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# SOURCE ROCK EVALUATION WITH INTERPRETATION OF WIRELINE LOGS: A CASE STUDY OF LOWER INDUS BASIN, PAKISTAN

*N. AADIL, M.H. TAYYAB and A.M. NAJI

Department of Geological Engineering, University of Engineering and Technology, Lahore, Pakistan

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The qualitative interpretation of the log data succeeds in translating the inherited log responses into organic content and source rock identification. The quantitative interpretation of the petrophysical parameters helped in determination of the total organic content and source rock potential. The criteria for distinguishing shale from sedimentary layers are low density, high sonic transit time, high porosity and high resistivity of shales. The responses of wireline logs in relation to the increasing of organic matter (OM) content is detected through crossplot technique. By this way, the organic matter is identified with increasing in gamma-ray values, sonic transit-time, neutron porosity, resistivity and with reduction in the formation bulk density. The open hole well log data (DLL, FDC, BHC and CNL) of SANN-1 well of Kirthar Trough, Southern Indus Basin (Sindh province) Pakistan, is utilized to determine the organic content of Lower Goru and Sember formations. In this paper, an attempt was made to establish a quantity correlation between standard well logs (sonic, density, neutron and resistivity) and total organic carbon by means of a technique called ΔLogR. In calculating total organic carbon content (TOC), porosity/resistivity overlay technique was used. TOC measured by Δ logR technique at depth interval between 3270 to 3585 meters yielded an average value of 2.78% for Lower Goru Formation and 3.31% for Sember formation. These values were in agreement with the reported values in the literature.

**Keywords**: Kirthar trough, Southern Indus Basin, Petrophysical parameters, Goru and Sember Formation, Well log data, TOC

## 1. Introduction

Source rocks are mostly formed of fine-grained sediments such as mudstones and shales, or micritic limestones with sinificant amount of organic content. A rule of thumb, used by petroleum geochemists, is that rocks sourcing commercial amounts of hydrocarbons normally have a TOC value of more than 1% (by weight) although their ultimate commerciality depends on other factors such as organic matter type and expulsion/drainage efficiency [1].

The literature indicates the use of wireline logs for Source Rock (SR) evaluation. Gamma-ray spectral log technique was used for identifying source rocks with high organic-organic contents [2]. The density log was used for estimating organic matter content [3]. Dellenbach et al. used transit-time and gamma-ray curves and showed a linear relationship with organic richness [4] while Meyer and Nederlof (1984) introduced a method involving a combination of resistivity, density and sonic logs which differentiates between source rocks and nonsource rocks from combination of logs [5]. Multivariate analysis of log data was used to characterize source rocks. Passey et al. (1990) invented a new technique called ΔlogR [6]. This technique employs the overlaying of porosity logs (sonic, density and neutron) and resistivity log for identifying and calculating total organic carbon [7].

The interpretation of Organic Matter (OM) from Wireline Logs (WLL) is confirmed from lower density, slower sonic velocity or higher sonic transit time, frequently higher uranium content, higher resistivity and higher hydrogen and carbon concentrations. Therefore, the logs used for this purpose include density, sonic, gamma ray, neutron and resistivity [8]. This paper discusses the effect that organic matter has on the response of common well logging tools, and proposes an easily implemented curve overlay method that is calibrated for organic richness and maturity.

***Area of Study*** - The research has been carried out in the Kirthar Trough of Southern Indus Basin, Sindh province, Pakistan [9, 10]. In Kirthar Trough, the study area (Figure 1) is considered as one of the promising areas scattered all over the Southern part of this petroliferous province. Accordingly, intensive exploration and drilling were done in the previous years. The selected well is SANN-1 which had been evaluated geochemically for source rock [11] and has a complete set of well log data for the evaluated rock units (Cretaceous Lower Goru and Sember Formations). In SANN-1, according to the Geochemical report, the most prospective source-rock interval within the oil window occurs between 3,270 and 3,585 m. The Lower Goru and Sember Formation at this depth are within the zone of peak oil generation. Geochemical data provided,

