Petrophysical Characteristics and Uncertainty Analysis Using Well Log Data

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Abstract

In the present study, well logs data of 6 gas and oil wells from the Nile Delta (Qawasim and Abu Madi formations) and Western Desert (Bahariya formation) are investigated in details using Interactive Petrophysics (IP 3.6) software to examine the reservoir properties and characterize the reservoir architecture. In addition, uncertainty analysis was executed on the output petrophysical properties to account for the variations in the output values induced by random, systematic and model-based errors of the input data. The lithological and petrophysical analysis of log data from six wells showed that the Qawasim and Abu Madi formations are clean sandstone. Petrophysical analysis showed good porosity (22%-23.2%) in the pay zone of Qawasim and in Abu Madi (21%) formations. In Bahariya formation, the calculated porosity falls between 16% and 22% for the identified pay zones. The average water saturation of Abo Madhi Pay zones close to 36%, while Qawasim pay zones fall between 19.6 to 24.6 % and in Bahariya pay zones fall between 15.7% to 27.8 %. Typically, low average volume of clay (VCLAVG) reports in both Qawasim and Abu Madi pay zones that fall between 8 % and 12 %, and such value may markedly increase to approach 17.9% as reported in Bahariya zone of pay zones of WD-1 well. Normally, uncertainty and sensitivity analysis in the studied wells showed that in Qawasim formation the N/G is largely affected by clay volume cut-offs, Gamma ray clean, measured Gamma ray and Sw cut-offs. While porosity calculations were strongly affected by clean Gamma ray, measured Gamma ray and porosity cut-offs and hydrocarbon density. However, the major influences on Sw calculations are restricted to Archie parameters (m and n), Sw cut-offs, Gamma ray clean and deep resistivity. Alternatively, clay volume showed a significant sensitivity to clean Gamma ray, measured Gamma ray, porosity cutoff, and clay volume cut-offs

Keywords: *Application of genetic algorithm, Centrifugal Pumps Maintenance, Preventive maintenance.*

1. Introduction

Petrophysical analysis plays an important role in a reservoir study, as it provides the primary input data for characterization of subsurface formations and resources. By definition, formation evaluation involves the process of using borehole measurements to evaluate the subsurface formations. These measurements include basically wireline logging, core analysis and well test. A well log is a record of continuous geophysical measurements of a parameter(s) against depth gathered in a well bore [1]. It is useful to identify/correlate subsurface units, determine physical properties/ lithology of rocks, and the fluids content.

Wireline logs can be categorized based on the principles of operation or usage. This involves either measurable physical parameters or deducted characteristics made from these measurements [2]. Characterizing a reservoir requires qualitative parameters which depend on particular reservoir characteristics such as lithology (sandstone versus limestone), reservoir fluid (oil, water, or gas), rocks sorting (fine grained, coarse grained, medium grained, shaly, clean, porous, fractured) and the materials used while drilling the well as the mud type (fresh water mud, saline water mud, or oil-based mud). Common petrophysical properties needed for formation evaluation typically include porosity, water saturation, permeability, net pay thickness and mineral or rock volumes. The petrophysical parameters are the key factor in the reservoir rock characterization as well as the understanding and predicting the reservoir performance.

Reservoir characteristics of well logs are always associated with some type of uncertainty. The sources of this uncertainty usually associate inherent errors due to input parameters, uncertainties in tools response, and/or errors in laboratory measurement [3]. These error sources are important enough to justify the assessment of uncertainty especially, the uncertainty in reservoir parameters obtained from well logs [4]. Monte Carlo analysis represents a powerful technique to evaluate the probable risk involved in exploration projects, development projects, and estimate the truth of reservoir models [3]. Uncertainty in petrophysical parameters remains a challenge for reservoir characterization, and accurate petrophysical analysis may still involve limited number of skeptic reservoir properties. The first use of Mont carol simulation is reported in the business where the technique is applied to estimate the risk in business projects [5].

2. Methodology

To accomplish the objectives of this work, wireline logs from six wells are utilized. In the present study, six Las files of well log data from ND-1, ND-2, ND-3, ND-4, WD-1 and WD-2 wells were available for analysis. All well logs data analysis and calculations were completed using Interactive petrophysics-IP V3.6 software [6]. Detailed analysis on petrophysical parameters, uncertainties are presented in the following sections:

2.1. Petrophysical analysis

Various techniques have been developed to estimate reservoir properties. The proper technique depends on the available data set and reservoir condition. The various logging techniques currently in use to calculate the reservoir petrophysical properties are derived using the following interpretation procedures:

2.1.1. Lithology Identification

In IP V3.6, two lithology models of multi minerals analysis are developed, either as three mineral components (sandstone, siltstone, and clay) using density and neutron logs, or four minerals' components (sandstone, limestone, dolomite, and clay) if density, neutron, sonic, and photo electric effect logs are available. In the present study, density and neutron logs are available, in addition to gamma ray, resistivity and PE logs that are used in lithology interpretation.

