Reservoir evaluation from well logs: A case study of "Beda" Oil Field, Sirte Basin

* Entesar. A. Haman,
Department of Petroleum Engineering , Faculty of Oil and Gas Engineering
University of Zawia,, *Libya*
I.Haman@zu.edu.ly

الملخص

تقدم هذه الدراسة نتائج تحليل اللوغاريتمات لمجموعة من السجلات الجيوفيزيائية تشتمل على سجلات أشعة جاما (GR) والمقاومة (LLD) والنيوترون (PHIN) والكثافة (PHID) من ثلاثة آبار في حقل "بيدا" الواقع في حوض سرت. تم إجراء التحليل لتقييم حقول الهيدروكربون ، أي تحديد هوية الخزان الحامل للهيدروكربونات ودراسة خصائص المكمن بناءً على بيانات السجل من الآبار الثلاثة. تم تحديد سبعة عشر منطقة اهتمام (أجسام الدولوميت) وربطها عبر هذا المجال. تم تحديد ثلاثة من هذه الدولوميت على أنها خزانات هيدروكربونية محتملة. المعلمات البتروفيزيائية المحسوبة لطبقات المكمن لها مسامية ، مدى Ø من (0.195٪ - 19.57٪) وتشبع هيدروكربوني ، نطاق Sh من (0.75٪ إلى 0.96٪). يشير التحليل إلى أن الخزانات (الرمل) توجد على عمق يتراوح من (5045 إلى 5120) مع نفاذية نسبية للزيت تتراوح من 1.58 إلى 136.76 مليون يوم. تشير هذه النتائج بشكل عام إلى أن وحدات كربونات المكمن في حقل "بيدا" تحتوي على تراكمات كبيرة من الهيدروكربون.

Abstract

This study presents the log analysis results of a suite of geophysical logs comprising gamma ray (GR), resistivity (LLD), neutron (PHIN) and density (PHID) logs from three wells in "Beda" Field located in the Sirt Basin. The analysis was carried out to evaluate the fields hydrocarbon prospect i.e. identity hydrocarbon bearing reservoir and study reservoir properties based on log data from the three wells. Seventeen zones of interest (dolomite bodies) were delineated and correlated across this field. Three of these dolomites were further identified as potential hydrocarbon reservoirs. The computed petrophysical parameters for the reservoir layers have porosity, Ø range of (0.195% - 19.57%) and hydrocarbon saturation, Sh range of (0,75% to 0.96%). The analysis indicates that reservoirs (sand) are encountered at depth range of (5045 to 5120) with relative permeability to oil ranging from 1.58 to 136.76 md. These results on the whole suggest that the reservoir carbonate units of "Beda" Field contain significant accumulations of hydrocarbon.

Keywords: Petrophysical parameters, hydrocarbon porosity, reservoir, log analysis, Sirt Basin.

1. Introduction

The Beda Oil Field is located within latitude **28° 04´** and longitude **19° 48´** In the Sirt Basin (Figure 1). The general purpose of well log analysis is to convert the raw log data into estimated quantities of oil, gas and water in a formation. In this study, the objectives of using the gamma ray (GR), resistivity, neutron (PHIN) and density (PHID) logs includes the determination of lithologic units, differentiating between hydrocarbon bearing and non-hydrocarbon bearing zone(S) within identity reservoir(S), definition of reservoir geometry by means of well to well correlation and determination of the petrophysical parameters value of zones of interest (reservoirs) in the field such as porosity, permeability, gross thicknesses, water saturation and hydrocarbon and hydrocarbon saturation.

