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# Improving Petrophysical Interpretation of Conventional Log by Determination of Real Bed Boundaries

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## Abstract

Proper determination of bed boundaries in layered reservoirs is vital for accurate petrophysical interpretation of conventional logs. In the wellbore, logs continuously measure physical properties of reservoir while the properties change stepwise. This continuous representation of logs may lead to ignorance of some high potential reservoir zones. The main reasons for continuous nature of logs in laminated reservoirs are the influence of shoulder beds on the reading of logging tools and low vertical resolution of these devices.In this paper we optimized a Laplacian filter to detect bed boundaries in conventional well logs. These blocking-based boundaries are validated with FMI derived bed boundaries. Then the calculated petrophysical properties including porosity and volume of minerals and fluids are distributed into the detected beds. Comparison of petrophysical interpretation of logs based on blocking and FMI derived bedding showed that the petrophysical properties realistically distributed into beds in layered reservoirs with the blocking technique. The results also showed that blocking reduces the uncertainties, because it realistically distribute the petrophysical properties inside real geological beds and alter the noises.

**Keywords:** Bed boundary, Blocking, Image Log, Carbonate reservoir.

## Introduction

A sedimentary bed is a thickness of rock marked by well-defined divisional planes (bedding planes) separating it from above and below layers. Beds can be differentiated via age, color, composition, particle size or fossil content. In oil and gas reservoir formations, bedding planes are determined by means of core, image log or wireline logs. Petrophysical evaluation of layered reservoirs, for instance carbonates, is sensitive to beds properties [1]. Combination of the effects of bed thickness and physical contrasts of beds with vertical resolution of logging devices leads to smooth continuous behavior of wireline logs. In thin layered reservoirs, the responses of wireline logs are completely different from the real status of the beds because the logging tools record the average of several thin layers. A real example of this kind of error is depicted in (Fig. 1). It presents a layered carbonate reservoir which the results of petrophysical interpretation of conventional

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logs was compared with image log. In a 1.5 m interval, highlighted by a box, the wireline logs shows a bed composed of 65% Anhydrite, 18% dolomite, 8% limestone and 5 % shale (Track-T2). In this status the layer is a non-reservoir. In contrary, the image log (FMI) of this interval shows four different uniform beds (Anhydrite, dolomite, limestone and shale) which separated by sharp bedding planes. It means that, in thin layered reservoirs, if we trust the conventional logs, it leads to serious error because the petrophysical properties of the beds, e.g. porosity, are the average of several thin beds which is completely different from the reality. This misinterpretation leads to uncertainty in determination of high potential reservoir zones, matching logs with core data, determination of RFT test locations and the locations of perforations.

A 1.5 m zone comprising of 4 separate anhydrite, dolomite, limestone and shale beds which misinterpreted in convensional petrophysical interpretation as a mixture of the 4 minerals (Fig. 1). In order to reduce the uncertainty of petrophysical interpretation in thin layered reservoirs, bed planes should be determined with high confidence. Then the outputs of petrophysical interpretation of wireline logs including porosity, saturation and lithology recalculated in the recognized beds.

Presence of thin layers with extreme properties in carbonates, make conventional approaches to fail in accurate determination of petrophysical properties. Response of logging tools in front of these thin beds are strongly affected by their shoulder beds. Therefore the recorded value is an average of all beds in the influence area of the tools [6]. The impact of shoulder beds is a function of the thickness, contrast in physical properties and vertical resolution of logging tools. Heidari et al. (2012) reported that for beds thinner than 2 ft, the determination error of porosity and composition is significant and it increases with decreasing the thickness of the beds [4].