2.1.2 Clay Volume Calculations

Clay volume can be calculated using several methods such as gamma ray log, resistivity log, and neutron-density integration [7]. In the present study, clay volume is estimated from gamma ray log. It is considered the best tools for identifying and calculating the clay volume according to the following equation (1).

$$\mathrm{Vcl\ Gr} = \mathrm{Gr} - \mathrm{Gr\ clean}/\mathrm{Gr\ clay} - \mathrm{Gr\ clean} \quad (1)$$

Where:

GR clean: Gamma ray matrix (clay free zone)

GR clay: Gamma ray shale (100% clay zone)

GR: Gamma ray API-API unit

Vcl: Volume of clay

2.1.3 Porosity Calculations

Porosity is defined as the ratio of pore volume to bulk volume of the rock. Porosity might be total (for whole existing pore volume) or effective porosity (for connected pore) in the rock. Total porosity can be estimated from a single log (sonic, density and neutron) or the combination of two logs (neutron – density), while effective porosity involves subtraction porosity shale from the total porosity of volume of shale.

In the present study, the porosity is calculated using neutron-density logs combination. The density porosity can be calculated from the bulk density measurements of the density log according to equation (2). To calculate a reliable porosity, porosity corrected for shale content from density and neutron logs is calculated using equation (3) and (4). [8] [9].

$$\phi_D = \rho ma - \rho b / \rho ma - \rho f \quad (2)$$

Where:

$\boldsymbol{\rho_{ma}}$: The matrix density

$\boldsymbol{\rho_f}$: The fluid density

$\boldsymbol{\rho_b}$: The log density

Get the corrected neutron and density porosity

$$\phi_{DC} = \phi_D - [\mathrm{Vsh} * (\phi_D)\mathrm{shale}] \quad (3)$$

$$\phi_{NC} = \phi_N - [\mathrm{Vsh} * (\phi_N)\mathrm{shale}] \quad (4)$$

The effective porosity will be determined from equation for gas zone (5). But oil zones, the simple arithmetic average of ϕ_D and ϕ_N is used.

$$\phi e = \sqrt{\phi_{DC^2} + \phi_{NC^2}}/2 \quad (5)$$

Where:

$\emptyset_{DC}$: Corrected Density Porosity log

$\emptyset_{NC}$: Corrected Neutron porosity log

$\boldsymbol{\phi e}$: The effective porosity

2.1.4 Water Saturation

In this study, Indonesia equation is preferred to calculate water saturation because it is flexible to involve the effect of various parameters such as lithological composition, true resistivity (R_t), clay resistivity, tortuosity, (a), and cementation factor, (m). Equation (6) presents the Indonesia formula [7].

$$\frac{1}{\sqrt{R_t}} = \left(\sqrt{\frac{\emptyset^m}{a \times R_w}} + \frac{V_{sh}^{\left(1-\frac{V_{sh}}{2}\right)}}{\sqrt{R_{sh}}} \right) \times S_w^{\frac{n}{2}} \quad (6)$$

To delineate the net pay several porosity, water saturation, and clay content cut-off values have been tested. The optimum cut-off values that seem acceptable industry-wise reported 7% for porosity, 65% for formation water saturation, and 20% for shale volume cut-off. Such values wisely constrained the net pay zones for reservoir intervals with high potential to contain hydrocarbon. All calculations and analysis are completed using Interactive Petrophysics -IP V3.6 software.

2.2 Uncertainty Analysis to petrophysical parameters

Most petrophysical properties used in integrated studies are obtained through a multiple process, including data acquisition (measuring), calibration, processing, and interpretation (Dewan, 1983; Theys, 1997) [10] [11]. Each of these processes has uncertainty that affect the results of a petrophysical analysis. After reservoir characterization and estimation of (Φavg, $\boldsymbol{Sw}_{\mathbf{avg}}$, Vclayavg, and N/G) for all pay zones, the distribution of the possible errors associating the interpretation parameters is delineated. Using errors distributions, Monte Carlo simulation randomizes these parameters and performs multi simulation through the analysis. Subsequently, the results of each simulation are gathered to be displayed in a statistical distribution chart. A typical work flow chart applied in uncertainty analysis is shown in Figure 1.

