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Total organic carbon content deduced from resistivity-porosity logs overlay: a case study of Abu Roash formation, Southwest Qarun field, Gindi Basin, Egypt

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ABSTRACT
The present work evaluates the hydrocarbon potentiality of Abu Roash Formation in SWQ-25 well, Southwest Qarun (SWQ) Field, Gindi Basin, Egypt. The estimation of total organic carbon content (TOC) has been deduced using the overlay between deep resistivity and porosity logs. The results show that Abu Roash A Member is fair to good source rock (TOC ranges from 0.50 to 1.28 wt. %). While, Abu Roash D Member contains fair to very good TOC values (from 0.77 to 2.92 wt. %). In contrast, Abu Roash B and E members display poor to good source rocks, with TOC varies between 0.36 to 1.74 wt. % and 0.32 to 1.42 wt. %, respectively. However, Abu Roash C Member (with TOC varies between 1.50 and 2.19 wt. %) and Abu Roash F Member (with TOC differs from 1.54 to 3.16 wt. %) indicate a good to very good source rock intervals. The neutron porosity–resistivity overlay matches the density-resistivity overlay in carbonate members (A, B, C, D and F members) but a lack of resemblance in clastic units (E and G members).

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1. Introduction

The Gindi Basin (Figure 1) is a rift basin formed in the Jurassic-Early Cretaceous time due to the opening of the Neo-Tethys Sea and the Atlantic Ocean (Moustafa 2008). It is located in northern Western Desert and underwent inversion and dextral shearing during the Late Cretaceous time (Moustafa 2008; Sarhan 2017; Sarhan and Collier 2018). The main hydrocarbon reservoirs in Southwest Qarun (SWQ) Field are the sandstones of Bahariya Formation and Kharita Formation (Sarhan et al. 2017a; Sarhan 2019) and the fractured carbonates of Abu Roash D Member (Sarhan et al. 2017b). The SWQ-25 well located at longitude 30° 31′ 14.410” E and latitude 29° 46′ 18.611” N, Southwest Qarun field, Gindi Basin.

The Upper Cretaceous Abu Roash Formation is overlain by chalky limestone of the Santonian-Maastrichtian Khoman Formation and underlain by the sandstones of the Cenomanian Bahariya Formation. It is composed of alternations of clastics and carbonates deposited under shallow marine environment (EGPC, 1992). This Formation is divided into seven members, namely A to G from the top to the base. The B, D and F units consist of limestone; however, A, C, E and G units contain variable amounts of sandstone, shale and siltstone (Figure 2).

The Abu Roash Formation is one of the most effective source rocks belongs to the Upper Cretaceous section of the Western Desert. The E, F and G members characterised by organic-rich intervals with fair to good potential for oil production (Sestini 1995; Schlumberger 1995; Lüning et al. 2004). Generally, the Abu Roash F Member represents the most potential source rock interval with total organic carbon (TOC) in the range of 1.5–2.5% up to 6% (Labib 1985; Lüning et al. 2004).

The SWQ-25 well produces oil from the Bahariya Formation in the Southwest Qarun Field with no available geochemical data (rock-eval pyrolysis and vitrinite reflectance). Therefore, using available well log data can be used as a supplementary tool to calculate TOC contents.

Gamma-ray, resistivity and porosity logs (density, neutron and sonic) are the most common wireline logs that are used to recognise organic-rich intervals in sedimentary successions. Generally, organic matter of marine depositional environment (kerogen type I and II) is associated with radioactive elements, such as uranium, which result in increased gamma-ray readings. Additionally, the presence of oil within the pores of mature source rocks leads to an increase of 10% or more in resistivity readings (Meyer and Nederlof 1984).

Moreover, the occurrence of organic matter decreases the bulk density of shale; thus, organic-rich shales have lower bulk density values relative to non-source shales that have matrix densities range between 2.67 and 2.72 g/cm^3 (Makky et al. 2014). However,

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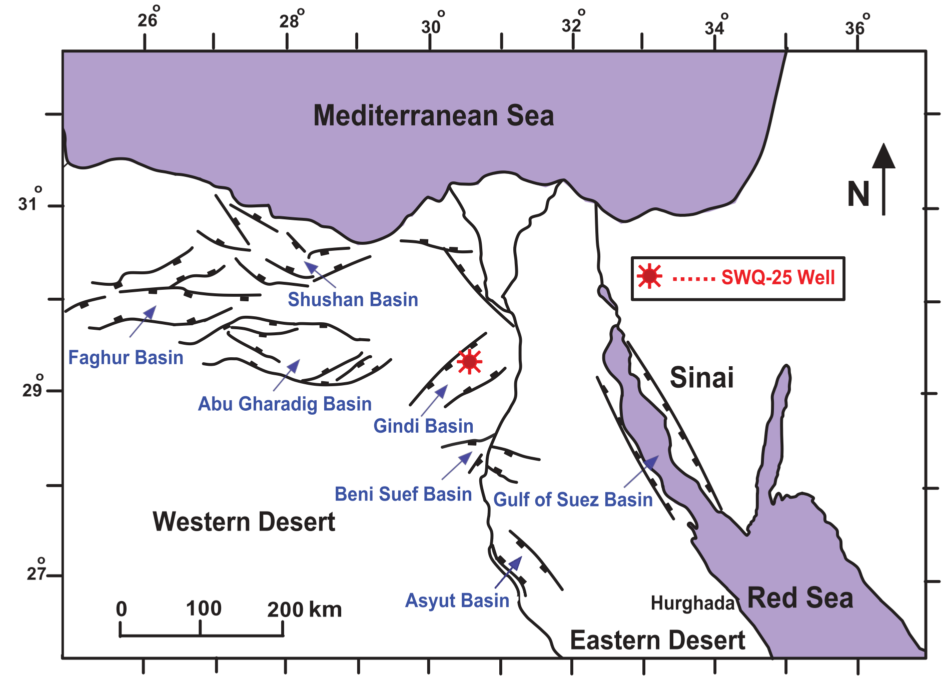

Figure 1. Regional map represents the location of SWQ-25 well with in Gindi Basin in northern Western Desert (Simplified by Sarhan, 2017 after Bosworth et al. 2008).

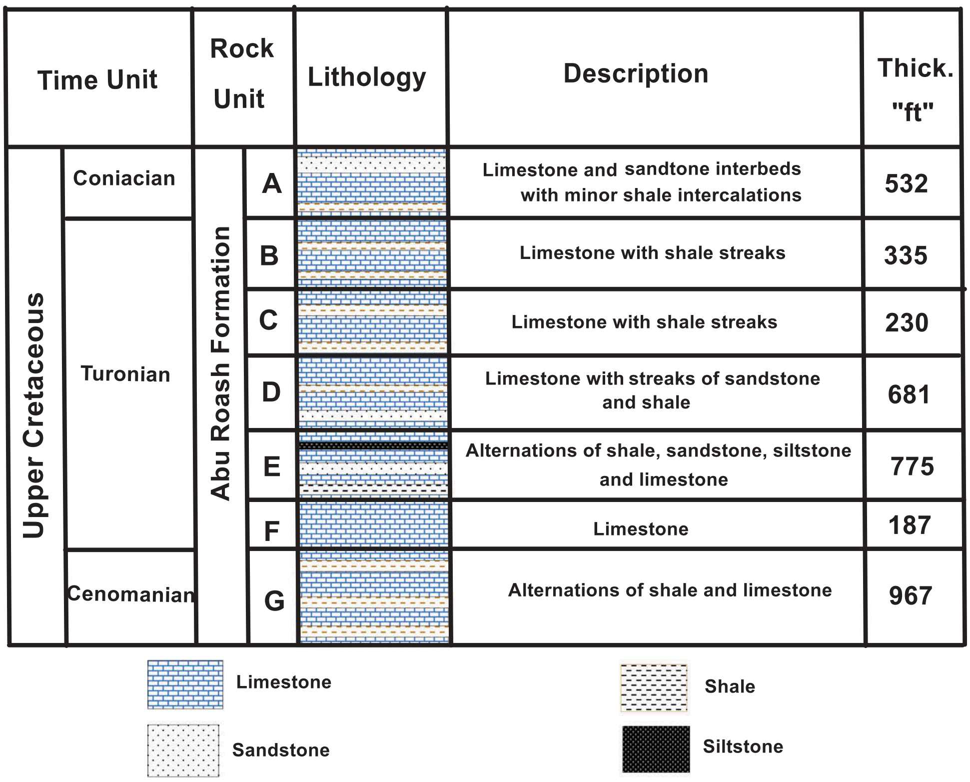

Figure 2. Lithostratigraphic succession of the Abu Roash Formation based on the available mud log of the SWQ-25 well.

neutron log values increase in response to the presence of hydrocarbon whereas the interval transmit time increases in mature source rock.

This study aimed to evaluate hydrocarbon potentiality of the Abu Roash Formation in a single well location. SWQ-25 well located in Southwest Qarun (SWQ) field, Gindi Basin. This evaluation based on porosity – and resistivity log data according to the Δ log R technique (Passey et al. 1990). The calculations of the total organic carbon (TOC) contents utilise resistivity (LLD) and porosity (RHOB and NPHI) logs overlays.

2. Data and technique

The present study is based on the available data; mud log record, bit size (BS), caliper (CALI), gamma-ray (GR), deep laterolog (LLD), bulk density (RHOB), neutron porosity (NPHI) and photoelectric (PE) data. The data also include 20 2D seismic sections covering SWQ Field and tied to SWQ-25 well.

The resistivity – porosity overlay technique (Passey et al. 1990) assesses the organic-richness in clastic and non-clastic sedimentary rocks. A single porosity tool, such as a density log (RHOB) or neutron log (NPHI), overlays the deep resistivity log (LLD).

