Petrophysical Well Log Evaluation of Main Limestone Reservoir Units, North Iraq

Yahya Jarjees Tawfeeq

Petroleum Engineering Department, Kirkuk University, Kirkuk, Iraq

ABSTRACT

This paper presents results of a study conducted to determine and evaluate the petrophysical properties of "Main Limestone" reservoir units in north Iraq with a view to understand their effects on the reservoirs hydrocarbon prospect and oil productivity of the field. The evaluated properties include porosity, fluid saturation and net / gross thickness, which are obtained from wire-line logs. A full set of wire-line logs including of gamma ray, resistivity, neutron and density logs for three wells from Bai-Hassan oil field were analyzed for reservoir characterization of the field. The analyses carried out involves description of lithologies, identification of reservoirs and fluid types, wells correlation and determination of petrophysical parameters of identified reservoirs. Petrophysical parameters of "Main Limestone" reservoir rocks revealed that the reservoir unit (B) has the better properties compared with the other units. The majority of total porosity is primary porosity through the whole succession within the studied area. The water saturation is affected significantly by increasing the volume of shale, which was often greater than 10 %.

Key word: Petrophysical properties, Main limestone reservoir, North Iraq, well logs.

INTRODUCTION

Petrophysics is the study of physical properties of the reservoir rocks and their interactions with fluids (gases, liquid hydrocarbons). Detailed knowledge of the distribution of petrophysical parameters such porosity, permeability, water saturation and barriers influencing fluid flow are important for reservoir evaluation project.

Reservoir characterization is undertaken to determine its capability to both store and transmit fluid. Hence, characterization deals with the determination of reservoir properties/parameters such as porosity (Φ), permeability (K), fluid saturation, and Net Pay thickness. Because petroleum reservoir rocks must have porosity and permeability, we are most interested in the properties of porous and permeable rocks.

Porosity, which is a measure of reservoir storage capacity, is defined as the proportion of the total rock volume that is void and filled with fluids. Permeability is the capacity of a reservoir rock to permit fluid flow. It is a function of interconnectivity of the pore volume; therefore, a rock is permeable if it has an effective porosity.

The fluid saturation is the proportion of the pore space that is occupied by the particular fluid. A reservoir can be water either saturated (S_w) or hydrocarbon saturated ($1-S_w$) depending on the type of fluid it contains.

Many sub-surface data are obtained from drill coring and cuttings, but the method is highly expensive and has many limitations. Well logging provides a cheaper, quicker method of obtaining accurate sub-surface petrophysical data.

AIM AND OBJECTIVES OF THE STUDY

The aim of this study is to analysis the petrophysical parameters to qualify and quantify reservoirs in order to assess the production potential of main limestone reservoir in Bai-Hassan oil field. The objectives includes:

- Interpretation of porosity logs and porosity data.
- Identification the reservoir and non-reservoir rocks using gamma ray log.
- Analysis and interpretation of reservoir fluids.
- Identification of productive zones.
- Determination the depth and thickness of productive zones.
- Knowing the lithology through the identification of sand units from main limestone reservoir top sand to the last hydrocarbon-bearing sand.

LOCATION OF STUDY AREA

The "Bai-Hassan" oil field is locates near Kirkuk in North Iraq. The Iraqi Oil Company (IPC) and having come on production in 1960 have discovered the field in 1953. The structure of the field is about 40km long and about 3.5 km wide and consists of a longitudinal, sinusoidal, asymmetrical anticline. The southern limb of the structure is steeper (37°-65°) than the northeastern limb (22°-35°). **Figure (1)** below.

