



## **Estimation of Oil-Water Contact Level Using Different Approaches: A Case Study for an Iraqi Carbonate Reservoir**

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### **Abstract:**

In petroleum industry, an accurate description and estimation of the Oil-Water Contact (OWC) is very important in quantifying the resources (i.e. original oil in place (OIIP)), and optimizing production techniques, rates and overall management of the reservoir. Thus, OWC accurate estimation is crucial step for optimum reservoir characterization and exploration. This paper presents a comparison of three different methods (i.e. open hole well logging, MDT test and capillary pressure drainage data) to determine the oil water contact of a carbonate reservoir (Main Mishrif) in an Iraqi oil field "BG". A total of three wells from "BG" oil field were evaluated by using interactive petrophysics software "IP v3.6". The results show that using the well logging interpretations leads to predict OWC depth of -3881 mssl. However, it shows variance in the estimated depth (WELL X; -3939, WELL Y; -3844, WELL Z; -3860) mssl, which is considered as an acceptable variation range due to the fact that OWC height level in reality is not constant and its elevation is usually changed laterally due to the complicated heterogeneity nature of the reservoirs. Furthermore, the results indicate that the MDT test can predict a depth of OWC at -3889 mssl, while the capillary drainage data results in a OWC depth of -3879 mssl. The proper MDT data and SCAL data are necessary to reduce the uncertainty in the estimation process. Accordingly, the best approach for estimating OWC is the combination of MDT

and capillary pressure due to the field data obtained are more reliable than open hole well logs with many measurement uncertainties due to the fact of frequent borehole conditions.

**Keywords:** Oil-Water Contact, Free Water Level, MDT Test, Capillary Pressure, Well Logging

### الخلاصة:

في الصناعة النفطية، تقدير او حساب خط تماس النفط والماء مهم جدا لتقدير الكميات المخزونة من النفوط وكذلك لاختيار الطرق المثلى لاستخراج هذه الكميات بأقصى معدلات انتاج ضمن الادارة المتكاملة للمكمن. لذلك يعتبر التعيين الدقيق لقيمة خط تماس النفط مع الماء هو خطوة ضرورية جدا للتمثيل والاستكشاف المكمني الامثل. في هذا البحث تم تقديم مقارنة لحساب خط تماس النفط والماء من ثلاث طرق حيث تم حسابه بواسطة مجسات التجويف المفتوح، معلومات الضغط الشعري بالإضافة الى معلومات فحص الضغط الطبقي لمكمن كاربوني (المشرف) في حقل نفطي عراقي (ج) حيث تم التعامل ودراسة ثلاثة ابار ضمن هذا الحقل واستخدم برنامج **(Interactive Petrophysics IP)** لتفسير مجسات التجويف المفتوح. بينت النتائج ان خط تماس النفط والماء الذي تم حسابه عن طريق تفسير المجسات لمكمن المشرف الرئيسي كان بحدود (3881 م)، حيث كان هناك اختلاف عن العمق المقدر لكل بئر (بئر X-3939م، بئر Y-3844م، بئر Z-3860م) علما ان هكذا فرق في حسابات العمق تعتبر مقبولة لان أساسا خط تماس النفط والماء لا يعتبر ثابت وارتفاعه يتغير تبعا لتعقيد وعدم تجانس المكمن. بالإضافة الى ذلك، وضحت النتائج ان حسابات مستوى تماس النفط مع الماء من بيانات الضغط الطبقي كان يقدر بحدود (3889 م)، بينما قيمة عمق تماس النفط مع الماء من حسابات الضغط الشعري كان بحدود (3879 م).

الاستنتاج الاساسي يؤكد ان توفر البيانات الكافية لكل من الضغط الطبقي (MDT) وكذلك توفر أكثر بيانات حول تحليلات النماذج الخاصة (SCAL) سوف يقلل من نسبة الخطأ او عدم معلومية القيم وبالتالي دقة الدراسة. طبقا الى ذلك، ان أفضل طريقة لتحديد خط تماس النفط والماء في المكامن الكربونية هي باستخدام بيانات كل من الضغط الطبقي وكذلك بيانات الضغط الشعري لكون البيانات تكون أكثر دقة من بيانات المجسات بالتجويف المفتوح لكونها تكون متأثرة بكثير من الظروف المتعلقة بتجويف الابار.

### Introduction:

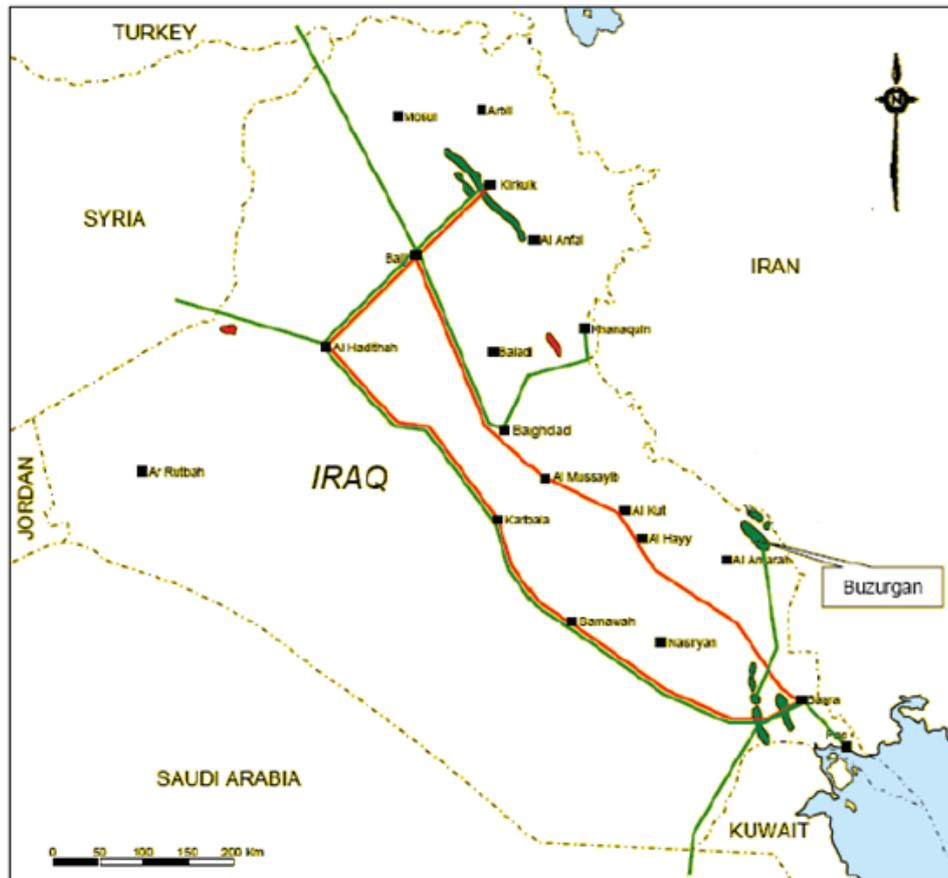
Oil-water contacts in a development wells usually are determined from water saturations derived from resistivity logs either by the detailed formation evaluation or by some quick look techniques. Unfortunately, well logs data is more frequently effected by many bad down hole conditions which give rise to erroneous in data acquisition and in turns less trusted and ambiguous interpretations [1, 2]. As its importance in quantifying the hydrocarbon reserve, hence, it is essential to utilize different approaches to evaluate the

OWC. An alternative and accurate method using formation tester and in combination with capillary pressure data can be used to validate the estimation process [3]. The proper data used in determination of OWC are given by the formation pressure testing tools such as modular dynamics tester (MDT) to measure formation pressure surveys through reservoir intervals [4]. When adequate data can be collected, the fluid contacts is determined very accurately by identifying the depths at the characteristic pressure gradients change [5].