In non-source or water-saturated rocks, the two curves track each other. However, in organic-rich source rocks or hydrocarbon reservoirs, these two curves separate. This separation, which occurs in organic-rich intervals, forms a gap due to the presence of organic matter leading to low readings for both its density and velocity values, while the resistivity curve characterised by high values in response to the presence of organic matter. The immature source rocks, where no hydrocarbons have yet been generated, this separation only occurs due to the response of the porosity curve. However, in mature source rocks, the resistivity increases as the porosity curve changes in response to the presence of hydrocarbon fluids. The magnitude of separation (Δ log R) in a source rock is a function of thermal maturity of organic matter. The equations used to calculate the TOC content (Passey et al. 1990) are:

$$\Delta\ \log R_{Neu} = \log_{10}(R/R_{baseline}) + 4.0 * (\Phi N - \Phi N_{baseline}) \quad (1)$$

$$\Delta\ \log R_{Den} = \log_{10}(R/R_{baseline}) - 2.50 * (\rho_b - \rho_{baseline}) \quad (2)$$

$$TOC = (\Delta\ \log R)_* 10^{(2.297 - 0.1688 * LOM)} \quad (3)$$

where:

$\Delta\ \log\ R_{Neu}$ and $\Delta\ \log\ R_{Den}$ are the separations related to the neutron and density logs, respectively.

ΦN is the neutron porosity opposite the interval of interest.

$\Phi N_{baseline}$ is the baseline value of the neutron porosity.

ρ_b is the bulk density value.

$\rho_{baseline}$ is the density baseline value.

TOC is the total organic carbon content in wt%.

LOM is the level of maturity.

The maturation of oil-prone kerogen starts at LOM equals 7, however, the over maturity will start when LOM reaches12 (Passey et al. 1990). Due to the lack of geochemical data, the present work used an average value of LOM (equals 10).

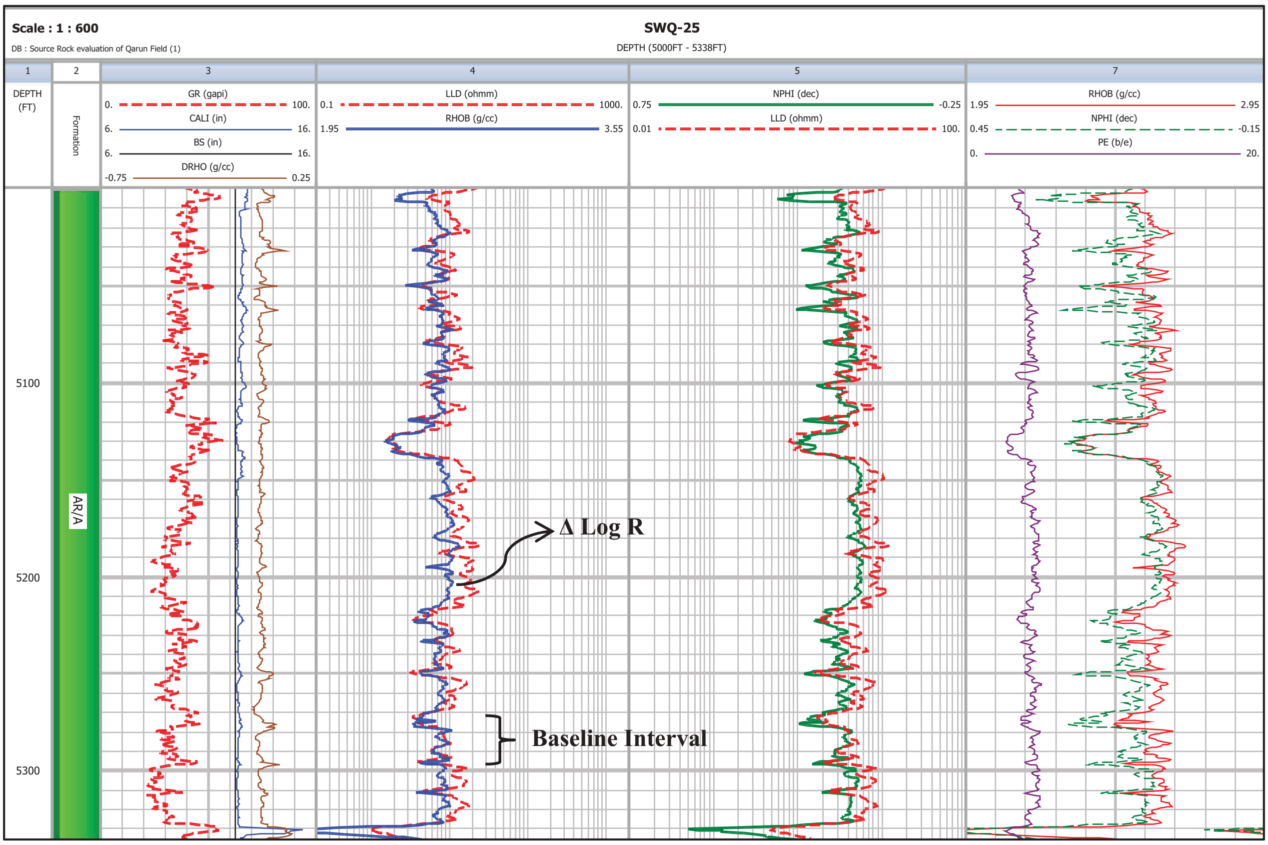

Figure 3. Well log suite showing the resistivity-porosity log overlay for the Abu Roash A member in the SWQ-25 well.

3. Results

Figures (3–7) represent the available well log suites for the Abu Roash A, B, C, D and F members. Generally, the neutron curve closely tracks the density curve and the PE equals 5 b/e, reflecting limestone lithologies (Track 7). However, many intervals show high gamma-ray values, left shift of the neutron curve relative to the density and decrease of the PE values to less than 5 b/e (usually varying between 4 and 5 b/e) indicating shaly carbonate horizons.

The caliper (CALI) and Bit Size (BS) curves show no or little separation from DRHO values around zero, as is displayed on Track (3) in Figures (3, 4, 6 and 7). This indicates excellent borehole conditions and reflects the validity of the recorded log values for the Abu Roash A, B, D and F Members.

In contrast, the Abu Roash C Member displays bad borehole conditions, as the caliper log (CALI) separates from the bit size curve (BS) and coupled with high DRHO values (approximately 0.25 g/cc) as is shown in Figure 5. The Density-Resistivity (LLD-RHOB) and Neutron-Resistivity (NPHI-LLD) combinations are presented in Tracks 4 and 5. These tracks have nearly identical features (Figure 3–7). RHOB-RLLD overlay shows separations against some intervals and tracks each other opposite others.

The Abu Roash F Member reflects the highest total organic carbon contents in Abu Roash Formation. It displays high values of Δ log R separation (Figure 7). The noticeable separations between RHOB-RLLD over the entire interval (Track 4) together with the good borehole conditions indicate that this member is an organic-rich source rock. Additionally, the shaly nature of the limestone matrix (PE between 4 and 5, Track 5) coupled with its high gamma-ray levels suggests that Abu Roash F Member is potential source rock.

Based on the available mud log report, both the Abu Roash E and G Members are clastic in nature. The Abu Roash E Member is essentially composed of alternating sandstone, shale and siltstone with minor limestone streaks, while the Abu Roash G Member is mainly contained shale with limestone interbeds. The low PE values between 2 and 3 b/e, the separation between the neutron and density curves, and the high GR values reflect the effects of shale (Figures 8 and 9).

The Abu Roash E Member has intervals with good and others with bad borehole conditions (Figure 8). However, the Abu Roash G Member displays predominant bad borehole conditions, as the caliper log reads more than the bit size value, which is equal to 13 inches in the examined well (Figure 9). Thus, all of the readings obtained from the Abu Roash G Member are expected to be inaccurate; hence, it is eliminated from the TOC calculations.

The GR-PE-LLD and GR-PE-RHOB Z plots (Figures 10–12) show that the main matrix constituent in A, B, C, D and F Members is limestone. This is evidenced by the PE values of 4 to 5 b/e in