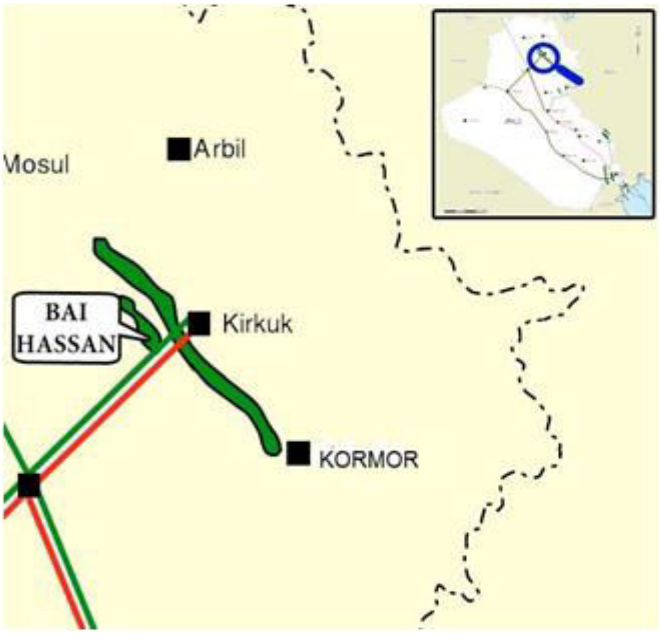

Figure 1: Location map of the Bai-Hassn field.

The structure of Bai-Hassan consists of two main domes of Kithka at the southern east and Daoud at the western north. The two domes are separated by Shahal saddle, which its base is about 90m deeper than Daoud dome's crest. The crest of Kithka Dome is 335m higher than Daoud dome's crest.

This study focus on the three units which are Unit (A), Unit (A') and Unit (B) from Tertiary period reservoir sequences (Main Limestone) which comprise many economically important units particularly reservoir pay zone as shown in **table (1).**

Table 1: Tops and thickness of main limestone reservoir units under study.

Reservoir Units	Tops (m) / thickness (m)		
	Well No.1	Well No.2	Well No.3
Unit A	1562/18	1579/26	1560 / 10
Unit A'	1580/22	1605 / 13	1570 / 21
Unit B	1602/55	1618 / 29	1591 / 65

MATERIAL AND METHODS

A. Preliminary Work

The study was initiated with the collection of data (electronic copies of the wire line logs) obtained from three wells from Daoud dome in Bai-Hassan oil field. As a first step, the available logs were scanned and digitized. The NeuraLog V2010.11 Software was used for the digitization of the logs. One reading per 0.25m depth was selected for recording the input data measurements. The processes of interpretation are achieved by using Interactive Petrophysics (IP) version 3.5 and Schlumberger PETREL 2009 Software.

B. Data Analysis

The analysis of petrophysical logs in this study based on qualitative and quantitative determination of the properties of main limestone reservoir in Bai Hassan field.

1. Qualitative Data Analysis

The gamma ray (GR) log were examined for reservoir and non-reservoir rock information. In shale beds, gamma ray (GR) log which measures natural radioactivity in formations reflects the shale contents, hence this log was used for the identification of sand / shale lithology in the study area. The resistivity log in combination with the GR log were used to differentiate between hydrocarbon and non-hydrocarbon bearing zones. In hydrocarbon bearing formation, the resistivity log signatures show high resistivity values than when in water bearing formation. The outcome is presented as correlation panels shown in **Figure 2** below.

Figure 2: Correlation panel showing described main limestone reservoir across "Bai Hassan" oil field.

2. Quantitative Data Analysis

Quantitatively, the petrophysical parameters are estimated using empirical formulae as follows:

- **Clay Volume Determination**

Clay volume was derived from the gamma ray log. Calculation of gamma ray index is the first step needed to determine the volume of clay from gamma ray log **[1]:**

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

The calculated GRI is then used to determine the clay volume using Larionov equation for Tertiary rocks according to Dresser Atlas (1979) **[2]**:

$$Vcl = 0.083(2^{3.7*GRI} - 1) \quad (2)$$

Where,
V_{CL} =Volume of Clay
GRlog = Gamma Ray Log reading of formation
GRmin = Gamma Ray Matrix (Clay free zone)
GRmax = Gamma Ray Shale (100% Clay zone)

- **Porosity Calculation**

Total porosity was determined from combination of Neutron – Density derived porosities according to Schlumberger (1974) equation that may be expressed as;

$$\varphi_T = \frac{\varphi_N + \varphi_D}{2} \quad (3)$$

Where; $Ø_T$ = Total porosity derived from Neutron-Density log
$Ø_N$ = porosity derived from Neutron log
$Ø_D$ = porosity derived from Density log

