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Well Log Analysis of Nahr Umr, Shuaiba and Zubair Formations in EB-4 well of East Baghdad Oil Field, Iraq, using Rock Physics Templates (RPTs)

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Abstract
RPT is a method used for classifying various lithologies and fluids from data of well logging or seismic inversion. Three Formations (Nahr Umr, Shuaiba, and Zubair Formations) were selected in the East Baghdad Oil field within well EB-4 to test the possibility of using this method. First, the interpretations of the well log and Density – Neutron cross plot were used for lithology identification, which showed that Nahr Umr and Zubair formations consist mainly of sandstone and shale, while the Shuaiba Formation consists of carbonate (dolomite and limestone). The study was also able to distinguish between the locations of hydrocarbon reservoirs using RPT. Finally, a polynomial equation was generated from the cross plot domain (AI versus Vp/Vs) to estimate one parameter from the other in these formations, and vice versa.

Keywords: RPTs, Well logging, RHOB-NPHI, East Baghdad, Iraq

تحليل سجلات الآبار لتكاوين نهر عمر والشعيبة والزبير من البئر EB-4 في حقل نفط شرق بغداد باستخدام خصائص فيزياء الصخور (RPTs)

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الخلاصة
RPTهي طريقة تستخدم لتصنيف وتمييز الصخارية المختلفة والسوائل من بيانات الابار أو بيانات الانعكاس الزلزالي. تم اختيار ثلاث تكاوين (نهر عمر والشعيبة والزبير) في حقل نفط شرق بغداد ضمن البئر EB-4 لاختبار إمكانية استخدام هذه الطريقة. بدايةً تم استخدام تفسيرات سجل البئر و (Density – Neutron cross plot) للتعرف على الصخارية ، والتي أظهرت أن تكويني نهر عمر والزبير يتكونان أساسًا من الحجر الرملي sandstone والطفل shale ، في حين يتكون تكوين الشعيبة من الكربونيت carbonate (الدولومايت والحجر الجيري). تمكنت الدراسة أيضًا من التمييز بين موقع الخزانات الهيدروكربونية باستخدام RPT، وأخيراً ، تم إنشاء معادلة متعددة الحدود لتكون بمثابة وسيلة لتقدير Vp/Vs من AI لهذه التكاوين، والعكس بالعكس.

Introduction

The determination of differences of lithology and reservoir fluid as well as the elastic properties of rocks in the absence of some logs is a major challenge. To solve this challenge, Rock Physics Templates (RPTs) or models can be used. RPTs are a commonly used technique to screen or classify data of well logging, as well as seismic inversion data, for hydrocarbon and lithology probabilities during exploration [1], which was introduced earlier [2]. These templates include models of several

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lithologies and expected fluid along with porosity trends in the field of interest (Figure- 1). They explain different geologic trends, including compaction and depositional ones [3, 4, 5]. There are various forms of RPTs, but the most common is that between the acoustic impedance (AI) (x-axis) and Vp/Vs (y-axis), where the combination of these two elastic parameters is a good lithology and fluid indicator [6]. Other forms of RPT involve combining AI and shear impedance (SI), elastic impedance (EI), and others [7, 8].

Fluids-saturated sands have very high Vp/Vs ratio during the deposition, due to the very low shear modulus (μ) at low pressure. But, the Vp/Vs decreases as pressure and burial increase. On the other hand, AI increases if the grains are cemented , where the Vp and ρ both increase. The effects of mineralogy in RPT are very important because clays have higher Vp/Vs than quartz. In other words, increased clay content will lead to an increase in the Vp/Vs ratio. Concerning acoustic impedance, increasing clay content will have a different influence on it depending on whether the clay particles are pore filling or laminating. AI increases when the particles of clay are pore filling, and it decreases when the particles of clay are laminate. Finally, the Vp/Vs ratio and AI both decrease with increasing hydrocarbon (oil and gas) saturation. Thus, the lower-left angle of the RPTs is often mentioned as the hydrocarbon corner [9].

Nahr Umr Formation in southern Iraq was described to have Nahr Umr well (number-2) with a thickness of 200 m [10]. It consists of sandstones (medium to fine-grained) and black shales. A carbonate member may be present at the top of this well [11-14]. In the well EB-4, the thickness is 100.5 m (Figure- 5). This formation was subdivided into three lithostratigraphic units of variable thicknesses [15], on the basis of lithological variations and logs available form seven wells selected in central Iraq, including well EB-4. These units consist of sandstone interlaminated with siltstone and shale, with the occurrence of thin limestone beds and quartz arenites as the main constituent of the sandstone. According to well logs interpretation using the 2D indexed and probabilized self-organizing map (IPSOM) technique in Techlog software, an earlier work [16] divided this formation into three zones, also in Luhais Oil Field, Southern Iraq, and interpreted the lithology to be generally composed as sandstone interlaminated with siltstone and shale. As for the deposition environment, it was described as is a mixed environment (delta, river, and shallow marine)[17,18]. While other studies [12,15] interpreted the environments of deposition to indicate a shallow marine and fluvial-deltaic environments. The Shuaiba Formation consists entirely of dolomitic limestones [19]. Alwan [20] indicated that it consists of chalky limestone followed by porous limestone that contains bitumen at the top and at the bottom of the formation, which converts into chalky limestone and then into clay-limestone. This description was also mentioned in another publication [21]). Its thickness is 109.5 m in well EB-4 (Figure- 5). The Zubair Formation is considered as one of the most important oil and gas reservoirs in the lower Cretaceous formation in southern Iraq. In general, the Zubair Formation is divided into five lithological units [22, 23]. It consists of alternating coarse- to fine-grained sandstones, siltstones and dark-grey shales, with some beds of carbonates [13, 19]. This was also indicated by other articles [24- 26]. Its thickness in the well EB-4 is 429.5 (Figure- 5). As for the deposition environment, it consists of fluvio-deltaic, deltaic and marine environments [25].

Location and Geological Setting

The East Baghdad oil field is located at the eastern side of Baghdad city, central Iraq (Figure- 2). This oil field was discovered by the Iraq National Oil Company (INOC) using a 2D seismic survey for the period 1974-1975. This oil field was found to have a large anticline structure with many longitudinal and transversal faults. Khasib Formation represents the main reservoir in this oil field and consists of heavy to light oil [27]. Light oil in the Zubair Formation was discovered in the year 1979 [28]. Tectonically, this oil field belongs at the near platform flank of the Mesopotamian foredeep [29, 30]. This oil field contains many reservoirs Formation, which are, from the younger to the older age, Hartha (Upper Cretaceous), Tanuma (Upper Cretaceous), Khasib (Upper Cretaceous), Rumaila (Middle Cretaceous), Nahr Umr (Middle Cretaceous) and Zubair (Lower Cretaceous) Formations. This study discusses three Formations in this well; Nahr Umr, Shuaiba, and Zubair Formations, as in Figure- 3.