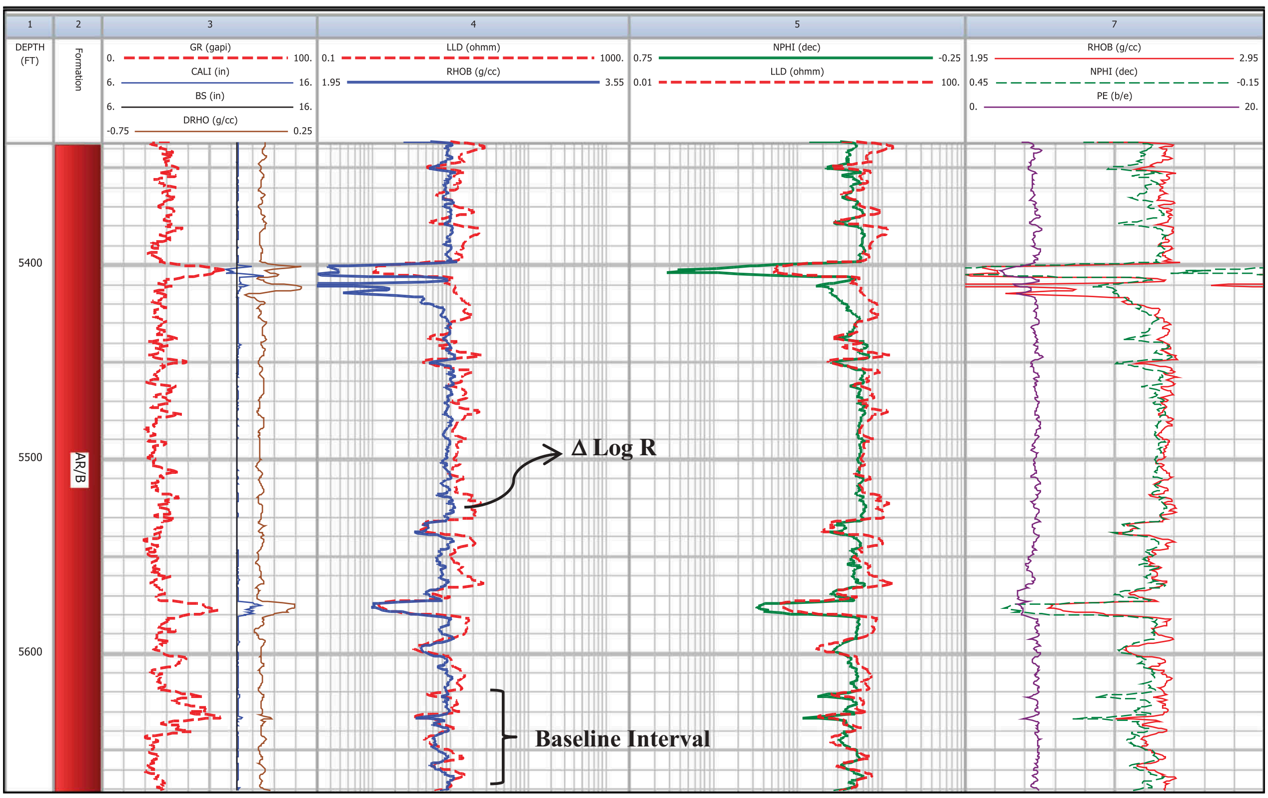

Figure 4. Well log suite showing the resistivity-porosity log overlay for the Abu Roash B member in the SWQ-25 well.

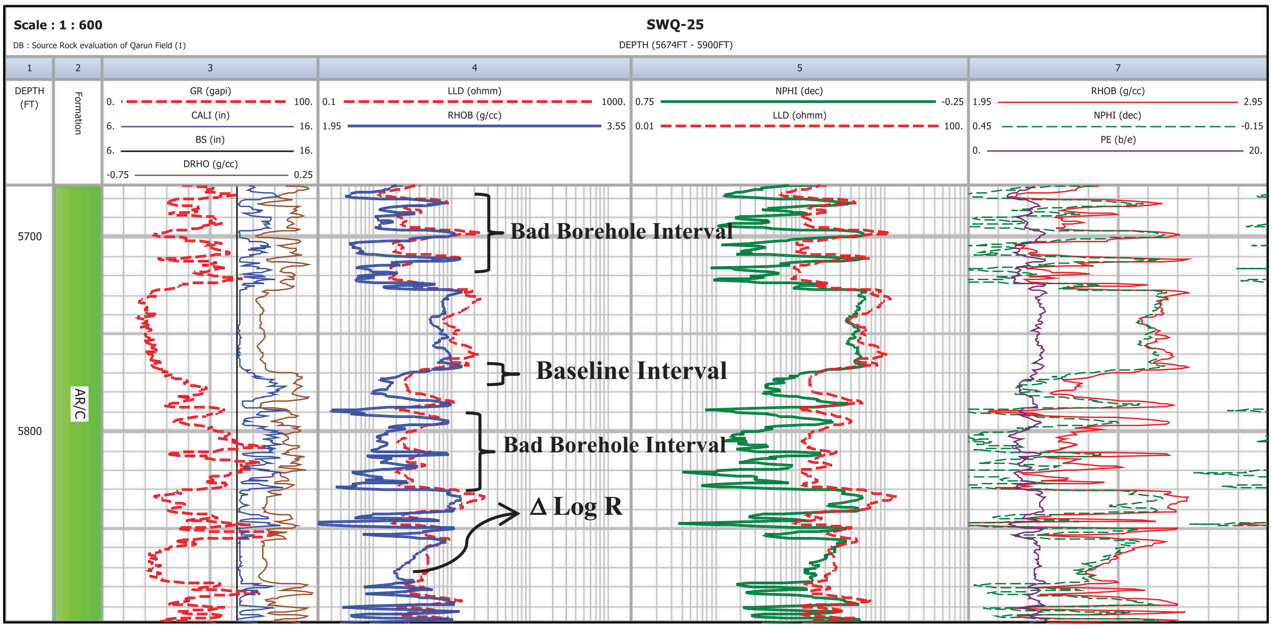

Figure 5. Well log suite showing the resistivity-porosity log overlay for the Abu Roash C member in the SWQ-25 well.

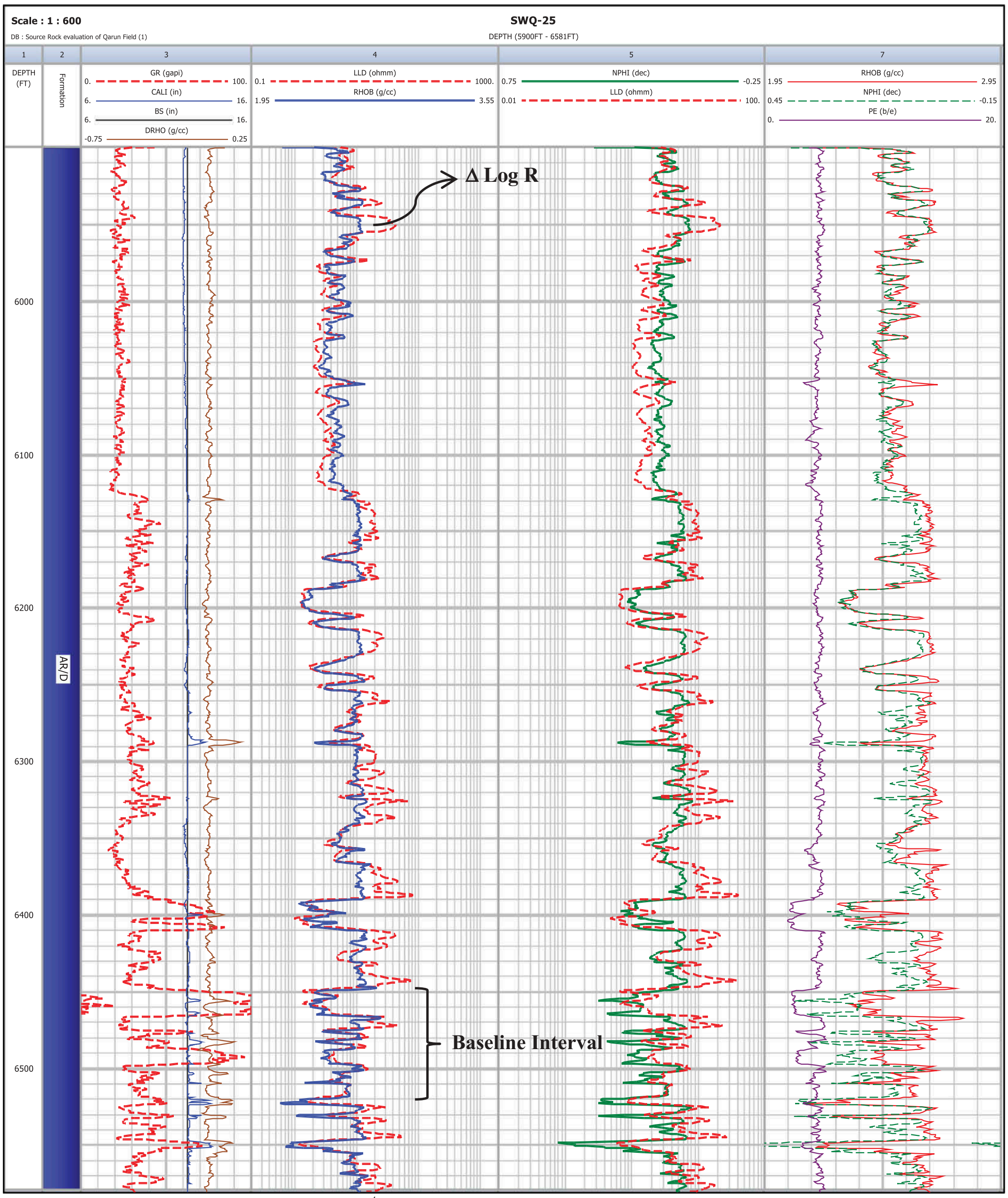

Figure 6. Well log suite showing the resistivity-porosity log overlay for the Abu Roash D member in the SWQ-25 well.