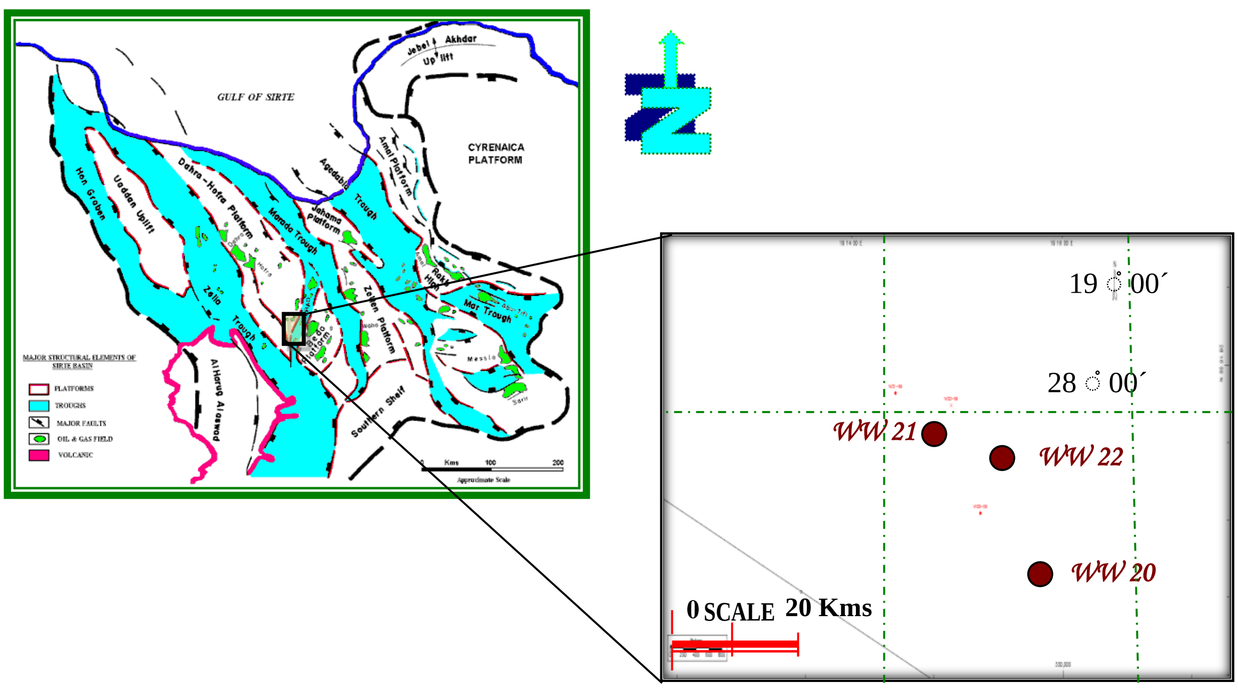

Fig. 1. Showing location of WW Field & insert is the base map indicating wells location.

1.1 Geology of the Area

The Sirte Basin, which is located on the north central part of Libya, is bounded by Mediterranean Sea to the north, Jable Eggi and Tibesti Arch to the south and southeast, Gargaf Arch to the Southwest, Jable Asowda- Nafousa Uplift to the west; Cyrenaica Platform to the east & northeast (Fig 2). The Sirt Basin covers an area of approximately 600,000km² that extends about 1200 km in the N-S and 700 km in the E-W directions (Hallett, 2002 and Elakkari, 2005). It is considered to be as a major continental rift basin that was formed during the Lower Cretaceous time (Fatyan and Sawzi, 1996; Guiraud and Bosworth, 1997). Rifting, which has proceeded in a triple junction fashion that include the Sirte, Tibesti, and Sarir

Arms, was peaked in the Late Cretaceous, and ceased in the Early Tertiary (Gras and Thusn, 1998; Van Houten, 1980).

The Sirte Arm, which consists of a serious of north westerly-oriented horsts and grabens connects in its southeast end with the E-W Sarir and the northeasterly oriented Tibesti arms (Fig 2). Most of the sedimentary cover in the Sirt Basin consist of the Late Cretaceous-Tertiary Rocks of variable lithology's and grain sizes (Fig 2). This variation combined with the unique structural style has made the Sirte Basin one of the most petroleum provinces in the world.