However, variations in the OWC are common from well to well due to differences in petrophysical properties of the formation (reservoir heterogeneity). In practice, an average value of the OWC is used in reserve estimation when volumetric methods are used. [6]

### **Field Background:**

"BG" oilfield is located in the southeastern Iraq close to the Iraq-Iran border as shown in Figure (1). Structurally, "BG" oilfield ranges about (40km \* 7km) with two domes in the north and south respectively, the south dome is shallower and covers bigger area. "BG" oilfield has two sets of reservoirs, Tertiary Asmari and Cretaceous Mishrif. 7 pay zones are divided in the Mishrif reservoir, which is MA, MB11, MB12, MB21, MB22, MC1 and MC2. The main pay zone is distributed in lower part of Mishrif reservoir. The main pay zone MB21 of Mishrif oil reservoir in "BG" oilfield has an oil-water system and is an edge water structure stratigraphic reservoir with wide oil-water transition zone. The pay zones of MC1 are also an edge water structure stratigraphic reservoir. The natural energy in Mishrif oil reservoir of the oilfield is weaker than that in Asmari reservoir of Abu Ghirab oilfield and Asmari reservoir of Fauqi oil field but is stronger than that in Mishrif reservoir of Fauqi oilfield. "BG" oilfield was put into production in November 1976 and are produced from the Mishrif reservoir with regular well pattern and large well spacing (>800 m). The production rate reached 40kbbbls/d before it was shut down for more than ten years during 1980- 1998 due to the Iraq–Iran war. After the oilfields resumes production in 1998, it has maintained the production level at about 35kbbbls/d. Pay zone MB21 contribute 95% oil production of "BG" oilfield with the cumulative production of 172.96 MMSTB. During the rehabilitation Period, about 44 new wells are proposed to be drilled in “BG” Field.



**Fig. (1) Location map of the study area**

### **Methodology:**

The main steps for achieving this work can be summarized as shown below:

- 1- Collect open hole logs data, special core analysis (SCAL) and MDT pressure data for X, Y and Z wells.
- 2- Import the LAS files of log data for each well into **Interactive Petrophysics (IP 3.6)** software.
- 3- Estimate shale volume for each digit log interval for each well by using raw log data of gamma ray based on old rock module (Larionov).
- 4- Identify the lithology from the neutron-density cross plot.
- 5- Compute formation porosity from Neutron-density and sonic in washout zones.
- 6- Compute water saturation using Archi's equation model.
- 7- Adjust Pickett plot parameters with reference to water zone.

- 8- Detect OWC from open hole logging interpretations (CPI) depended on water saturation.
- 9- Interpretation of MDT raw data to determine free water-level (FWL).
- 10- Derive universal capillary pressure curve from special core analysis data (SCAL).
- 11- Determine minimum threshold pressure or displacement pressure (Pd).
- 12- Combine capillary pressure curve (SW vs Height) with MDT and estimate OWC.

For more details, the initial stage of this research involves estimation of oil water contact of MB21 unit for Mishrif reservoir in "G" oil field using the measured open hole well logs data of three wells (Well-X, Well-Y and Well-Z) such as (Spontaneous Potential, Gamma Ray, Density, Sonic, Neutron and Resistivity logs). All las files of these wells have been collected and imported to interactive petrophysics IP 3.6. Before starting the interpretation process, data quality check and environmental corrections of bad borehole conditions have been performed.

1-Shale volume estimation based on gamma ray values using old rock module (Larionov) which is applicable for Cretaceous Mishrif rocks giving by the following equations [7]:

$$Vsh = 0.33 * [2 (2 * IGR) - 1] \quad (1)$$

$$IGR = (GRlog - GRmin) / (GRmax - GRmin) \quad (2)$$

2- Total porosity is calculated from Neutron density cross plot using the following equations [7]:

$$\emptyset D = (\rho ma - \rho b) / (\rho ma - \rho f) \quad (3)$$

$$\emptyset t = (\emptyset N + \emptyset D) / 2 \quad (4)$$

$$\emptyset e = \emptyset t * (1 - Vsh) \quad (5)$$

Sonic porosity is used in wash out intervals in combination with Neutron porosity using the following equations:

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

$$\emptyset = \emptyset S * 0.7 \quad \text{gas effect correction} \quad (7)$$

$$\emptyset = \emptyset S * 0.9 \quad \text{oil effect correction} \quad (8)$$

$$\emptyset Scorr = \emptyset S - (Vsh * \emptyset Ssh) \quad (9)$$

3- Water and hydrocarbon saturation estimations:

Archie module was used to estimate water saturation in the uninvaded and invaded zones using Archie equation [7]:

$$S_w = \{(a * R_w) / (R_t * \emptyset^m)\}^{1/n} \quad (10)$$

$$S_{xo} = \{(a * R_{mf}) / (R_{xo} * \emptyset^m)\}^{1/n} \quad (11)$$

$$S_h = 1 - S_w \quad (12)$$

$$R_{OS} = 1 - S_{xo} \quad (13)$$

A next step was to estimate OWC from MDT data interpretation to get the free water level (FWL) and in combination with capillary pressure data (special core analyses measurements) to finally derive the OWC. MDT interpretations involve graphing pressures vs depth data and discriminating the different fluids encountered in the reservoir from their distinct gradients whereas the oil and water gradients intersection represent the FWL. Therefore, data of available two wells (WELL X and WELL Y) were collected and quality checked for supercharges and bad tool readings and some reading points has been excluded from the interpretations.

Eventually, a universal capillary pressure ( $S_w$  vs height) called J-Leverett function has been derived for the entire formation from the available data of special core analysis of well BU-3 therefore the capillary pressure data was converted to reservoir conditions then J Leverett function has been calculated to normalize the variation in the petrophysical core properties ( $K\&\phi$ ). J ( $s_w$ ) curves then the normalized J ( $S_w$ ) curve has been converted to PC and the latter used to derive the saturation depth relationship and the corresponded  $S_w$  have been plotted on Cartesian graph for each core on same plot with different depth in MB21 reservoir. A universal J function has been derived with best fit to J ( $s_w$ ).