Density porosity is derived from the bulk density of clean liquid filled formations when the matrix density (ρma) and the density of the saturating fluids (ρf) are known, using Wyllie et al., (1958) **[3]** equation:

$$ØD = (\rho ma - \rho b) / (\rho ma - \rho f) \quad (4)$$

Where ρma = density of matrix (2.71 gm/cm3 for limestone, 2.87 gm / cm3 for dolomite, 2.61 gm / cm3 for sandstone), ρf = density of fluid (1 gm/ cm3 for fresh water, 1.1 gm/ cm3 for saline water),

The effective porosity (Øe) is then calculated, using equation of Schlumberger (1998): **[4]**

$$\varphi_e = \varphi_t * (1 - V_{clay}) \quad (5)$$

Sonic log (Δt) based on Wyllie time- average equation **[5]** was used to determine primary porosity

$$ØS = (\Delta tlog - \Delta tma) / (\Delta tfl - \Delta tma) \quad (6)$$

Where ØS = sonic derived porosity: Δtlog = interval tansit time in the formation; Δtma = interval transit time in the matrix; Δtfl = interval transit time in the fluid in the formation.
Secondary porosity index (SPI) was computed by the difference between total porosity and the primary porosity (that is determined from sonic log);

$$SPI = (Øt - Øs) \quad (7)$$

- **Water Saturations Determination**

To calculate water saturation, S_w of uninvaded zone, the method used requires a water resistivity R_w value at formation temperature calculated from formation water analysis in laboratory by known salinity of formation water, NaCl concentration in formation water at specific interval and temperature by the following equation **[6]:**

$$Rw@75 = 0.0123 + \frac{3647.5}{[NaCl(ppm)]^{0.955}} \quad (8)$$

Water saturation (Sw) of a reservoir's un-invaded zone is calculated by the Archie (1942) formula **[7]:**

$$S_w = \left(\frac{a\ R_w}{R_t\ \varphi^m}\right)^{\frac{1}{n}} \qquad (9)$$

Where:
Sw = water saturation of the un-invaded zone.
R_w = resistivity of formation water at formation temperature.
R_t = true formation resistivity from deep induction or deep laterolog corrected for invasion)
φ = porosity.
a = tortuosity factor.(assumed to be 1.0)
m = cementation exponent.(assumed to be 2.0)
n = saturation exponent.(assumed to be 2.0)

Water saturation of a formation's flushed zone (Sxo) is also based on the Archie equation, but two variables are changed: mud filtrate resistivity (Rmf) in place of formation water resistivity (Rw) and flushed zone resistivity (Rxo) in place of un-invaded zone resistivity (Rt).

$$S_{xo} = \left(\frac{a\ R_{mf}}{R_{xo}\ \varphi^m}\right)^{\frac{1}{n}} \qquad (10)$$

Where:
Sxo = water saturation of the flushed zone
Rmf = resistivity of the mud filtrate.
Rxo = shallow resistivity from microlaterolog.
Water saturation of the flushed zone (Sxo) and water saturation of the un-invaded zone (Sw) can be used as an indicator of hydrocarbon movability. The difference between Sxo and Sw represented movable hydrocarbon saturation (MOS) that moved or flushed out of the zone nearest the borehole by the invading drilling fluids (Rmf).

- **Determination of Hydrocarbon Saturation**

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.

$$S_h = 1 - S_w \qquad (11)$$

- **Moveable and Residual Hydrocarbon Saturation Calculation.**

Moveable hydrocarbon saturation was calculated based on Schlumberger's (1998) equation **[8]**:

$$MOS = S_{xo} - S_w \qquad (12)$$

Where, if the value of Sxo is much larger than Sw, then hydrocarbons in the flushed zone have probably been moved.
Residual oil saturation (ROS) can be calculated from Archie water saturation using Schlumberger's (1987) equation **[9]:**

$$ROS = 1 - S_{xo} \qquad (13)$$

- **Estimation of Movable Hydrocarbon Index.**

The movable hydrocarbon index (MHI) was derived using:

$$MHI = \frac{S_w}{S_{xo}} \qquad (14)$$

Where MHI > 1 implies that hydrocarbon was not moved during invasion and MHI < 0.6 implies that hydrocarbon was moved during invasion. The parameters Sw and Sxo are water saturation of the uninvaded zone and the flushed zone respectively.

