

## Quantification of Organic richness through wireline logs: a case study of Roseneath shale formation, Cooper basin, Australia.

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**Abstract.** The late Carboniferous-Middle Triassic, intracratonic Cooper basin in northeastern South Australia and southwestern Queensland is Australia's foremost onshore hydrocarbon producing region. The basin comprises Permian carbonaceous shale like lacustrine Roseneath and Murteree shale formation which is acting as source and reservoir rock.

The source rock can be distinguished from non-source intervals by lower density, higher transit time, higher gamma ray values, higher porosity and resistivity with increasing organic content. In current dissertation we have attempted to compare the different empirical approaches based on density relation and  $\Delta$  LogR method through three overlays of sonic/resistivity, neutron/resistivity and density/resistivity to quantify Total organic content (TOC) of Permian lacustrine Roseneath shale formation using open hole wireline log data (DEN, GR, CNL, LLD) of Encounter 1 well. The TOC calculated from fourteen density relations at depth interval between 3174.5-3369 meters is averaged 0.56% while TOC from sonic/resistivity, neutron/resistivity and density/resistivity yielded an average value of 3.84%, 3.68%, 4.40%. The TOC from average of three overlay method is yielded to 3.98%.

According to geochemical report in PIRSA the Roseneath shale formation has TOC from 1 – 5 wt %. There is unpromising correlations observed for calculated TOC from fourteen density relations and measured TOC on samples. The TOC from average value of three overlays using  $\Delta$  LogR method showed good correlation with measured TOC on samples.

### 1. Introduction

The common source rocks are shales and micritic limestones (Tissot, and Welte, 1984). The organic matter is important constituent in source rock. The rock considered source rock with commercial amounts of hydrocarbons with more than 1 wt% total organic content and the commerciality also depend upon other factors like type of organic matter, expulsion/drainage history (Hunt, 1996). The non-source rock also contain organic matter but less than 1 wt% (Passey et al.1990). The methods for evaluation of organic richness and maturity of source rock through laboratory methods are total organic carbon (TOC) analyses, pyrolysis, elemental analysis, vitrinite reflectance, thermal alteration index, gas chromatography and visual kerogen description). The interpretation of organic matter from wireline logs is based on physical properties i.e lower density, higher compressional slowness, high gamma rays, higher resistivity and high hydrogen and carbon concentration. Therefore the logs preferred for source rock evaluations include density, sonic, gamma ray, neutron and resistivity (Serra, 1986; Herron, 1988). In this paper comparative analyses has been carried out to compute total organic richness through different proposed empirical relations and their correlations with geochemical results performed on samples).

#### 1.1 Geological setting

The studied area lies in Nappameri trough of Cooper basin, South Australia. The Cooper basin is predominantly gas producing with light liquid component (Heath, 1989; Boreham and Summons, 1999). The Complete geochemical analyses has been carried out in selected well (Encounter1) with complete set of wireline logs for Roseneath Formation (Beach). This formation comprises mostly shale with streaks of sandstone. In Encounter 1 according to geochemical report the studied formation is most prospective source rock interval within gas window between 3174.5-3369m. Thus the studied area only restricted to this column.



