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Original Article

Integration of conventional logs and formation micro imager for evaluation of the thinly bedded intervals in Bahariya Formation, Yomna field, Abu Al-Gharadiq Basin, Western Desert, Egypt

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ABSTRACT

Some reservoirs exhibit low electrical resistance and high estimated water saturation, despite it can produce hydrocarbon, associated with low water cut. These types of reservoirs are considered as unconventional reservoirs and well known as low resistivity pays (LRP). The identification and evaluation of such kind of unconventional reservoirs are very challenging and important for some oil and gas reservoirs. Low resistivity contrast between the low resistivity hydrocarbon - bearing zones, adjacent to the water zones and shaly zones could mislead the hydrocarbon evaluation and leads to bypassing of a considerable volume of resources. Evaluation of the laminated sand-shale sequence is controlled by some factors, such as; the lithology, mineral composition, compaction, thickness and resistivity. The thin beds may have a low resistivity value due to the effect of presence within a conductive thick shale bodies. The present study imposes an advanced interpretation technique for more accurate identification of the thin beds intervals, which are usually bypassed in case of using the conventional log tools. For better evaluation of the thinly bedded laminated sections and in order to maximize the hydrocarbon potentiality. By application of both the traditional log tools and resistivity images logs as well as Thomas – Stieber Method on Bahariya Formation in Yomna Field; it was found that the porosity, hydrocarbon saturation and net pay thickness for all the Bahariya reservoirs were enhanced with a different percent, based on the laminated and thin beds interval for each well. It is highly recommended to adjust the current study in next the wells with nuclear spectroscopy and NMR logs for calibration of clay volume, porosity and estimation of volumes of conductive Intervals.

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1. Introduction

The case study of the present research deals with the Cenomanian Bahariya in the Western Desert, Egypt, as it one of the most important hydrocarbon reservoirs in Egypt. Characterizing the Upper Bahariya complex possesses several challenges; because this complex formation comprises reservoir rock units and several seals, therefore we must understand the petrophysical characteristics, to assess the potential of the formation.

As Halisch et al, 2009 have pointed out that, only limited detailed Petrophysical reservoir characterizations of the Bahariya formation made, in close combination with geological and mineralogical investigation, have been reported in literatures (El-Sayed et al, 1993 and Athmer, 2006).

Usually, the subsurface reservoir rocks are not homogeneous in their petrophysical properties. They may contain thin beds, that can’t be recognized by the conventional logging tools, in response of the relatively low resolution of these tools in unraveling the hidden layers (Saxena and Klimentos, 2004). Thinly laminated sand/shale sequences are often mistaken as low-resistivity wet sands, in spite of their high hydrocarbon saturations. As the electric current has a tendency to pass through path of the least resistance, conventional resistivity logs will read the low resistivity in such formations, exhibiting laminated sand/shale sequences.

The thin laminated sand-shale sequences have a great distribution in different types of depositional environments, such as fluvial bars, deep water submarine sediments deltaic deposits, and turbidities, considerable amounts of hydrocarbon reserves, may be trapped within the thin sands beds.

2. Geologic Setting

The northern Western Desert of Egypt characterized, by east-west and northeast –southwest tectonic sedimentary basins, is most important one. The study area is located at the easternmost flank of the Abu Gharadig basin (Fig .1). The Yomna field comprises a series of 3-way faulted anticlines as formed in response to a transpressive tectonic regime. Pay is present throughout the Upper Bahariya, the subject of this paper, which is Cenomanian in age (Fig .2).

The stratigraphic sequence of Western Desert basin as well as this column penetrated by Yomna wells, can be summarized as follows: -

•Moghra Formation. (Lower Miocene)

•Dabaa formation (Upper Eocene– Oligocene).

•Apollonia Formation (Lower– Middle Eocene).

•Khoman Formation (Santonian - Maastrichtian).

•Abu Roash Formation (Upper Cenomanian– Coniacian).

•Bahariya Formation (Lower Cenomanian).

•Kharita Formation (Albian).