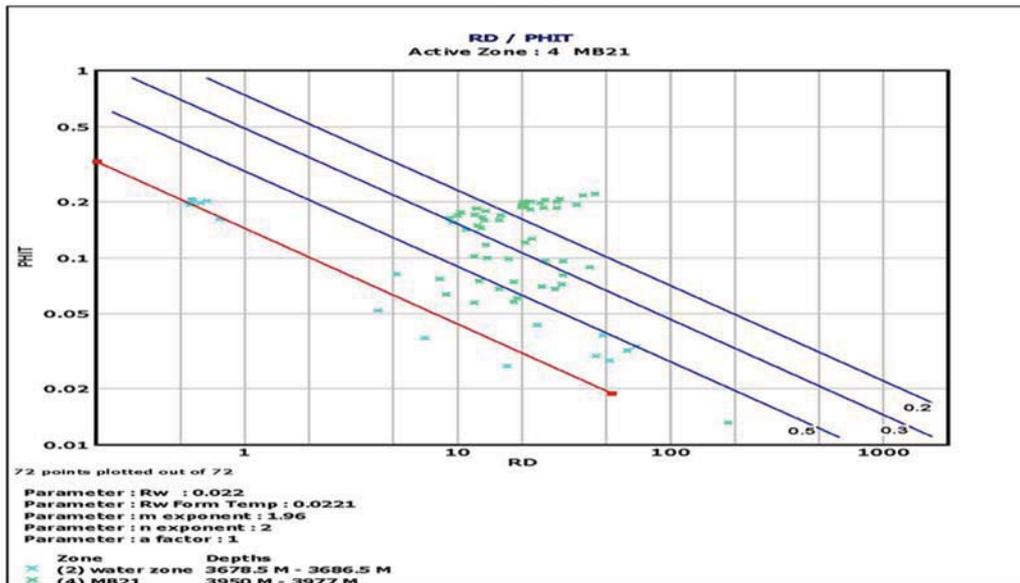
Finally, the following equations can be applied to estimate OWC based on the universal saturation-height relationship, Pd value, height above FWL, and FWL value:

$$P_c = (\rho_w - \rho_{hc}) * h * 3.281 * 0.433 \quad (14)$$

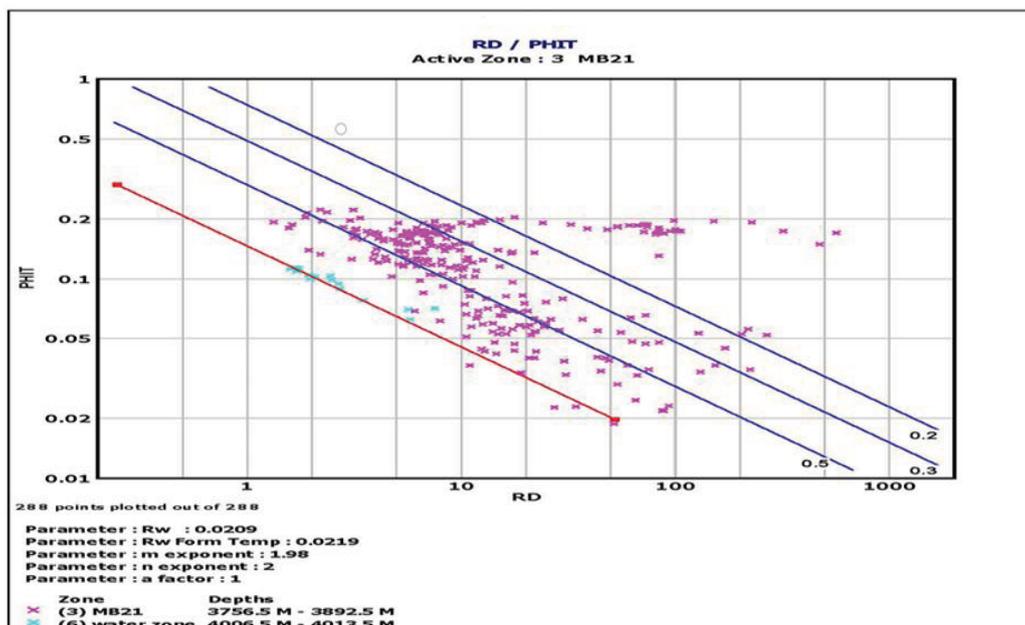
$$WOC = FWL - H \quad (15)$$

**Results & Discussion:**

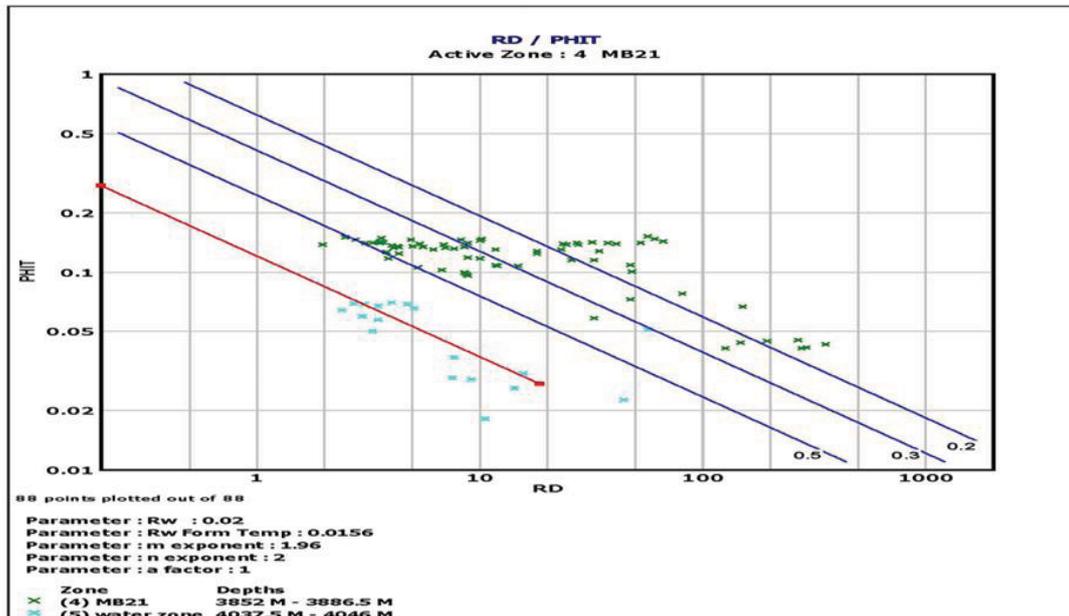
Firstly, the results of Picket plot for all three candidate wells presents that default Archie parameters ( $a=1$ ,  $m=2$ ,  $n=2$ ) for limestone formations and  $R_w$  value equal to 0.02 from lab analysis are consistent with ones derived from Picket plot as presented in Figures (2) to (4).



**Fig. (2) WELL X Picket plot**



**Fig. (3) WELL Y Picket plot**



**Fig. (4) WELL Z Picket plot**

The well correlation between these three candidate wells in this work is presented in the Figure (5) to make a good comparison and guide for lithology identification and well log interpretation. Figures (6) to (8) display lithology identification by using neutron and density cross plot method which is in accordance with the geological information of the interpreted intervals. The results of interpretations introduced limestone lithology with little shale contamination in insignificant percentages. In addition, it indicates that the data quality of neutron and density are highly suitable for being used in the interpretations.