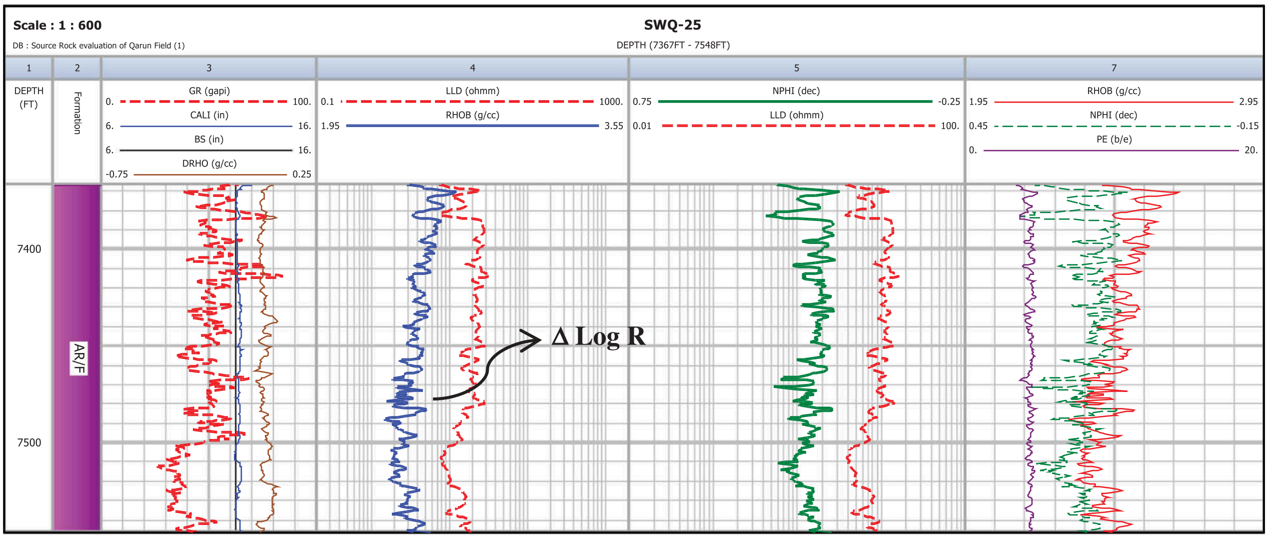

Figure 7. Well log suite showing the resistivity-porosity log overlay for the Abu Roash F member in the SWQ-25 well.

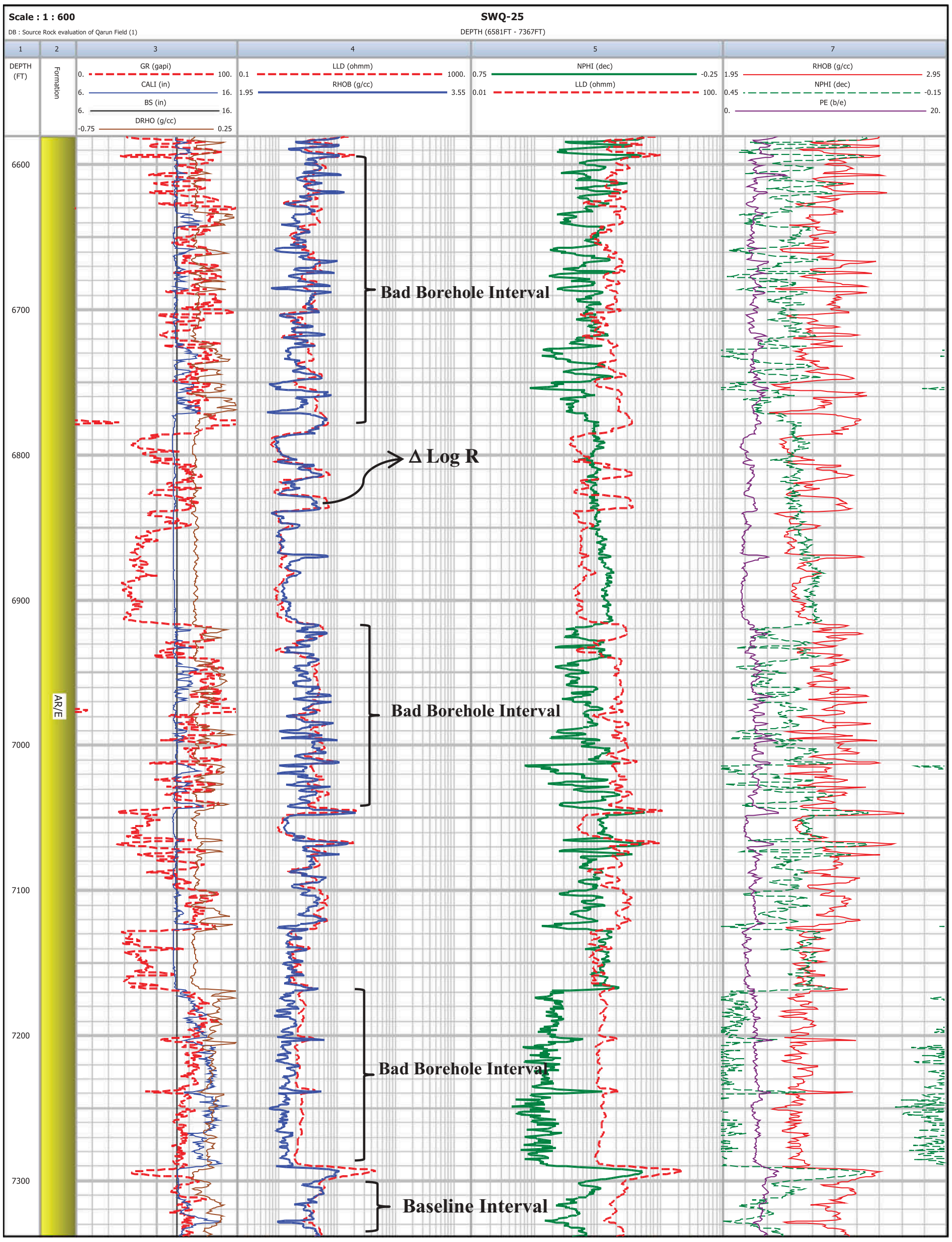

Figure 8. Well log suite showing the resistivity-porosity log overlay for the Abu Roash E member in the SWQ-25 well.

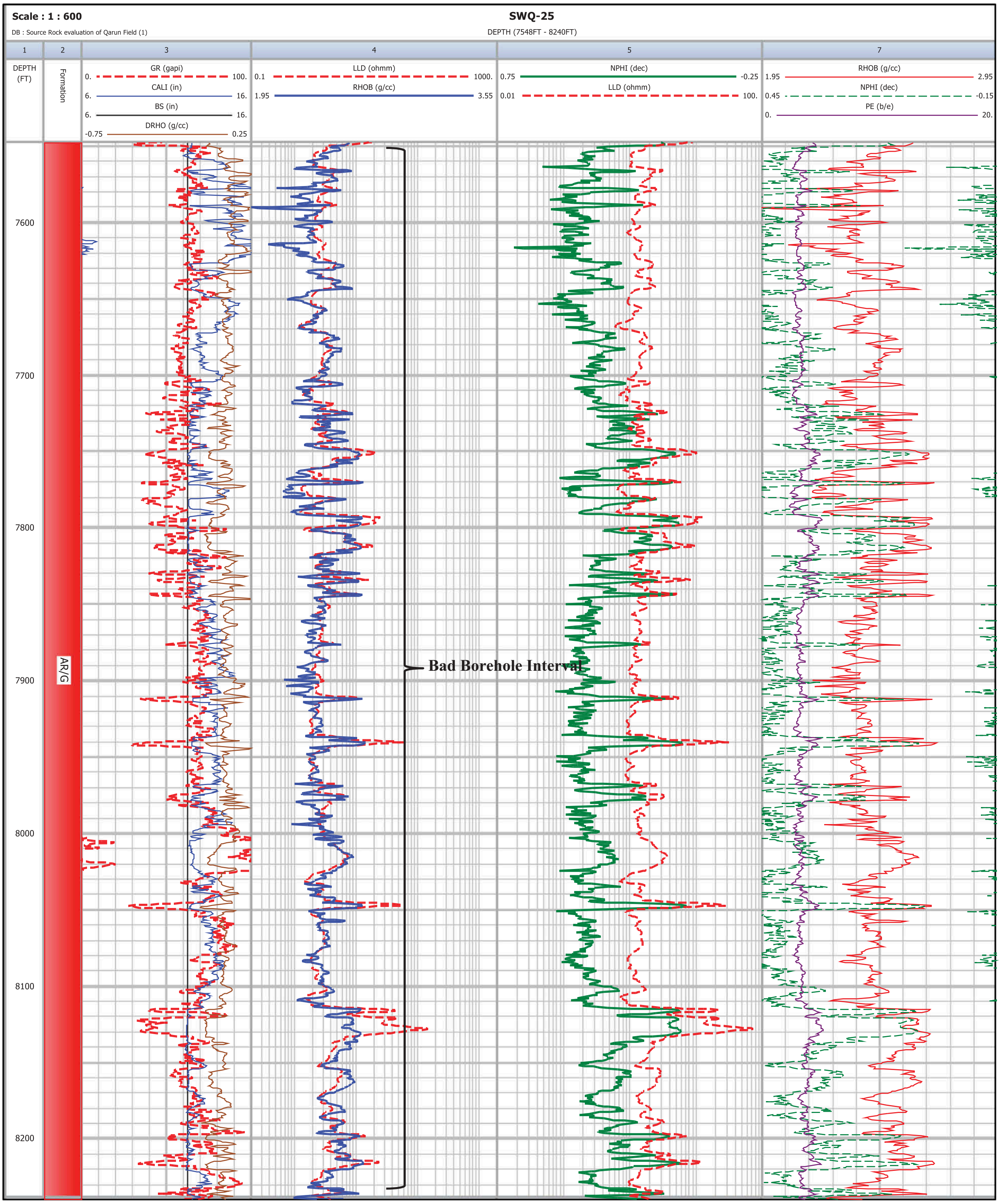

Figure 9. Well log suite showing the resistivity-porosity log overlay for the Abu Roash G member in the SWQ-25 well.

limestone. However, the main matrix in the Abu Roash E Member is shale, which is reflected by its PE value of 3 b/e. The outlined points display low densities below the normal density of limestone (i.e. 2.7 gm/cm^3), and less than the normal density of shale (i.e. 2.4 gm/cm3) with high gamma-ray values and high resistivity values. These are indications for the occurrence of organic matter within the interpreted source rocks.