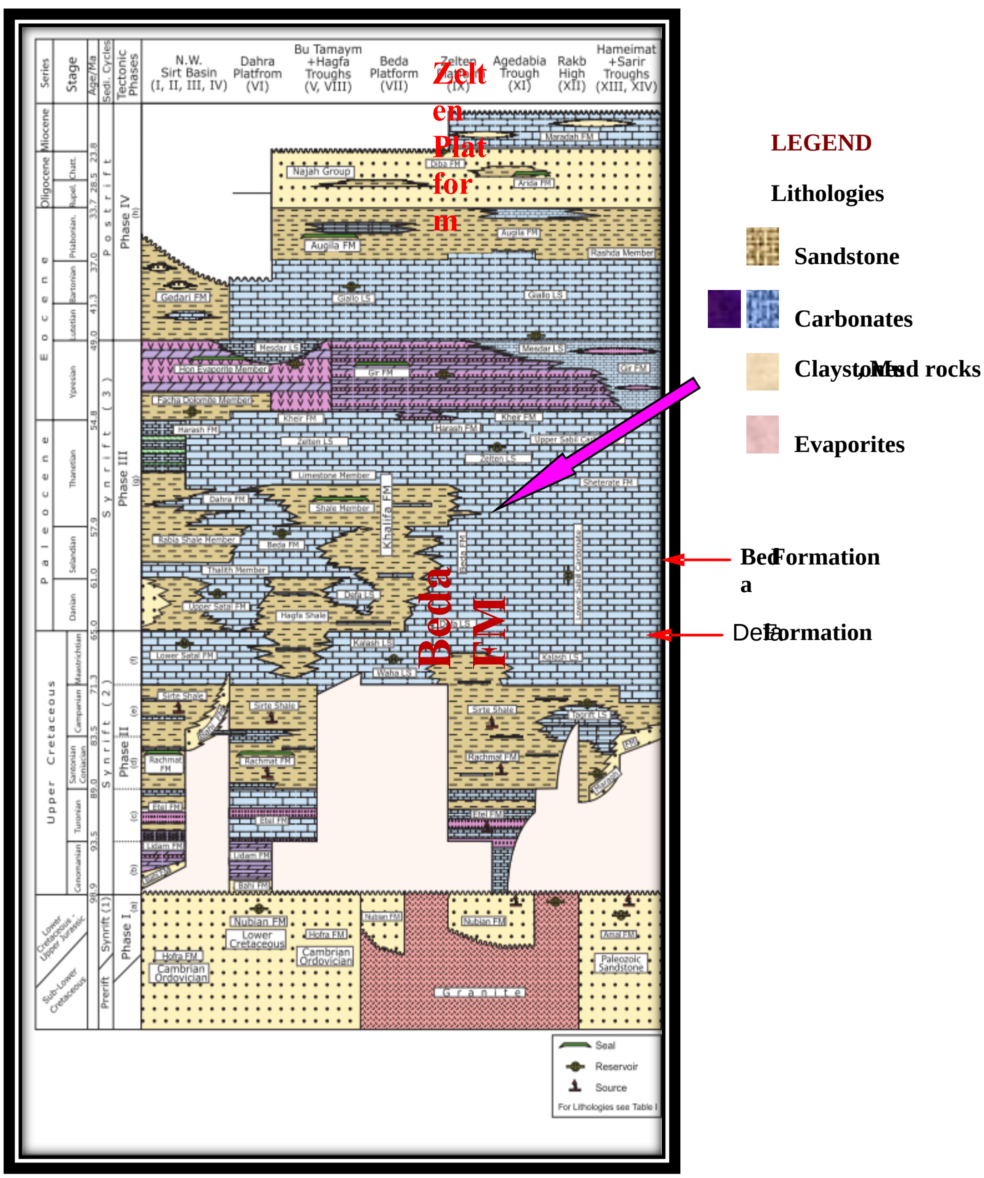

Fig. 2. Geological cross section showing stratigraphic units of the Sirt Basin (Modified from Barr and Weegr, 1972).

The Beda Field consists of two separate pools which are combination traps. The trap consist of a faulted anticlinal component with up dip permeability barriers in a southwest direction along the anticlinal axis. Further discussion and analysis of the Beda structure is presented in the geophysical review and in mapping of the oil reservoirs.

The Beda Formation consists mainly of limestone with subordinate dolomite and calcareous shale. It becomes more argillaceous to the northwest whereas Barr and Weegar (1972) subdivided it into a lower, predominantly argillaceous limestone member (Thalith Member) and an upper shale unit (Rabia Member). The Thalith and Rabia Members reach thicknesses of 118´ and 214´ respectively. The carbonates of the Beda Formation were deposited under shallow marine conditions. Argillaceous sediments accumulated under deeper shelf conditions with some open marine influence.

1.2 Log Analysis

The initial step in this log analysis is to identity the zones of interest i.e. clean sand with hydrocarbon. Gamma ray (GR) log which measures natural radioactivity in formations (track 1 in Figure 3),was used in the identification ofdolomite/shale lithology in the study area. The deep laterolog (LLD) represented in (track 2 Figure 3) in combination with the GR log were used to differentiate between hydrocarbon and non-hydrocarbon bearing zones. Consequently, The zones of interest for the petrophysical interpretation were defined in terms of clean zones with hydrocarbon saturation (low GR and high resistivity).