- **Net to Gross ratio Determination**

A porosity cut-off of 10% and water saturation, Sw, cut-off of 60% were used to define the quality of the reservoir rock. The net reservoirs were defined by the porosity greater than 10% .For the net pay, if the water saturation within the reservoir is less than 60%, it is considered to contain hydrocarbon. The results were found in Table 2 below.

- **Bulk Volume Water Analysis**

The bulk volume water analysis depends on two essential parameters; water saturation, and porosity. The bulk volume water in uninvaded zone (BV_W) and bulk volume water in the invaded zone (BVxo) can be calculated according to the following equations;

$$BV_w = S_w . \varphi \quad (15)$$

$$BV_{xo} = S_{xo} . \varphi \quad (16)$$

Table 2: Summary of the Average Petrophysical Parameters for Three Units in Bai-Hassn Oil Field.

Unit	Well	Depth (Meter)	Gross (Meter)	Net pay (Meter)	Ratio Net/Gross	Pay Zone Average porosity	Pay Zone Average Water Saturation
A	Well No.1	1562-1580	17.5	0.38	0.021	0.236	0.076
	Well No.2	1579-1605	26	2.25	0.087	0.13	0.346
	Well No.3	1560-1570	10	0.13	0.013	0.166	0.288
A'	Well No.1	1580-1602	23	3.25	0.141	0.192	0.157
	Well No.2	1605-1618	13	2.13	0.163	0.123	0.09
	Well No.3	1570-1591	21	9.5	0.452	0.167	0.303
B	Well No.1	1602-1655	52.5	49.25	0.938	0.181	0.331
	Well No.2	1618-1647	29	27.25	0.94	0.177	0.225
	Well No.3	1591-1656	65	26.63	0.41	0.185	0.452

- **Mineral & Lithological Determination**

The porosity combinations cross plots (M-N, and ØN- ρb) were used to identify main lithology and mineralogy, according to Schlumberger (1974) equations:

$$M = (\Delta tfl - \Delta tlog) / (\rho b - \rho f) \times 0.01 \quad (17)$$

$$N = (\text{Ø}Nf - \text{Ø}N) / (\rho b - \rho f) \quad (18)$$

The M-N cross plots showed calcite as main mineral and less amounts of dolomite with calcite matrix , while the RHOB (ρb) vs. PHIN (ØN) cross plots show the lithology of three main limestone reservoir units in Bai-Hassan oil field. Figure 3 below.

The productivity of each delineated reservoir units are estimated by evaluating results of their calculated petrophysical parameters using equation (1) – (16).

RESULTS AND DISCUSSION

The methodology as previous reported the quantitative interpretation of the described main limestone reservoirs in each well. Table 3 and Figure 4 are represents the results of some computed petrophysical parameters for three well in reservoir units A, A' and B, while Figure 5 is presented some computed petrophysical parameters as correlation panels. Table 4 which is represent overall average petrophysical properties for three units.

Figure 3 "B" shows that the most points fall on limestone line and only a few points fall on the dolomite line, which indicates the dominance of limestone lithology of main limestone reservoir. Whereas Figure 3 "B" of (M-N) cross plot shows that the calcite is the main mineral in main limestone reservoir succession in Bai-Hassan field with some dolomite. This Dolomite resulted by dolomitization processes and formed secondary porosity especially in unit B.

The reservoir units (A, A' and B) of main limestone reservoir represent limestone, therefore, they show low GR log values. The derived petrophysical properties show that the main limestone reservoir has intermediate to good petrophysical properties. According to the interpreted well logs, we note that, in all units the secondary porosity values are very low. The effective porosity (Φ) is low in unit (A) and has moderate values in unit (A'), while it has good values in unit B.

Net to Gross values are characterized by low values in unit (A), moderate values in unit (A'). Good values are characterized in unit (B). The movable hydrocarbon index (MHI) results indicate that the unit (B) has MHI less than 0.6, which implies that hydrocarbon, was moved during invasion. The hydrocarbon bearing reservoir units in the study field have hydrocarbon saturation, Sh ranging from less than 20% to more than 70% indicating that the proportion of void spaces occupied by water is low consequently high hydrocarbon saturation and high hydrocarbon production. The movability of hydrocarbon in each reservoir was determined (see Table 3 and table 4) and considered satisfactory for the production of hydrocarbon.