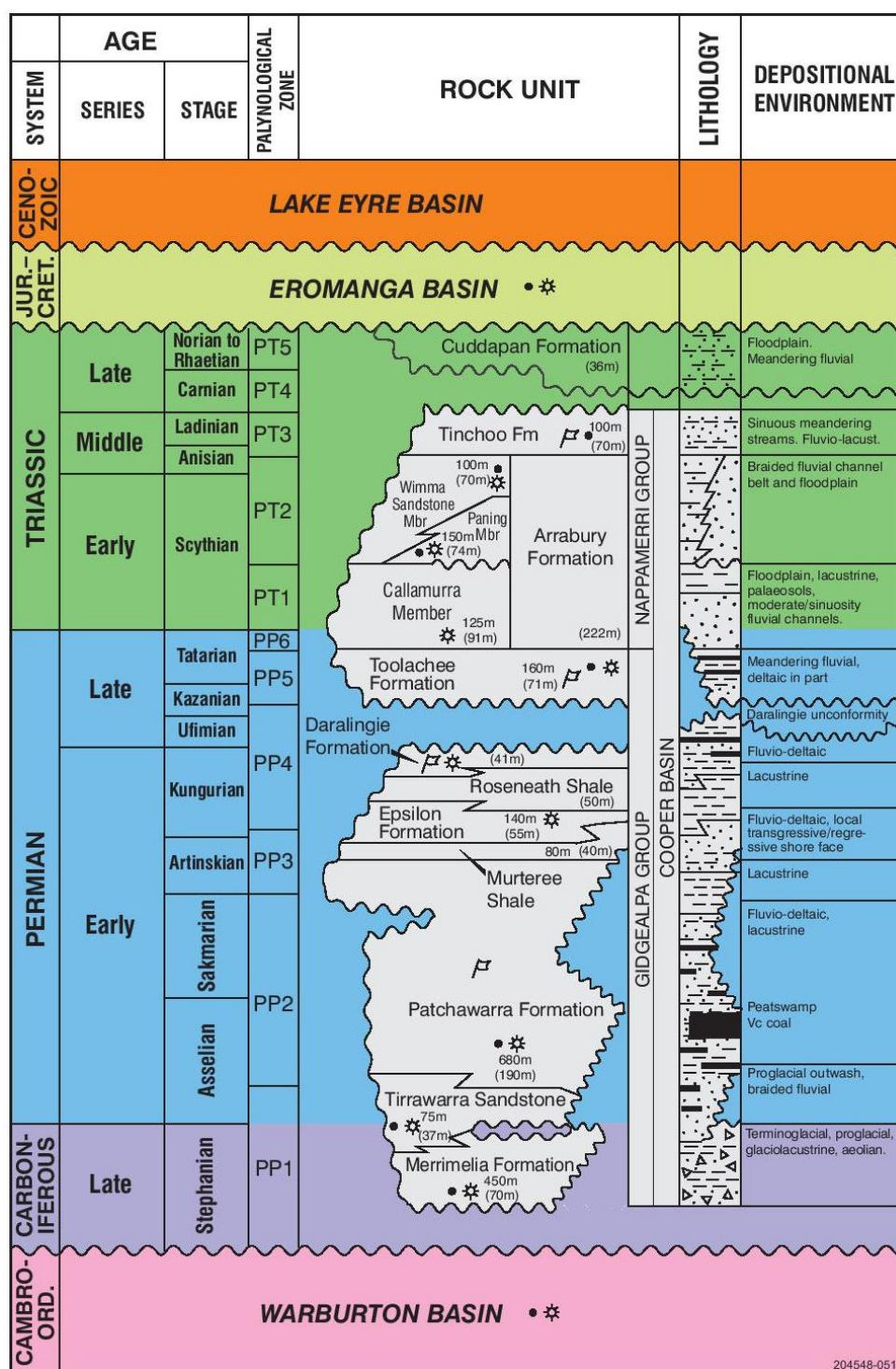


Figure 1: Stratigraphic column for Cooper basin (BEACH ENERGY).

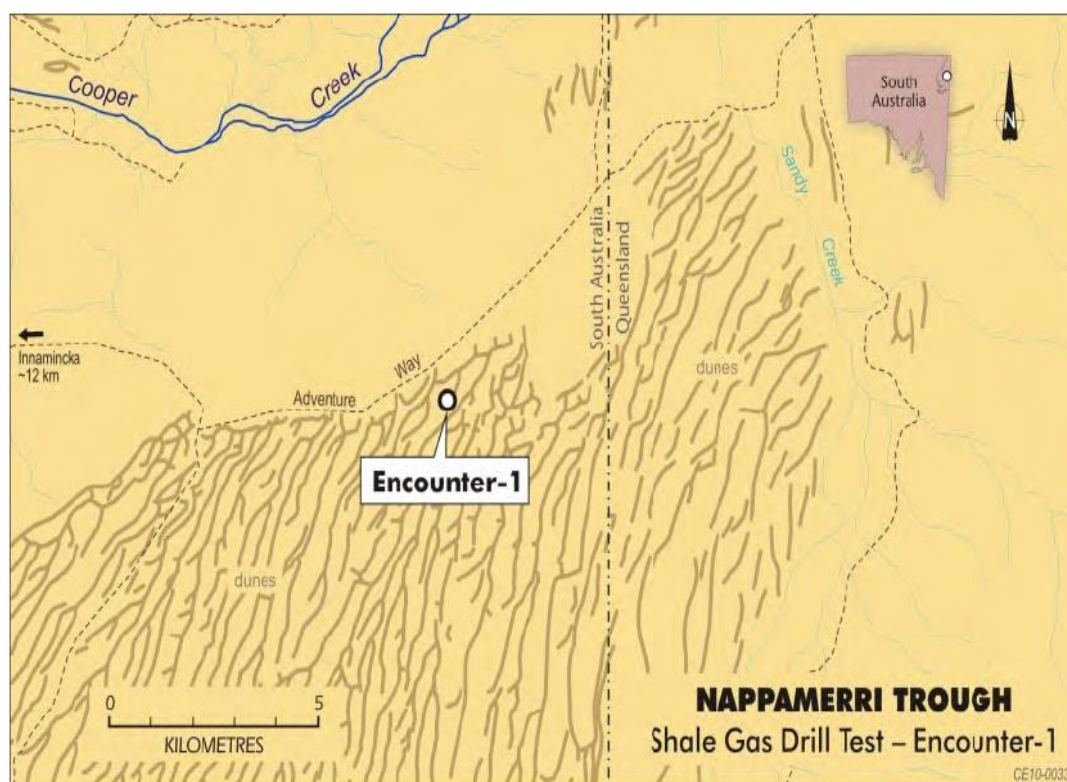


Figure 2: Location map for studied well (BEACG ENERGY).

## 1.2 Log response to organic –rich rocks

The responses of available logs (GR, Rt,  $\phi N\Delta t$ , pb) to organic content can be summarized as follows:

### 1.2.1 Gamma ray Logs

It has been common to identify and quantify organic richness using well logs. Schmoker (1981) proposed the relationship between total gamma ray intensity and organic shales in the Appalachian Basin. The Organic rich source rocks can have high radioactivity and attributed to high gamma ray reading. This natural radioactivity is attributed to uranium, thorium and potassium contents. It can be concluded that high concentration of uranium in source rocks is due to planktons because planktons absorb uranium ions from sea water and trace elements that contributed for Uranium enrichment in source rocks.

### 1.2.2 Formation Density logs

The difference in densities between rock matrix and OM can be used as a tool in identification and quantification of organic richness in source rock. The common matrix densities varies from 2.6-2.9 gm/cc. While OM has specific gravity in the range of 0.95-1.05 gm/cc. This low specific gravity of OM is in line with specific gravity of fresh water. The organic matter is part of the matrix in source rock and reduction in bulk density can be expected with OM (Autric, 2002).