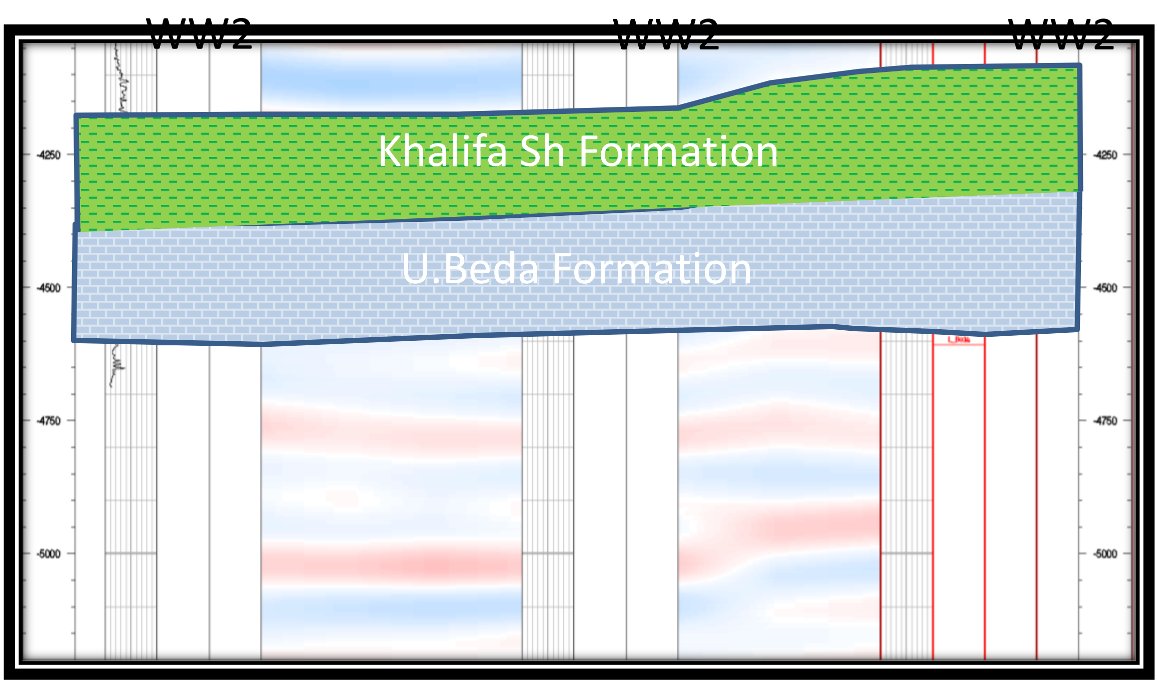

Fig. 3. Lithologic Correlation Panel of Hydrocarbon Bearing Reservoir of Bedea Field, Sirt Basin.

The formation density and neutron logs were used for the differentiation of the various fluid types. The gas zones are interpreted from crossover of the porosity logs i.e. formation density and neutron logs, oil zones are based on high resistivity values and water zones corresponds to very low resistivities.
The next step is shale volume estimation; shale volume (Vsh) was calculated using the Dresser Atlas, 1979 formula in equation (1) which uses values from the gamma ray (GR) in equation (2)

$$\boldsymbol{Vsh} = \mathbf{0.083\ (2^{(3.7/GR)} - 1)} \ldots\ldots\ldots\ldots \boldsymbol{Eq.}(\mathbf{1})$$

$$\boldsymbol{IGR} = \frac{\boldsymbol{GRiag - GRmia}}{\boldsymbol{GRmax - GRmin}} \ldots\ldots\ldots\ldots \boldsymbol{Eq.}(\mathbf{2})$$

In equation (2), IGR is the gamma ray index, GRlog is the picked log value while GR minimum and GR maximum indicate values picked in the sand and shale base lines respectively.
Porosity, $\emptyset_D$ was determined (Dresser Atlas, 1979) by substituting the bulk density readings obtained from the formation density log within each reservoir into the equation (3).

$$\emptyset_D = (\boldsymbol{\rho_{ma}} - \boldsymbol{\rho_b})/(\boldsymbol{\rho_{ma}} - \boldsymbol{\rho_f}) \ldots\ldots\ldots\ldots \mathbf{Eq.(3)}$$

And where ρ_b , ρ_f and ρ_{ma} are Matrix Density, formation bulk density and fluid density respectively.

To calculate water saturation, SW the method used in this study requires a water resistivity Rw value at formation temperature calculated from the porosity and resistivity logs within clean water zone, using the Ro method given by the following equation:

$$\mathbf{Rw} = \frac{\emptyset^{m}\, R_o}{a} \ldots\ldots\ldots\ldots \boldsymbol{Eq.}(\mathbf{4})$$

RW is the water resistivity at formation temperature, Ø and Ro are the total porosity and deep resistivity values in the water zone respectively. Tortuosity factor is represented as “a” used 1 for all wells in the study area and “m” is the cementation exponent, usually used 2 for all wells in the WW Field (Asquith and Krygowski, 2004). In the water zone, saturation should be equal to 1, as water resistivity RW at formation temperature is equal to Rwa.
Water saturation, SW can then be calculated using Archie’s method, given by:

$$\boldsymbol{S_W} = \left(\frac{R_W}{R_{Wa}}\right) \mathbf{1/n} \ldots\ldots\ldots\ldots \boldsymbol{Eq.}(\mathbf{5})$$

Where n is the saturation exponent and Rwa is water resistivity in the zone of interest, calculated in the same manner as Rw at formation temperature (Archie, 1942).
Hydrocarbon saturation, Sh is the percentage of pore volume in a formation occupied by hydrocarbon. It can be determined by subtracting the value obtained for water saturation from 100% i.e.

$$\mathbf{S_h} = (\mathbf{100} - \mathbf{S_w})\% \ldots\ldots\ldots\ldots \boldsymbol{Eq.}(\mathbf{6})$$

Permeability, K of each identified reservoir is calculated using equation (7)

$$\mathbf{K} = \sqrt{\frac{\phi^2 \times 250}{S_{wir}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Eq. (7)$$

Where Swir is the irreducible water saturation (Tixier, 1949).