Table 1 shows the input well log data and the calculated Total Organic Carbon (TOC) contents for the zones of interest within the Abu Roash

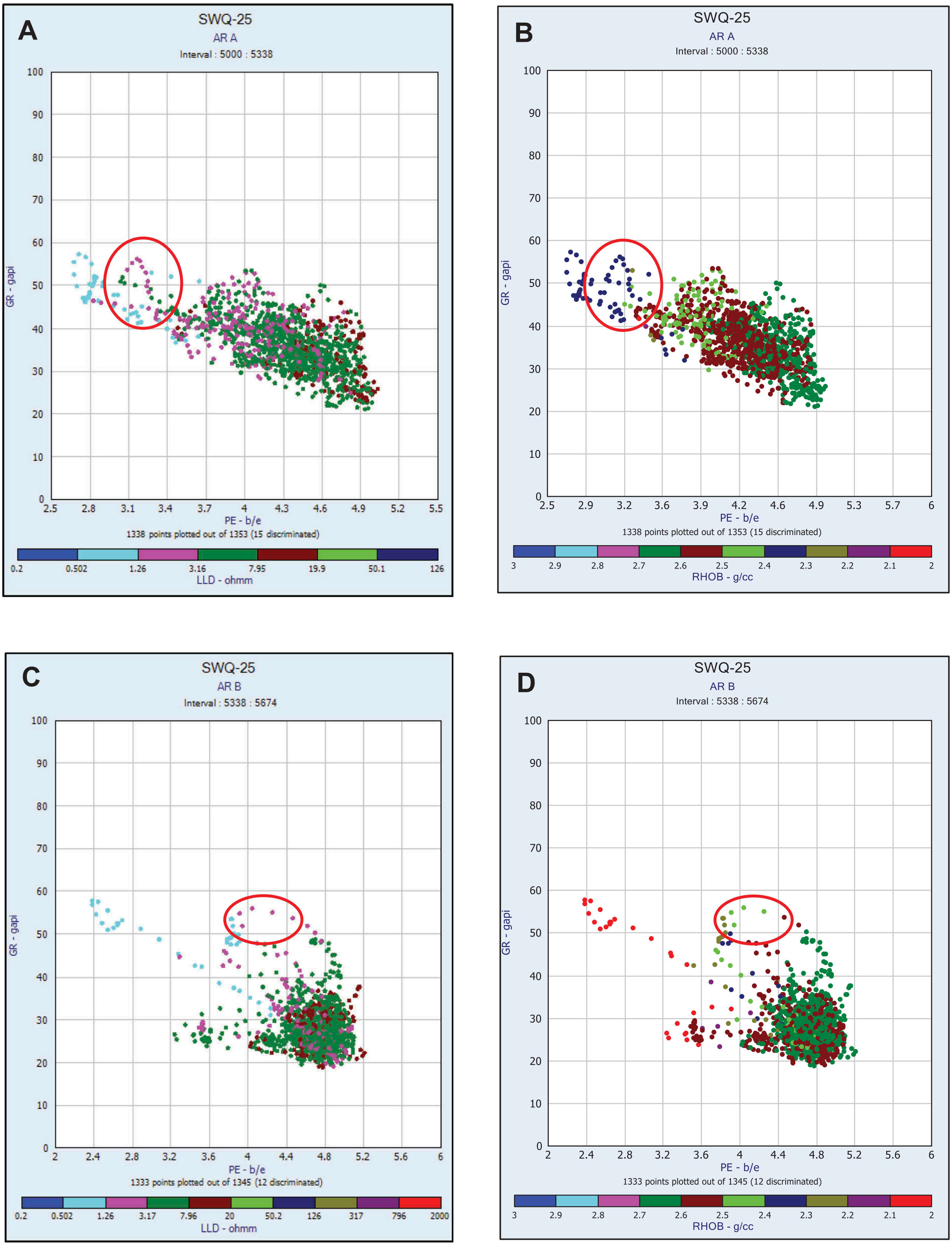

Figure 10. The GR-PE-LLD and GR-PE-RHOB Z-plots for the Abu Roash A member (Figures A and B) and the Abu Roash B Member (Figures C and D) in the SWQ-25 well. The outlined plotted points reflect the effects of hydrocarbon occurrence.

Formation using the applied technique. The quality evaluation of each member based on its calculated TOC content, as described according to Peters (1986), is shown in Table 2.

The calculated TOC contents of the Abu Roash A Member range from 0.50 to 1.28 wt. %, which indicate that it is a fair to good source rock. In Abu Roash B Member, the TOC values range from 0.36

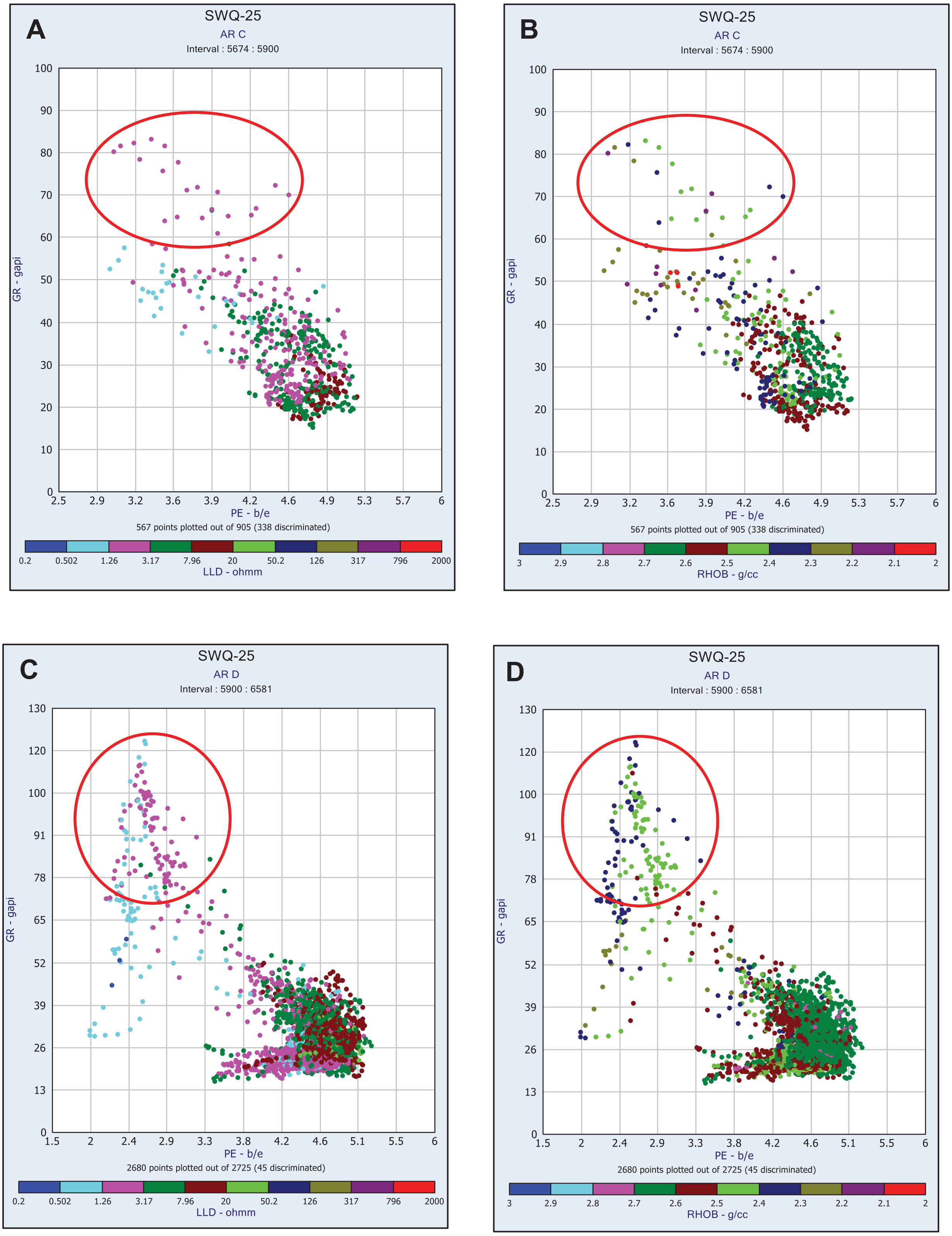

Figure 11. The GR-PE-LLD and GR-PE-RHOB Z-plots for the Abu Roash C member (Figures A and B) and the Abu Roash D member (Figures C and D) in the SWQ-25 well. The outlined plotted points reflect the effects of hydrocarbon occurrence.

to 1.74 wt. % reflects poor to good source rock. However, the TOC contents of the Abu Roash C Member range from 1.50 to 2.19 wt. % indicating good to very good source rock. The TOC contents of the Abu Roash D Member range from 0.77 to 2.92 wt. %, which reveal that it is fair to very good source rock. The TOC content in the Abu Roash E Member varies between 0.32 and 1.42 wt. %, thus reflects poor to good source rock. Finally, the calculated TOC contents in the Abu Roash F Member