### 1.2.3 Resistivity and sonic logs

The increase in maturity and hydrocarbon generation replace the conductive pore water with nonconductive hydrocarbons that drastically increase resistivity (Meissner (1978)). The resistivity increases in mature source rocks due to generation of non-conducting hydrocarbons (Nixon (1973), Meissner (1978), Schmoker and Hester (1989)). This response makes it possible tool for maturity indicator in organic rich source rock. The OM has low velocity while high transit time 180  $\mu$ s/ft (Mendelson and Toksoz 1985). The log response to OM depends upon distribution of OM in matrix.

The OM has low velocity while high transit time  $180\mu\text{s}/\text{ft}$  (Mendelson and Toksoz 1985). The log response to OM depend upon distribution of OM in matrix.

#### 1.2.4 Neutron logs

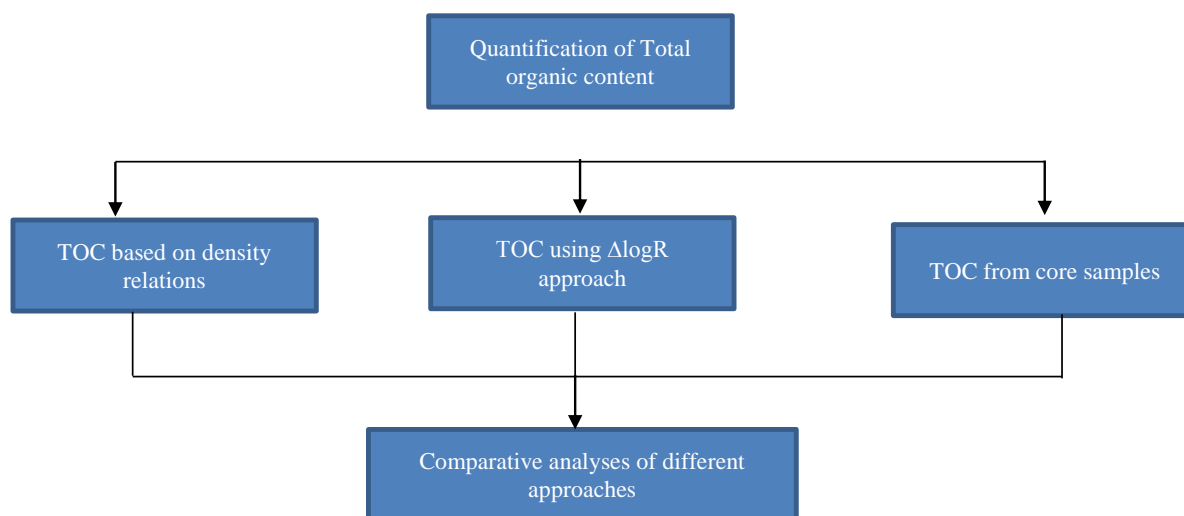
The neutron log porosity is relatively high in source rocks than non-source rocks because neutron tool measure hydrogen concentration which is present in water and hydrocarbons in rocks. The neutron response to OM is average 67 porosity units (Mendelson and Toksoz 1985) while matrix response are relatively close to zero.

## 2. Literature review

The premise studies have revealed the potential importance of wireline logs for source rocks evaluation. Beers, 1945, Swanson, 1966, Schmoker (1981), Supernaw et al., 1978: fertl and Rieke, 1980 used gamma-ray spectral log for identification and quantification of organic richness with concept that gamma ray reading increase with increase in organic matter and organic matter is attributed to uranium associated with organic matter Schmoker (1981) proposed the relationship between total gamma ray intensity and organic richness for Devonian shales but he noted that extreme need to be taken when applying this technique to evaluate source rock in areas outside of specific Appalachians region. Schmoker and Hester (1983) used density log for estimating total organic content with observation that density log can be effected with heavy minerals such as pyrite that must be corrected base on linera relationship between pyrite and organic matter. Dellenbach et al. (1983), Autric and Dumesnil (1984, 1985) developed method using gamma ray and sonic log to provide parameters that linearly relate to organic richness. Murray (1968), Nixon (1973), Meissner (1978) and Schmoker and hester (1989), used resistivity logs for estimation of organic content. Meyer and Nederlof (1984) introduced the method involving combination of resistivity, density and sonic logs by crossplot of density/resistivity or a transit time /resistivity but their method discriminates source and non-source rocks without attempting to quantify the organic richness (Passey et al, 1990). This limitation has been fulfilled by Pessey et al, 1990 by introducing the DlogR overlay method A subsection

## 3 Methodology

The comparative analysis has been carried out for quantification of total organic contents. The TOC analyses were carried out in interactive petrophysics software using fourteen empirical relationships based on density log and  $\Delta$  log method proposed by Passey et al, 1990. The software also give TOC in Wt% by doing regression analyses based on density log. While  $\Delta$  log method was used with an overlay of the resistivity log with sonic, density, or neutron logs and then their average TOC wt% were estimated. The flowchart of methodology is given below:





The  $\Delta \log R$  method used the resistivity log with properly scaled on porosity logs. The technique used the concept that two curves parallel to each other and can be overlain in organic clean rocks while separation between two curves occur in organic rich rocks. This separation is termed as  $\Delta \log R$  which is used to compute TOC in wt%.