The productivity of each delineated reservoir rock at the zone of interest are estimated by evaluating results of their calculated petrophysical parameters using equation (1) – (7).

Lithologic correlation of equivalent strata across the three wells was done using the gamma ray log. Equally, identified potential hydrocarbon reservoirs in the various wells were correlated using the gamma ray and resistivity logs to know their lateral and vertical extent. Their results are presented as correlation panels in Figure 3.

2. Results and Interpretation

The litho-Stratigraphic correlation is a visual process which provides knowledge of the general stratigraphy of an area (Amigun, 1998). Figure 3 shows a composition of skeletal, oolitic and micritic limestones with minor dolomite. In the Beda study area, the Formation has been informally divided into an upper and lower Member and is observed to increase with depth along with a corresponding decrease in shale layers. The division is based on electric log character, with the Lower member being a more shale section particularly toward the base. The Upper section is the main oil bearing reservoir interval The Lower Member is of a restricted shelf to shallow open marine section and consists mainly of calcilutites and limey shales. The Upper section consists of calcarenites and dolomites that exhibit the most favorable reservoir properties. This pattern in the Sirt Basin indicates a based on a simplistic model that the Beda carbonate and shale section is a transgressive/regressive sequence of shoaling upward units. Each sequence is a carbonate unit that shoals upward as reflected by a shaly lower portion that becomes more carbonate rich in an upward direction. The upward shoaling sequence is terminated by a flooding surface marked by an influx of shales. Thus, the upper surface of each reservoir layer is generally marked by a relatively sharp contact between clean and porous limestone (upper shoal) and an overlying shale rich section (lower shoal or shale flooding surface. Identification of these upward shoaling sequences formed the bases of the reservoir layering. The shale breaks or flooding surfaces can be identified across Beda pool.

Table, 1 Summary of Results from log analysis in well WW21 In Beda Field

Depth	CA LI	DT	GR	NPHI	RD	RHO B	SP	IGR	Vsh	Ø		F	Sw	Sh	K	Rw
feet	in	Us/ft	API	m³/m³	Ohm.m	g/mc³	mv	API	%	%			Archi	%	Darcy	Ohm.m
5045	8.5	76	34	22.341	2	2.5	510	0.42	0.26	15.76		0.02	0.06	0.94	2125.38	101.16
5050	8.6	71	11	25.268	34	2.4	488	0.06	0.03	17.86		0.01	0.01	0.99	2523.94	2635.97
5055	8.5	65	9	20.448	122	2.5	478	0.03	0.01	14.46		0.02	0.01	0.99	2051.36	7044.64
5060	8.5	67	13	19.110	4	2.5	475	0.10	0.05	13.51		0.02	0.04	0.96	1853.20	204.22
5065	8.5	72	12	25.676	58	2.4	475	0.07	0.03	18.15		0.01	0.01	0.99	2571.64	4665.20
5070	8.6	69	14	17.400	27	2.5	477	0.11	0.05	12.30		0.02	0.02	0.98	1728.64	1247.04
5075	8.6	67	23	14.659	7	2.6	484	0.24	0.13	10.35		0.03	0.04	0.96	1424.14	237.46
5080	8.6	63	24	14.468	3	2.6	494	0.26	0.14	10.21		0.03	0.06	0.94	1373.32	93.09
5085	8.6	61	18	11.233	4	2.6	490	0.17	0.09	7.93		0.04	0.06	0.94	1064.82	88.14
5090	8.5	60	27	15.877	3	2.7	500	0.31	0.18	11.20		0.02	0.05	0.95	1520.75	128.50
5095	8.6	75	18	26.666	7	2.3	476	0.17	0.09	18.85		0.01	0.02	0.98	2627.73	558.01
5100	8.5	74	19	25.084	1	2.4	478	0.19	0.10	17.72		0.01	0.06	0.94	2368.90	77.06
5105	8.6	83	10	36.830	25	2.1	477	0.04	0.02	26.04		0.01	0.01	0.99	3683.78	3334.02
5110	8.6	78	10	27.152	13	2.3	478	0.05	0.02	19.20		0.01	0.02	0.98	2697.02	1166.51
5115	8.6	70	9	14.645	26	2.4	485	0.03	0.01	10.35		0.03	0.02	0.98	1451.81	930.72
5120	8.7	52	10	6.258	6	2.7	500	0.05	0.03	4.42		0.10	0.07	0.93	587.59	65.71