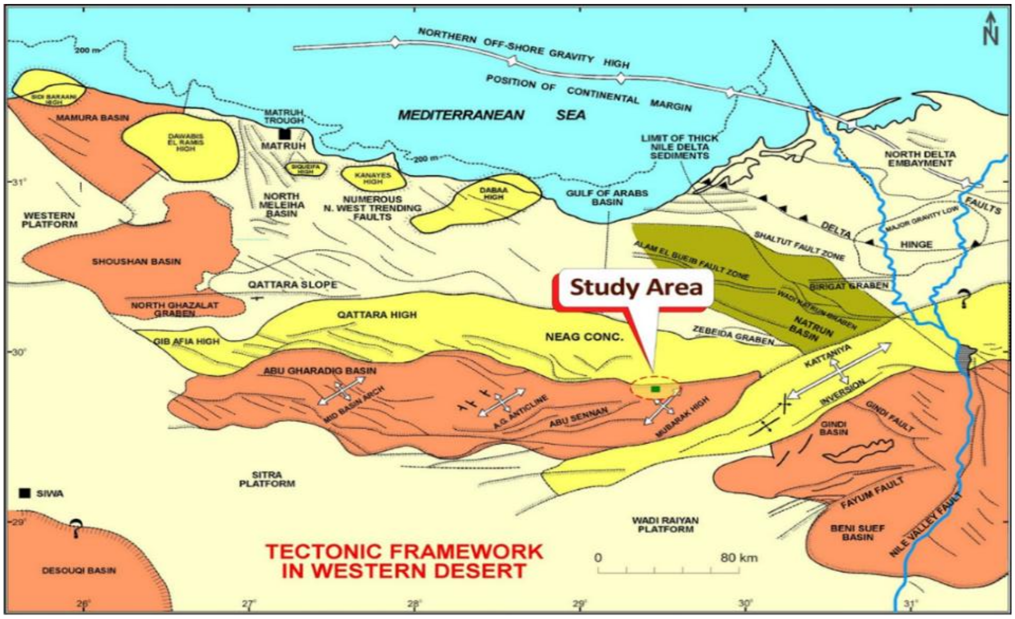

Fig. 1: Structural divisions of northern Western Desert basin, (Bayoumi, 1996).