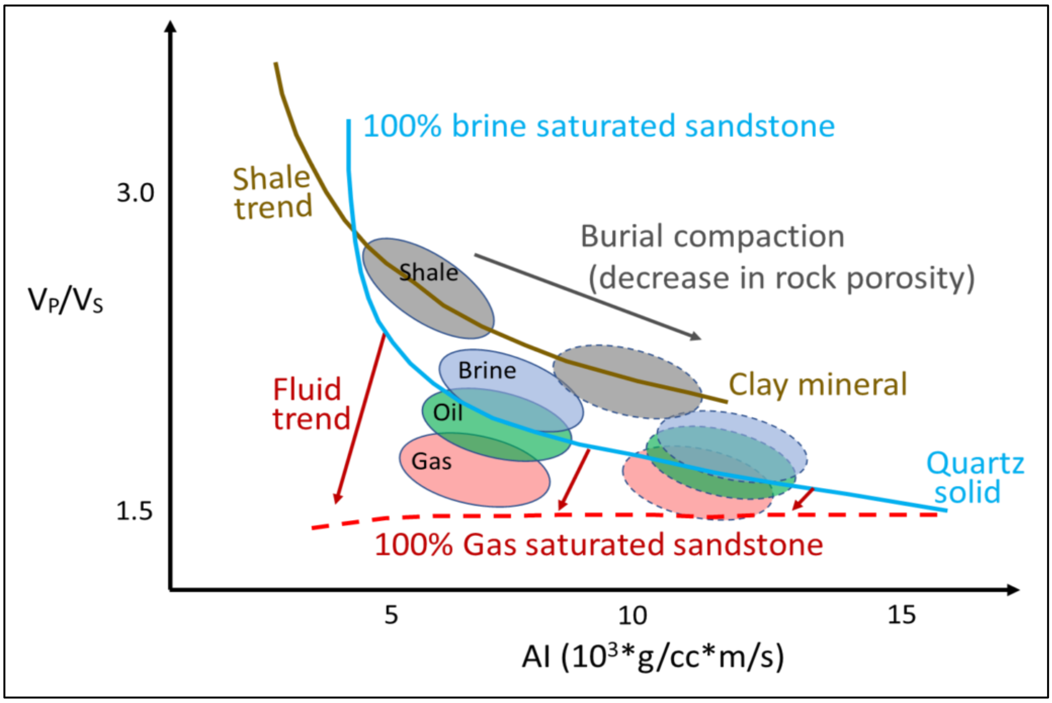

Figure 1-The RPT notion. The arrows indicate different geologic trends (shale trend, fluid trend, porosity, and compaction trend) [9].

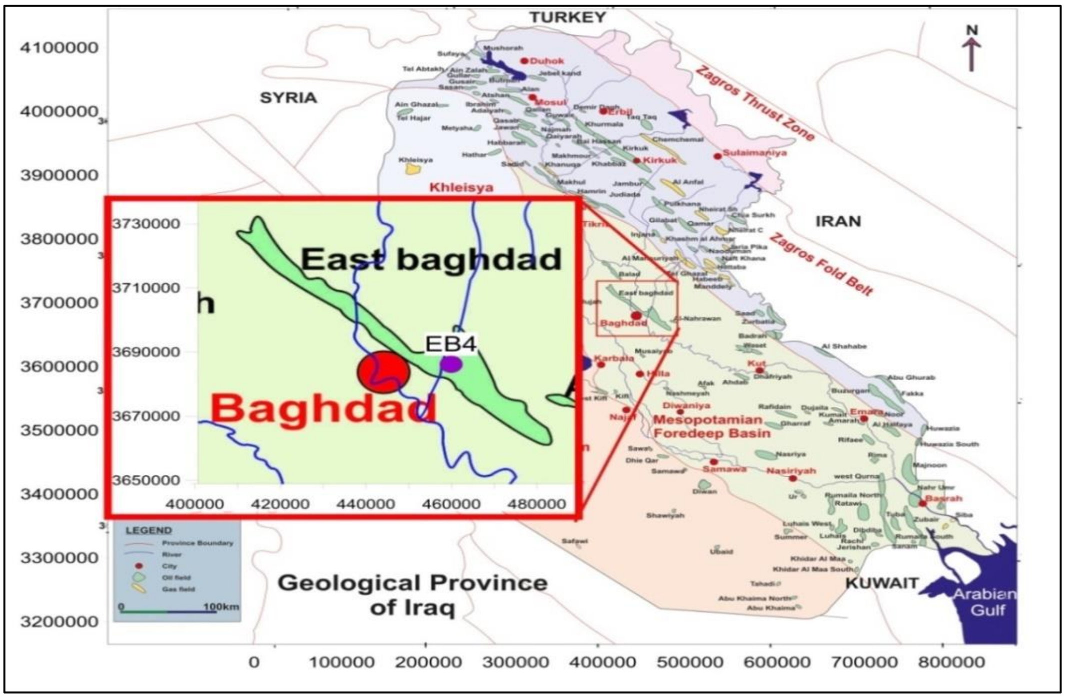

Figure 2- A map of the locations of oil and gas fields in Iraq showing the well EB-4. Coordinates of study area boundaries (WGS-84 UTM Zone- 38) modified after [16].

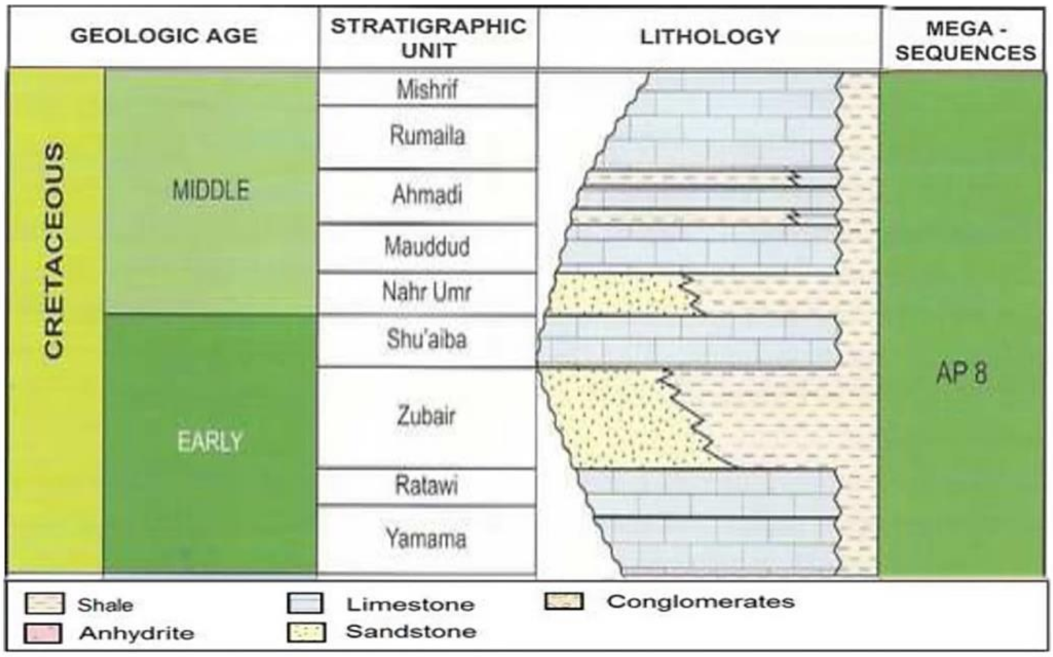

Figure 3- Stratigraphy column in East Baghdad Oil Field of the Cretaceous period in Iraq [19].