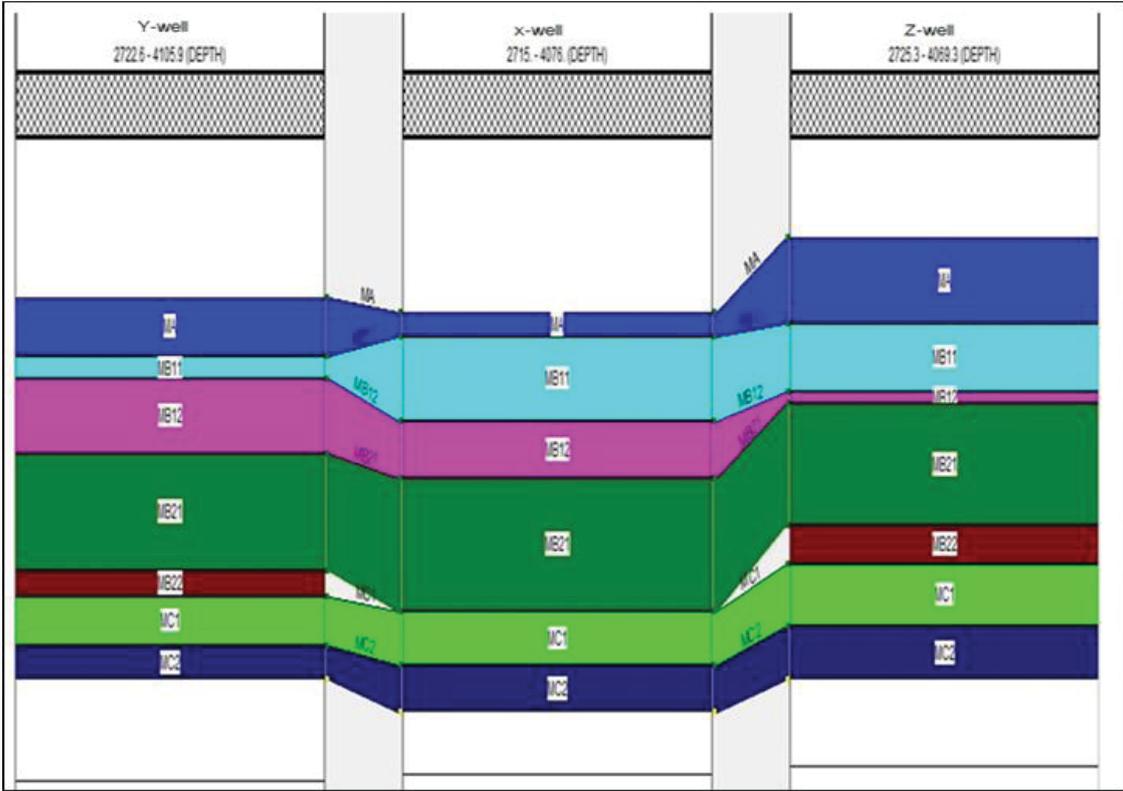


Fig. (5) Well Correlation for all three studied wells

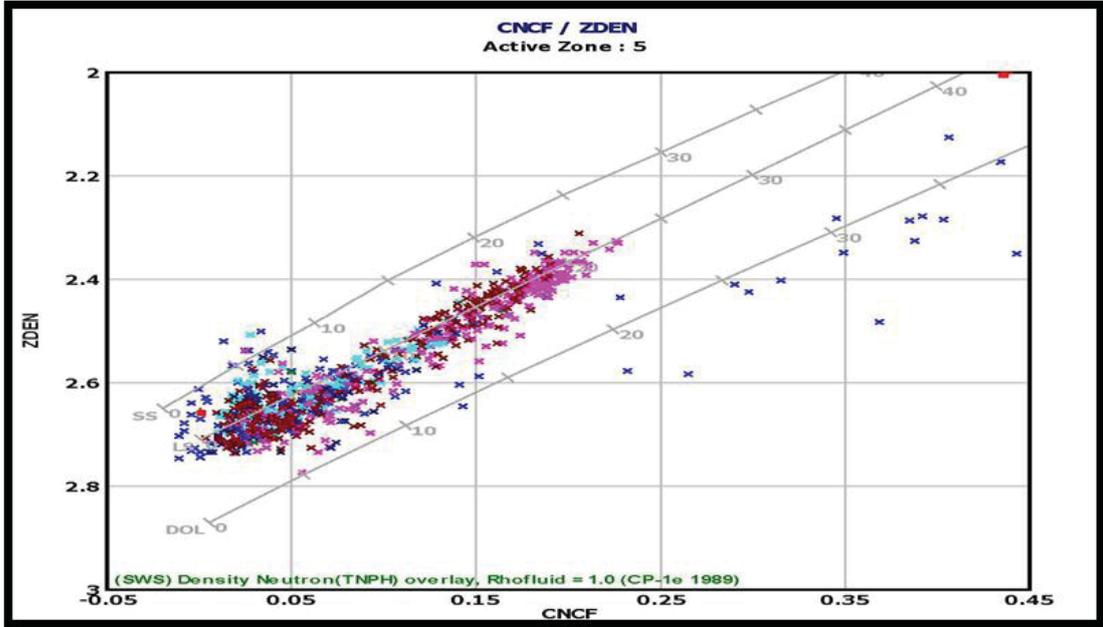


Fig. (6) WELL X cross plot of Neutron-density (limestone)

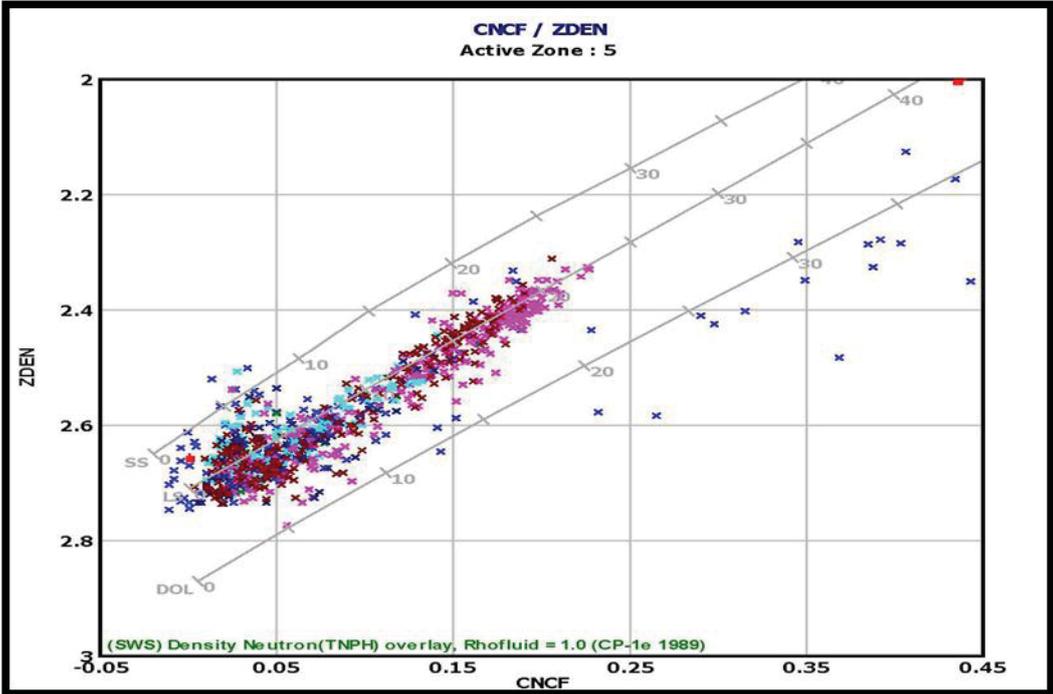


Fig. (7) WELL Y cross plot of Neutron-density (limestone)