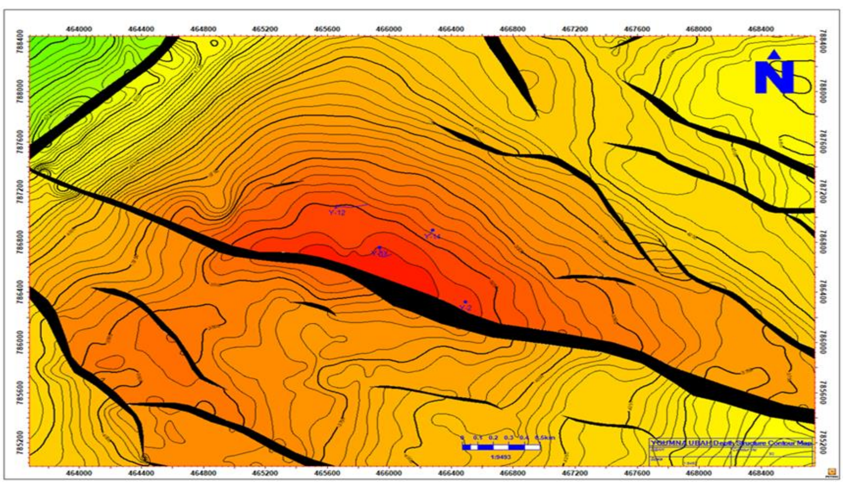

Fig. 2: Depth structure contour map on top of Upper Bahariya member

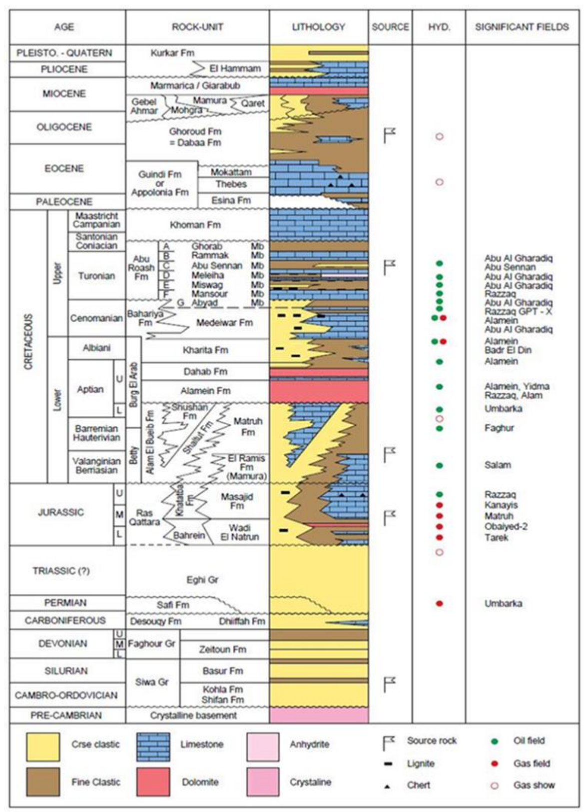

Fig.3: Generalized lithostratigraphic column of the Western Desert (Schlumberger, 1995).

3. Material and Methodology

Well log data acquisition in Yomna field wells acquired a suite of open-hole data with Triple Comb technologies which, done in all wells of Yomna field, with core data analysis acquired in Yomna-02, Yomna-12 and Yomna-14 wells. The well logs consist of classical logging and advanced

Technology, extending from caliper (CAL), Gamma-ray (GR), to several electrical logs (Rxo & Rt), Density, Neutron logs and resistivity image logs. A conventional and advanced suite of open-hole wireline logs were run by Schlumberger in all the wells. The main measurements acquired in the wells of different runs, include: -

•Gamma-Ray, Caliper and Spontaneous Potential

•Porosity Logs– (Density, Neutron and sonic)

•Resistivity Logs – (Deep Induction, spherically focused Laterolog and Micro-Spherically focused logs).

•Resistivity image logs.

“Thin beds” are beds thinner than the vertical resolution of the logging devices. Thin beds of clay, silt and fine-grained sand, distributed within a hydrocarbon-bearing sand, significantly reduce the apparent resistivity measured by a conventional induction or lateralog tool (Fig-3). Moreover, the fine-grained layers frequently have high irreducible water saturation and therefore the reservoir can produce oil or gas, with zero water-cut. When thin laminae of sand and shale are intersected by a wellbore, the electrical current from the resistivity tool is shorted, due to the high conductivity of the shale laminae.

Yomna -14 well is the selected well to apply the integration between conventional, advanced; such as formation micro image (FMS), wire line logs and Thomas – Stieber method, to obtain more accurate Petrophysical evaluation for the Bahariya Formation in Yomna Field. The interpretation starts with gathering and reviewing all the available log data, it will be helpful to have image data for, confirming the presence of laminations.

For the purpose of reservoir characterization and thin bed analysis two, different techniques are used to verify the effect of thin beds and estimate the laminar shale concentrations, which has an importance in the evaluation of hydrocarbon-in-place. It is important to understand the two techniques, as the data processing concepts are entirely different. The two techniques are:

1. Thin bed analysis and laminar shale concentration, using the Resistivity Image tool.

2. Thomas – Stieber method, to determine the laminar shale concentrations.

3.1. Laminar shale concentration, using the Resistivity Image tool.

A threshold was selected on the FMI Rxo curve, to calculate the laminar shale concentration from FMI measurements. Values below the threshold were considered representative of shale, whereas values above the threshold were considered representative of sand.