Methodology

The suite of logs DT, GR, RHOB, and NPHI at well EB-4 was discussed. The procedure followed in the analysis of the well log is divided into two major stages (Figure- 4a). Petrel software (V.2016.3) was used to interpret the data in the first stage, depending on the variation in the relations between the considered logs which are summarized in (Table-1) and (Figure- 4b). The results obtained from the interpretation of well logs by petrel software and the table are shown in Figure- 5.

The second stage includes the determination of Shear-wave (Vs) after converting the P-sonic (µsec/ft) to P-wave (m/s) using the relationship ($Vp = \frac{0.3048}{DT} * 10^6$). The empirical equation which was previously described [31] is used widely for obtaining the Vs from Vp value for sandstone rock; the following relation is used: Vs=0.8043Vp−0.8561, while for the shale rocks, the relation used is Vs=0.7724Vp−0.8668 [31].

Using Vp, Vs, and density (ρ) values, many elastic parameters can be determined, such as Acoustic Impedance, Shear Impedance, Vp/Vs ratio, Young's Modulus, and others. In the next step, these elastic parameters were cross-plotted to predict the lithologies and hydrocarbon zones.

Table 1- General log responses to various rocks

Lithology	Gamma-Ray (GR)	Density (RHOB)	Neutron (NPHI)	Sonic (DT)
Shale (SH)	Hi	Low	V.Hi	Hi
Silt (SLT)	Mod	Low	Hi	Mod
Sandstone (SST)	Low	Mod	Low-Mod	Low
Limestone (LST)	Low	Hi	Low	V. Low
Dolomite (DOL)	Low	Hi	Low	V. Low
Anhydrite (ANH)	V. Low	V.Hi	V. Low	V. Low

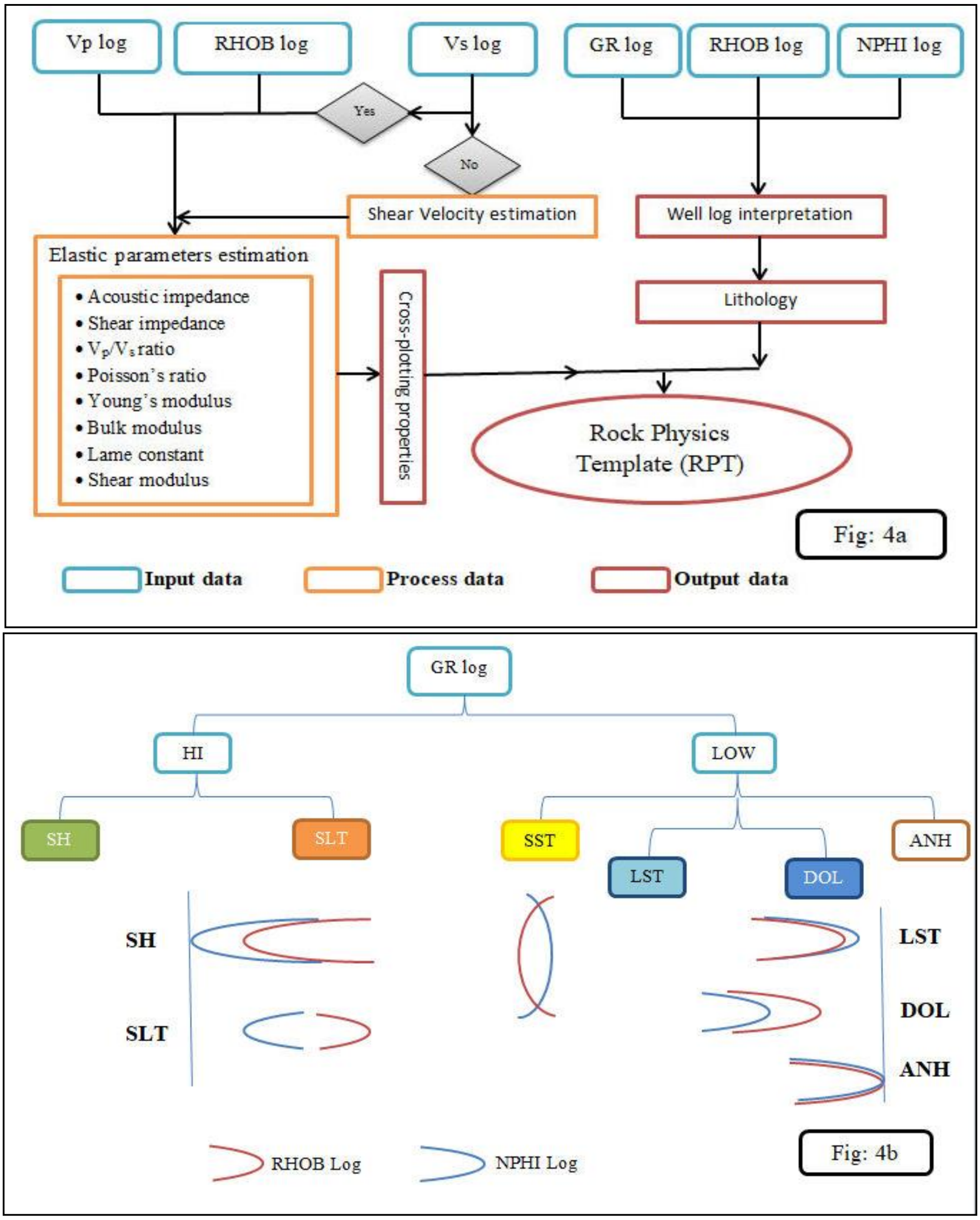

Figure 4- a- The main project workflow, b- the shape of logs response for each rock

Results and Discussion

1-Well log Interpretation

Three logs (GR, RHOB, and NPHI) were combined to determine the lithology at particular depth intervals.

Gamma-ray (GR) log measures the natural radiation released by the rocks and is used to find out the type of lithology [32]. Accordingly, the response of GR log increases because of the increased concentration of radioactive material (U, Th, and K) in shale. Clean sandstones and carbonates normally have low radioactive materials and thus represent low GR readings. Density (RHOB) log measures the bulk density (solid matrix and fluids) of a formation and is also used to determine the porosity, while the Neutron (NPHI) log is used to directly determine formation porosity. When these three logs are used together, lithologies can be determined [33].