Depth	CALI	Gross	NET	N/G	GR	IGR	Vsh	Ø		F	Sw	Sh	K	Rw
feet	in	m	m	%	API	API	%	%			Archi	%	Darcy	Ohm.m
5045	8.5	23	0	0	34	0.42	0.26	15.76		0.02	0.06	0.94	2125.38	101.16
5050	8.6	13	17	1.30	11	0.06	0.03	17.86		0.01	0.01	0.99	2523.94	2635.97
5055	8.5	28	4	0.14	9	0.03	0.01	14.46		0.02	0.01	0.99	2051.36	7044.64
5060	8.5	27	0	0	13	0.10	0.05	13.51		0.02	0.04	0.96	1853.20	204.22
5065	8.5	24	13	0.54	12	0.07	0.03	18.15		0.01	0.01	0.99	2571.64	4665.20
5070	8.6	24	4	0.16	14	0.11	0.05	12.30		0.02	0.02	0.98	1728.64	1247.04
5075	8.6	21	1	1.04	23	0.24	0.13	10.35		0.03	0.04	0.96	1424.14	237.46
5080	8.6	78	0	0	24	0.26	0.14	10.21		0.03	0.06	0.94	1373.32	93.09
5085	8.6	26	8	0.30	18	0.17	0.09	7.93		0.04	0.06	0.94	1064.82	88.14
5090	8.5	35	10	0.28	27	0.31	0.18	11.20		0.02	0.05	0.95	1520.75	128.50
5095	8.6	126	99	0.76	18	0.17	0.09	18.85		0.01	0.02	0.98	2627.73	558.01
5100	8.5	22	0	0	19	0.19	0.10	17.72		0.01	0.06	0.94	2368.90	77.06
5105	8.6	29	0	0	10	0.04	0.02	26.04		0.01	0.01	0.99	3683.78	3334.02
5110	8.6	0	0	0	10	0.05	0.02	19.20		0.01	0.02	0.98	2697.02	1166.51
5115	8.6	0	35	0	9	0.03	0.01	10.35		0.03	0.02	0.98	1451.81	930.72
5120	8.7	0	0	0	10	0.05	0.03	4.42		0.10	0.07	0.93	587.59	65.71

In Table 2, some of the calculated petrophysics parameters were subjected to statistical analysis by considering their values across all the delineated reservoir in the three wells.
Their results were expressed respectively as: average gross thickness, average net thickness, average n/g (net/gross ratio), average porosity, average permeability, average water saturation and average hydrocarbon saturation. Figures 4, 5 and 6 described the frequency distribution of the effective porosity, permeability and hydrocarbon saturation in well (WW 21) for ex.

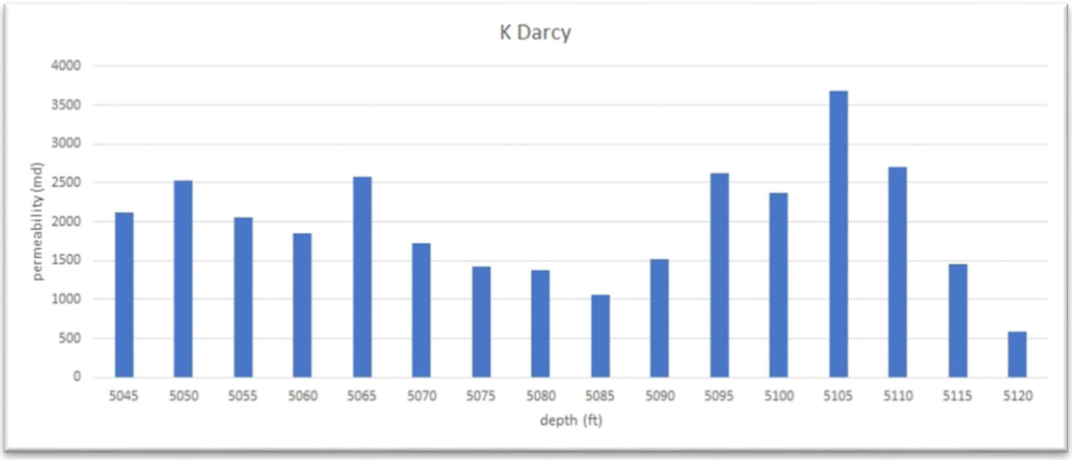

Fig. 4. Showing bar-chart of Depth vs. Ø for Upper Beda Formation, in well WW21 in the study area, central Sirt Basin.

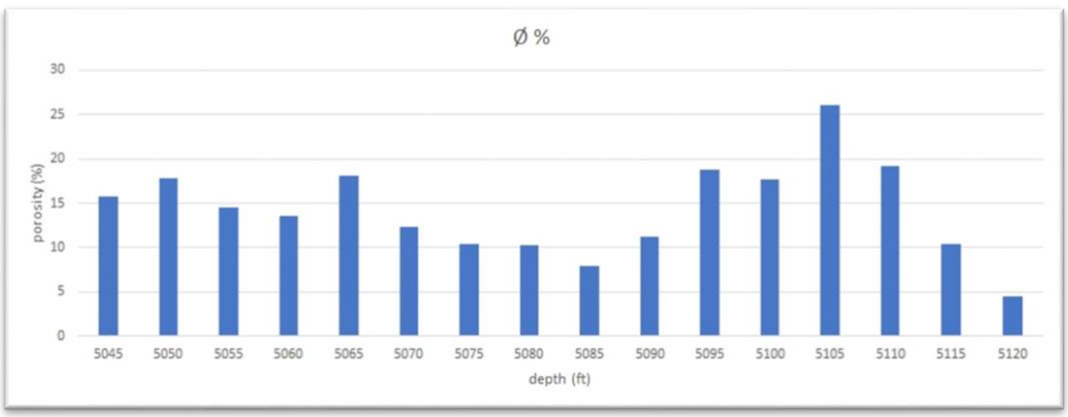

Fig. 5. Showing bar-chart of Depth vs. K for Upper Beda Formation, in well WW21 in the study area, central Sirt Basin.