Sudden changes in physical properties of thick beds are sharply reflected in the logs. In these cases the bed boundaries can be easily determined from the inflection

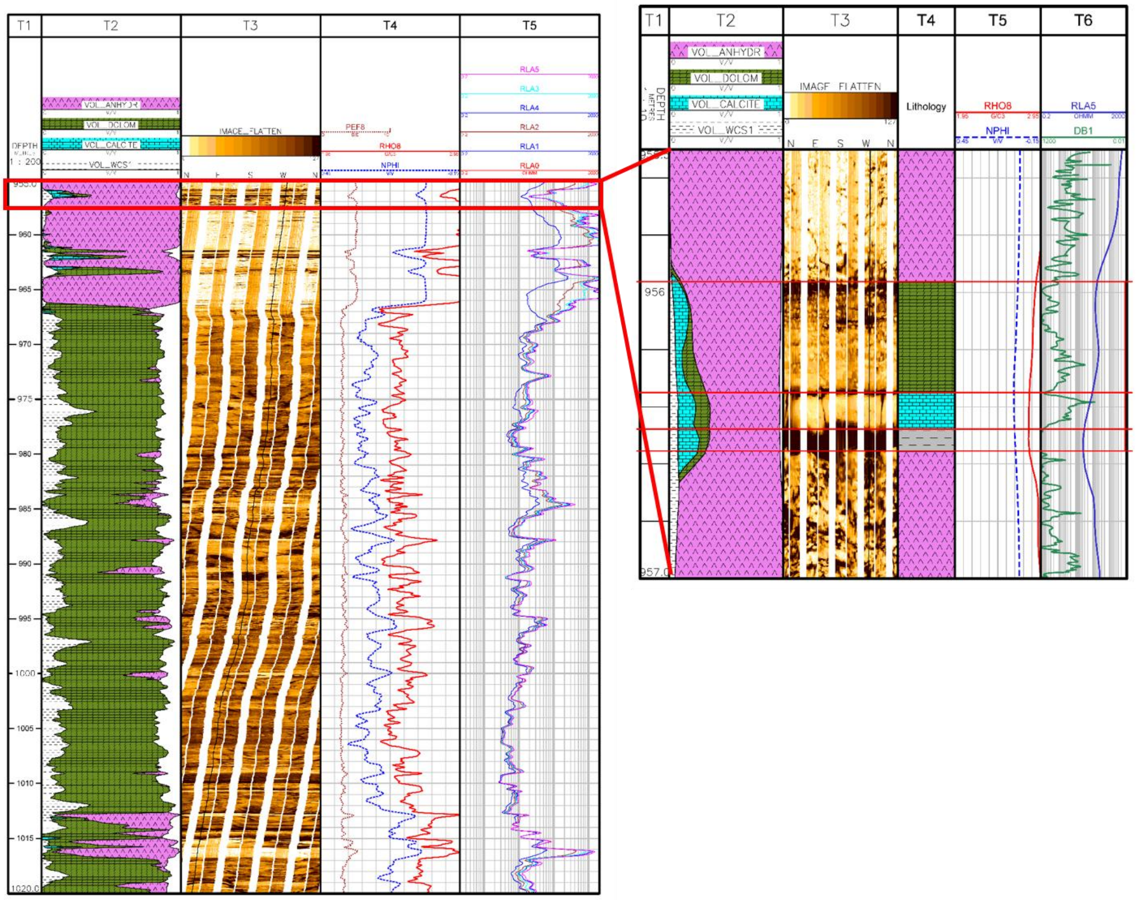


**Figure 1.** A 1.5 m zone comprising of 4 separate anhydrite, dolomite, limestone and shale beds which misinterpreted in convensional petrophysical interpretation as a mixture of the 4 minerals