In the present study, the curve of the gamma log shows low to moderate values in the upper part of the Nahr Umr Formation. In contrast, the values increase in the lower part of the formation (Figure- 5).

Compared to other logs (RHOB and NPHI), there is a sequence of sand and silt at the top and shale at the bottom of the Formation.

The study showed that the carbonate content predominates the Shuaiba Formation due to a decrease in the reading of GR and NPHI logs, and an increase in the RHOB logs reading. As the results also indicate the emergence of some anhydrite points in this formation. As for the Zubair Formation, it consists of a continuous sequence of sand, silt, and shale. It is also worthy to note that both Nahr Umr Formation and Zubair Formation consist of sandstone and shale. However, the gamma-ray (GR) values are higher in Zubair Formation than Nahr Umr Formation, whereas the density (RHOB) values are higher in Nahr Umr Formation, meaning that they are opposite in properties despite the similarity in the lithology. RHOB-NPHI cross plot might explain this difference.

2- Neutron-density cross plotting

The neutron (x-axis)–density (y-axis) cross plot is the main and most important method for determining lithology [34]. Figure- 6 illustrates in detail the lithology and averaged porosity for Nahr Umr Formation in the 2D domain. Cross plotting shows that the data are highly concentrated on the sandstone window with some shale and siltstone. It is observed that some data reach the limestone window, which might be an indicator that there is a calcite supplier somewhere in the Nahr Umr Formation. A few isolated points (with low density and moderately porosity) in this formation refer to a hydrocarbon indicator. In Shuaiba Formation, similar to the previous interpretation, the cross-plot in Figure- 7 shows that the dominant lithology is dolomite and limestone with few points of sandstone, originating from the bottom of the Shuaiba Formation that interference with Zubair Formation, as in Figure- 5. Figure- 8 of Zubair Formation shows that most plotting points distribute on the sandstone window and zone of shale and siltstone, with few points falling on the limestone window. Many of the isolated points in this formation indicate high hydrocarbon content.

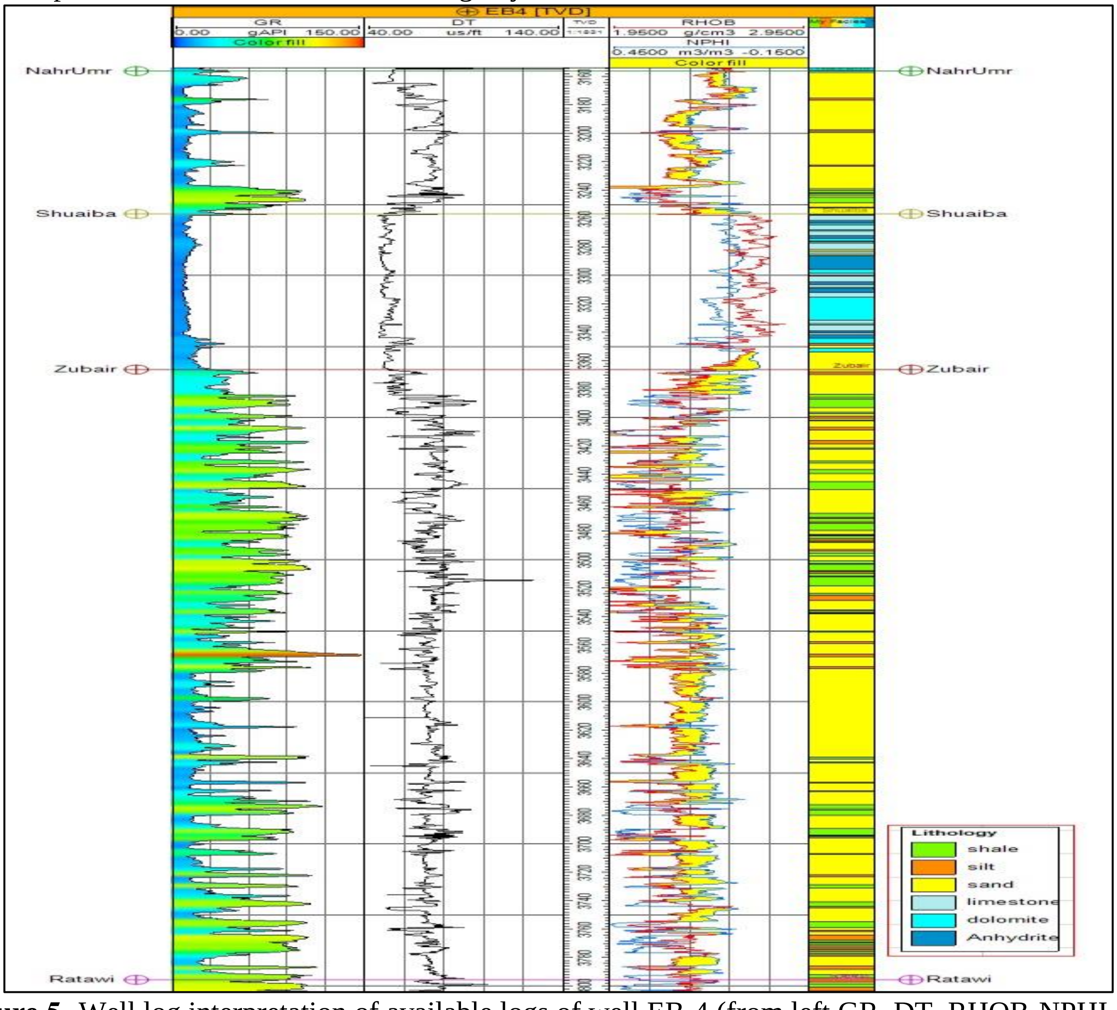

Figure 5- Well log interpretation of available logs of well EB-4 (from left GR, DT, RHOB-NPHI, and Lithology).