* Corresponding author : naseemaadil90@gmail.com

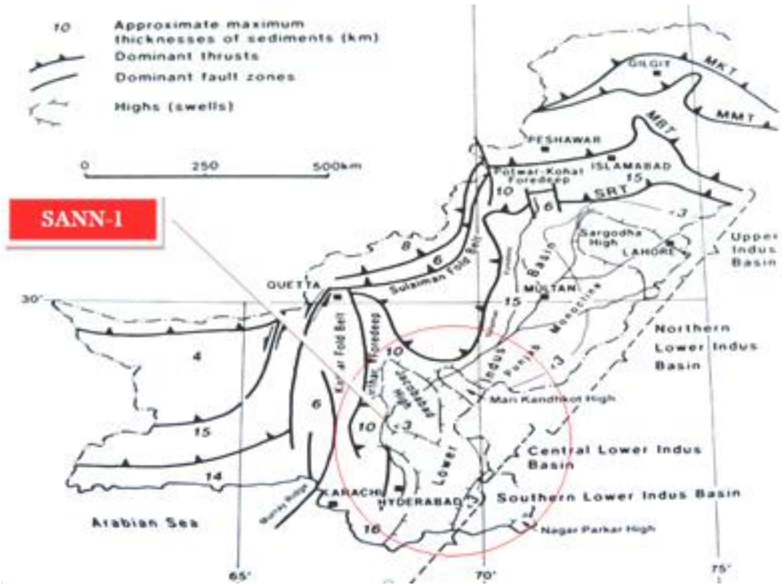


Figure 1. Location Map of Southern Indus Basin and SANN-1 well

supports the existence of high quality oil and gas source rocks throughout the well, with this 315-m-thick interval between 3270-3585 m in the Sember and overlying Lower Goru Formation . Thus we restricted our study only to this column. The formations comprises mainly of shale with thin streaks of sandstone as shown in stratigraphic column (Figure 2).

## 2. Log Responses of Organic-Rich Rocks

The expected responses of the available logs (GR, ρb, Δt, ϕN and Rt) to increasing organic content can be summarized as below :

### 1. *Gamma-ray Logs*

Organic-rich rocks can be relatively highly radioactive due high concentration of uranium, thorium and potassium.

### 2. *Formation Density Logs*

Specific gravities of OM are estimated to be in the range of 0.95 to 1.05 gm/cc [5]. This is in line with the specific gravity of fresh water and contrasts significantly to common matrix densities of 2.6 to 2.9 gm/cc [5, 8]. As the OM is considered to form part of the matrix in a source rock, reduction in bulk density can be expected [12].

### 3. *Resistivity Logs*

Source rocks indicate high resistivity values measured by spherically focused logs due to its anisotropic properties. The resistivity of source rocks increases significantly with increase of free oil in pores and fractures, and with maturity. This makes it possible to use resistivity as a maturity indicator for a given source rock formation. In as much as TOC content is electrically non-conductive, high TOC content can increase resistivity of the host above the resistivity value of the same rock devoid of TOC [13].

### 4. *Sonic Logs*

Average transit time of 180μs/ft is suggested for OM. The acoustic log response to OM is the increasing of the transit time over 140μs/ft depending upon the distribution of organic matter in the matrix [14].

### 5. *Neutron Logs*

The neutron tool measures hydrogen concentration, which is present as water and hydrocarbons in rocks. Neutron log porosity responses are higher in source rocks than in non-source rocks. The neutron response to OM is estimated to average 67 porosity units, whereas matrix responses are typically close to zero.

## 3. Methodology

*ΔLogR technique* is applied in this paper to quantify Total Organic Content (TOC). The overlay of properly scaled porosity log with resistivity curves is used in this technique. In organic lean rocks, the two curves parallel each other and can be overlain. In organic-rich rocks or reservoir rocks, a separation between the curves occurs. By using the gamma ray log, reservoir rocks are identified. Therefore, the separation in organic-rich intervals is measured and called ΔlogR parameter. Such a parameter is used to calculate the total organic carbon content (T0C).