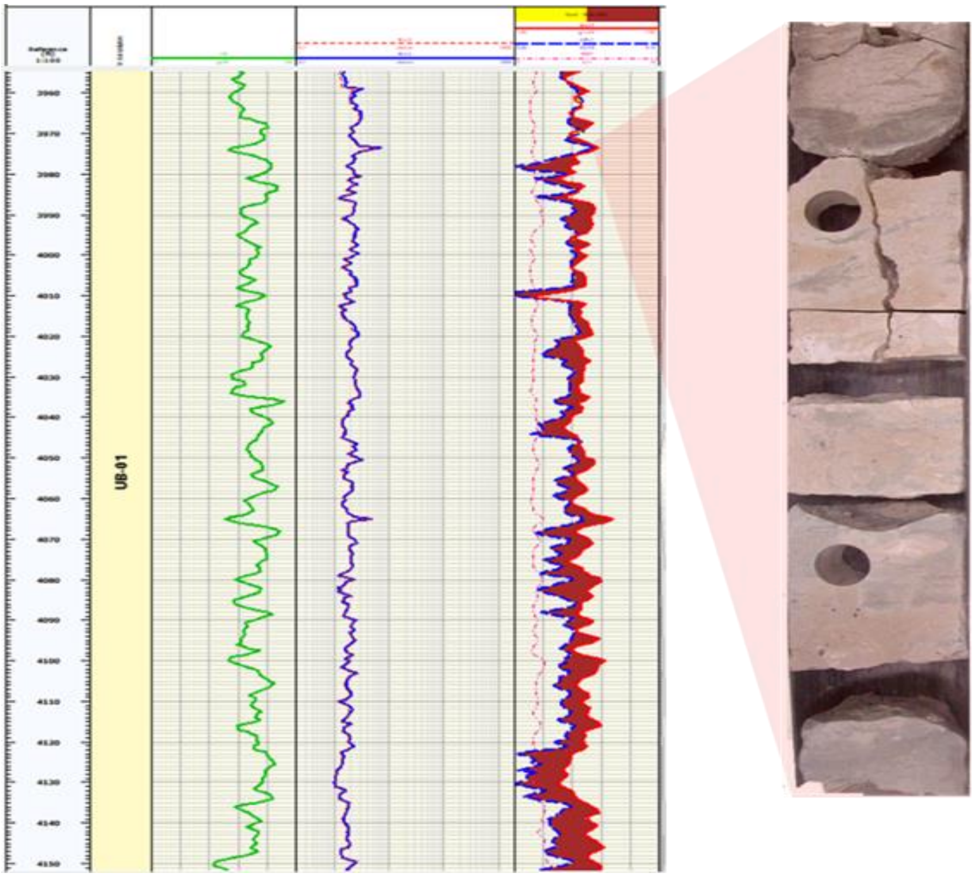

Fig. 4: - Discrepancy between porosity measurements from low-resolution log and core plug analyses for a thin (1-ft) bed. These values indicate the low porosity zone in core (8%) was not accurately reflected by the log measurement (13%). The higher log value was affected by the adjacent high porosity zones

The threshold was iteratively refined until the laminar shale concentrations estimated by the FMI measurements, and their core images were in acceptable agreement (Passey et al., 2006). The same threshold was then used to estimate the laminar shale concentration in uncored depth intervals. To compare results, laminar shale concentration determined from FMI measurements was spatially smoothed by applying an averaging filter of length equal to the vertical resolution of the other wireline measurements (2 ft.). This method provided consistent results when FMI measurements accurately detected the bed boundaries. Laminar shale concentration calculated can be over or under-estimated depending upon the adjacent bed resistivity, when the bed thicknesses are lower than the vertical resolution of the FMI measurements. Moreover, variations in formation fluid and grain sizes affect the FMI measurements, which in turn can lead to erroneous estimations of laminar shale concentration. (Figure -5), track 4 compares the FMI Rxo curve and the core image. It can be observed that the, FMI Rxo curve broadly identifies the variations in lithofacies, that are visible on the core image.

By using the resistivity (Rxo) curve, which resulted from the formation micro image processing and calibration, it can be need to calculate the volume of laminated shale using the image resistivity curve. Comparing the values obtained for the volume of clay, using the conventional tools, such as (GR, Neutron & density) and the volume of clay, which result from the image resistivity curve, it is observed that the volume of clay reached from image analysis is lower than the volume of clay, using the conventional tools. So that the classic Petrophysics interpretation is not able to determine the exact volume of shales in thin layer shaly sand interval due to the fact that since layer thickness is less than log resolution so several layers are averaged at each depth and the log reading would be only an average value and is not representative for each of them.