Therefore, density ( $\rho b$ ), sonic ( $\Delta t$ ), neutron ( $\phi N$ ) and resistivity (LLD) were properly scaled (-100  $\mu\text{sec}/\text{ft}$ , 0.50 fraction porosity per two logarithmic resistivity cycles, i.e. a ratio of -50  $\mu\text{sec}/\text{ft}$  to one resistivity cycle). The baseline conditions were calculated in fine-grained non-source rocks when two curves overlain each other. The separation of two curves were established as organic rich intervals while non-source rock intervals were established on overlain conditions of two curves. The expressions used to calculate  $\Delta \log R$  are::

$$\Delta \log R_{\text{sonic}} = \log 10\left(\frac{R}{R_{\text{baseline}}}\right) + 0.02(\Delta t - \Delta t_{\text{baseline}}) \dots\dots\dots(1)$$

$$\Delta \log R_{\text{Neutron}} = \log 10\left(\frac{R}{R_{\text{baseline}}}\right) + 4.00(\phi N - \phi N_{\text{baseline}}) \dots\dots\dots(2)$$

$$\Delta \log R_{\text{Density}} = \log 10\left(\frac{R}{R_{\text{baseline}}}\right) - 2.50(\rho b - \rho b_{\text{baseline}}) \dots\dots\dots(3)$$

Where  $\Delta \log R$  is separation,  $R$ ,  $\Delta t$ ,  $\rho b$  and  $\phi N$  are resistivity in ohm-m, compressional slowness in  $\mu\text{sec}/\text{ft}$  and neutron porosity in fraction respectively and  $R_{\text{baseline}}$ , are resistivity corresponding to  $\Delta t_{\text{baseline}}$ ,  $\phi N_{\text{baseline}}$  and  $\rho b_{\text{baseline}}$ . The constant values 0.02, 4.00 and 2.50 are the ratios between scales of resistivity and each of sonic, neutron and density log. The empirical relations used to compute TOC is ::

$$TOC = (\Delta \log R) * 10^{(2.297 - 0.168 * LOM)} \dots\dots\dots(4)$$

Where TOC is total organic content (wt%) and LOM is measured level of maturity which is obtained from vitrinite reflectance or thermal alteration index using maturation indicator (Hood et al(1975)).

### 3.1 Use of Sonic/resistivity overlay

The resistivity log with range 0.1-1000ohm-m in logarithmic scale and sonic log with 200-0  $\mu\text{s}/\text{ft}$  in linear scale showed good overlay. The expression used to compute  $\Delta \log R$  is :

$$\Delta \log R_{\text{sonic}} = \log 10\left(\frac{R}{R_{\text{baseline}}}\right) + 0.02(\Delta t - \Delta t_{\text{baseline}})$$

Where  $\Delta \log R$  is separation between curves,  $R$  is resistivity in Ohm-m,  $R_{\text{baseline}}$  is resistivity corresponding to  $\Delta t_{\text{baseline}}$ , 0.02 is based on ratio of compressional slowness cycle amount per one resistivity cycle. For Enconter 1 well,  $R_{\text{baseline}} = 10\text{ohm-m}$  and  $\Delta t_{\text{baseline}} = 100 \mu\text{s}/\text{ft}$ . The TOC were computed using empirical relations given below:

$$TOC = (\Delta \log R) * 10^{(2.297 - 0.168 * LOM)}$$

The TOC calculated using this relation is compared with TOC measured from geochemical analyses of samples represented by black dots.

## 4 Results and Discussion

The correlation were established between TOC from logs and TOC from samples which clearly indicated accuracy of each method. The TOC from density relation is 0.56 wt% (averaged) which is inconsistent with TOC from  $\Delta \log R$  method (3.98 wt%) and core samples as shown in Figure 3-7 with volume of shale and lithology determined using gamma ray log. The comparative analyses were carried out between TOC from density relations,  $\Delta \log R$  and TOC from samples. There is promising correlations were observed between  $\Delta \log R$  averaged and TOC from samples. While the individual response of the sonic/resistivity, neutron/resistivity and density/resistivity overlay did not indicate the appreciable correlation with organic richness from samples. Similarly the unpromising correlation observed between organic richness by density relation and organic richness from samples accuracy of

the standard deviation of difference (absolute error in wt%) between TOC from samples and TOC from log were calculated. The standard deviation of TOC from averaged  $\Delta \log R$  method and samples is  $\pm 1.7$  which indicate very promising correlation between them while standard deviation of difference for individual sonic/resistivity, neutron/resistivity and density/resistivity overlay are  $\pm 2.3$ ,  $\pm 2.10$  and  $\pm 2.01$  respectively. The Standard deviation for TOC based on density regression and density average are 2.07 and 2.48 respectively as shown in Table 1-5 below.