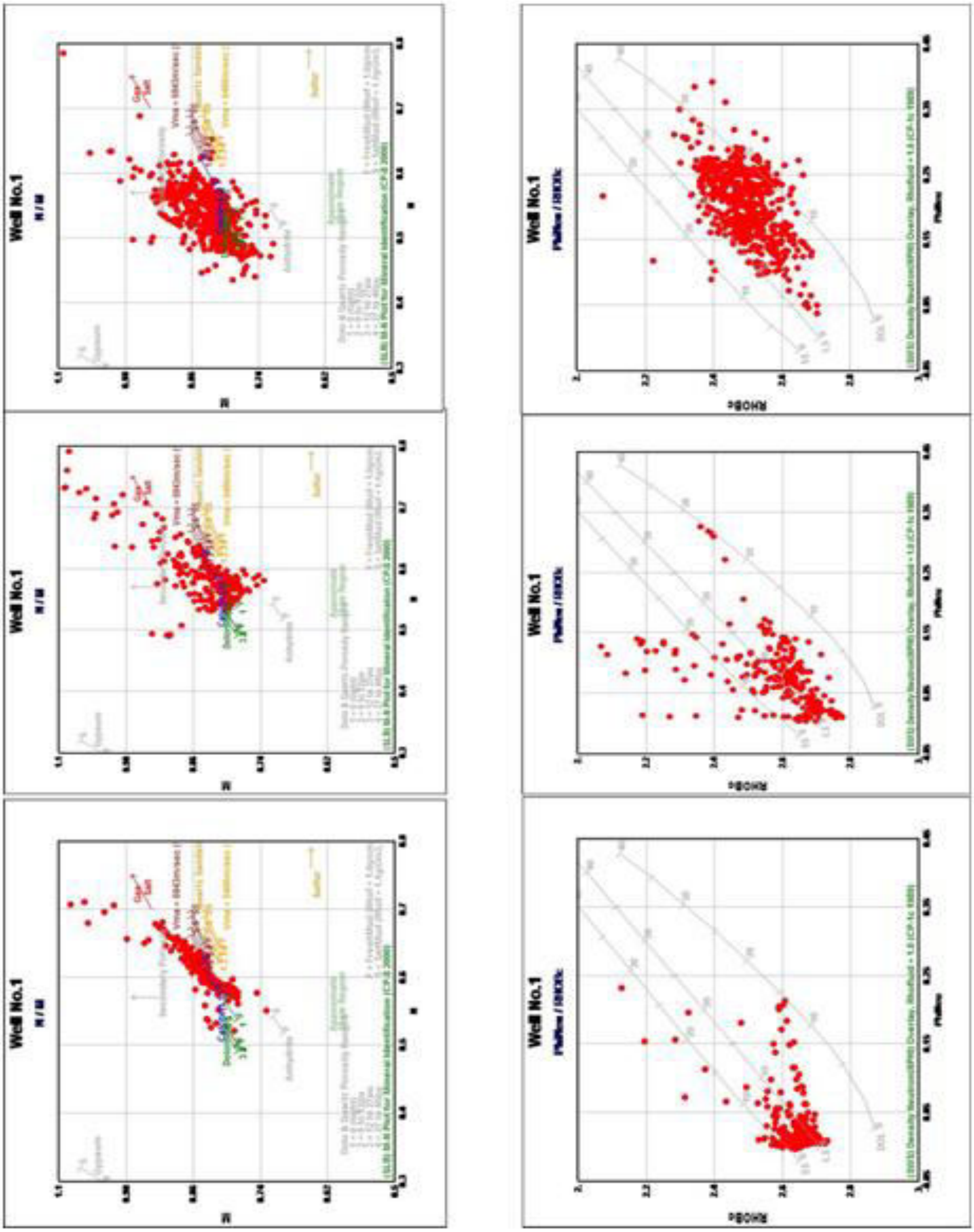

Figure 3: Lithology and mineralogy of three main limestone reservoir units in Bai-Hassan oil field.