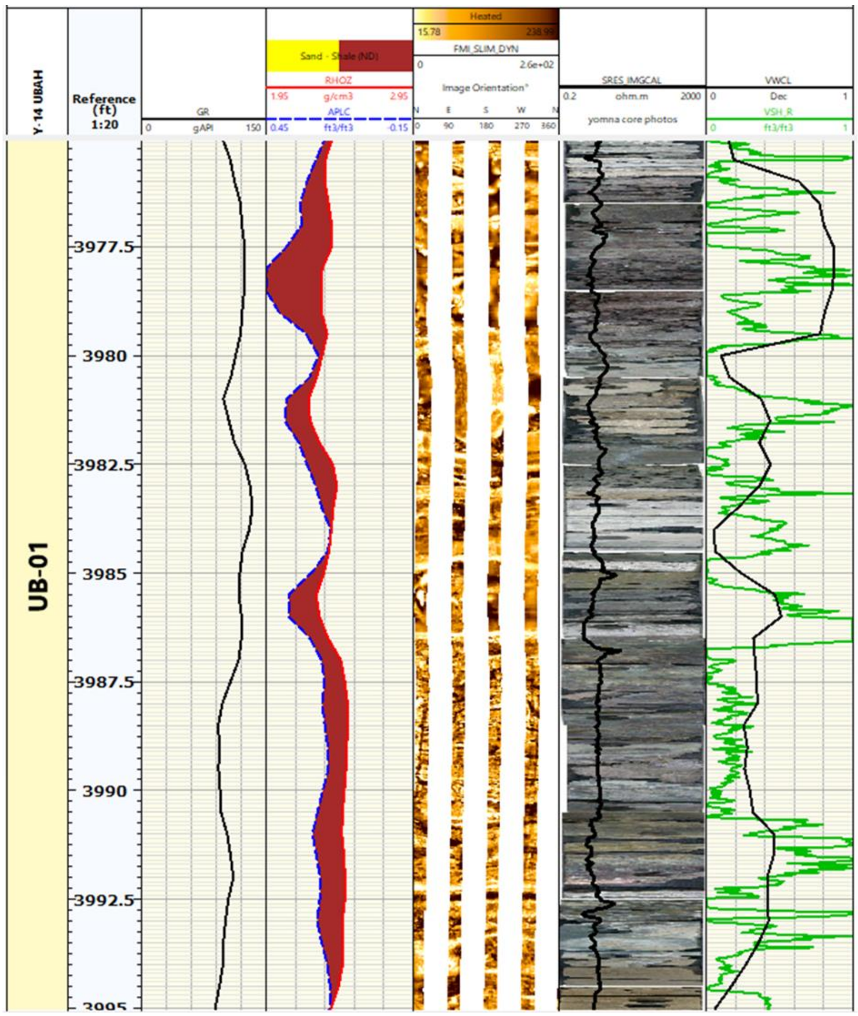

Fig.5: Comparison of the volumetric laminar shale concentrations estimated from the FMI measurements and core images. FMI measurements detected most of the lithofacies, which were observed on the core photographs. Track 1: depth. Track 2: Density, neutron and PEF curves. Track 3: FMI image. Track 4: core photographs and FMI resistivity curve. Track 5: volumetric shale concentrations estimated from density logs, neutron logs (VWCL) and FMS measurements (VSH_R).

3.2. Volumetric Laminar Shale Concentration from Thomas-Stieber's Method.

Total shale concentration, Vsh, and total porosity, Φt , are input data to the Thomas Stieber model (T-S). This method is used to estimate the volumetric laminar shale concentration, Vsh-lam, volumetric dispersed shale concentration, Vsh-disp, and sand porosity, Φsd. In the present study, the T-S model was restricted to the laminar and dispersed shale concentrations, due to absence of structural shale. The primary assumption in the T-S model is that the porosity end points, maximum sand porosity, Φsd-max, and shale porosity, Φsh , remain constant across the analyzed depth section of the reservoir. However, when the formation has been reworked by diagenesis, porosity end points vary with depth. The equation used to estimate the volumetric laminar shale concentration with the T-S model is given by the following equation:-

$$\boldsymbol{Vsh - lam} = \frac{\emptyset t - \emptyset sdmax + Vsh\,(1 - \emptyset sh\,)}{(\,1 - \emptyset sdmax)}$$

