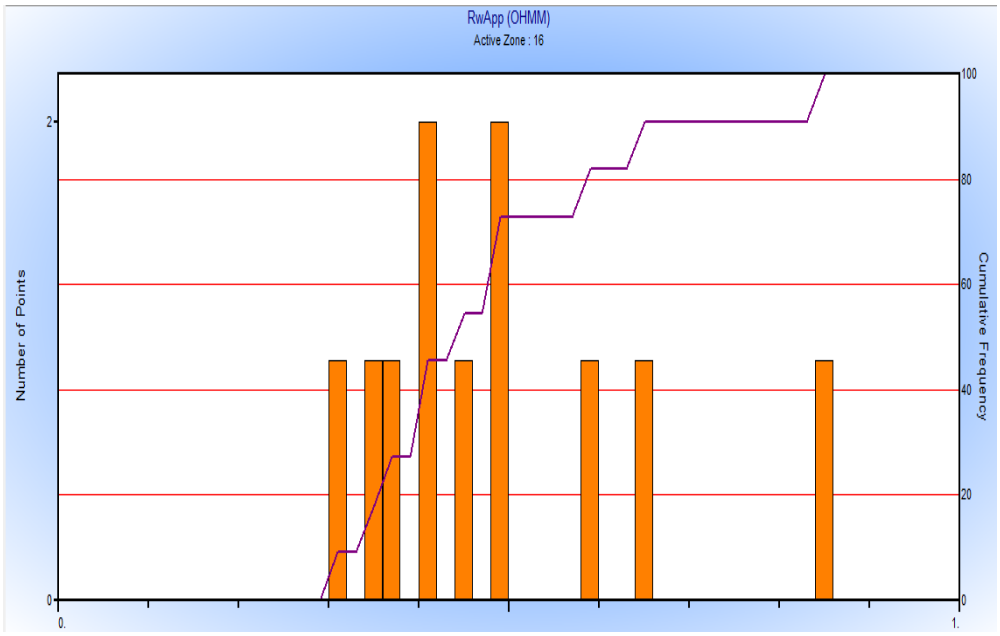
The Indonesian equation depends on resistivity of shale and resistivity of apparent water so we have to control them within zones precisely from crossplot of (volume of clay and LLD) and (volume of clay and MSFL) described in figures (4.12) and (4.13) below.



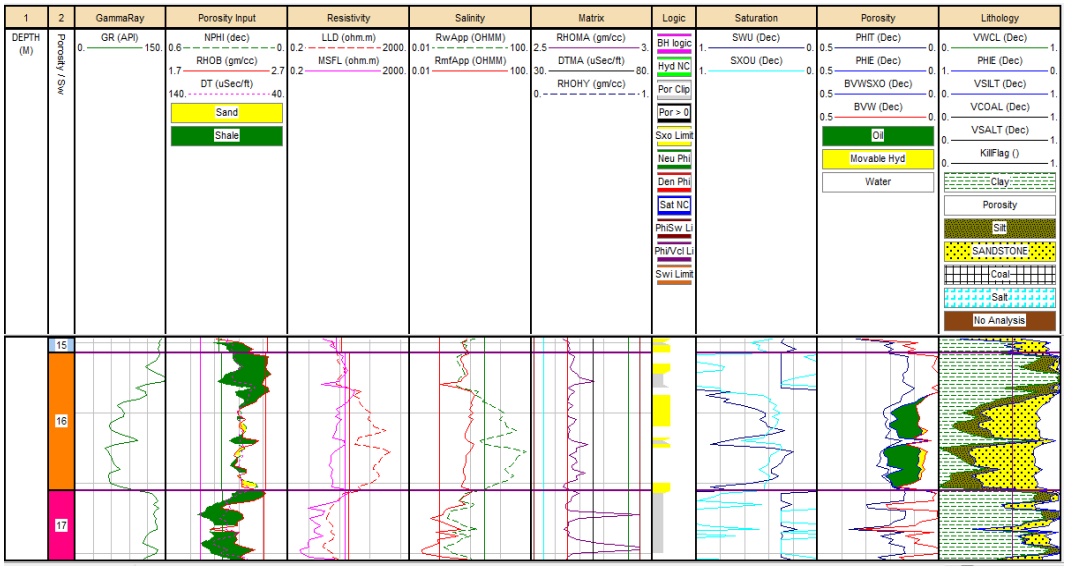
Figure(4.12):shows the crossplot of volume of clay and LLD around zone of interest.



Figure(4.13):shows the crossplot of volume of shale and MSFL around zone of interest.



Figure(4.14): shows apparent water resistivity histogram around zone of interest.



Figure(4.15):shows porosity and water saturation plot around zone (16) using IP.

4.3.5. Permeability Model:

Permeability is one of the important parameters of a reservoir, which describes the ability of fluid flowing through the rock and is a main controlling factor on the productivity of formations.