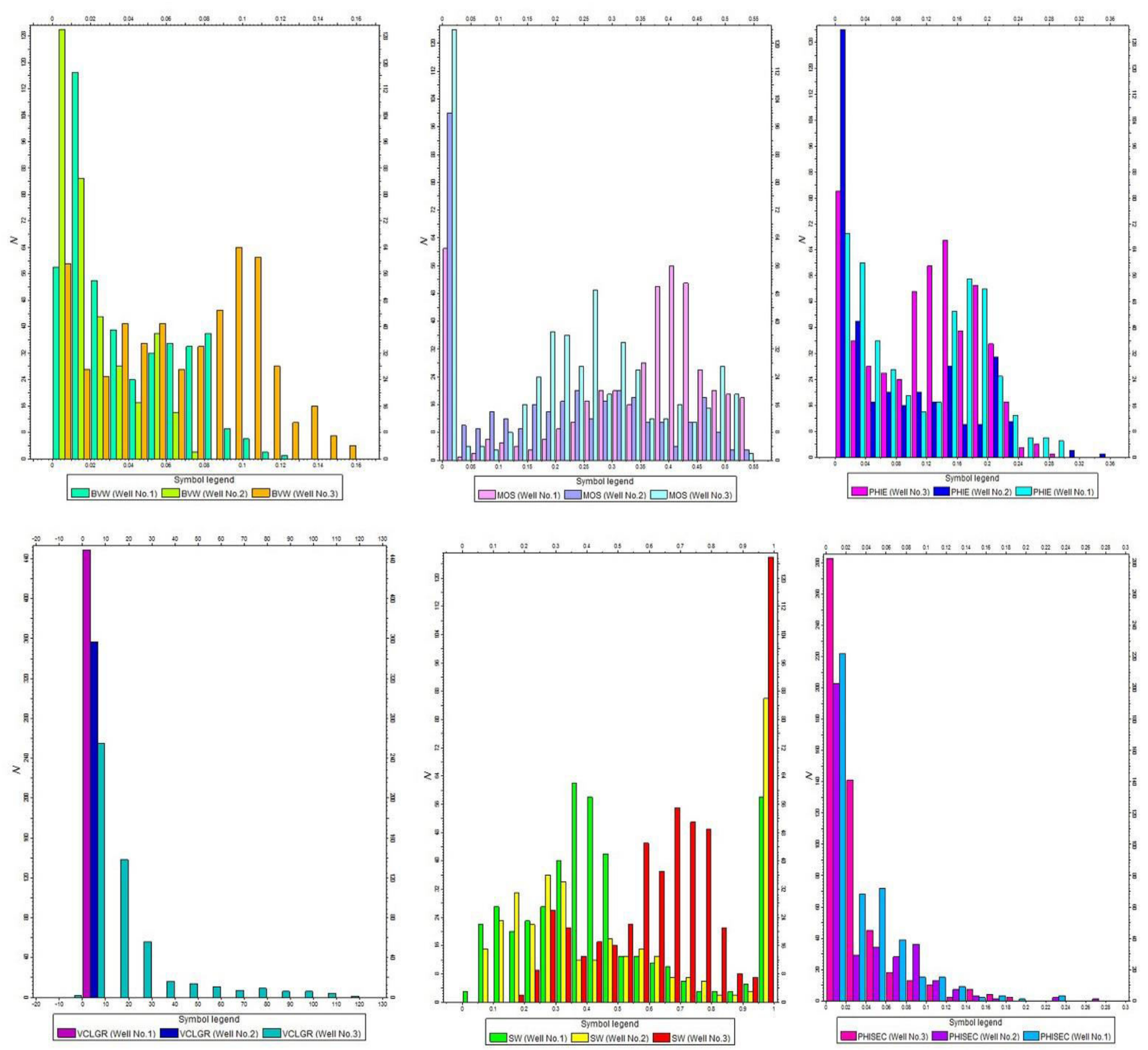

Figure 4: Chart showing relationship between Three Reservoir Units of some Computed Petrophysical Properties.