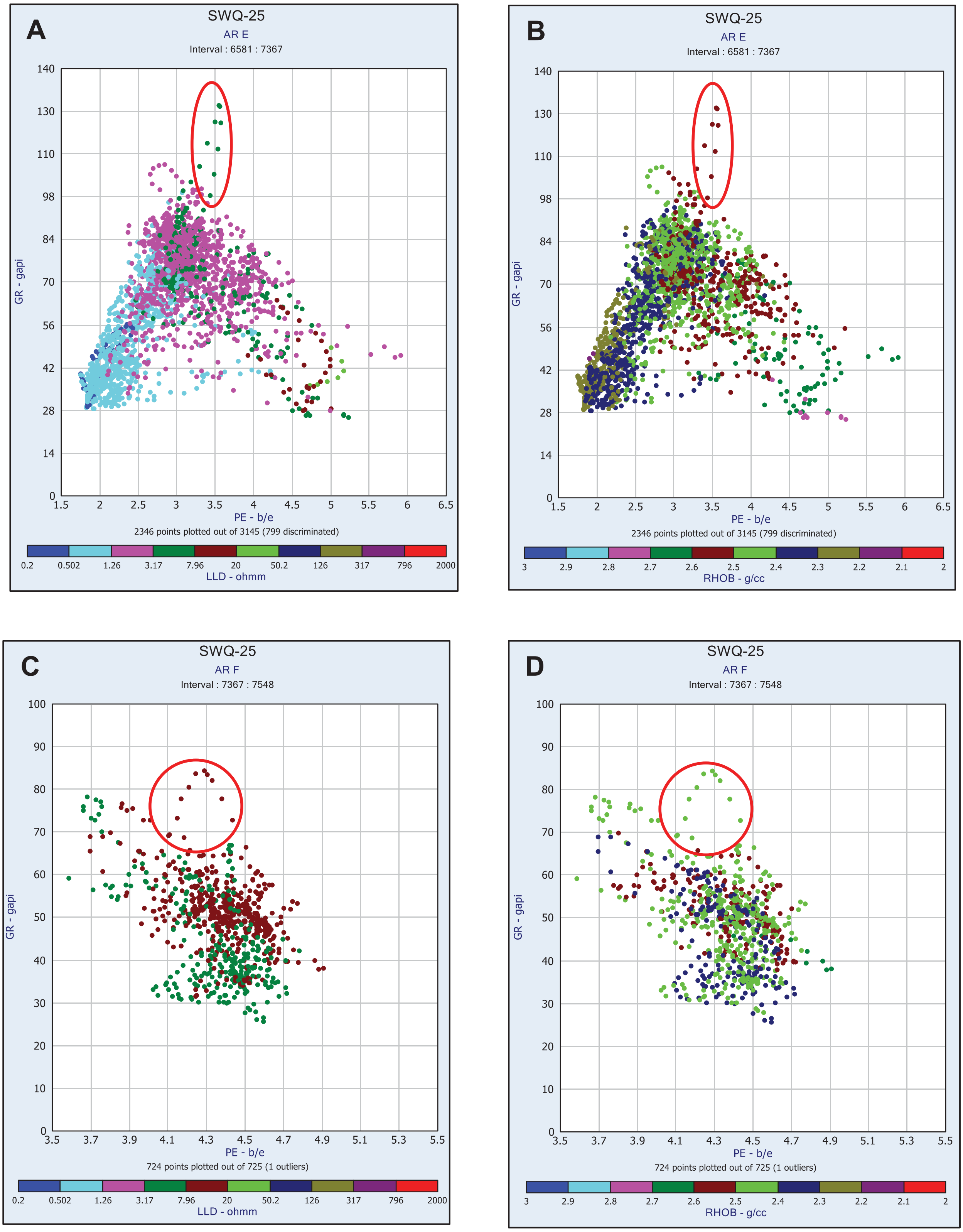

Figure 12. The GR-PE-LLD and GR-PE-RHOB Z-plots for the Abu Roash E member (Figures A and B) and the Abu Roash F member (Figures C and D) in the SWQ-25 well. The outlined plotted points reflect the effects of hydrocarbon occurrence.

range from 1.54 to 3.16 wt. % indicates good to very good source rock.

4. Discussion and conclusions

The technique of Passey et al. (1990) can be used to quickly assess organic-rich zones in sedimentary successions, especially when geochemical data are not available. This technique is based on the overlays between the porosity and resistivity logs. The magnitude of the separation (Δ log R) between these curves is directly proportional to the TOC contents in the source rocks.

This technique has been applied in this study to evaluate all members of Abu Roash Formation in

Table 1. Input well logs data and calculated Total Organic Carbon (TOC) content for the selected zones within Abu Roash Formation in SWQ-25 Well.

Rock Unit	Total Interval (ft)	Depth (ft)	G R (API)	R_t (Ω m2/m)	ρb (gm/cm^3)	Pe (b/e)	$Φ_N$ (%)	Δ Log R	TOC (LOM = 10)	Baseline Interval
AR/A	5000–5338	5015	39	4.9	2.56	4.22	0.13	0.12	0.50	Depth (5277–5296 ft)
		5150	32	10.8	2.62	4.56	0.06	0.31	1.28	$R_{baseline}$ = 5.2
		5201	31	9.25	2.63	4.49	0.06	0.21	0.85	$ρb_{baseline}$ = 2.62
		5257	31	7.81	2.59	4.61	0.10	0.25	1.01	Figure (3)
		5302	27	5.3	2.57	4.62	0.11	0.13	0.54	
		5318	27	9.08	2.63	4.93	0.09	0.20	0.81	
AR/B	5338–5674	5344	28	7.41	2.62	4.56	0.09	0.13	0.56	Depth (5620–5670 ft)
		5388	31	8.1	2.63	4.6	0.06	0.14	0.60	$R_{baseline}$ = 5.4
		5422	26	9.19	2.54	4.88	0.09	0.42	1.74	$ρb_{baseline}$ = 2.62
		5478	37	8.77	2.6	4.84	0.05	0.25	1.05	Figure (4)
		5523	31	10.7	2.62	4.41	0.06	0.29	1.21	
		5560	28	7.32	2.59	4.51	0.08	0.20	0.84	
		5588	26	8.04	2.61	4.66	0.07	0.19	0.80	
		5614	27	7.41	2.64	4.89	0.07	0.08	0.36	
AR/C	5674–5900	5735	20	9.09	2.59	4.85	0.08	0.50	2.03	Depth (5765–5770 ft)
		5748	23	6.39	2.58	4.24	0.07	0.37	1.50	$R_{baseline}$ = 7.44
		5759	24	8.36	2.61	4.88	0.08	0.41	1.66	$ρb_{baseline}$ = 2.68
		5871	22	2.66	2.36	4.39	0.21	0.54	2.19	Figure (5)
AR/D	5900–6581	5949	25	18.3	2.64	4.87	0.04	0.54	2.19	Depth (6448–6520 ft)
		6144	44	8.57	2.64	4.85	0.07	0.22	0.89	$R_{baseline}$ = 4.65
		6176	29	8.64	2.65	4.75	0.06	0.19	0.77	$ρb_{baseline}$ = 2.62
		6223	34	10	2.65	4.66	0.06	0.25	1.02	Figure (6)
		6259	23	9.01	2.61	4.94	0.06	0.31	1.26	
		6300	30	10.2	2.63	4.60	0.05	0.32	1.29	
		6310	34	10.70	2.63	4.67	0.06	0.33	1.34	
		6318	33	17.10	2.67	4.88	0.04	0.44	1.78	
		6336	27	20.20	2.68	4.70	0.05	0.48	1.95	
		6377	27	18.40	2.65	4.83	0.04	0.52	2.11	
		6418	28	9.50	2.59	4.79	0.08	0.38	1.54	
		6443	24	36.80	2.69	4.81	0.04	0.72	2.92	
		6472	44	17.30	2.64	4.96	0.05	0.52	2.11	
		6578	26	14.50	2.60	5.01	0.05	0.54	2.19	
AR/E	6581–7367	6811	69	3.33	2.47	2.87	0.24	0.18	0.73	Depth (7303–7340 ft)
		6833	77	3.37	2.50	3.02	0.26	0.08	0.32	$R_{baseline}$ = 2.46
		7000	93	3.19	2.48	3.08	0.28	0.14	0.57	$ρb_{baseline}$ = 2.49
		7037	63	2.52	2.37	2.80	0.23	0.31	1.27	Fig. (7)
		7103	90	3.1	2.39	2.78	0.35	0.35	1.42	
		7114	78	2.47	2.45	3.01	0.31	0.10	0.41	
AR/F	7367–7548	7375	58	7.01	2.52	3.98	0.23	0.38	1.54	
		7397	53	14.10	2.53	4.56	0.15	0.38	1.54	
		7432	43	12.80	2.52	4.71	0.14	0.64	2.59	
		7469	56	10.60	2.43	4.32	0.20	0.78	3.16	
		7493	45	5.74	2.36	4.61	0.18	0.69	2.80	
		7512	30	4.24	2.34	4.56	0.25	0.61	2.48	
		7532	32	7.82	2.39	4.39	0.22	0.75	3.05	
		7543	43	7.25	2.50	4.31	0.18	0.44	1.8	
AR/G	7548–8240	Bad Hole Condition (Caliper > 13 inch) (i.e. Caliper – Bit Size = + ve)								

Table 2. Source rock evaluation based on Total Organic Carbon (TOC) content and Rock- Eval pyrolysis data (after Peters 1986).

	Total Organic Carbon (TOC) Content (wt %)		S1 (mgHc/gToc)		S2 (mgHc/gToc)	
Quality	From	To	From	To	From	To
Poor	0	0.5	0	0.5	0	2.5
Fair	0.5	1	0.5	1	2.5	5
Good	1	2	1	2	5	10
Very Good	> 2		> 2		>10	

SWQ-25 well, SWQ Field in Gindi Basin. This well was drilled to facilitate hydrocarbon production from the underlying Cenomanian Bahariya Formation. Therefore, the Abu Roash Formation in this well didn't have any interest to the drilling company; hence, no geochemical analyses have been performed on this formation, and the logging data are the only available data for the examined Formation.

The NPHI-RLLD overlays correlate very well with the overlays of the density-resistivity (RHOB-RLLD) in all the entire members of the Abu Roash Formation, except for the E and G Members. This is because most of these members (A, B, C, D and F) are essentially composed of limestone, while the E and G Members mainly comprise clastics.