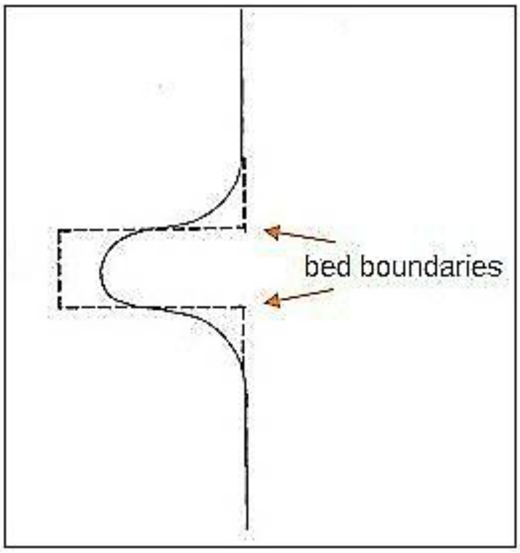


**Figure 2.** Schematic representation of log responses in layered formations (Kerzner and Frost, 1984)

points; but in thin layers, even sharp changes cannot be determined from logs responses. In thin layered reservoirs, first challenge in petrophysical interpretation is finding the proper location of bed boundaries. These beds should be corresponds to real geological beds with constant properties [9].

The main sources for determining bed boundary are core, image logs and wireline logs. Core and image logs are not frequent in most wells, so the only practical method is utilizing the logs to determine bed boundaries. The technique which determine bed boundaries is called blocking. Blocking convert a continuous log into a discrete which has a constant value in each bed and sharp change in the location of bedding planes (Fig. 2).

Kerzner and Frost (1984) introduced the concept of blocking for logs readings improvement [6]. Heydari et al. (2012) used an inversion method to simultaneously find the bed boundaries and calculate petrophysical properties in the beds in an iterative process [4]. Popielski et.al. (2012) determined the bed boundaries from the logs and core data via distinguishing the real sedimentary layers [11]. Blocking the logs improves the petrophysical evaluation via:

- Determination of real beds boundaries
- Correct the effects of shoulder beds
- Removing the noisy data by smoothing the logs.

The main objective of this paper is to optimize the blocking method to distinguish the real beds boundaries by comparing the beds boundaries with image logs; we also quantify the amount of improvements on the petrophysical properties.

## Materials and Methods

### *Blocking Methods*

Generally, the edge detection methods can be used for determination of bed boundaries in well logs. There are several blocking methods including Laplacian, Multiscale, Cluster and Kuwahara [12]. These methods try to determine boundaries via detecting edges and average the property in each block [3]. In the other word, the methods detect sharp changes in log as bed boundaries. In this study, we used the Laplacian filter to detect bed boundaries. The Laplacian of a function $f$ at a point $t$ is the rate at which the average value of $f$ over spheres centered at $t$, deviates from $f(t)$ as the radius of the sphere grows [8]. Laplacian is given by the sum of second partial derivatives of the function with respect to each independent variable.

$$\nabla^2 f = \left[\frac{\partial^2 f}{\partial x^2}\right]$$

The Norm of the Laplacian operator ($||\nabla f||$) controls the sharpness of the detected beds.

$$||\nabla f|| = \sqrt{(\frac{\partial^2 f}{\partial x^2})^2}$$

Blocking finds the abrupt changes (steps, jumps, shifts) in the mean level of a log. This essentially captures the rate of change in the log value gradient. Laplace filter renders a sharp boundary but gives several zeros corresponding to small variations, resulting in false edges. Thus, in the ideal continuous case, detection of zero-crossings in the second derivative captures local maxima in the gradient.

By considering a small "window" of the log, blocking look for evidence of a step occurring within the window. The window slides across the log, one depth step at a time. The evidence for a step is tested by statistical procedures. Alternatively, a nonlinear filter such as the median filter is applied to the signal. Such filters attempt to remove the noise whilst preserving the abrupt steps.