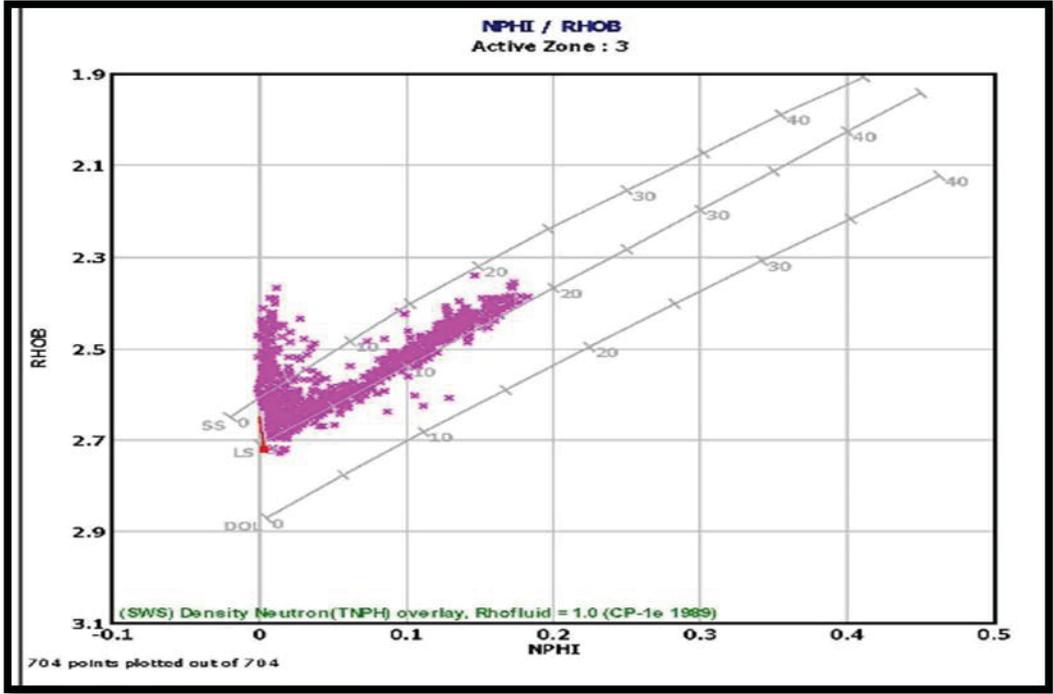


Fig. (8) WELL Z cross plot of Neutron-density (limestone)

Thirdly, the final results of CPI interpretations are presented in Figures (9) to (11) of the three wells for MB21 unit. Clearly, the interpretations show the estimated oil water contact indicated by 100% water saturation just below the oil leg. Obviously, it is variant from well to well due to the significant heterogeneity especially in the permeability lateral distribution along the formation under study. The average estimated depth of oil water contact for MB21 is about -3881 mssl. The detail results of the OWC from log interpretations for all three wells are tabulated below in Table (1).