Table 3. Some Computed Average Petrophysical Parameters for Three Main Limestone Reservoir Units

parameter	Well No. 1			Well No. 2			Well No. 3		
	Unit A	Unit A'	Unit B	Unit A	Unit A'	Unit B	Unit A	Unit A'	Unit B
BVW	0.011	0.024	0.065	0.016	0.009	0.037	0.012	0.042	0.088
PHIE	0.031	0.074	0.175	0.037	0.041	0.166	0.024	0.107	0.155
PHISEC	0.009	0.03	0.044	0.009	0.026	0.073	0.004	0.044	0.023
PHIT	0.037	0.084	0.186	0.052	0.044	0.168	0.028	0.114	0.166
SW	0.511	0.485	0.352	0.550	0.514	0.226	0.818	0.537	0.657
SXO	0.852	0.783	0.801	0.788	0.673	0.488	0.95	0.867	0.919
VCL	0.024	0.051	0.041	0.067	0.014	0.008	0.048	0.067	0.135
MHI	0.573	0.573	0.472	0.686	0.701	0.498	0.843	0.597	0.708
MOS	0.337	0.306	0.378	0.238	0.158	0.268	0.132	0.330	0.254
ROS	0.152	0.209	0.270	0.212	0.327	0.505	0.050	0.133	0.089
Di	17.853	21.402	26.657	25.821	24.261	36.026	15.537	15.143	15.370
PhiSon	0.040	0.064	0.137	0.044	0.026	0.102	0.046	0.087	0.137
PhiNeu	0.027	0.073	0.218	0.046	0.035	0.193	0.022	0.104	0.197
PhiDen	0.047	0.075	0.127	0.052	0.036	0.143	0.037	0.105	0.125
Rt	148.6	41.644	25.230	259.942	404.245	52.501	107.162	24.156	6.965
Ro	66.11	15.7	3.55	18	93.6	6.89	16.4	63.1	7.71