Once we have computed a measure of edge strength (typically the Laplacian magnitude), the next stage is to apply a threshold, to decide whether boundaries are present or not. The lower the threshold, the more boundaries will be detected, and the result will be increasingly susceptible to noise and detecting boundaries of irrelevant features in the log. Conversely a high threshold may miss subtle boundaries, or result in fragmented boundaries. If the boundaries thresholding is

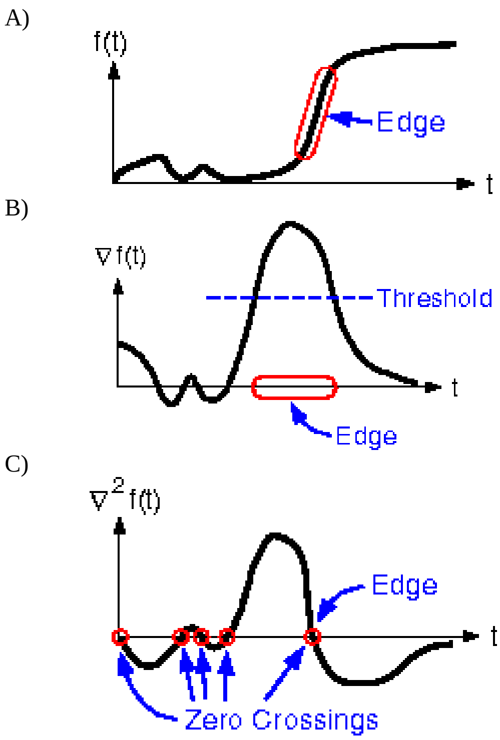


**Figure 3.** Sketch of bed boundary detection by means of Laplacian filter [1]

applied to just the gradient magnitude, the resulting boundaries will in general be thick. Some type of boundaries thinning post-processing is necessary in such cases [5].

Edge thinning is a technique used to remove the unwanted spurious points on the log boundaries. This technique is employed after the log has been filtered for noise (using median, Gaussian filter). The blocking operator detect the boundaries and then smooth it using an appropriate threshold value. This removes all the unwanted points.

Figure 3 shows how the Laplacian filter detect a boundary. First the derivative of the log was taken with respect to depth (t). In the derivative, the approximate location of the bed boundary was determined (Fig. 3-b). Then by taking the second derivative with respect to depth, the exact location of the boundary was determined (Fig. 3-c).

***Determination of bed boundaries using conventional logs***

Wireline logs' responses reflect the physical properties of beds and their fluids. These properties are mineralogical composition, pore structures and fluids types. Any change in these properties cause excursion in well logs. The amounts of changes in the log responses are depend on the physical contrast of the two adjacent beds. Actually there are some anomalies in the reading of logs which are: shoulder bed effect, thin beds and borehole environment.

The case study dataset comes from a laminated carbonate reservoir in South of Iran. The formation consists of dolomite, anhydrite and limestone.

First of all, in order to quantify the results of blocking, core porosity and the effective porosity derived from interpretation of well logs (PHIE) were blocked using the bed boundaries extracted from FMI. The core porosity blocked by FMI beds was used as