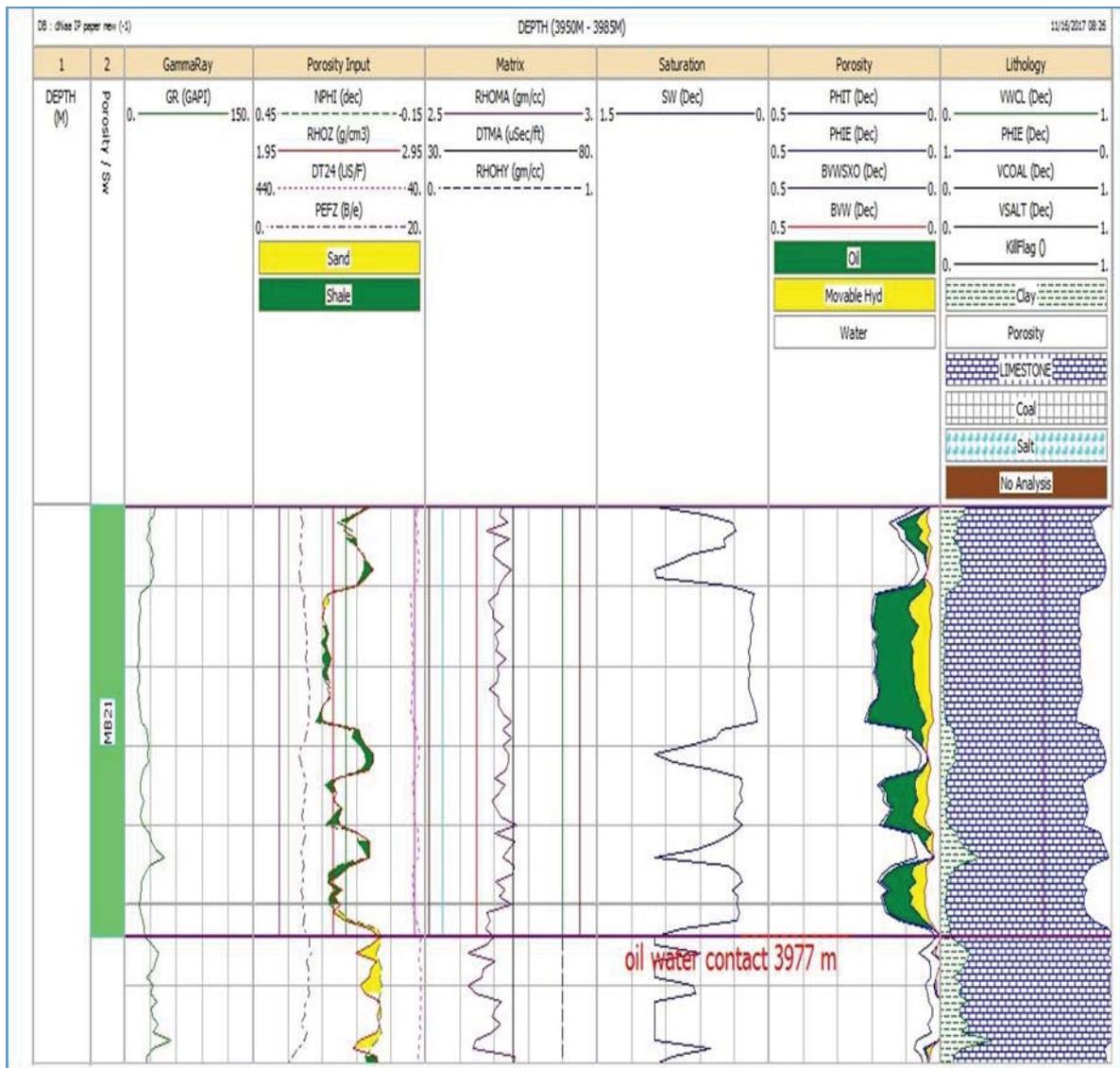


Fig. (9) Computer Processing Interpretation (CPI) of well WELL X

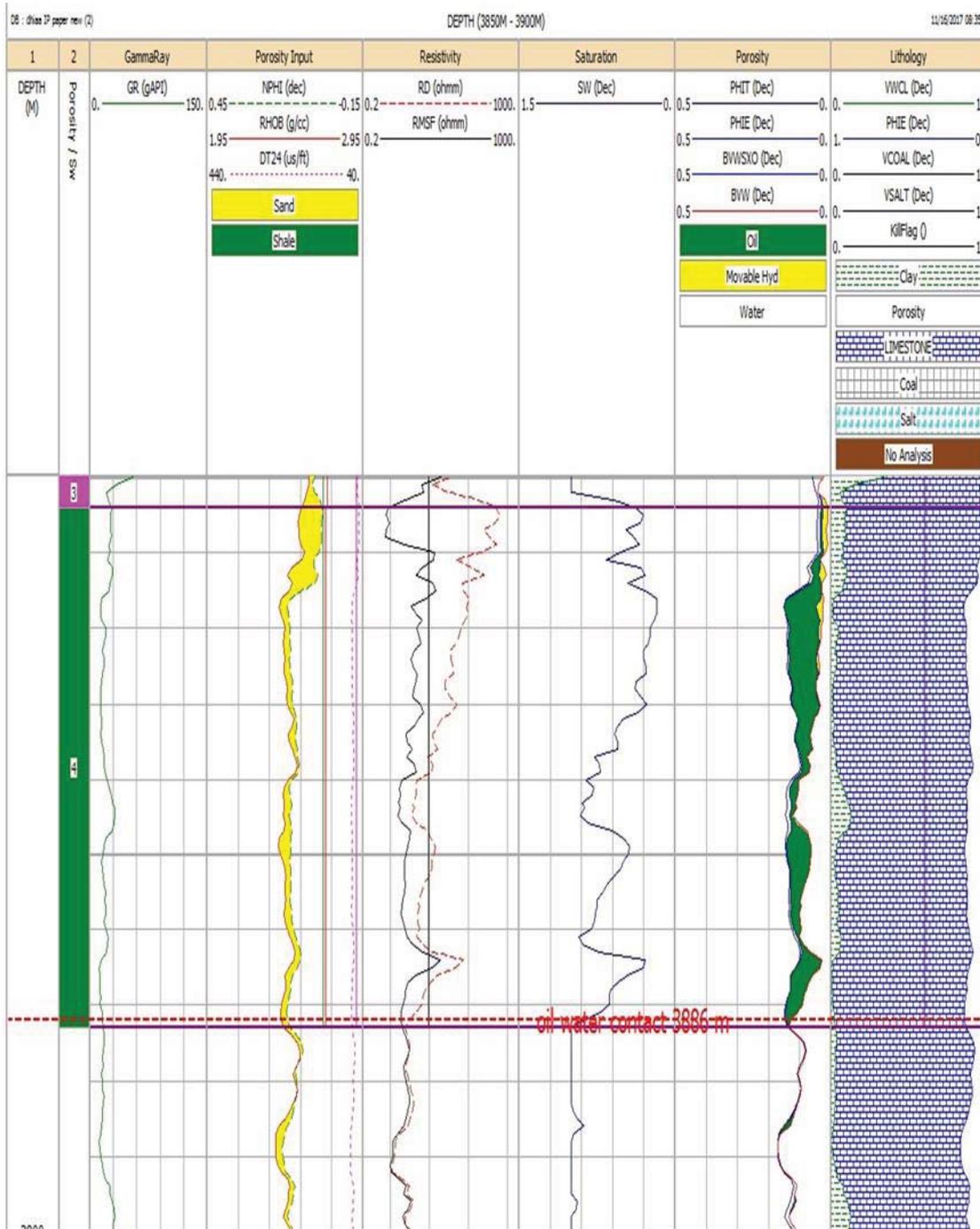


Fig. (10) Computer Processing Interpretation (CPI) of well WELL Y

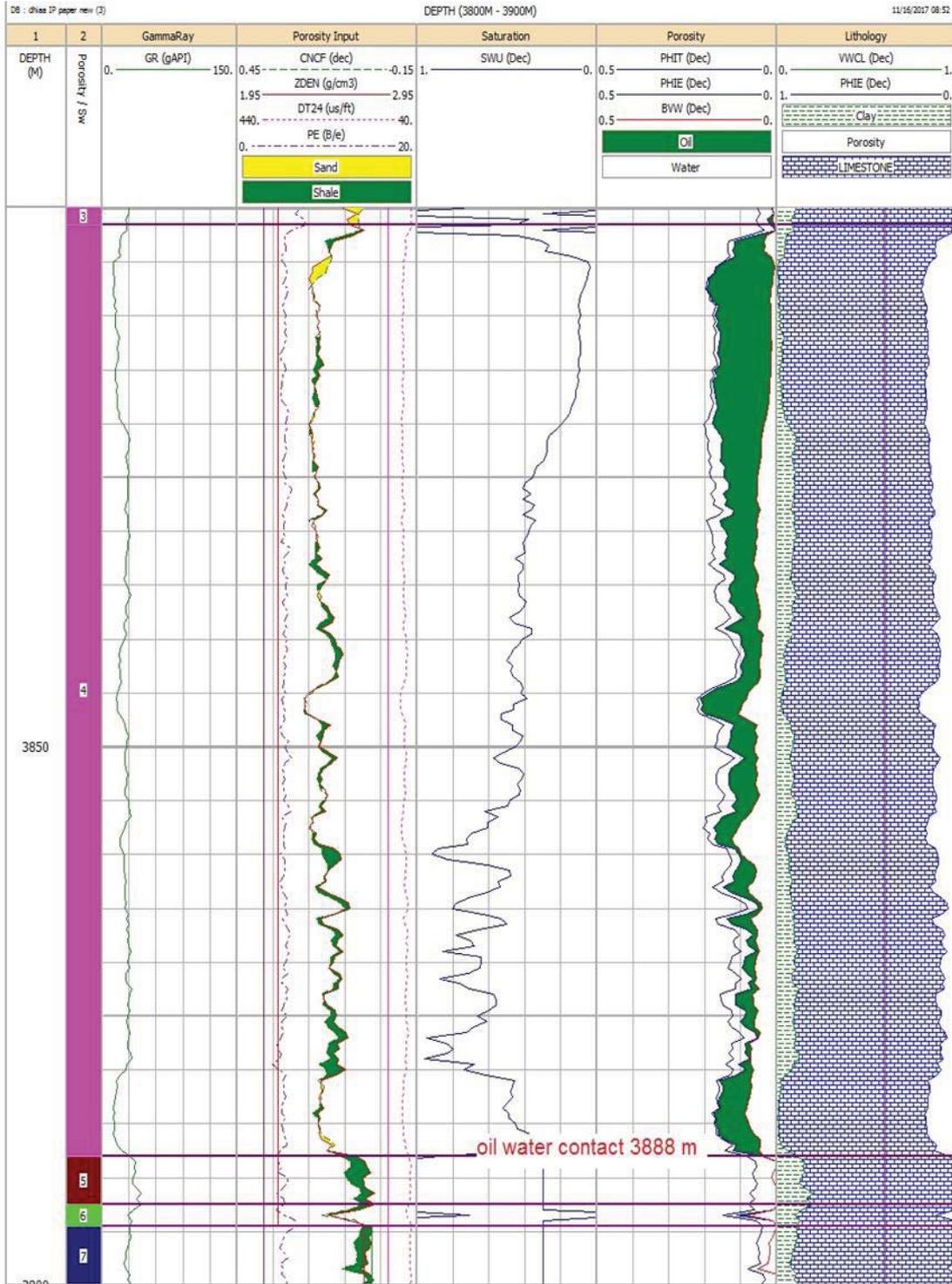
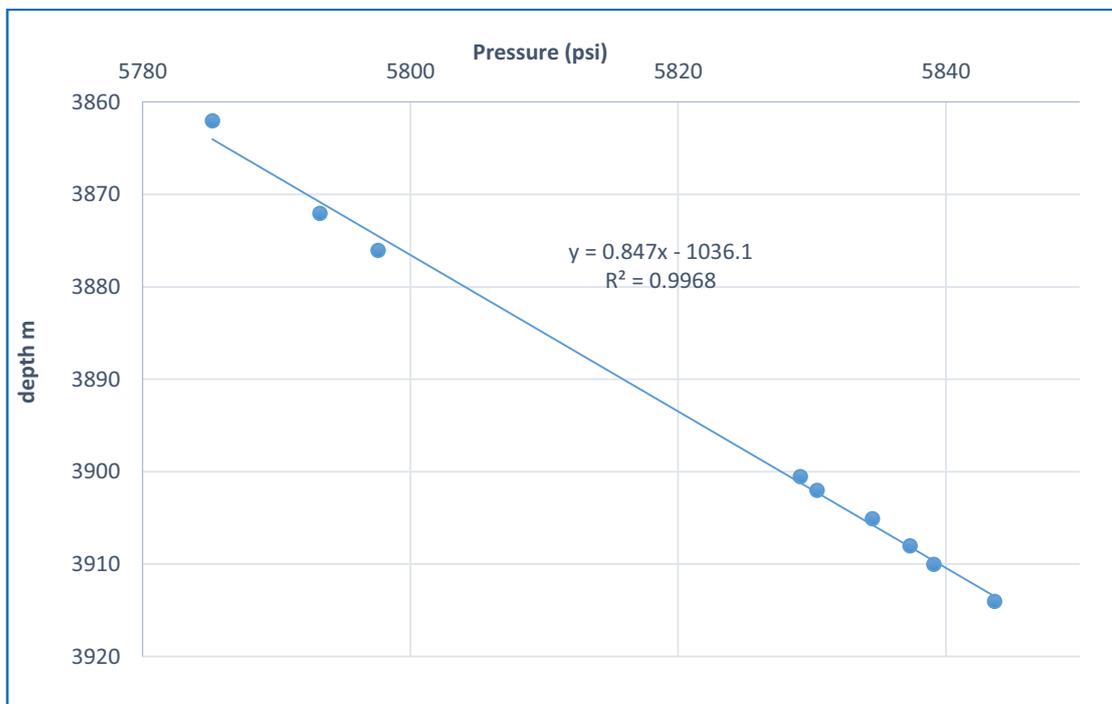