The most important point in this work is that, in both the Abu Roash E and G Members, there is a lack of resemblance between the RHOB-LLD and PHIN-LLD overlays. This is attributed to the clastic nature of both members. However, the overlays of the other members, which are carbonate in nature, including the Abu Roash A, B, C, D and F Members, show complete resemblance. Therefore, it can be concluded that the use of Δ log R technique is preferentially applied to the non-clastic rocks rather than the clastic sedimentary successions to evaluate their source rocks potentiality.

The most promising source rock in the Abu Roash Formation is the Abu Roash F Member, within which its TOC contents reaches 3.16 wt. % representing good to very good source rock.

The findings of the current work are confirmed by specific characteristics stated in the mud log for SWQ-25 well. These characteristics include the presence of oil-stained limestone and sandstone intervals within the different members of the Abu Roash Formation, which are shown in Figures (13 and 14). Additionally, the shale intervals in different members are dark grey, brown and green-grey in colour (Figure 14). Moreover, chromatographic analyses show gas peaks against

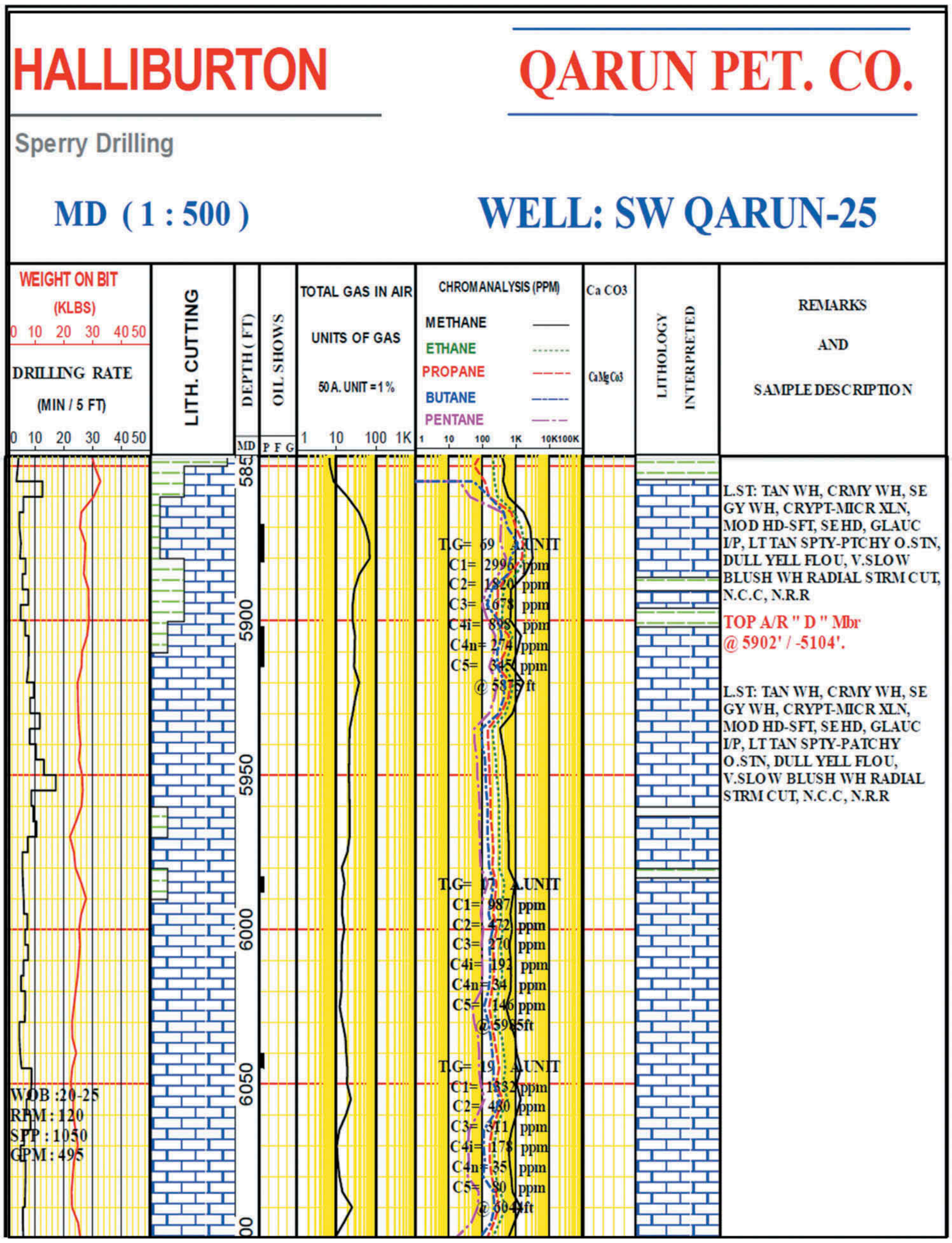

Figure 13. Available mud log chart for the lowermost part of the Abu Roash C member and the uppermost part of the Abu Roash D member in the SWQ-25 well. Note that the descriptions of the limestone intervals contain spotty (SPTY) and patchy (PTCHY) oil-stained (O. STN) limestones. Note the presence of gas trips from the chromatographic analysis.

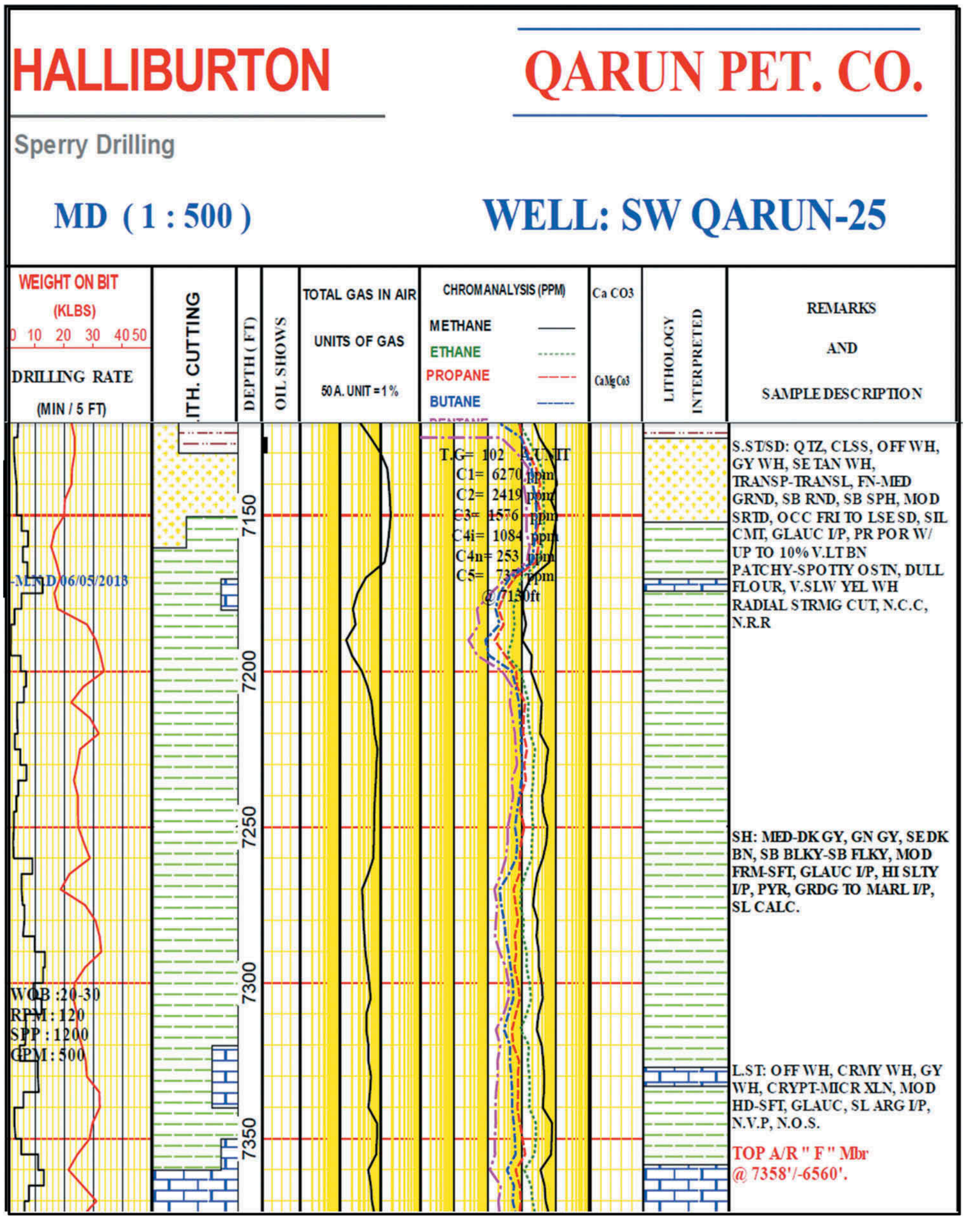

Figure 14. Available mud log chart for the lowermost part of the Abu Roash E member and the uppermost part of the Abu Roash F member in the SWQ-25 well. Note that the description of the sandstone interval contains patchy (PTCHY) and spotty (SPTY) oil-stained (O. STN) sandstones. In addition, the shale bed displays dark grey (DK GY), green-grey (GN GY) and brown (BN) colours. Note the presence of gas trips from the chromatographic analysis.

several limestone intervals of the Abu Roash Formation (Figures 13 and 14). All of these criteria support the presence of organic matter within the Abu Roash Formation in the SWQ-25 well.