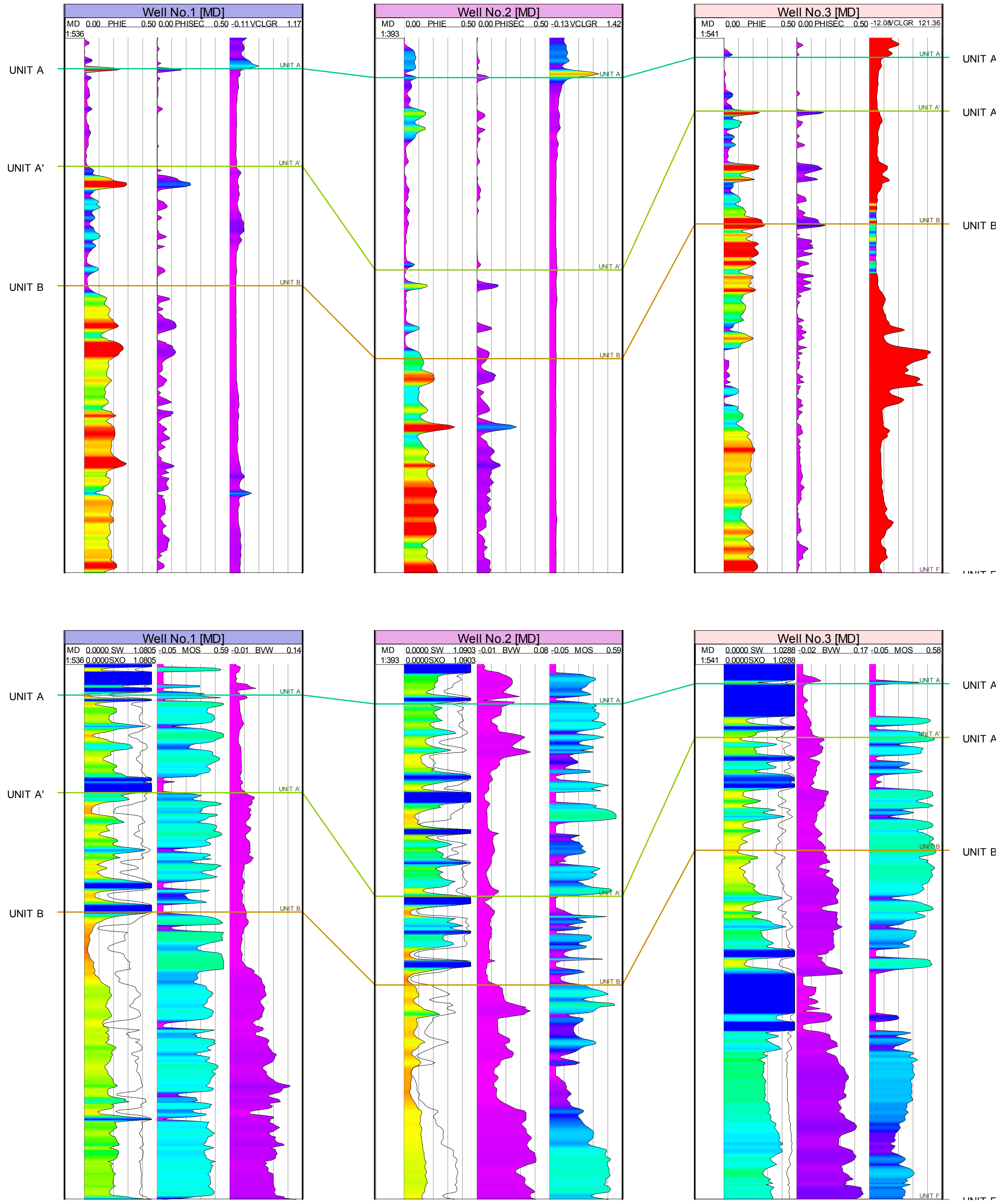

Figure 5: Correlation panel showing Some Computed Petrophysical Parameters for Three Main Limestone Reservoir Units

Table 4: Summary of the Overall averages of Petrophysical parameters

parameter	Overall Average		
	Unit A	Unit A'	Unit B
BVW	0.013	0.025	0.063333
PHIE	0.030667	0.074	0.165333

PHISEC	0.007333	0.033333	0.046667
PHIT	0.039	0.080667	0.173333
SW	0.626333	0.512	0.411667
SXO	0.863333	0.774333	0.736
VCL	0.046333	0.044	0.061333
MHI	0.700667	0.623667	0.559333
MOS	0.235667	0.264667	0.3
ROS	0.138	0.223	0.288
Di	19.737	20.26867	26.01767
PhiSon	0.043333	0.059	0.125333
PhiNeu	0.031667	0.070667	0.202667
PhiDen	0.045333	0.072	0.131667
Rt	171.9013	156.6817	28.232
Ro	33.50333	57.46667	6.05

CONCLUSION

The petrophysical properties evaluation of Bai-Hassan oil field for its reservoirs characterization was made possible by careful analysis and interpretation of its well logs. The results shows the reservoir unit B having average porosity of 16% indicating a suitable reservoir quality and average hydrocarbon saturation more than 60% implying high hydrocarbon production. These results in additions with the other reservoir parameters such as oil movability index (MHI) values and pay zone thickness suggest that this unit has high hydrocarbon potential and a reservoir system whose performance is considered satisfactory for hydrocarbon production. Statistical analysis indicate that unit (B) is good reservoir as compared to unit (A) and unit (A') in the Bai-Hassan oil Field.

REFERENCES

[1]. Schlumberger, "Log Interpretation", vol. II-Applications, New York. (1974).
[2]. Dresser Atlas, "Log Interpretation Chart. Houston. Dresser industries", 107p. (1979).
[3]. M. R. J. Wyllie, A. R. Gregory, and G. H. Gardner, An experimental non-stainless movement (Residual Oil Saturation ROS) at wells Rt-5, and Rt-7, while the minimum values (ROS) and increasingly so values (MOS) at the well Rt-4.
[4]. Schlumberger, "Cased Hole Log Interpretation Principles / Applications", Houston, Schlumberger Wireline and Testing, 198p. (1998).
[5]. Schlumberger**,** Cased Hole Log Interpretation Principles / Applications, Houston, Schlumberger Wireline and Testing, 198p. (1998).
[6]. Mian, Mohammed A., "Petroleum Engineering Handbook for Practicing Engineer", Tulsa, Oklahoma, 1991.
[7]. G.E. Archie, "The Electrical Resistivity Log as an Aid in determining some Reservoir Characteristics", AIME, Vol.146, p.54. (1942).
[8]. Schlumberger, "Log interpretation charts, USA. (1987).
[9]. J.A. Kupeez, and L.S. Land, Progressive re-crystallization and stabilization of early stage dolomite: lower Ordovician Ellen burger group, West Test Taxes, International Association of sedimentologists, special publication, (1995).