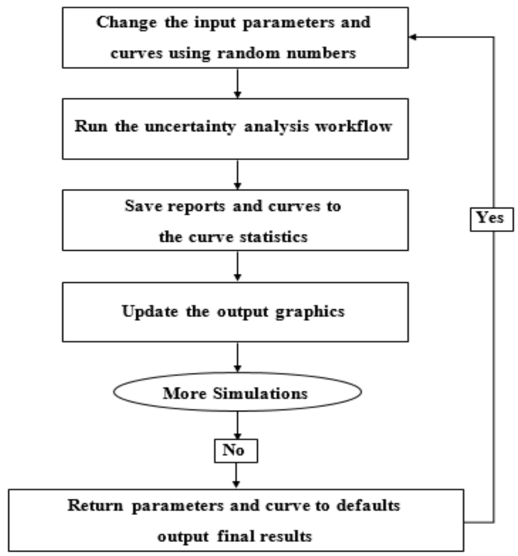

Figure 1: Typical workflow applied in uncertainty analysis for petrophysical interpretation

3. Results and Discussions

The petrophysical characterization of Abo Madi, Qawasim and Bahariya Formations in the wells (ND-1, ND-2, ND-3, ND-4, WD-1 and WD-2) are presented in some details where the average values of reservoir properties are presented. For each well, several petrophysical characteristics including porosity, water saturation, volume of clay, cut-offs, and net/gross are calculated and the full interpretation of each well is analyzed separately. Figure 2 presents a sample of petrophysical interpretation in ND-1 well. While cutoffs and pay results in well ND-1 well are shown in Figure 3.

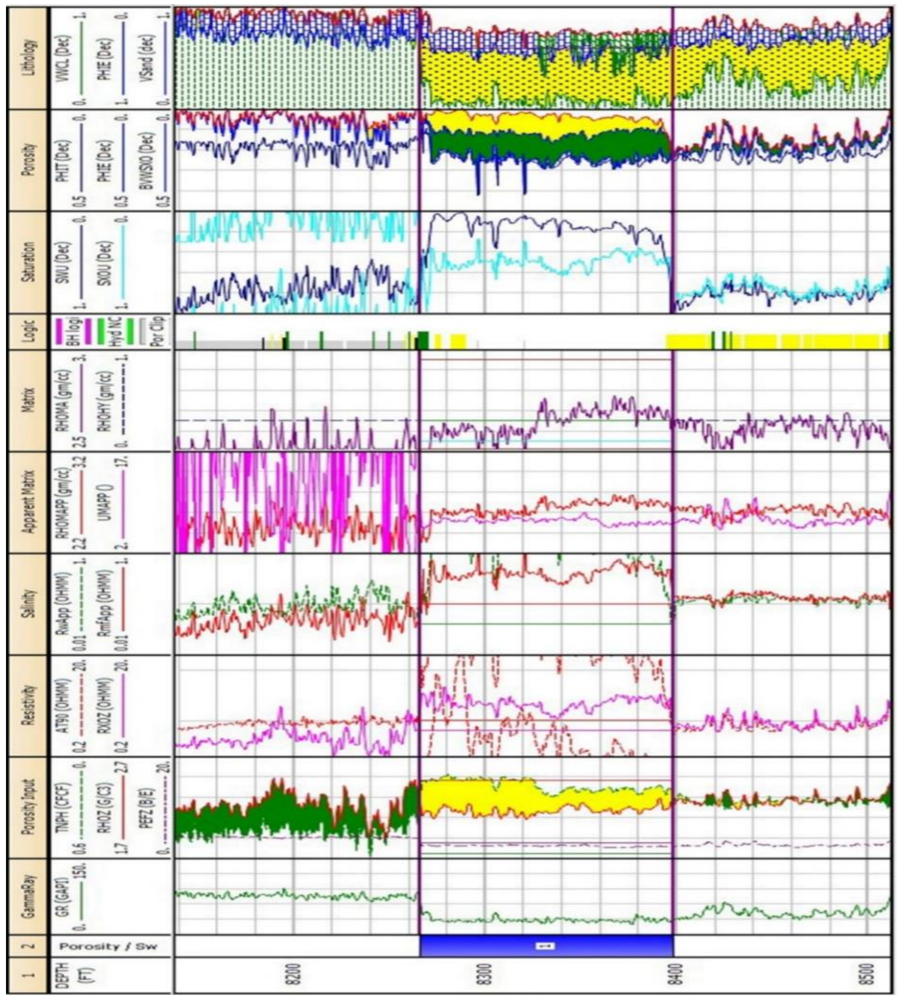

Figure 2: A sample of log analysis in ND-1well.