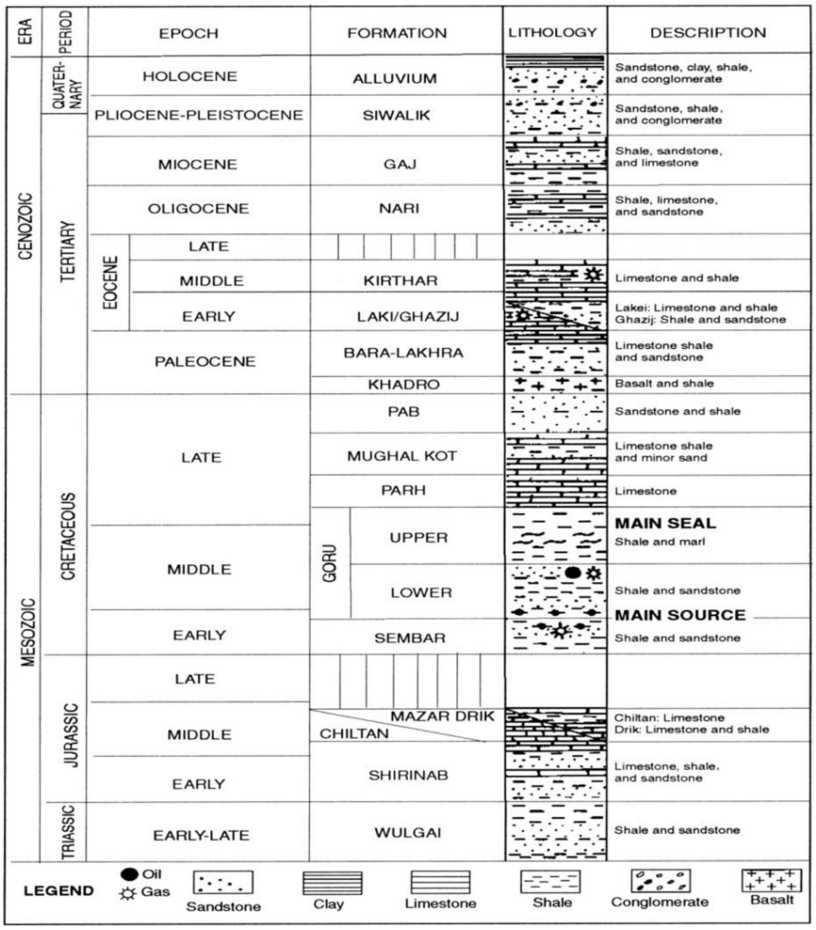


Figure 2. Generalized stratigraphic sequence and occurrence of hydrocarbons in the Southern Indus basin (modified after Shah. 1977; Raza et al., 1990)

By this way, the porosity curves ($\Delta t$, $\varphi N$) and the resistivity curve on Deep Induction Logs (ILD) are scaled (-100 μsec/ft, 0.50 fraction porosity per two logarithmic resistivity cycles, i.e. a ratio of -50 μsec/ft to one resistivity cycle). The curves are base-lined in fine grained non-source rocks. A baseline condition exists when the two curves are directly overlying each other over a significant depth range. It is established in a given lithology of the studied formation and sometimes in the formation above or below. The organic-rich intervals are recognized by separation of the two curves after establishing the baseline. The separation is designated as $\Delta$ log R and can be measured at each depth increment on the scale of the resistivity log.

The algebraic expression for the calculated $\Delta$ logs R from the sonic/resistivity and neutron / resistivity overlays are:

$$\Delta \log R_{Sonic}=\log_{10}(R/R_{baseline})+0.02x(\Delta t - \Delta t_{baseline}) \quad (1)$$

$$\Delta \log R_{Neutron}=\log_{10}(R/R_{baseline})+4.00x(\varphi N-\varphi N_{baseline}) \quad (2)$$

Where $\Delta$ log R is the separation measured in logarithmic resistivity cycle. R is the resistivity measured in ohm-m by the logging tool. $R_{baseline}$ is the resistivity corresponding to the $\Delta t_{baseline}$ and $\varphi N_{baseline}$ values when the curves are baselined in nonsource, clay-rich rocks. $\Delta t$, and $\varphi N$ are the sonic and neutron log readings. The constant values 0.02 and 4.00 are the ratios between the scales of the resistivity and each of sonic and neutron logs, respectively. The $\Delta$ log R separation is linearly related to the TOC content and is a function of maturity. The empirical equation for calculating TOC content in organic rich rocks from $\Delta$ log R is:

$$TOC = (\Delta \log R) \times 10^{(2.297 - 0.1688 \times LOM)}$$

Where TOC is the total organic carbon content and measured in wt% and LOM is the measured level of maturity. LOM is obtained from the vitrinite reflectance (Figure 3) or thermal alteration index by using the maturation indicators [15].