Fig. (11) Computer Processing Interpretation (CPI) of well WELL Z

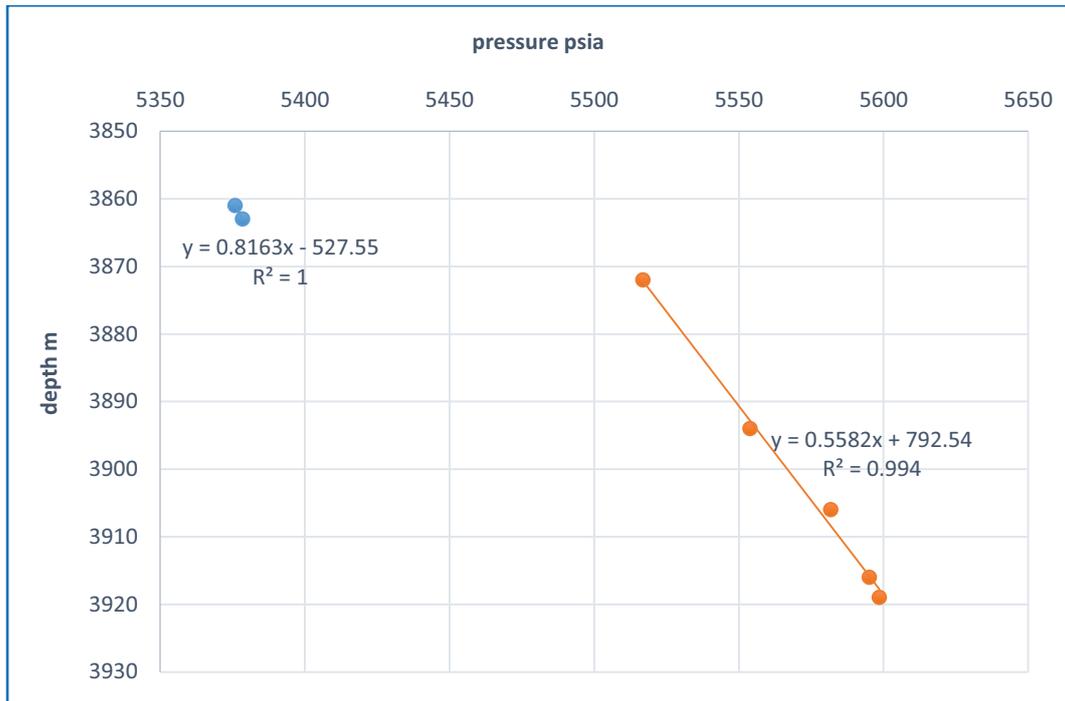
**Table (1) OWC for all three wells from log interpretation results**

Well name	Well-X	Well-Y	Well-Z
<b>OWC m MD</b>	3977	3886	3888
<b>RTKB m</b>	38.2	41.6	28
<b>OWC m MSSL</b>	3939	3844.4	3860

Regarding the results of MDT interpretations are displayed in Figures (12) & (13). Noticeably, it can be inferred from the interpretation results that no adequate MDT data has been measured since all pressure tests are conducted only in the oil zone of MB21 and no test points were performed in the water column. Therefore, it was impossible to predict the free water level with these available data. For Well- X, the interpretation results present an oil density of 0.85 gm/cc which is belong to just the oil zone and no measurements extended below the oil interval as shown in Figure (12). Figure (13) displays the interpretation results of WELL-Y whereas the first two points are valid with an oil density of 0.81 gm/cc, while the other points on the second straight line is not valid due to the error in the measurement tool itself or as a result of supercharge effect.



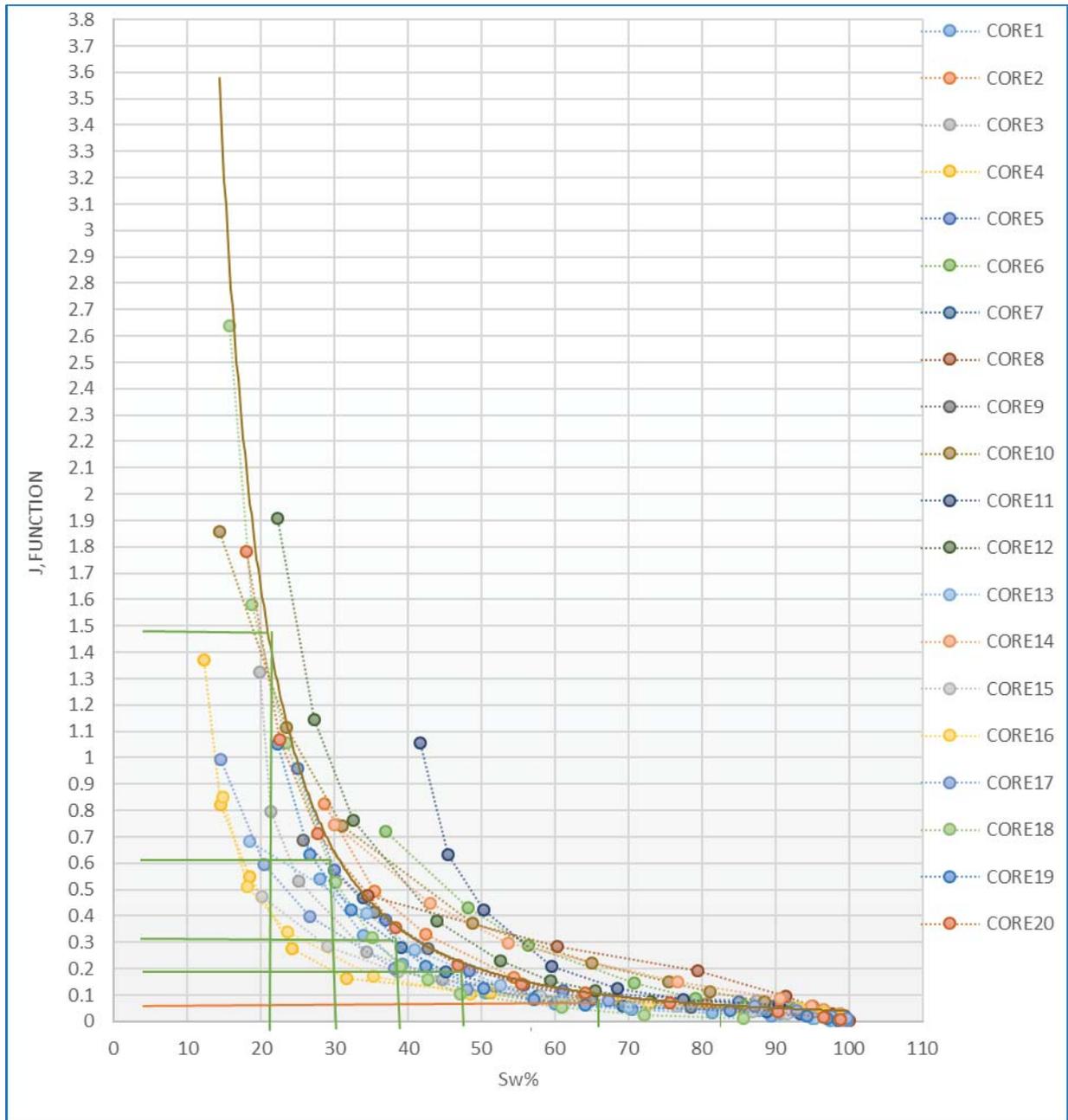
**Fig. (12) WELL-X MDT data interpretation**