Another support for the present evaluation was obtained from an internal report in the Qarun Petroleum Company. This evidence concerns the results of the pyrolysis analysis of the Abu Roash F Member in SWQ-1 well, which is located at the intersection of latitude 29°45′ 44.90” N and longitude 30°31′ 21.20” E, Southwest Qarun (SWQ) Field (i.e. very close to the examined SWQ-25 well). The pyrolysis analysis revealed that its TOC contents range from 1.69 to 3.28 wt. % and are mostly above 2 wt. %. This outcome matches the outcome of the present work, within which the calculated TOC contents in the Abu Roash F Member range from 1.54 to 3.16 wt. %, and most of its TOC contents are above 2 wt. % (Table 1). Additionally, the calculated S2 values (which represent the quantity of released hydrocarbons from the samples during pyrolysis process) of the Abu Roash F Member in the SWQ-1 well are high; they vary between from 7.63 to 18.66 mg HC/G.

All of the fore mentioned results support the main conclusion of the present work, which considers the

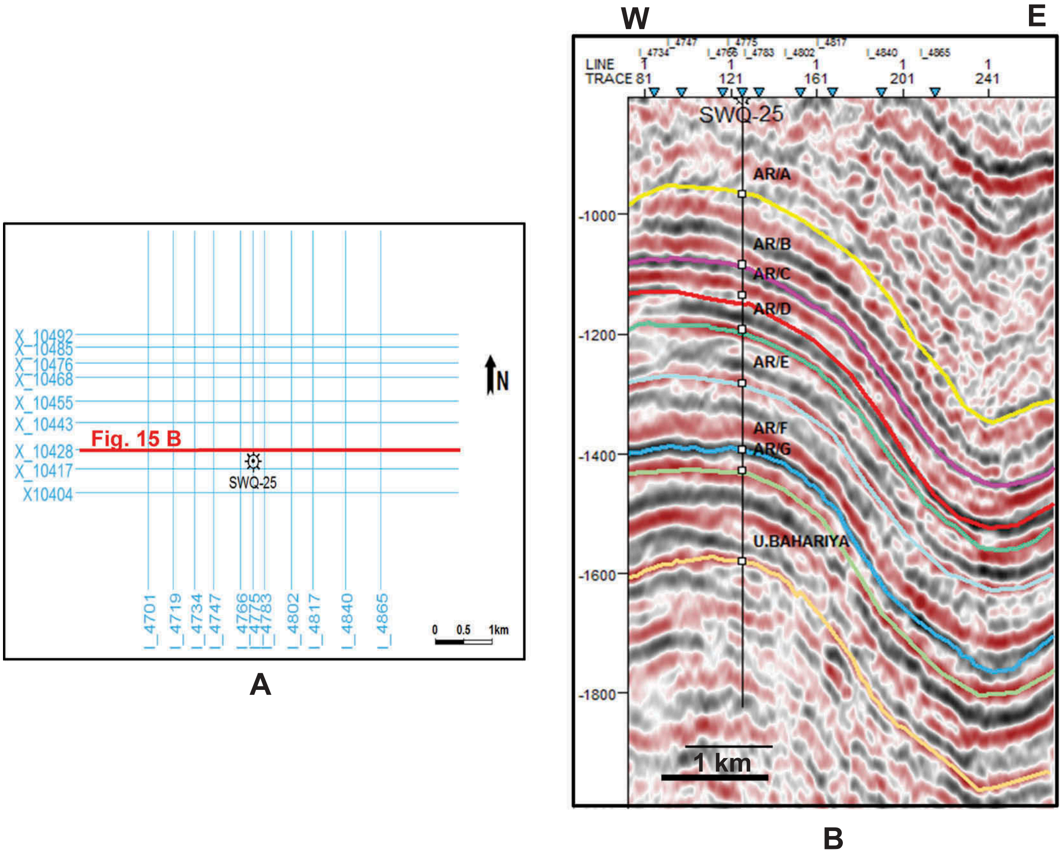

Figure 15. (a) Seismic lines covering study area showing the location of SWQ-25 Well, South West Qarun (SWQ) Field, Gindi Basin. (b) Interpreted seismic line no. X-10428 showing picked seismic horizons corresponding the different members of Abu Roash Formation by tying to SWQ-25 well.

Abu Roash Formation in SWQ-25 well as a potential source rock for hydrocarbon generation in Gindi Basin especially the Abu Roash C, D and F Members. Hence, these members represent unconventional hydrocarbon prospects in this basin.

Figures (15 and 16) are thickness maps for the different members of Abu Roash Formation in the area of study based on seismic stratigraphic interpretation. These maps help to distinguish the thickness variation for each member in the study area in order to define the highest economic reserves of the buried organic matter within each unit which is a function of both TOC% and thickness of each member.

In conclusions, the Δ log R technique may be used to detect the organic-rich source rocks based on the well logs data before performing the geochemical analysis required for the interested zones. Also, it is highly recommended to perform geochemical analyses on the rock cuttings of Abu Roash members in SWQ-25 well, SWQ Field, Gindi Basin. These analyses include the most popular techniques that are used to evaluate hydrocarbon source rocks, such as pyrolysis and vitrinite reflectance (%Ro) analyses. This will yield accurate values of the level of maturation in the SWQ-25 well instead of the assumed average value of LOM equals10 which has been used in this paper. Accordingly, the accuracy of the TOC calculations will be increased.

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Author contributions

M.A. Sarhan: obtaining data; writing manuscript; preparing figures, tables and mathematical calculations; seismic interpretation; and corresponding author.

M.A. Sarhan & A.M.K. Basal: idea; title; qualitative and quantitative well logging analysis.

Disclosure statement

No potential conflict of interest was reported by the authors.

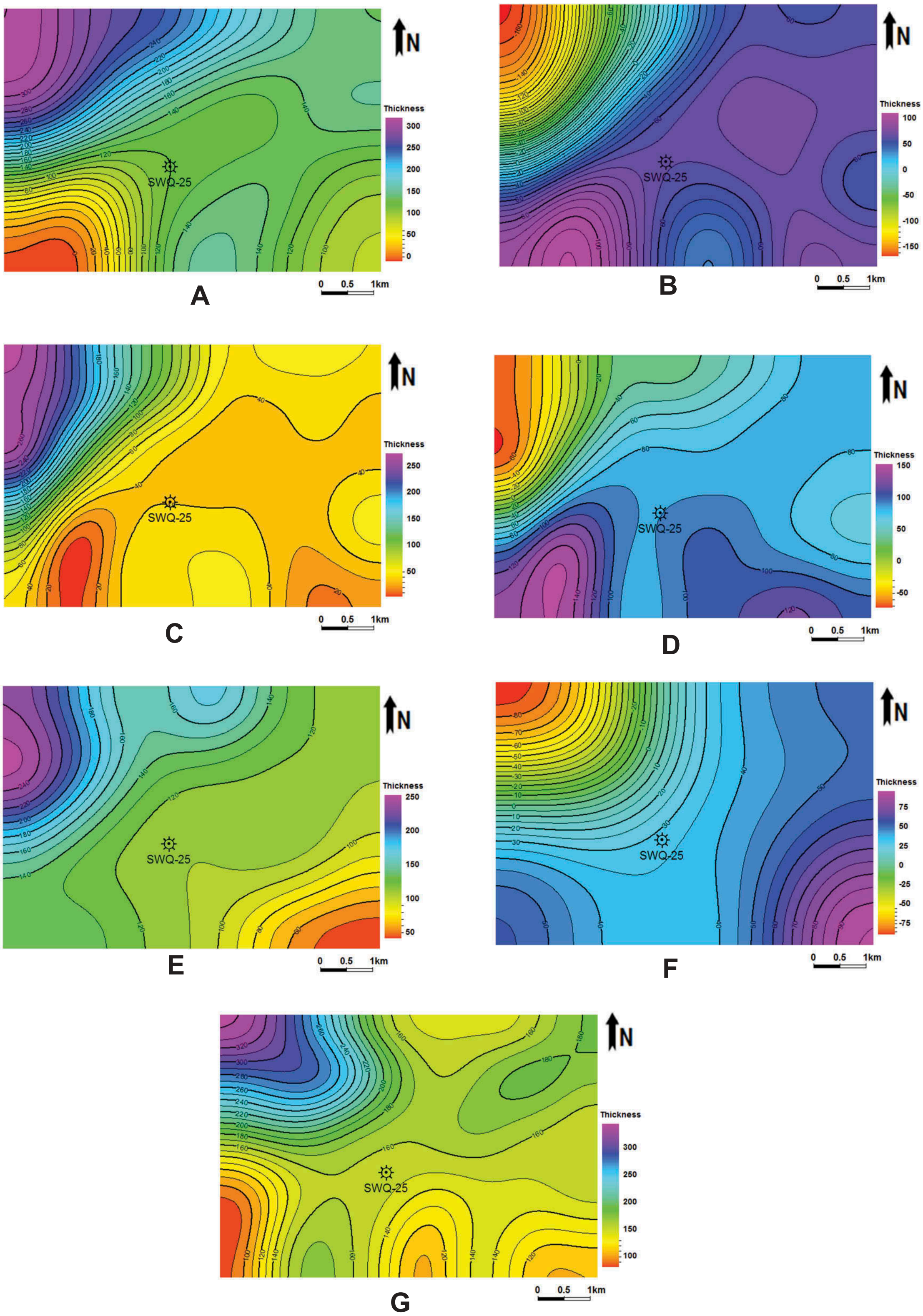

Figure 16. Time-thickness contour maps of the picked seismic intervals representing different members of Abu Roash formation within the South West Qarun (SWQ) Field, Gindi Basin. (a) Abu Roash A member, (b) Abu Roash B member, (c) Roash C member, (d) Abu Roash D member, (e) Abu Roash E member, (f) Abu Roash F member and (g) Abu Roash G member. Note that, the increase of thickness of Abu Roash a, c, e, g members to northwest direction, while, the thickness of Abu Roash b, d and f members decrease to the northwest direction.

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