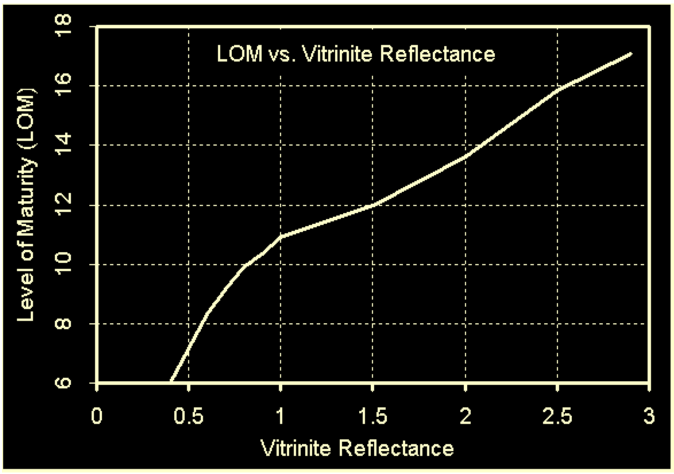


Figure 3. Relationship between vitrinite reflectance and LOM.

## 4. Discussion

### 4.1. *Use of Sonic and Resistivity Log*

Resistivity log, with a registered range of 0.1–1000 ohm-m in logarithmic scale and sonic log, which ranges from 210 to 40 µs/ft in linear scale, show a good overlay in SANN-1 (Figures 4 and 5). This occurred when changing range of special resistivity log is considered from 0.01–1000 ohm-m and the sonic log is 210 to -40 µs/ft. The algebraic expression for the calculation of Δ LogR from the sonic/ resistivity is:

$$\Delta \log R_{Sonic} = \log_{10}(R/R_{baseline}) + 0.02 \text{ x } (\Delta t - \Delta t_{baseline})$$

where ΔLogR is the separation of curves measured in logarithmic resistivity cycles, R is the resistivity measured in ohm-m by the logging tool, Δt is the measured transit time in µs/ft, $R_{baseline}$ is resistivity corresponding to the $\Delta t_{baseline}$ value when the curves are baseline in non source rocks and '0.02' is based on the ratio of transit time cycle amount per one resistivity cycle. In SANN-1 well, $\Delta t_{baseline}$ = 85 µs/ft, and $R_{baseline}$ = 5 omh-m were selected. The TOC in source rocks is calculated from the following empirical equation from ΔLogR is:

$$TOC = (\Delta \log R) \text{ x } 10^{(2.297 - 0.1688 \text{ x } LOM)}$$

According to calculated ΔLogR and LOM = 9 to 11 definition in accordance with experimental results obtained from geochemical analysis of samples, the TOC amounts were calculated and shown in Figure 3 [15]. The TOC from this technique is compared with the results of TOC from geochemical analysis represented by black dots.

### 4.2. *Comparison with Sample Data*

Calibration and accuracy of calculation of TOC - The correlation calculated TOC from log technique and the measured TOC from geochemical analysis (Figure 3) reflects a good agreement between them in many intervals. So, the standard deviation of difference (standard deviation of the absolute error in wt% between measured TOC and ΔLogR derived TOC values) obtained is ± 1.4 (wt%), as shown in Table 1. Similar to the method used for the sonic/resistivity overlay, standard deviation of difference obtained for neutron/resistivity overlay is ±1.37 (wt%), as shown in Table 2.

## 5. Conclusion

Source rock identification and quantification, using wireline logs, is considered as the up-to-date technique. The evaluation system begins by revealing the expected responses of the wireline logs (GR, BHC, FDC, CNL and LLD) to increasing organic content. Increase of gamma ray, sonic travel times, neutron porosity, resistivity and decrease of density may be the result of increased OM content but this is not necessarily always true in all cases. There are no absolute values definable for these logs of organic matter. Porosity/resistivity techniques clearly show that logs can be used to identify organic-rich formations.

The calculated TOC values derived from Δt/Rt, φN/Rt ranged from 0.2 wt% to more than 6.0wt% for Lower Goru and Sember formations. This indicated their organic character with high percentage of total organic content. Therefore, the calculated TOC, as derived from these overlays reflect that the Lower Goru and Sembar formations are the most important source rocks in this study area with considerable quantities of organic matter.