Up to now, however, none of the current well logging techniques can be used to measure it directly. In this study the Timur method has been used to estimate formation permeability. The most obvious control on permeability is porosity. This is because larger porosities mean there are many more and broader pathways for fluid flow.

4.3.5.1. Timur Equation:

$$K = a \times \frac{\emptyset^b}{Swi^c} \ldots\ldots (4.12)$$

Where:

K= permeability md.

Ø = porosity , fraction.

Swi = irreducible water saturation .

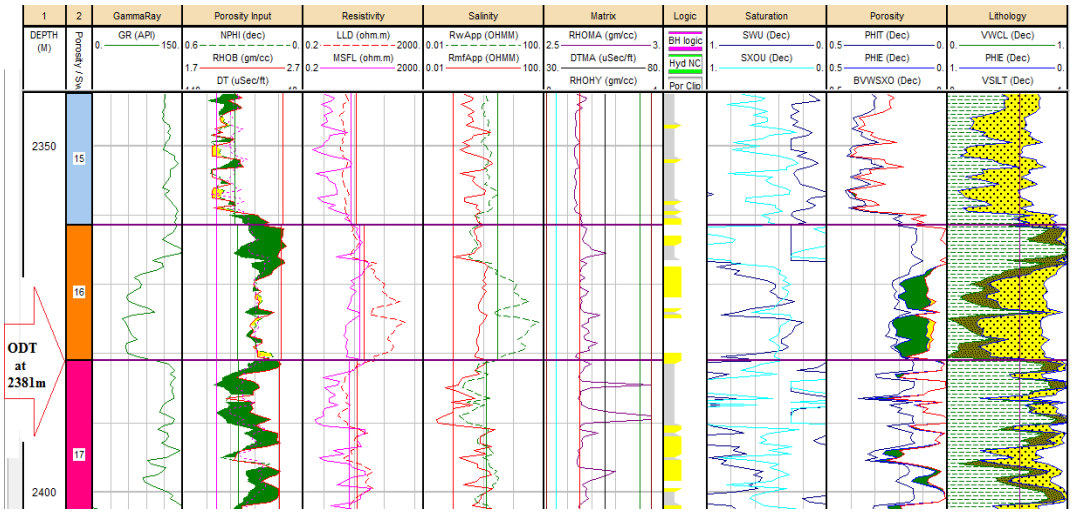
a = 8581.0 (constant).

b = 4.4 (constant).

c = 2.0 (constant).

4.3.6. Fluid Contact Determination:

Based on log response for oil pays and water zones, OWC is determined from LLD, and RMSL curves, as well as testing results as no pressure data is available in this study. Figure(4.16) displays oil down to (ODT) in Abu gabra formation on the log plot in well Sharaf(1) (2381.0 mKB) only as no oil bearing zone detected in the other two wells.



Figure(4.16): shows the ODT below the zone of interest.

4.3.7. Reservoir / Pay Cutoff Definition:

Cutoff values such as shale volume, porosity, and water saturation are very important parameters in calculation of OOIP. Based on the log interpretation and DST, as well as the previous study results, the following Cutoffs can be adopted:

Vsh = 50.0%

PHIE = 10.0%

Sw = 70.0%

Zone #	Zone Name	Zone Top	Zone Bottom	Zone Color
1		1226.	2195.5	Default
2		2195.5	2211.5	Default
3		2211.5	2367.	Default
4		2367.	2381.	Default
5		2381.	2724.5	Default

Table (4.4): illustrates cutoff zone depths for sharaf(1).

Zone #	Gross Interval	Net Res	Net/Gross Res	Av Phi Res	Av Sw Res	Av Vcl Res	PhiH Res	PhiSoH Res	VclH Res
1	969.50	786.25	0.811	0.238	0.989	0.238	187.04	2.09	187.25
2	16.00	10.25	0.641	0.174	0.583	0.317	1.79	0.74	3.25
3	155.50	89.75	0.577	0.269	1.000	0.286	24.11	0.01	25.68
4	14.00	13.25	0.946	0.222	0.499	0.007	2.94	1.47	0.10
5	343.50	222.00	0.646	0.226	0.973	0.196	50.25	1.37	43.56

Table(4.5): illustrate the reservoir results after cutoff for sharaf(1).

Zone #	Gross Interval	Net Pay	Net/Gross Pay	Av Phi Pay	Av Sw Pay	Av Vcl Pay	PhiH Pay	PhiSoH Pay	VclH Pay
1	969.50	3.50	0.004	0.242	0.642	0.126	0.85	0.30	0.44
2	16.00	9.00	0.563	0.172	0.532	0.311	1.54	0.72	2.80
3	155.50	0.00	0.000	---	---	---	---	---	---
4	14.00	10.00	0.714	0.230	0.406	0.000	2.30	1.37	0.00
5	343.50	8.00	0.023	0.178	0.615	0.389	1.42	0.55	3.11

Table(4.6): illustrate the pay results after cutoff for sharaf(1).