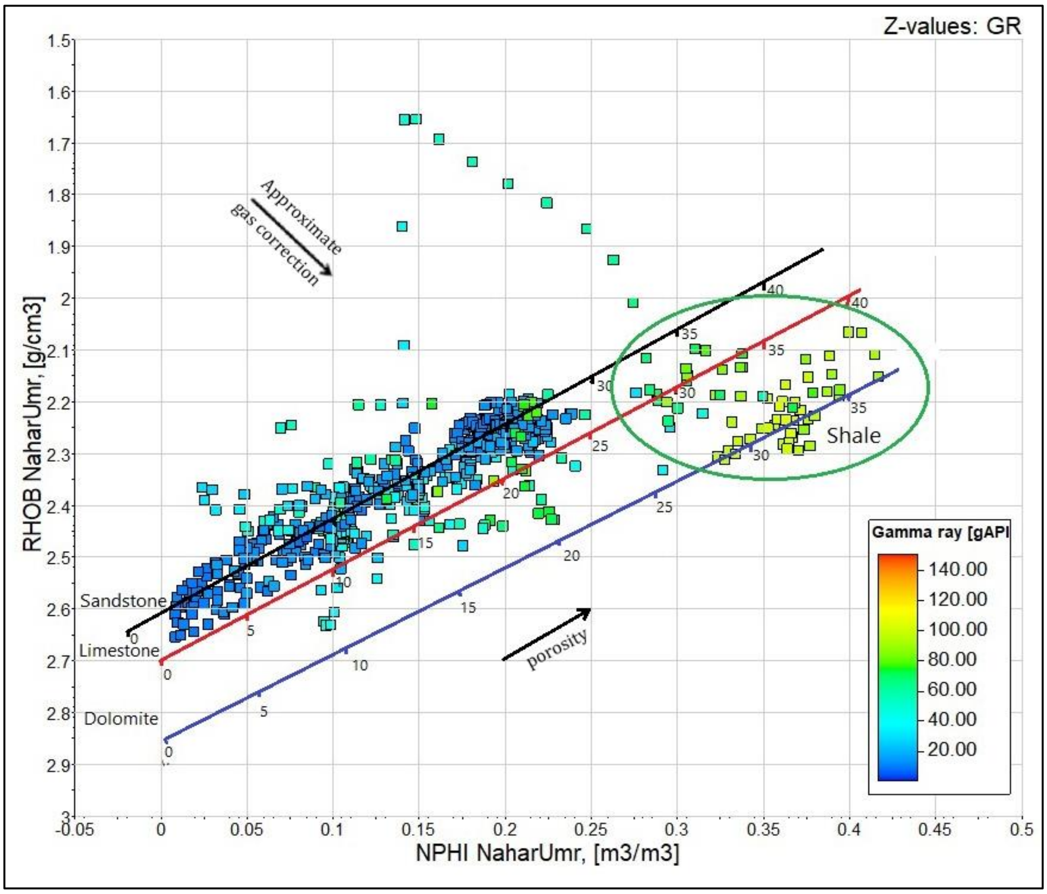

Figure 6- A cross plot of NPHI and RHOB of well EB-4 in Nahr Umr Formation.

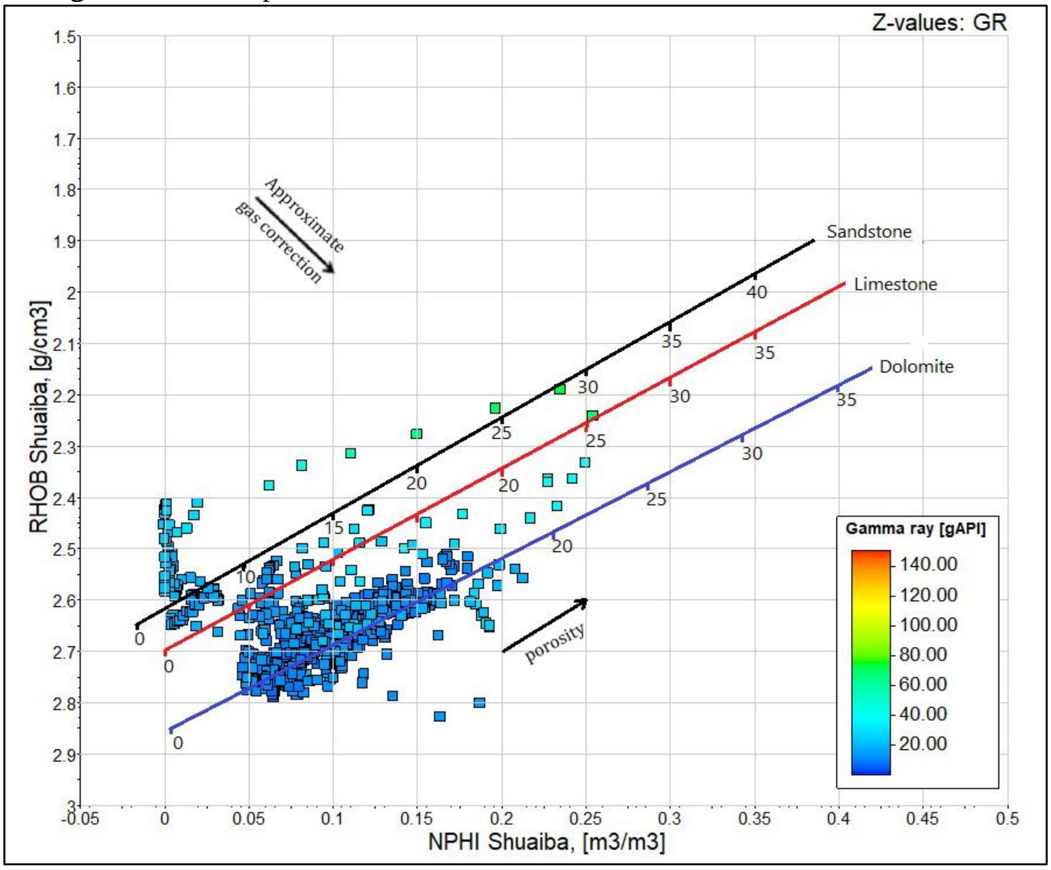

Figure 7- A cross plot of NPHI and RHOB of well EB-4 in Shuaiba Formation.