**Table 1: Comparison of accuracy between TOC averaged  $\Delta \log R$  and Sample.**

Sample No.	TOC_sample (wt%)	TOC_Log (wt%)	Absolute Error (wt%)
1	9.02	4.4017	4.6183
2	4.75	3.9791	0.7709
3	1.95	2.05	-0.1
4	6.12	4.3711	1.7489
5	2.35	3.9708	-1.6208
6	6.43	3.6706	2.7594
7	6.82	6.7	0.12
8	3.72	3.6903	0.0297
9	2.03	2.1	-0.07
10	2	4.2	-2.2
11	2.11	2.11	0
12	2.48	3.93	-1.45
13	2.31	3.9492	-1.6392
14	1.85	1.9	-0.05
15	2.8	2.8	0
16	1.58	1.58	0
17	1.8	3.333	-1.533
18	2.17	3.7003	-1.5303
Standard deviation of difference = $\pm 1.7$			

$\pm 1.7$

**Table 2: Comparison of accuracy between TOC from sonic/resistivity overlay and Sample**

Sample No.	TOC_sample (wt%)	TOC_Log (wt%)	Absolute Error (wt%)
1	9.02	0	9.02
2	4.75	0	4.75
3	1.95	0	1.95
4	6.12	0.2276	5.8924
5	2.35	0	2.35
6	6.43	0	6.43
7	6.82	0	6.82
8	3.72	0	3.72
9	2.03	0	2.03
10	2	0	2
11	2.11	2.4184	-0.3084
12	2.48	0	2.48
13	2.31	0	2.31
14	1.85	0	1.85
15	2.8	0	2.8
16	1.58	0	1.58
17	1.8	0.0146	1.7854
18	2.17	0.6856	1.4844
Standard deviation of difference = $\pm 2.3$			

$\pm 2.3$

**Table 3: Comparison of accuracy between TOC from neutron/resistivity overlay and samples.**

Sample No.	TOC_sample (wt%)	TOC_Log (wt%)	Absolute Error (wt%)
1	9.02	4.0635	4.9565
2	4.75	3.7269	1.0231
3	1.95	3.7819	-1.8319
4	6.12	4.1051	2.0149
5	2.35	3.7861	-1.4361
6	6.43	3.6253	2.8047
7	6.82	4.2676	2.5524
8	3.72	3.5184	0.2016
9	2.03	4.1555	-2.1255
10	2	4.0198	-2.0198
11	2.11	3.8055	-1.6955
12	2.48	3.8793	-1.3993
13	2.31	3.8792	-1.5692
14	1.85	3.6564	-1.8064
15	2.8	3.887	-1.087
16	1.58	3.5459	-1.9659
17	1.8	3.1681	-1.3681
18	2.17	0.6856	1.4844
Standard deviation of difference = $\pm 2.10$			

$\pm 2.10$

**Table 4: Comparison of accuracy between TOC from density/resistivity overlay and samples**

Sample No.	TOC_sample (wt%)	TOC_Log (wt%)	Absolute Error (wt%)
1	9.02	4.1321	4.8879
2	4.75	3.7856	0.9644
3	1.95	3.8345	-1.8845
4	6.12	3.944	2.176
5	2.35	3.613	-1.263
6	6.43	3.5975	2.8325
7	6.82	4.1397	2.6803
8	3.72	3.4197	0.3003
9	2.03	3.6838	-1.6538
10	2	3.7894	-1.7894
11	2.11	3.5164	-1.4064
12	2.48	3.8306	-1.3506
13	2.31	3.5022	-1.1922
14	1.85	3.5125	-1.6625
15	2.8	3.5705	-0.7705
16	1.58	3.3708	-1.7908
17	1.8	2.8132	-1.0132
18	2.17	2.7838	-0.6138
Standard deviation of difference = $\pm 2.01$			

$\pm 2.01$

Table 5: Comparison of accuracy between TOC from density regression and samples.

Sample No.	TOC_sample (wt%)	TOC_Log (wt%)	Absolute Error (wt%)
1	9.02	4.4017	4.6183
2	4.75	3.9791	0.7709
3	1.95	4.0754	-2.1254
4	6.12	4.3711	1.7489
5	2.35	3.9708	-1.6208
6	6.43	3.6706	2.7594
7	6.82	4.3119	2.5081
8	3.72	3.6903	0.0297
9	2.03	4.1038	-2.0738
10	2	4.0793	-2.0793
11	2.11	4.1292	-2.0192
12	2.48	3.9521	-1.4721
13	2.31	3.9492	-1.6392
14	1.85	3.8227	-1.9727
15	2.8	3.9609	-1.1609
16	1.58	3.6756	-2.0956
17	1.8	3.333	-1.533
18	2.17	3.7003	-1.5303

Standard deviation of difference =  $\pm 2.07$ 

Table 6: Comparison of accuracy between TOC from averaged density relations and Samples

Sample No.	TOC_sample (wt%)	TOC_Log (wt%)	Absolute Error (wt%)
1	9.02	0.6122	8.4078
2	4.75	0.2852	4.4648
3	1.95	0.8058	1.1442
4	6.12	1.2296	4.8904
5	2.35	0.7699	1.5801
6	6.43	0	6.43
7	6.82	0	6.82
8	3.72	0.9223	2.7977
9	2.03	0.6077	1.4223
10	2	0.7204	1.2796
11	2.11	2.878	-0.768
12	2.48	0	2.48
13	2.31	0.9647	1.3453
14	1.85	0.4037	1.4463
15	2.8	0.4287	2.3713
16	1.58	0.3422	1.2378
17	1.8	1.0673	0.7327
18	2.17	1.5766	0.5934