Where: Vsh-lam is the volumetric laminar shale concentration,

Φt is the total porosity,

Φsd-max is the maximum sand porosity,

Vsh is the total volumetric shale concentration, and Φsh is the shale porosity

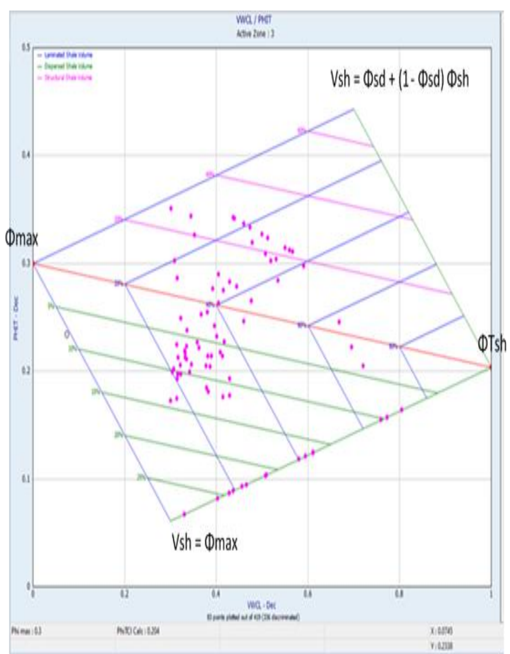

Fig. 6: Yomna- 14 Well Thomas-Stieber Xplot porosity versus shale volume, after Juhasz, 1986.

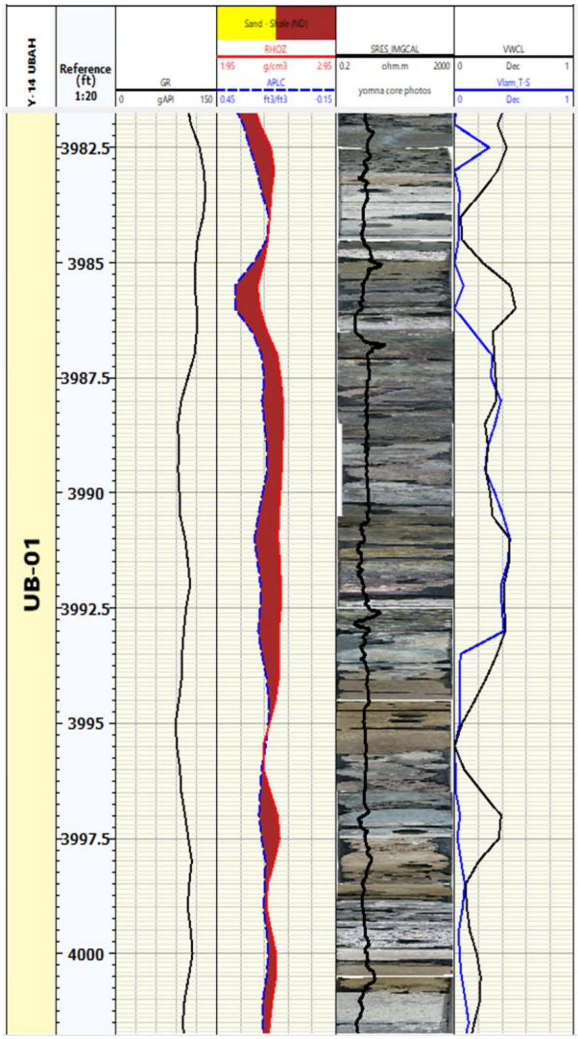

Fig.7: Comparison of volumetric laminar shale concentration estimated with different methods. Track 1: depth. Track 2: Gamma-ray. Track 3: Density, neutron and PEF curves. Track 4: core photographs and FMI resistivity curve. Track 5: volumetric laminar shale concentrations from Thomas-Stieber's (Vlam_T-S) method and shale concentrations estimated with density, neutron logs (VWCL).