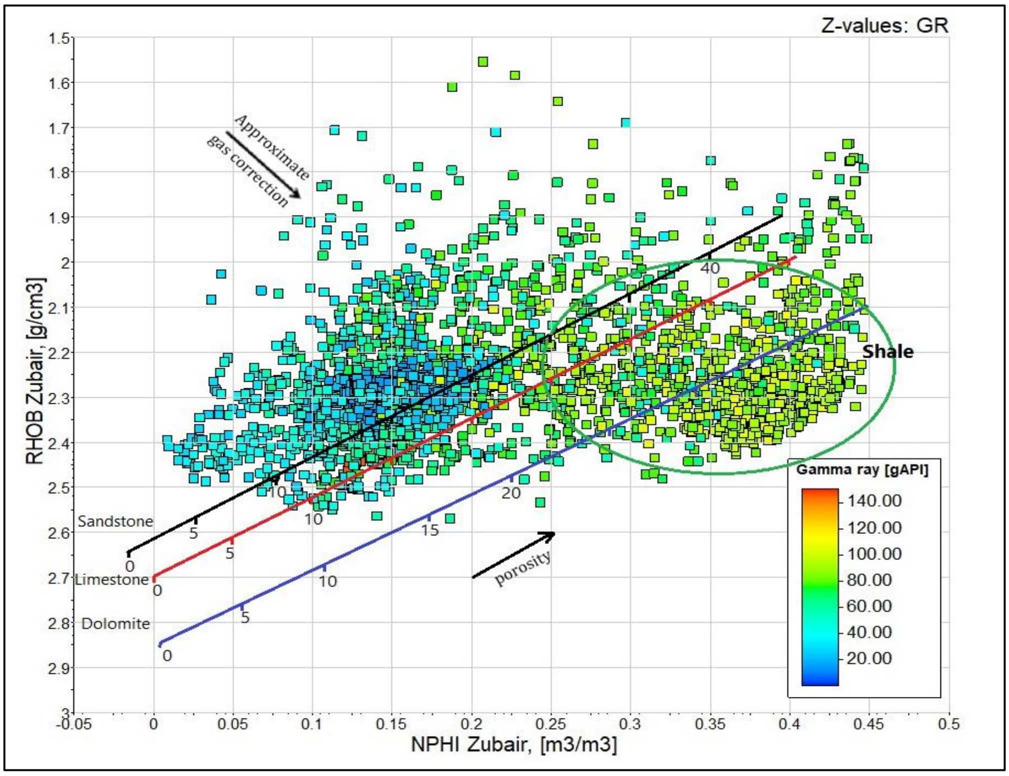

Figure 8- A cross plot of NPHI and RHOB of well EB-4 in Zubair Formation.

3- RPTs analysis

The proposed three formations were analysed to further differentiate and separate between fluid and lithology using RPT that provides a relationship between rock properties, such as porosity and fluids saturation, to the elastic properties that drive the seismic response, such as Vp, Vs, and density. Thus, the analysis of rock physics enables the estimation of rock properties that were previously only available by drilling from remotely sensed data. The cross plots between two or more of elastic parameters (e.g., AI and Vp/Vs) are used to discover or identify anomalies or scattered points which could be interpreted as hydrocarbon bearings or indicators [35]. Figures- 9, 10, and 11 show Vp/Vs versus AI cross-plots of Nahr Umr, Shuaiba, and Zubair Formations, respectively. The data points were color-coded using GR log. The logs (below) were color-coded based on the four groups defined in the cross-plot domain to identify the shale, oil sand, and brine sand and distinguish them on reservoir positions. The selected depth intervals from 3156 to 3256.5 m (measured depth, TVD, from Kelly bushing, KB) for Nahr Umr Formation are shown in Figure-9. To further describe the lithology, two depth intervals were identified, namely 3156–3237m and 3237–3256.5 m. The lithology description for these intervals is given in Table- 2.

The selected depth intervals for from 3256.5 to 3366 m (measured depth, TVD, from Kelly bushing, KB) for Shuaiba Formation are shown in Figure-10. The RPT analysis showed that the Shuaiba Formation has the highest acoustic impedance values and low values of Vp/Vs, which explains the carbonates-lithological nature of this formation. As for the Zubair Formation, the selected depth intervals from 3366 to 3795.5 m (measured depth, TVD, from Kelly bushing, KB) are shown in Figure- 11. The lithology results are provided in Table-2 of three depth intervals, namely 3366–3550 m, 3550–3660 m, and 3660-3795.5 m.

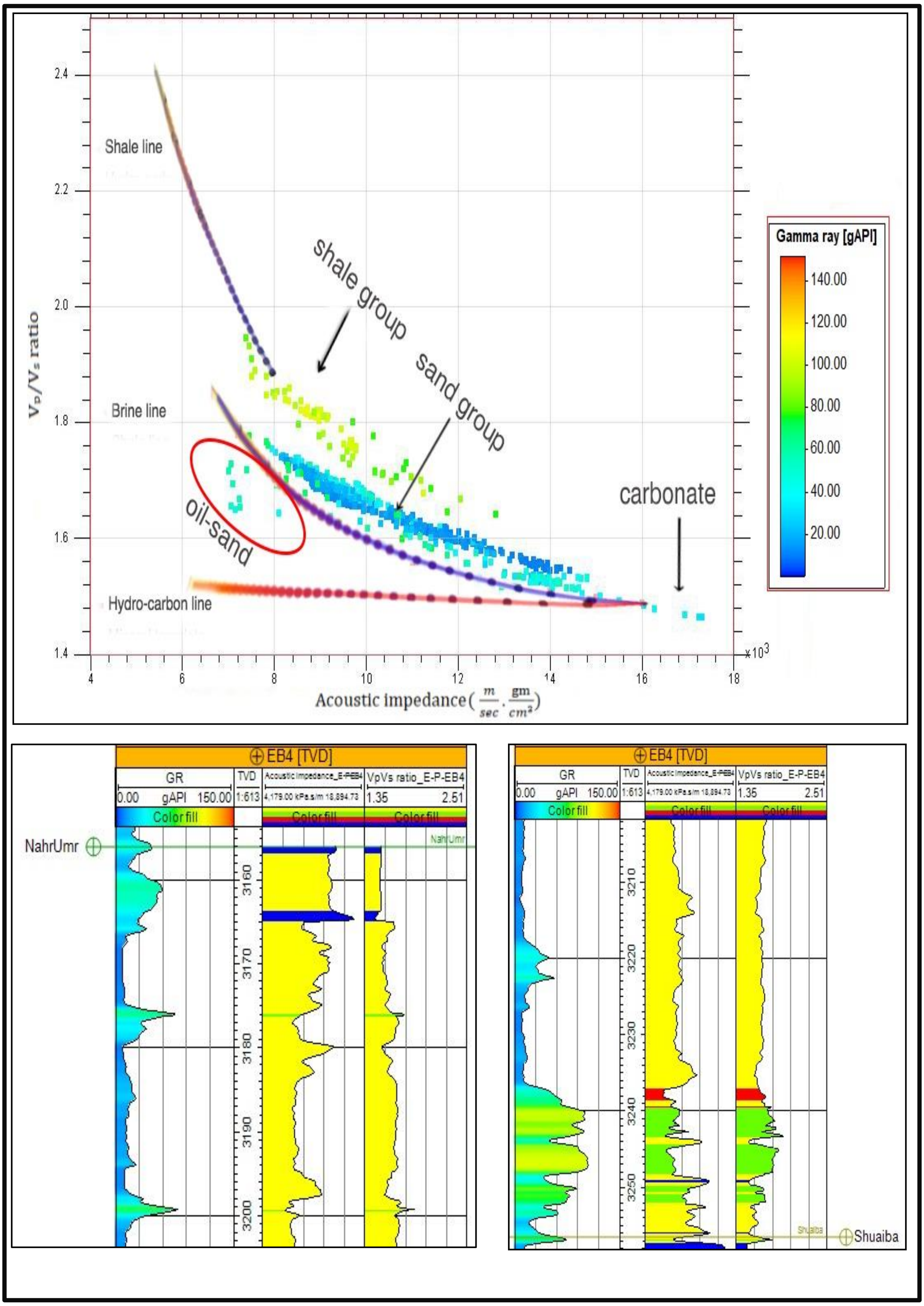

Figure 9- A cross plot of Vp/Vs and AI of well EB-4 in Nahr Umr Formation. The GR log was used to color-code data points. The logs of AI and Vp/Vs in the chart (below) were color-coded depending on the four zones on the cross plot domain (shale (green), sand (yellow), oil-sand (red), and carbonate (blue)).