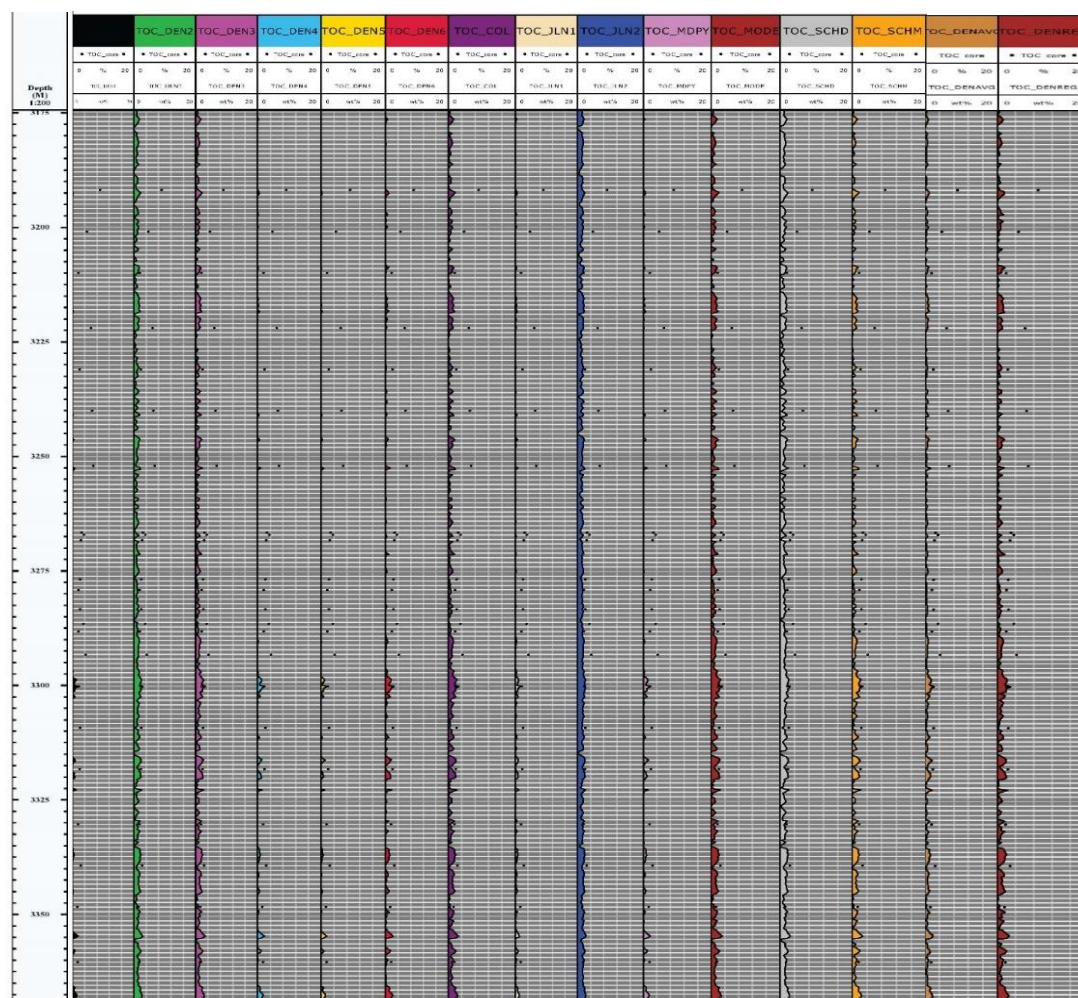
Standard deviation of difference =  $\pm 2.48$ 

Figure3: Showing comparison between TOC calculated from density relations and TOC measured on samples for Roseneath Formation.