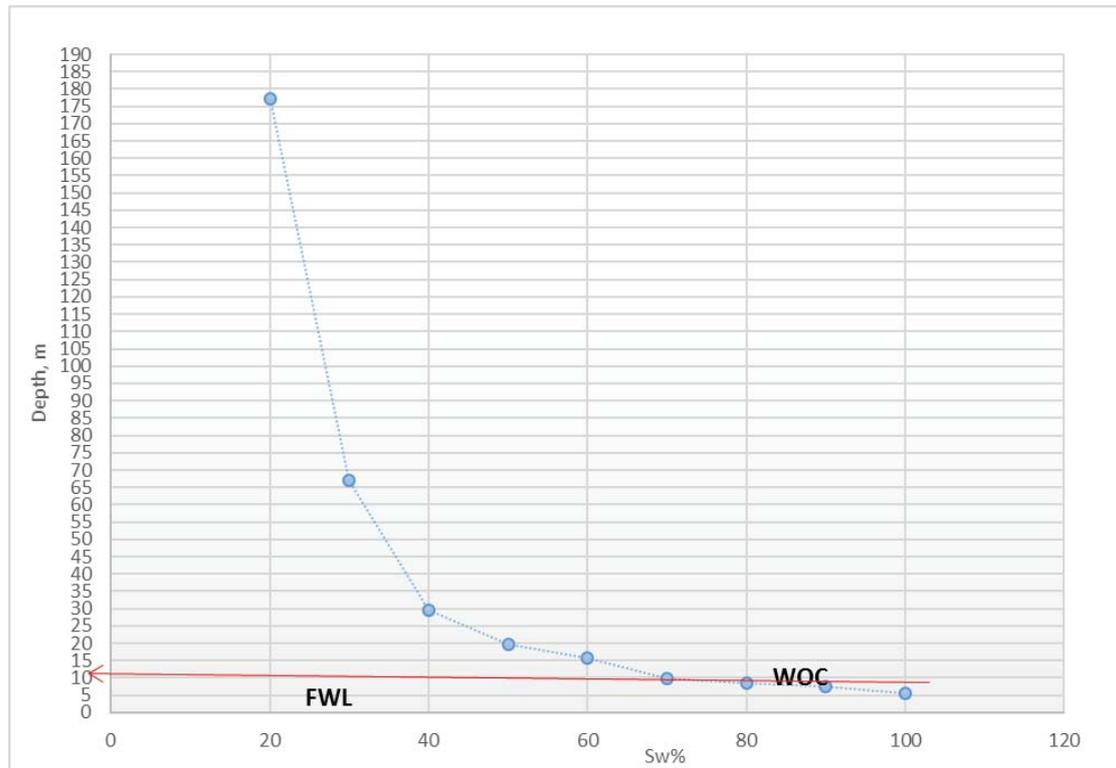
**Fig. (13) WELL-Y MDT data interpretation**

According to the current situation of no possibility to get FWL value from the Modular dynamic formation tester data, the value of FWL is obtained from the previous reservoir studies for the field under study. It seems that FWL value is close enough to the OWC with a value of -3889 mssl.

Finally, the results of deriving the universal saturation-height relationship are introduced in Figures (14 & 15). According to the results of SCAL data analysis, it seems that there is only 10 m (corresponding to minimum threshold pressure  $P_d$ ) distance between FWL and OWC. Accordingly, 9-the OWC is estimated by applying equations (14) & (15). The predicted OWC is -3879 mssl. This value is very close to that predicted from well log results with difference about 2 m only (less than 1%).



**Fig. (14) J function with Sw for all cores**



**Fig. (15) Water saturation Vs Depth**

### **Conclusions:**

- 1) OWC estimation from well logs interpretations introduced a noticeable variance due to the reservoir heterogeneity that gives rise to conclusion that more wells from different regions of the reservoir are needed to be evaluated to get an accurate value of the predicted OWC for whole reservoir.
- 2) The results of OWC prediction by using open hole log interpretations method presented a good agreement with that approach based on capillary pressure data.
- 3) The MDT pressure test data are failed to estimate the FWL depth due to the insufficient pressure measurements in the field under study, where all the pressure test points are carried out in the oil column only.
- 4) Adequate MDT data and more SCAL data are necessary to minimize the uncertainties in the OWC estimation process.
- 5) The best approach for estimating OWC is the combination of using capillary pressure and MDT data as a result of the data acquired are more dependable than open hole well logs which involved many measurement uncertainties due to the fact of frequent borehole conditions.

**Nomenclature:**

- ✚ OIIP: oil initial in place
- ✚ OWC: oil water contact
- ✚ MDT: modular dynamic tester
- ✚ SSL: sub sea level
- ✚ VSH: volume of shale
- ✚ IGR: Gamma Ray Index
- ✚ PC: Capillary pressure
- ✚ FWL: Free water level
- ✚  $J(s_w)$ : Leverett Function
- ✚ K: permeability
- ✚ PHI: porosity
- ✚ H: height correspond to minimum displacement pressure ( $P_d$ )
- ✚ GRlog: gamma ray reading from log
- ✚ GRmin: minimum gamma ray reading from log
- ✚ GRmax: maximum gamma ray reading from log
- ✚  $\emptyset D$ : density porosity
- ✚  $\rho_{ma}$ : matrix density
- ✚  $\rho_b$ : bulk density from log
- ✚  $\rho_f$ : fluid density
- ✚  $\emptyset N$ : neutron porosity
- ✚  $\emptyset_t$ : total porosity
- ✚  $\emptyset_e$ : effective porosity
- ✚  $\emptyset S$ : sonic porosity
- ✚  $\Delta t_{log}$ : interval transit time in the formation
- ✚  $\Delta t_{ma}$ : interval transit time in the matrix
- ✚  $\Delta t_{fl}$ : interval transit time in the fluid in the formation
- ✚  $\emptyset S_{corr}$ : corrected sonic porosity
- ✚  $\emptyset S_{sh}$ : apparent porosity of the shale
- ✚ Scal: special core analysis
- ✚  $P_d$ : minimum threshold pressure

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