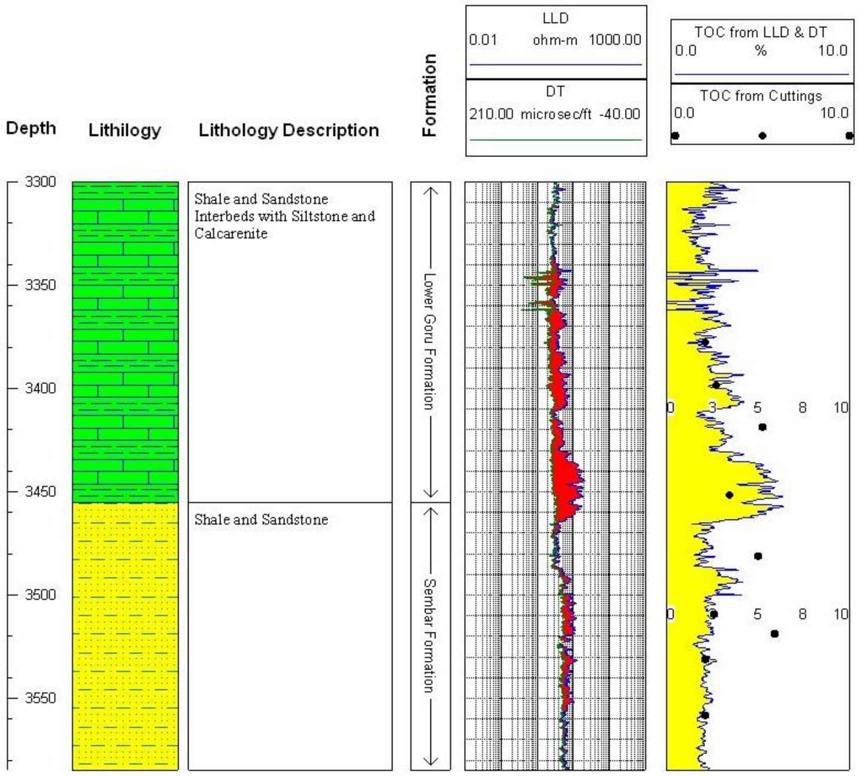


Figure 4. Resistivity/Sonic overlay of Lower Goru and Sembar formations in SANN-1 well.

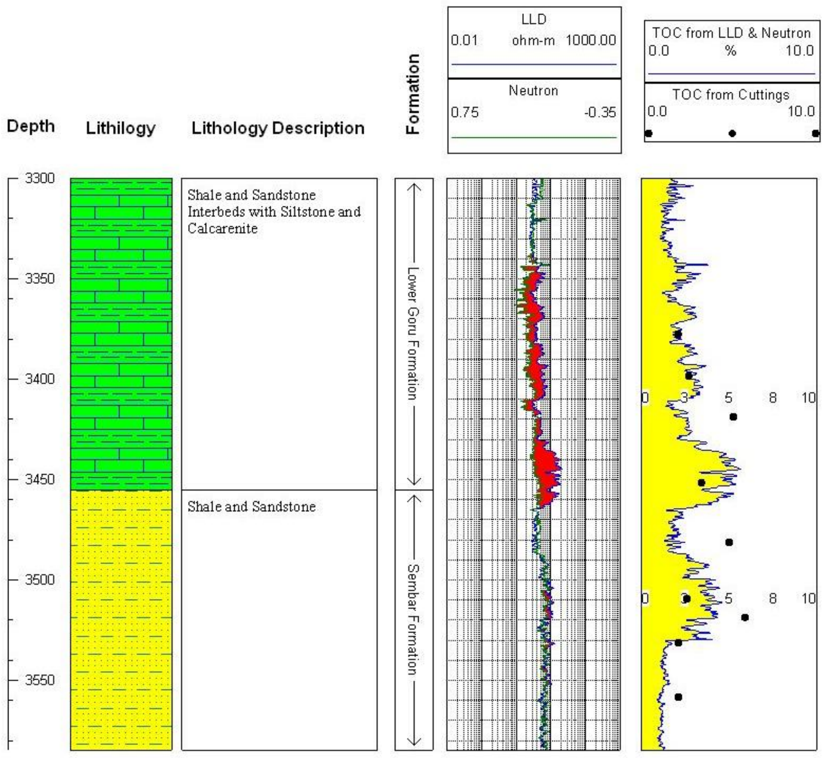


Figure 5. Neutron/Resistivity overlay of Lower Goru and Sembar formations in SANN-1 well.