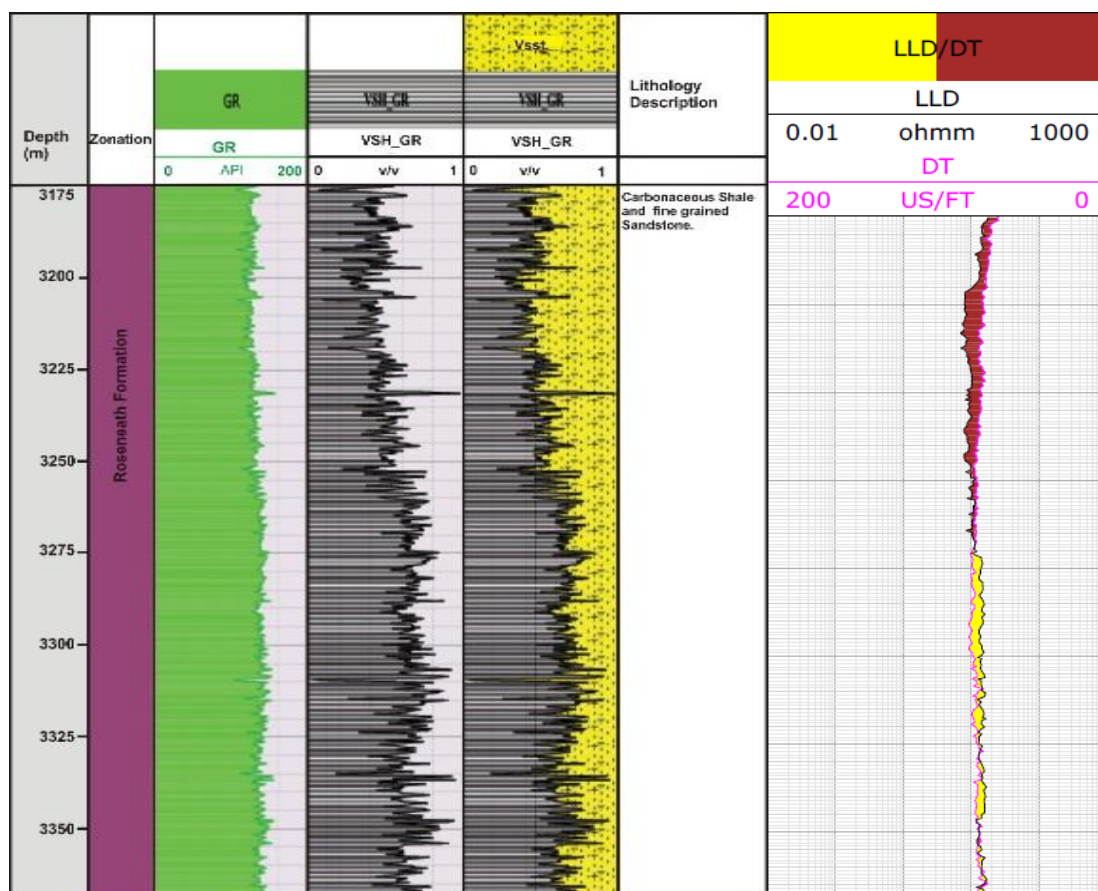
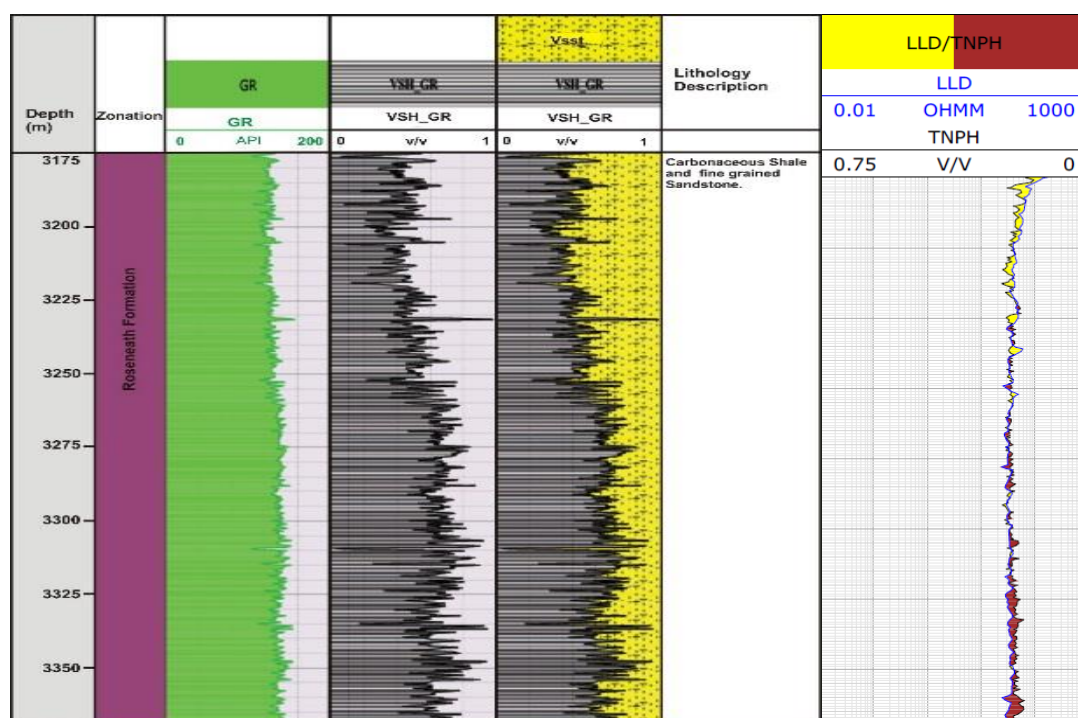
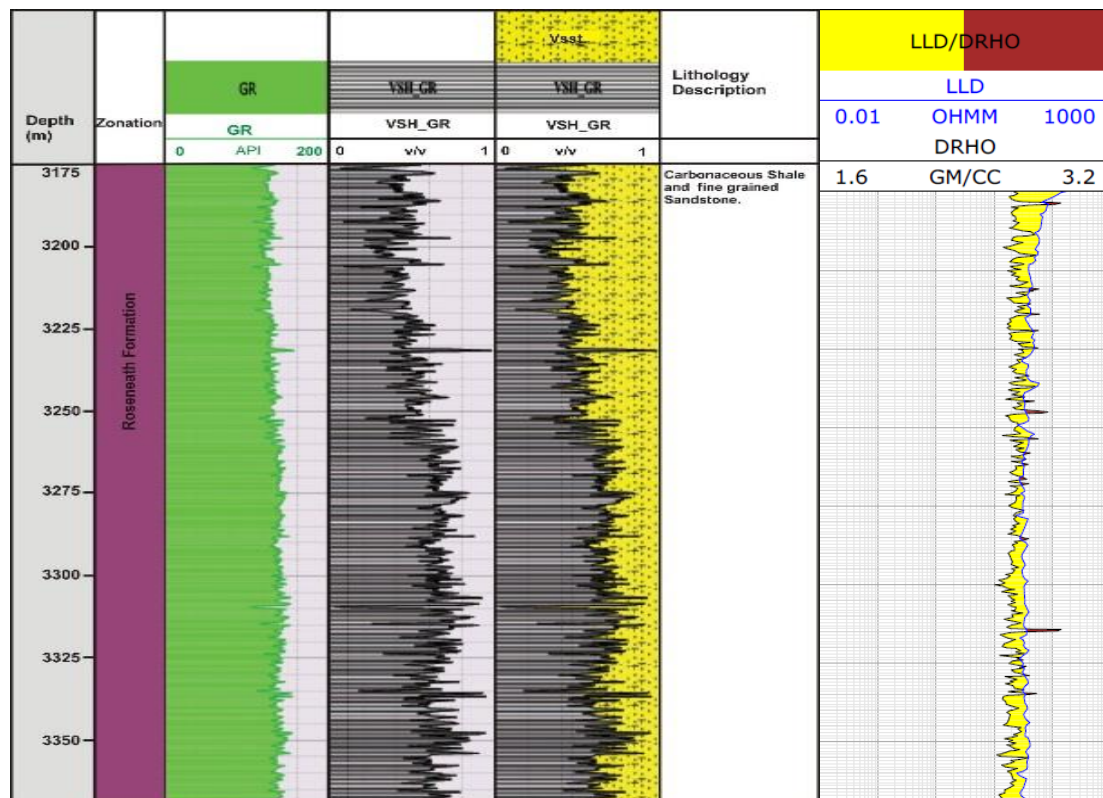
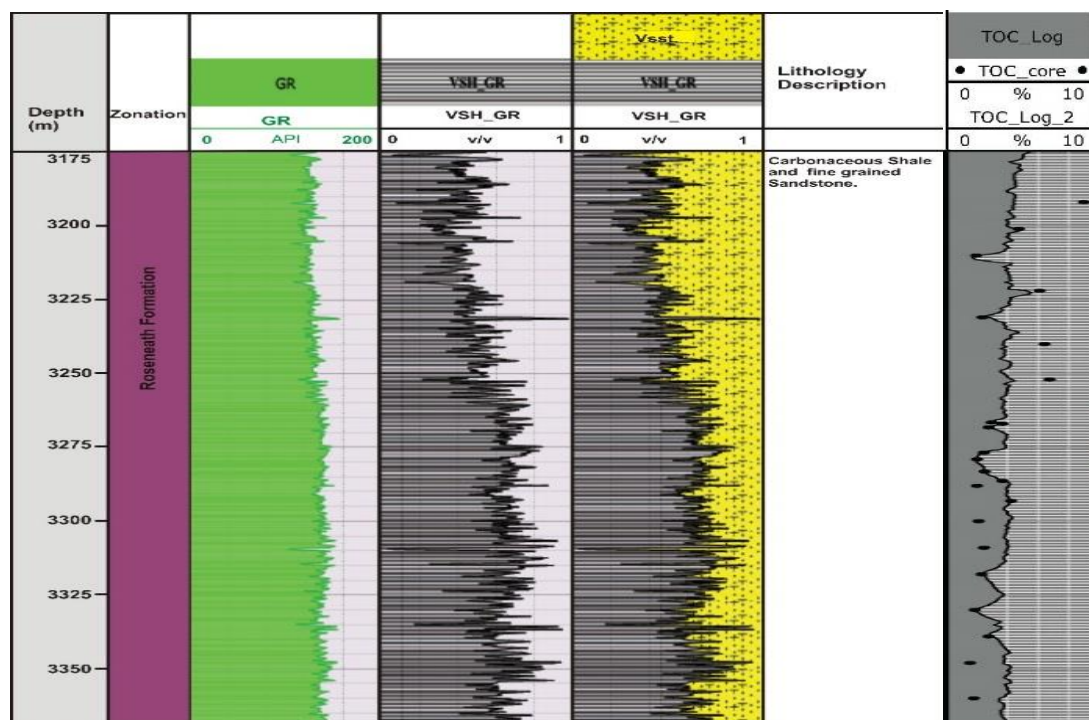