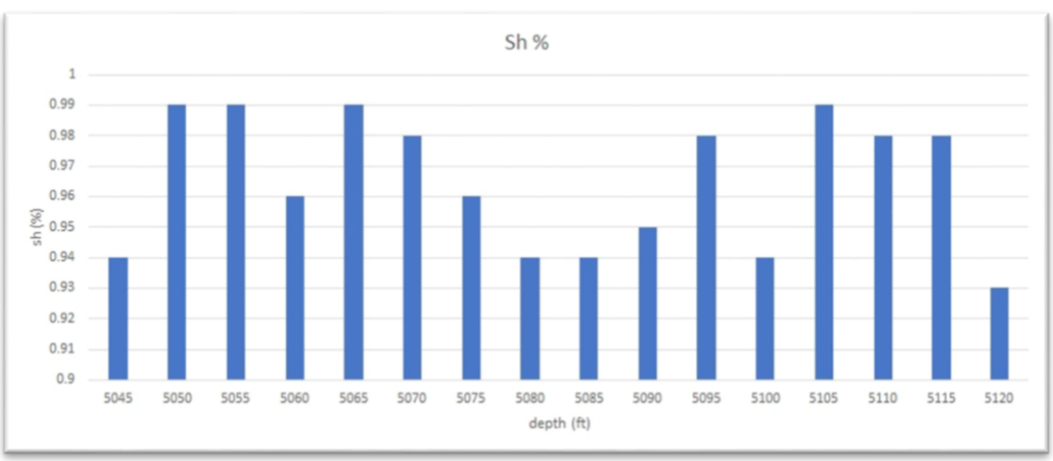

Fig. 6. Showing bar-chart of Depth vs. Sh for Upper Beda Formation, in well WW21 in the study area, central Sirt Basin.

Table. 2 Calculated petrophysics parameters of results from log analysis in all wells in Beda Field.

Wells	Ave Gross	Ave NET	Ave N/G	Ave Ø	Ave K	Ave Sw	Ave Sh
#	m	m	%	%	darcy	%	%
Well 20	13.54	09.12	0.6735	0.195	1.58	1.72	0.72
Well 21	26.59	11.24	0.4225	14.27	60.22	0.03	0.96
Well 22	28.21	13.25	0.4696	19.57	136.76	0.05	0.95

Figures. 7, 8 and 9 shown the samples in study area in the average effective porosity, permeability and hydrocarbon saturation in all wells. The reservoir layering of the Beda Formation is based on a simplistic model that the Beda carbonate and shale section is a transgressive / regressive sequence of shoaling upward units. Each sequence is a carbonate unit that shoals upward as reflected by a shaly lower portion that becomes more carbonate rich in an upward direction. The upward shoaling sequence is terminated by a flooding surface marked by an influx of shales. Thus, the upper surface of each reservoir layer is generally marked by a relatively sharp contact between clean and porous limestone (upper shoal) and an overlying shale rich section (lower shoal or shale flooding surface. Identification of these upward shoaling sequences formed the bases of the reservoir layering. The shale breaks or flooding surfaces can be identified across Beda pool.

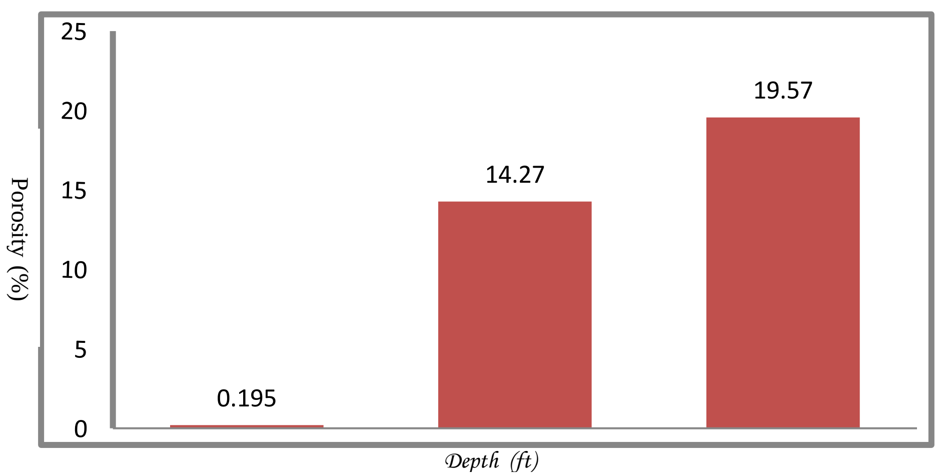

Fig. 7. Showing bar-chart of Depth vs. Ø for Upper Beda Formation, in all wells in the study area, central Sirt Basin.