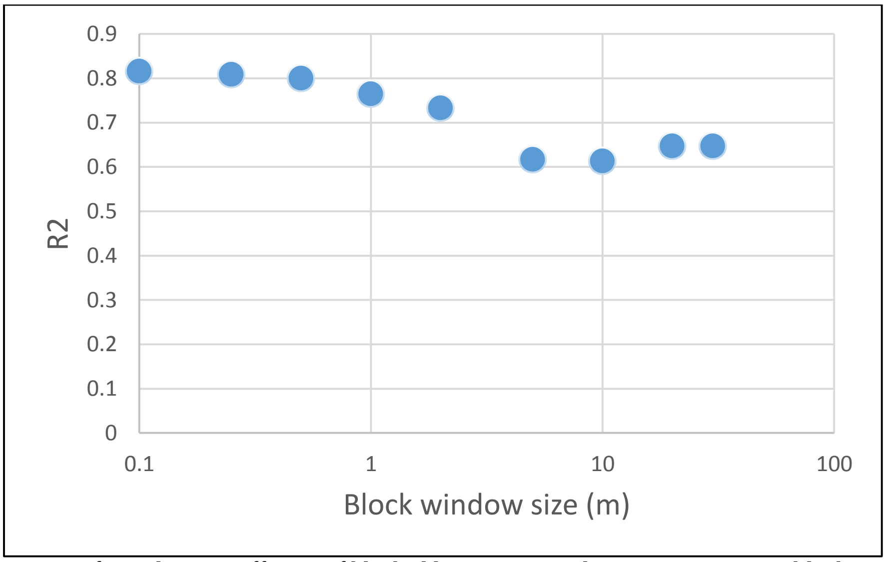


**Figure 4.** Variation of correlation coefficient of blocked log porosity and core porosity versus blocking window size

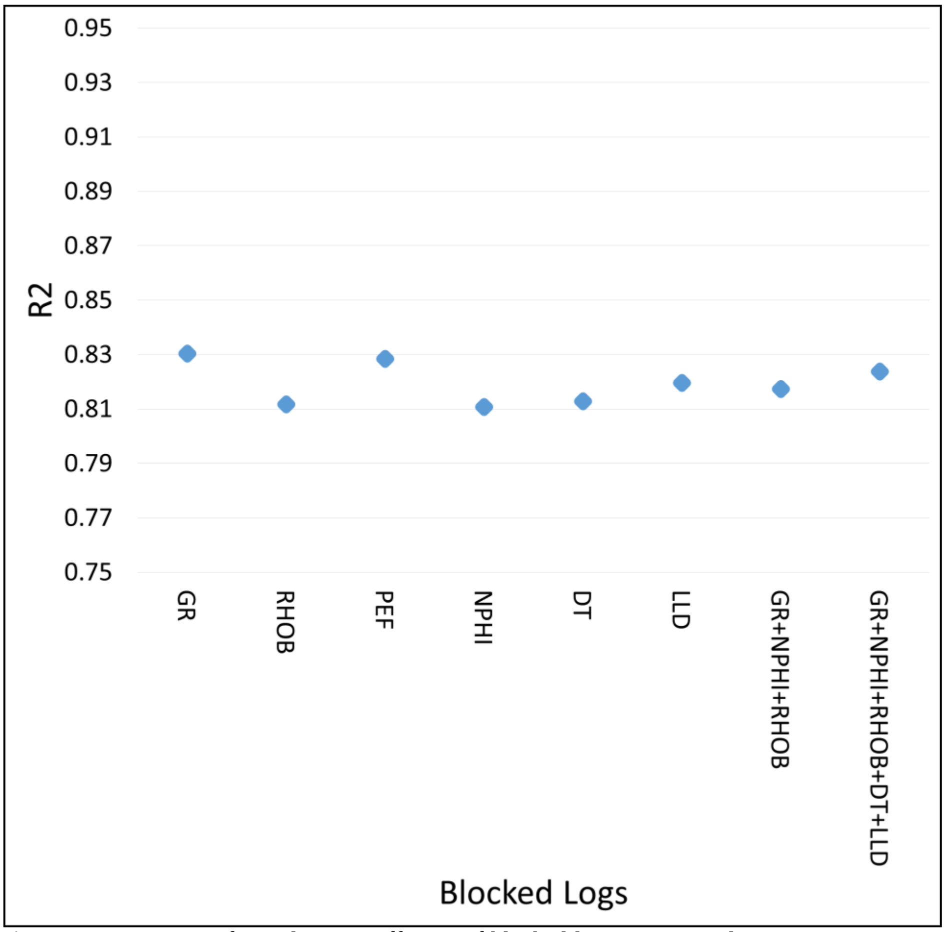


**Figure 5.** Variation of correlation coefficient of blocked log porosity and core porosity versus different log as input of the blocking algorithm

reference and the log blocked porosity was compared with it.

In order to apply the algorithm, a moving 0.1524 m window is applied to GR log. The window moves along the log and detect any deflection as a possible boundary and if the algorithm cannot see a boundary consider it as continuance of the above layer. The window size is important in this algorithm. Large window size ignore thin layers and sum up several thin layers. In contrary, a very small window detects very small variations which usually are considered as random noises. In order to determine the optimum size of window, the GR was blocked with different sizes of windows and then the log porosity was averaged in detected layers. The averaged log porosity were compared with core porosity which blocked by FMI derived boundaries. Figure 4 shows the variations in correlation coefficient versus the variations in window size. It indicate that the 0.1524 m window size has the highest correlation coefficient (0.8157).