Figure 4: TOC calculated from resistivity/sonic relations.

Figure 5: TOC calculated from  $\Delta \log R$  from neutron/resistivity overlay.



Figure 6: TOC calculated from  $\Delta \log R$  from density/resistivity overlayFigure 7: Showing promising correlation between TOC calculated from averaged  $\Delta \log R$  and TOC measured on samples.

## 5 Conclusion

The source rock evaluation from wireline logs is easy and quick method. The evaluation is based on response of each wireline logs (GR, CNL, DEN, DT,LLD) to increasing organic content. The increase of gamma ray, compressional slowness, neutron porosity, resistivity and decrease of density may be the consequence of increase in organic matter.

The comparative analyses indicated that the empirical relations proposed on density relations may be side specific and may not give promising results for other formation. According to PIRSA 2011, the Roseneath formation is kerogen type II and amount of TOC is 1 -5 wt% .The TOC from density relations vary from 0- 1.9 wt% with averaged 0.56 wt% for Roseneath formation which is inconsistent with sample data and published data. The TOC from sonic/resistivity, neutron/resistivity and density/resistivity overlay are 3.84 wt% , 3.68 wt% and 4.40 wt% averaged. While TOC from averaged of three  $\Delta \log R$  method is vary from 2-6wt% and 3.98 wt% averaged which is consistent with sample data. Therefore, the averaged TOC from  $\Delta \log R$  method is preferred which indicated that Roseneath formation has appreciable amount of organic matter. The log technique can be successful for quantification of organic richness if it is correlated with laboratory results. The result from  $\Delta \log R$  method showed good agreement with laboratory results.  $\Delta \log R$  is quick and reliable method to quantify organic richness. It is recommended to use average of  $\Delta \log R$  methods using different log suits for identification and quantification of organic richness before sampling of intervals.

The maturation history should be known before evaluating organic richness of formation.

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