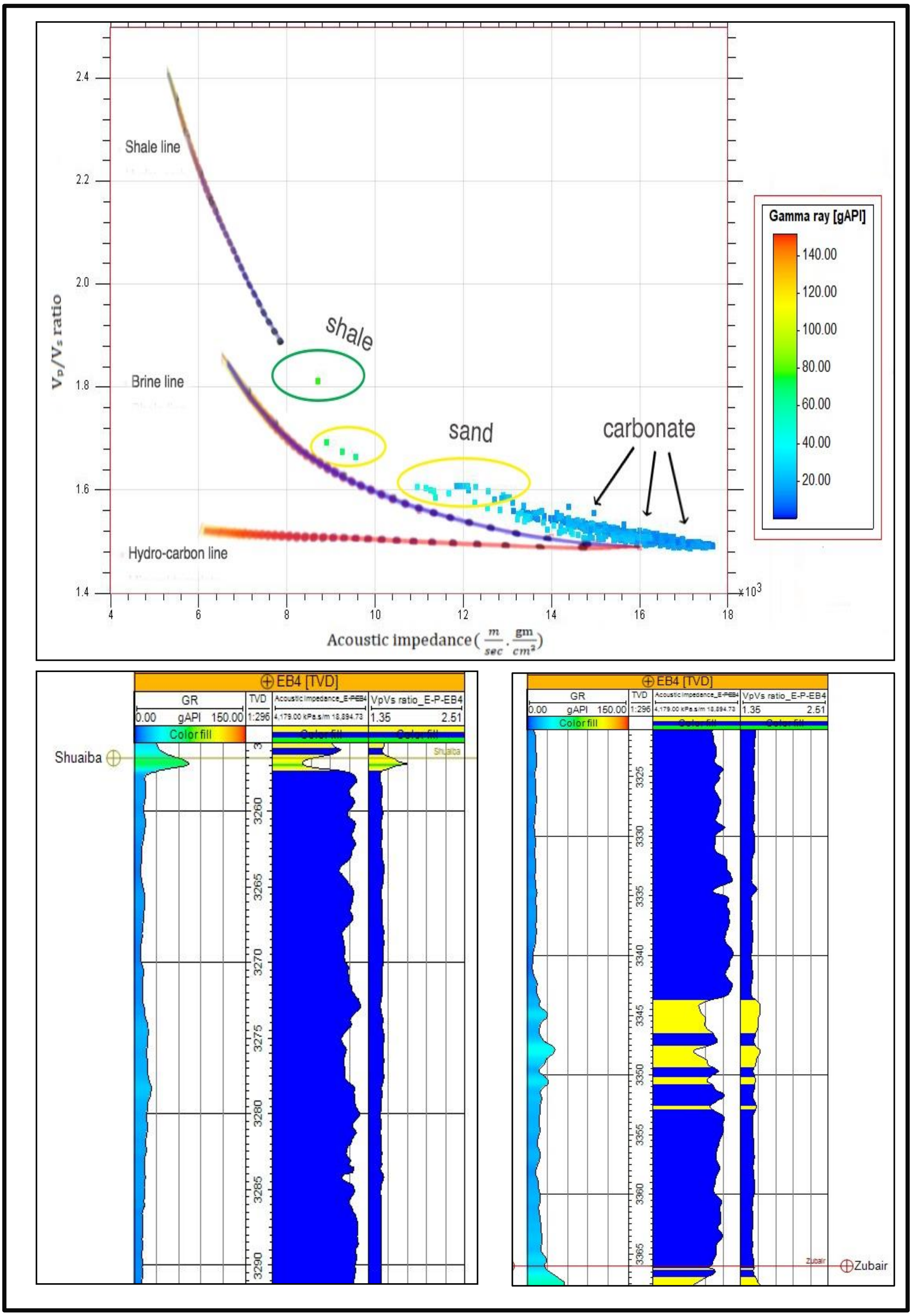

Figure 10- A cross plot of Vp/Vs and AI of well EB-4 in Shuaiba Formation. The GR log was used to color-code data points. The logs of AI and Vp/Vs in the chart (below) were color-coded depending on the four zones on the cross plot domain (shale (green), sand (yellow), oil-sand (red), and carbonate (blue)).