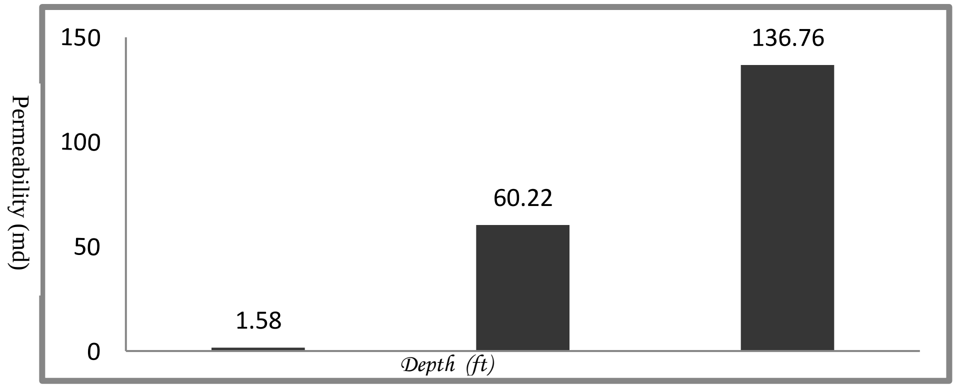

Fig. 8. Showing bar-chart of Depth vs. K for Upper Beda Formation, in all wells in the study area, central Sirt Basin.

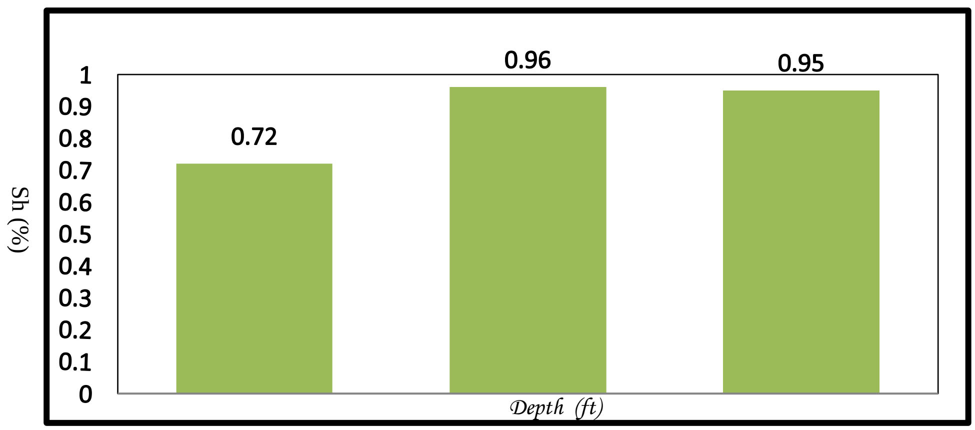

Fig. 9. Showing bar-chart of Depth vs. Sh for Upper Beda Formation, in all wells in the study area, central Sirt Basin.

3. Conclusions

1. The log analysis performed in this study shows that the reservoir carbonates units of "Beda Formation" in the study area contain significant accumulations of hydrocarbon.
2. The delineated zones of interest (seventeen in number) have an average net thickness of between (1.0 0 – 35.00 m), average effective from density log (RHOB) using porosity formula with shale correction by Dresser Atlas (1979) and these values were found to be high in almost all interpreted zones, ranging from .0195% to 19.57% (see figure 4). In the assessment of a wells productivity, the permeability of dolomite unit (reservoir rock) is an important parameter i.e. productivity is related to the mathematical product of permeability, k, and thickness, h of that unit. In Figure 5, the shale units" K having the highest value.

3. The hydrocarbon bearing carbonate(limestone with dolomite and calcareous shale) units in Beda field possess hydrocarbon saturation, Sh ranging from 0 – 0.96% porosity in the range of (o.195 to 19.57) and hydrocarbon saturation, Sh ranging from (0.75 to .096) which are favourable indicators for commercial hydrocarbon accumulation.
4. Further calibration of the log analysis parameters with core and production data is necessary to verify the calculated values, as the permeability's for some of the reservoir Beda Carbonate units are extremely high.

Acknowledgements

We would like to thank Department of PETROLUEM ENGINEERING (DPE), Thanks to some old friends from Geophysics Division, UNIVIRSITY OF ZAWIA, Libya.

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