Three clay distribution patterns are evident in the Bahariya Formation: dispersed clays, laminated clays/shales and structural clays (Figure 6). Dispersed clays are found between the sand grains. They fill pore spaces, coat or line pores. Thinly bedded and laminated days/shales are present throughout the cored intervals. They make up 12% to 54% and average 32% of the LR/LC intervals. The laminated method for shaly sand interpretation, through Thomas-Stieber (1975) model, is applied, to quantify the volume of laminated, dispersed and structural clay volumes. Comparing the result of laminated shale volume using Thomas – Stieber and shale volume using the conventional tools (GR, neutron and density), we can clarify that, the volume of shale using, Thomas – Stieber is lower than the volume of shale using the conventional tools.

4. Result and Discussion

The evaluated reservoir is an illustrative example of how the properties of rocks depend on the scale of its interpretation.Although the qualitative interpretation of heterolith reservoirs enables to identify the most perspective intervals, the quantitative interpretation is a challenge, especially when the beds are very thin and the correlation between high resolution microresistivity measurements and conventional logs is poor. The paper presents two different techniques for evaluating the thin beds. The first, a very detailed one, is based on high resolution microresitivity data processing and calibration. The second one - uses Thomas – Stieber method - to estimate the laminated shale volume. Both methods have advantages and limitations, and both should be performed simultaneously with the qualitative analysis, that are essential to specify oil saturated intervals. The evaluated models of the petrophysical properties of heterolithic reservoir allowed to re-define the pay zone intervals and to calculate the Net/Gross values. Table (1) presents the average values of porosity and water saturation in the defined pay zones.

Table 1: - Pay zones defined from the two evaluated

Flag name	Gross	Net	Average PHIE	Average SW
Formation Micro Imager interpretation				
PAY	263	170	21	54 %
Thomas – Stieber interpretation				
PAY	240	150	20	60 %
Conventional interpretation				
PAY	192	126	18 %	66 %

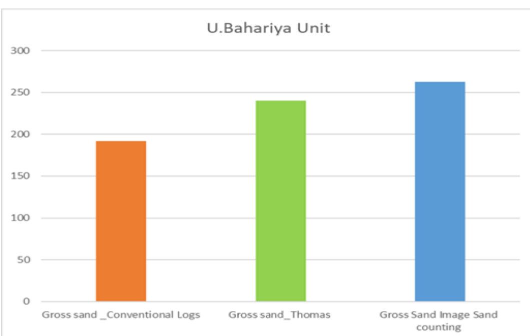

Fig. 8: Incremental Gross sand thickness for the upper Bahariya unit in Yomna-14 Well

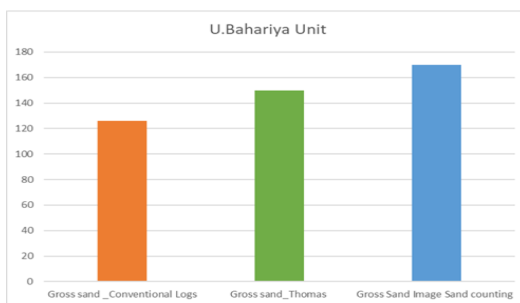

Fig. 9: Incremental Net pay thickness for upper Bahariya unit in Yomna-14 Well.

5. Conclusion

The first method (formation micro imager) showed a detailed interpretation of the thin beds in the Bahariya reservoir and estimating the laminated shale volume, which is based on high resolution variable of the formation resistivity micro imager. Meanwhile, the second method uses information from Thomas – Stieber method for estimating the volume of laminated shales through conventional well logs , but the model has a lower resolution. The conventional logging tool is not able to resolve the very thin laminas while the high resolution micro resistivity data are very sensitive and able to detect more details and lithology changes within the formation. The comparison between the two methods shows better compatibility within the thicker layers and worse when the beds are very thin. They allowed us to define the pay zones and to delineate the bed boundaries across the upper Bahariya reservoir. The volume of shale is very critical parameter for the net pay calculations. The Porosity, Hydrocarbon saturation and Net-pay thickness for the Bahariya reservoir has been increased with upgrading percent, based on the laminated and thin beds interval for each rock unit, through which the porosity increased by 10 percent, hydrocarbon saturation increased by 35 percent and the net-pay increased by 34 percent.

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