In order to determine which log(s) is most suitable for blocking, different logs were feed into the Laplacian algorithm. Blocking has been done with different logs, then log porosity (PHIE) was averaged based on each of them. The averaged porosity was compared with blocked core porosity. Correlation coefficient of blocking of each log(s) is shown in Figure 5. In the cross plot, the Y axis is between 0.75 and 0.95. Obtained correlation coefficient change between 0.80 and 0.83. The highest value obtained when GR was blocked.

***Re-computing the petrophysical properties using detected boundaries***

Petrophysical properties of the reservoir rocks including porosity, fluid saturation and volume of minerals can be obtained by core analysis and/or Petrophysical interpretation of wireline logs. The main sources of errors in the core data are uncertainties in the depth and conducting laboratory measurement in the ambient condition. Errors for log data come from the low vertical resolution of logging device and averaging the properties of several consecutive beds.

Conventional petrophysical evaluation of layered reservoirs comprises of continuous calculation of the volume of minerals and fluids which smoothly change while in reality the volumes must be discrete. Consequently, after determination of the bed

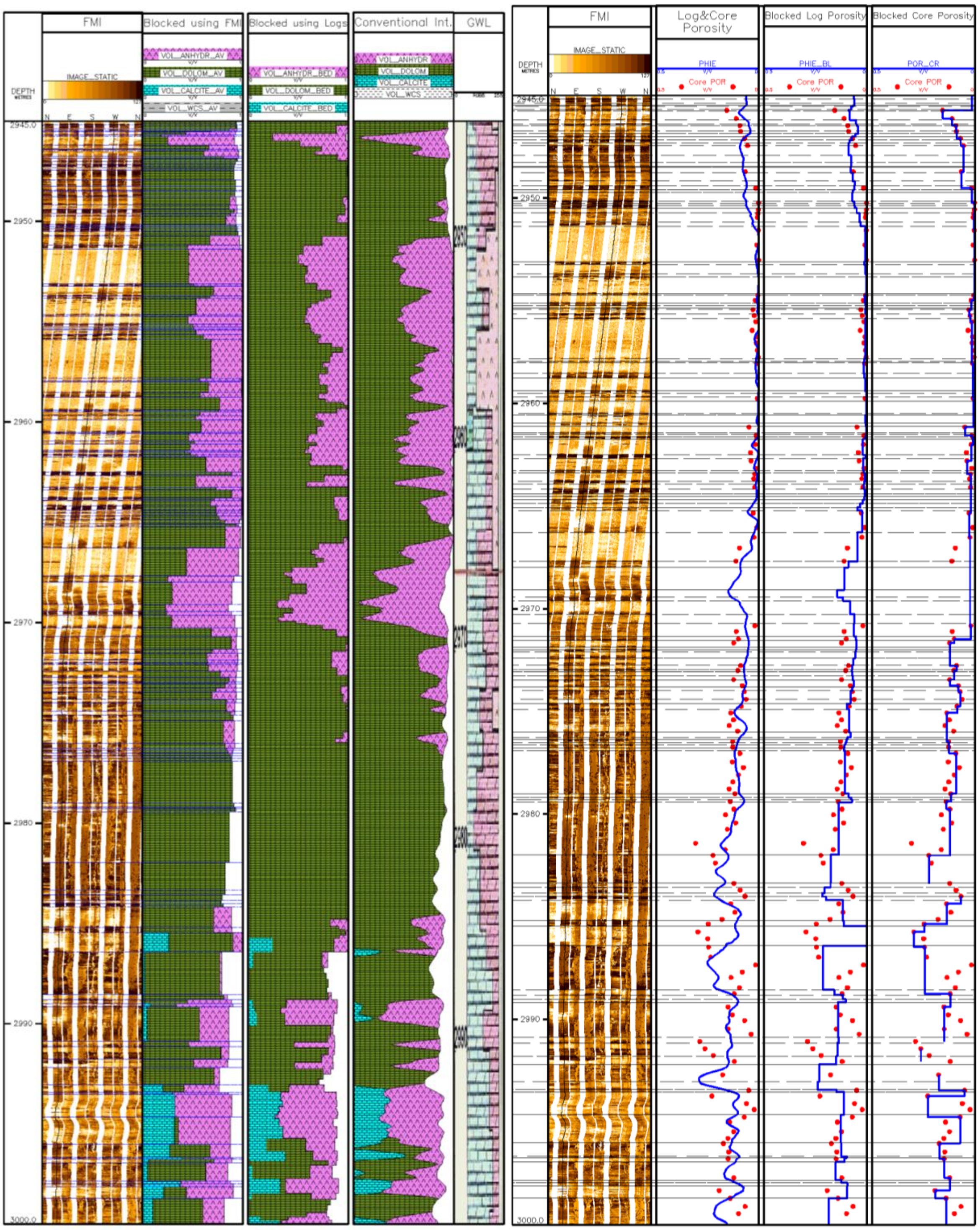


**Figure 6.** Blocked lithology (A) and porosity (B)

boundaries, the calculated volumes must be converted into the beds in a way that the petrophysical properties of the each layer remain constant.

Having obtained the optimum window size of the Laplacian filter and the best log as input of the blocking, the final bed boundaries were determined. The blocking was carried on by a Laplacian filter with 0.1524 m window size which applied on the GR to determine bed boundaries. Petrophysical properties of the formation which were calculated using a petrophysical routine were averaged inside each bed.

Figure 6 shows the blocked lithologies and porosity in the studied well. In (A) from left, the FMI with the trace of beds' boundaries, blocked lithology by FMI beds, blocked lithology by blocked GR's beds, lithologies from conventional interpretation and loithologies from cutting. In (B) from left, the FMI, core and log porosity, the blocked log porosity and the blocked core porosity are presented.