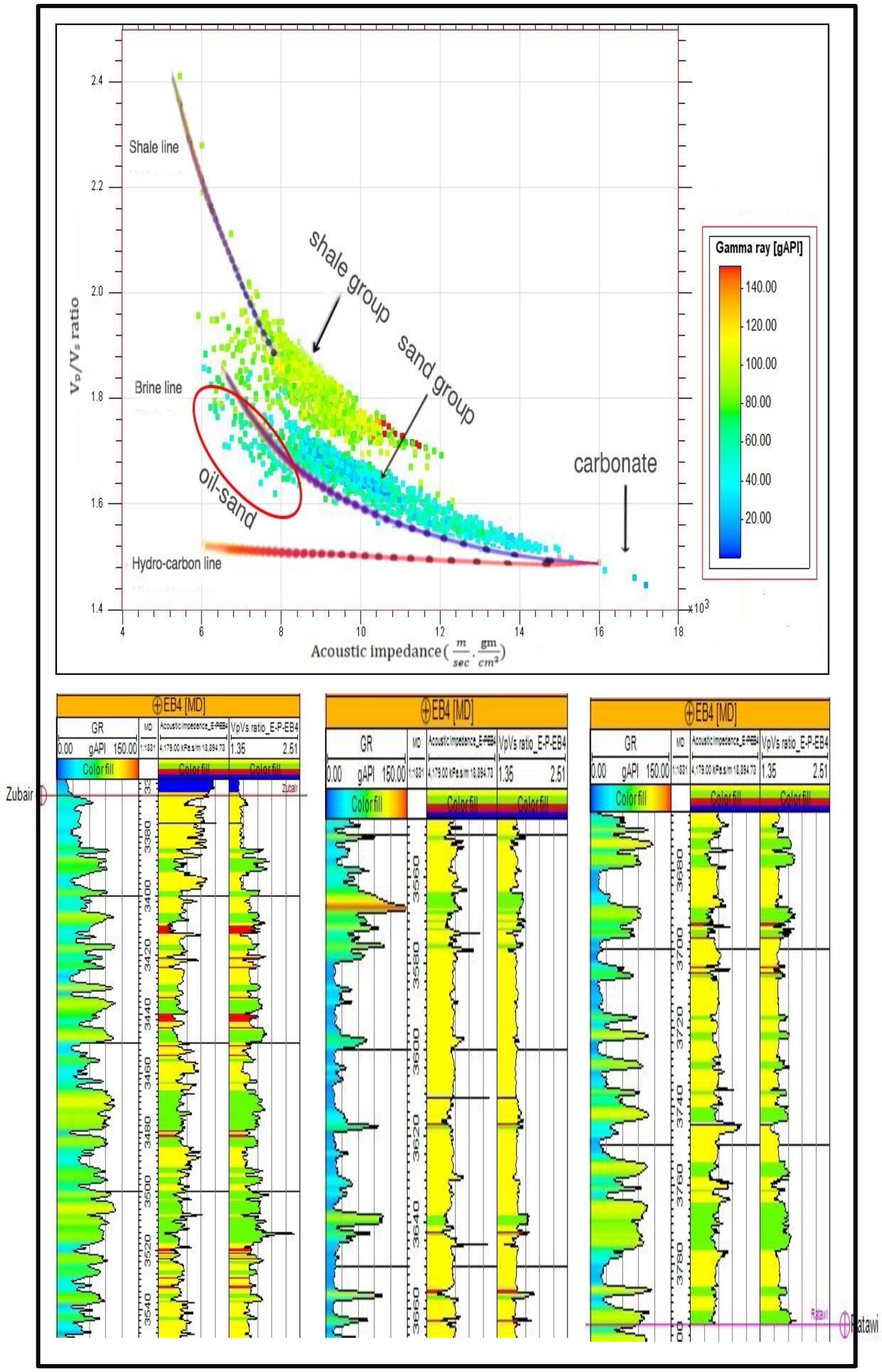

Figure 11- A cross plot of Vp/Vs and AI of well EB-4 in Zubair Formation. The GR log was used to color-code data points. The logs of AI and Vp/Vs in the chart (below) were color-coded depending on the four zones on the cross plot domain (shale (green), sand (yellow), oil-sand (red), and carbonate (blue))

Table 2- RPTs interpretation of Nahr Umr, Shuaiba, and Zubair Formations in well EB-4.

Formation	Interval (m)	Observations
Nahr Umr	3156–3237	- The entire interval is marked by the presence of sandstone with few carbonates at the top of the formation and thin layer of shale at the depths 3176 and 3199.5 m. - This interval is not a hydrocarbon-bearing zone.
	3237–3256.5	- Sandstone and shale with some carbonates (at depth 3250 m) are reported in this interval. - Few hydrocarbon indicators were observed at the bottom of this Formation (at depth 3238 m).
Shuaiba	3256.5- 3366	-Carbonates with some sandstone (at depth interval 3344-3350 m) are reported in this interval.
Zubair	3366–3550	- Consists of sandstone with high shale content in this interval. - Hydrocarbon indicators are very large, the following intervals appear to be hydrocarbon bearing: 3409-3413 m, 3419-3425 m, 3434-3435 m, 3440-3445 m, 3450-3455 m, 3479-3482 m, 3520-3522 m, and 3528-3535m.
	3550–3660	- This section mainly consists of sandstone with relatively high clay content at a depth of 3568 m and is capped by shale. - Some hydrocarbon indicators in the following intervals: 3568-3571 m, 3575 m, 3616-3618 m, 3637 m, 3640-3642 m, 3654-3655 m.
	3660-3795.5	- A sequence of sandstone and shale - A few hydrocarbon indicators in the following intervals: 3662-3663 m, 3670 m, 3694-3698 m, 3704-3708 m, 3723 m.

Finally, a polynomial equation from the second degree was generated from the cross plot between AI and Vp/Vs, as shown in Figure- 12, to estimate one parameter from the other in these formations.

$$y = 2.623 - 0.00013\,x + 4.17E - 9x^2$$

where: y = Vp/Vs, x = AI and R^2 = 0.7731.

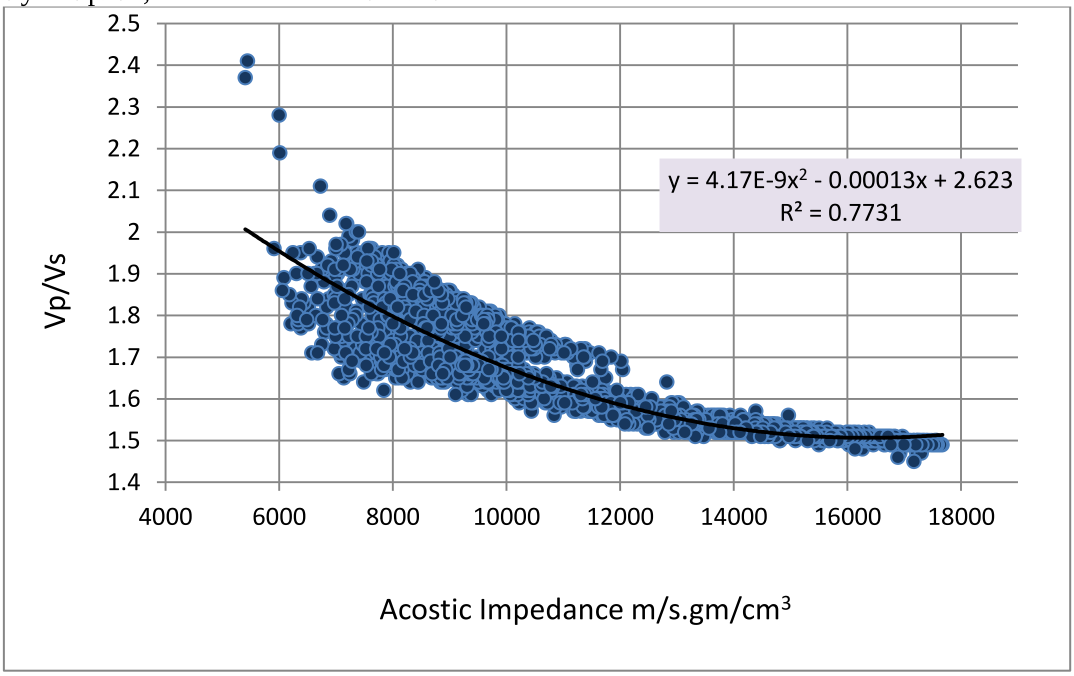

Figure 12- A cross plot of Vp/Vs against AI for Nahr Umr, Shuaiba, and Zubair Formations in well EB-4.

Conclusions

This study explains the methodology of using RPTs. The procedure followed in the analysis was divided into two major stages. First, the use of the well log data (DT, RHOB, and NPHI) to verify the selected RPT and determine lithologies. Second, the use of the selected RPTs to distinguish between different lithologies, porosity, and fluids within the well. These templates assisted in separate the sand from the shale and identified the locations of the hydrocarbon in the selected formations of the well EB-4. AI and Vp/Vs on the cross-plot domain with colour-coding using the GR log showed a good match between the two analyses. The equation created, which relates the acoustic resistance (AI) with Vp/Vs ratio, can be used to predict one parameter from the other in East Baghdad oilfield.

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