Table 1. Comparison of accuracy of predicted organic richness, by Resistivity/Sonic overlay.

| Sample No. | Measured TOC (wt%) | Calculated TOC (wt%) | Absolute Error (wt%) |
|---|---|---|---|
| 1. | 2.8 | 2.8 | 0 |
| 2. | 3.2 | 3.2 | 0 |
| 3. | 5.1 | 3.2 | 1.9 |
| 4. | 3.3 | 5 | -1.7 |
| 5. | 5 | 3 | 2 |
| 6. | 3 | 3 | 0 |
| 7. | 6 | 3.1 | 2.9 |
| 8. | 3 | 3 | 0 |
| 9. | 2.9 | 2.9 | 0 |
| Standard Deviation of Difference = ±1.4 (wt%) | | | |

Table 2. Comparison of accuracy of predicted organic richness, by Resistivity/Neutron overlay.

| Sample No. | Measured TOC (wt%) | Calculated TOC (wt%) | Absolute Error (wt%) |
|---|---|---|---|
| 1. | 2.8 | 2.8 | 0 |
| 2. | 3.2 | 3.2 | 0 |
| 3. | 5.1 | 3.2 | 1.9 |
| 4. | 3.3 | 5 | -1.7 |
| 5. | 5 | 3 | 2 |
| 6. | 3 | 3 | 0 |
| 7. | 6 | 3.1 | 2.9 |
| 8. | 3 | 3 | 0 |
| 9. | 2.9 | 2.9 | 0 |
| Standard Deviation of Difference = ±1.37 (wt%) | | | |

To enable log techniques to be fully evaluating and successfully applied for quantitative determination of organic matter, it is essential to correlate their results with laboratory geochemical analysis. Results from the $\Delta t/Rt$ and, $\varphi N/Rt$ overlays showed a good agreement with core data in estimating organic carbon content in this area, as shown in Figures 4 and 5.

Further, according to the geochemical report by OGDCL, the average TOC of Lower Goru formation is 2.35 wt% and that for Sembar formation is 3.26 wt%. The TOC measured by $\Delta$logR technique for the same interval yielded an average value of 2.78% and 3.31% for the respective formations. The standard deviation of the difference for both the overlays ($\Delta t/Rt$ and, $\varphi N/Rt$) came out to be ± 1.4 wt% and ± 1.37 wt% respectively (Tables 1 and 2).

**Recommendations**

- Because $\Delta$LogR is a simple and quick method in the recognition of the petroleum source rocks, it is recommended to use this method prior to the sampling of the intervals, where organic-rich layers are encountered.
- The ability to perform the $\Delta$logR technique at a well site using properly-scaled sonic and resistivity curves provides an excellent method for identifying organic-rich intervals to be sampled with a sidewall coring tool.
- The source rock intervals can be identified and evaluated if the maturation history of the formation is known.

## References


[1] J.M. Hunt, Petroleum Geochemistry and Geology. 2nd edition W.H. Freeman and Company, New York (1996)

[2] R.F. Beers, Radioactivity and organic content of some Paleozoic shales. American Assocation of Petroleum Geologists (AAPG) Bulletin **29** (1945) 1.

[3] J.W. Schmoker and T. C. Hester, Oil generation inferred from formation resistivity-Bakken Formation, Williston basin, North Dakota. Transactions of the Thirtieth SPWLA Annual Logging Symposium, paper (1989)

[4] J. Dellenbach, J. Espitalie and F. Lebreton, Source rock logging. Transactions of the 8th European SPWLA Symposium, paper D (1983).

[5] B.L. Meyer and M. H. Nederlof, AAPG Bulletin **68** (1984) 121.

[6] O.R. Passey, F.U. Moretti and J.D. Stroud, AAPG Bulletin **74** (1990) 1777.

[7] M.R. Kamali and A.A. Mirshady, Journal of Petroleum Science and Engineering **45** (2004) 141.

[8] S.L. Herron, L. Letendre and M. Dufour, AAPG Bulletin **72** (1988) 1007.

[9] I.B. Kadri, Petroleum Geology of Pakistan: Karachi, Pakistan Petroleum Limited (1995) pp. 275

[10] V.N. Quadri and M. Shuaib, AAPG Bulletin **70** (1986) 730.

[11] Robertson Research, A Petroleum Geochemical Evaluation of SANN-1 Well, Kirthar Trough, Southern Indus basin, Pakistan: Report Prepared for OGDCL, Pakistan (1989).

[12] Schlumberger, Log Interpretation Principles/ Applications: Houston, Schlumberger Educa-tional Services (1987) 198.

[13] A. Autric and P. Dumesnil, The Log Analyst **26** (1985) 36.

[14] J.G. Flower, Journal of Petroleum Technology **March** (1983) 638.

[15] A. Hood, C.C.M. Gutjahr and R.L. Heacock, AAPG Bulletin **59** (1975) 986.