Conventional evaluation of petrophysical logs involves continuous calculation of the volume of minerals and fluids while in reality the volumes must be discrete, if the formation is layered. Consequently, after determination of the bed boundaries, the calculated volumes must be converted into the beds in a way that the petrophysical properties of the each layer remain constant. In Figure 6-B, porosity and the volumes are calculated based on the detected bed boundaries. Thus the continuous appearance of the logs changed to a discrete pattern.

## Results and Discussion

The aim of petrophysical interpretation is to accurately determine the petrophysical properties of the reservoir layers from the recorded wireline logs. The first generation of petrophysical evaluation methods was deterministic in which each log is used for calculating one property. For example in this approach shale volume is calculated only from the GR. Mayer and Sibbit (1980) introduced a new method for petrophysical interpretation which is based on an optimization technique [10]. In this method, all logs are used to calculate all unknowns (volumes). In this method, a set of equations is constructed and all equations are solved simultaneously.

Even though the optimization method reduces the uncertainties of log interpretation but the errors of shoulder bed is still remaining in layered formations. In order to reduce this effect, the information of bed boundaries should be added to the petrophysical interpretation routine.

Figure 1 is an excellent example of layered formation which misinterpreted in the conventional petrophysical interpretation. In this figure, 4 separate beds are existed in a 1 m interval which mis-interpreted as a mixture of 4 lithologies. Based on the conventional interpretation, there is no reservoir zone in this interval because porosity is less than 2% and volume of anhydrite is more than 65% while FMI shows that dolomite layer is completely separated from other layers and its porosity is more than 12%. Consequently this layer can be good candidate for perforation. In this case, blocking technique removed noise readings of the logs and

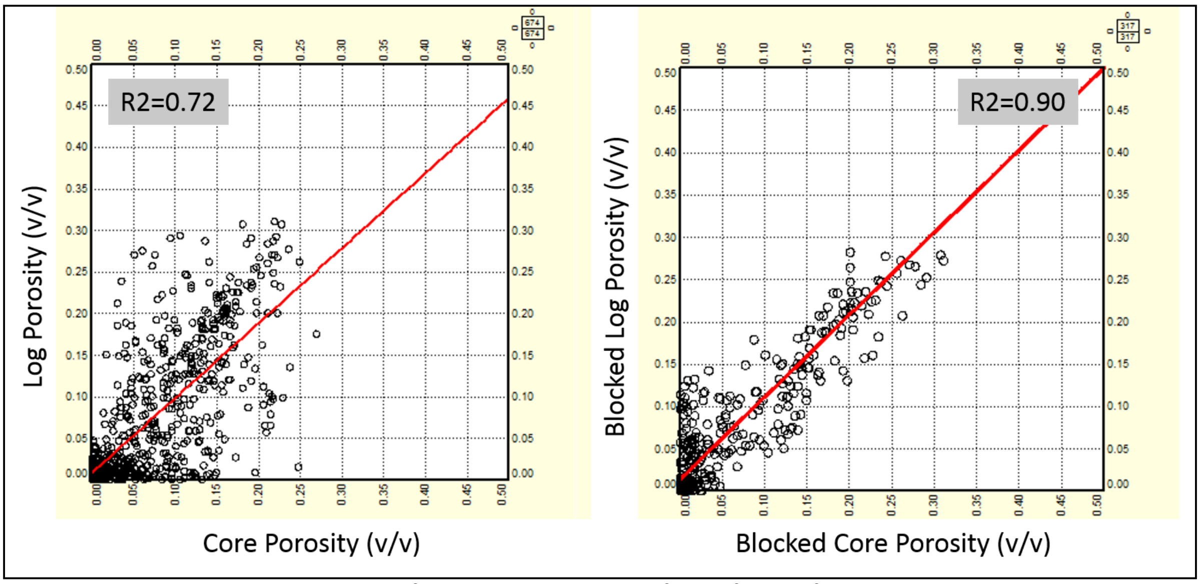


**Figure 7.** Cross plot of core and log porosity, before (left) and after (right) blocking

realistically distributed the calculated porosity among different beds.

In order to quantify the effect of blocking on the results of petrophysical interpretation of logs, cross plot of non-blocked and blocked log porosity versus core porosity created (Fig. 7**Error! Reference source not found.**). The cross plot on the left is core and log porosity without blocking and the cross plot on the right is the blocked core and log porosity based on the FMI bed boundaries. As it is evident, after blocking the porosity, the correlation coefficient increased from 0.72 to 0.90. FMI is a high resolution imager logs which shows all details of the formation like bed boundaries [7]. So that the bed boundaries extracted from the FMI shows the real geometry of the reservoir with high confidence.

It is worth mentioning that we should not expect blocking to convert a formation to pure layers completely. In some cases there are nodules of anhydrite inside dolomite or limestone layers which affects the responses of logs. For instance in Figure 6, 2985-87m, there are two dolomite layers which patches of anhydrite existed inside them. For cases like this, ignoring the volume of anhydrite increase the porosity of the layers unrealistically. So for this bed two lithologies is more appropriate. In addition, some beds may comprise of two or more lithologies. For example dolomitic limestone which is common in carbonate formations.

### *Conclusion*

Considering bed boundaries is very important for realistic interpretation of petrophysical logs and reducing the uncertainties associated with geometry of formation beds. Although not common in every well, image log is one of the accurate methods for determination of reservoir bed boundaries. In this study, we developed and successfully applied a blocking technique to indicate the bed boundaries and distribute the petrophysical properties within the identified beds. The results were successfully validated against FMI derived bed boundaries. The results show that blocking conventional logs, improve the lithology and porosity determination in a layered carbonate formation. It happened because blocking realistically distribute the petrophysical properties inside real geological beds and alter the noises.

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