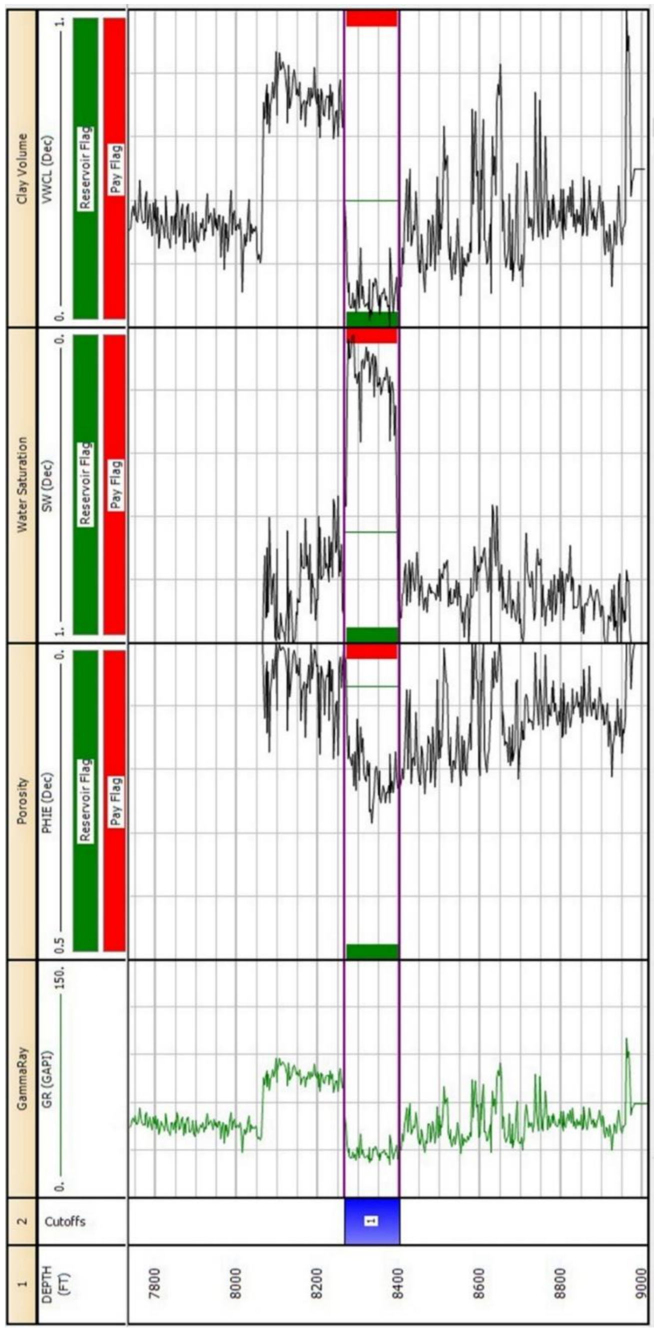

Figure 3: The pay results in ND-1 well.

Petrophysics Qawasim formations

Figure 2 shows an example to petrophysical interpretation on a Triple Combo display for well ND-1 that presents a suit of input log data set and the interpreted reservoir characteristics. The present lithological and petrophysical analysis of Qawasim Formation indicated indicated the development of one pay zone extending a long the depth between 8266ft to 8401.5ft in ND-1well and one pay zone extending between 9154ft to 9234ft in ND-4 well. The Results showed that Qawasim formation clean sandstone pay zone and the low shale content about (9 %) (Table 1). On the Neutron- Density cross plot of lithology identification, all point falls on sandstone line indicating the main lithology of Qawasim formation as sandstone. Generally, the pay results of ND-1 and ND-4 well indicated a marked change in the average water saturation calculations (16.4 % in ND-1) compared to (24.6%) in ND-4 well due to the nature of the fine-grained facies and depending on the cutoff values that used to get representive pay zones (Table 1). The average porosity showed match-able values in ND-1and ND-4 wells (21.1%), and clay content slightly higher value in ND-1 well (9.8%) while in ND-4 well equal (9.1%).

Petrophysics Abo Madi formations

Figure 4 shows an example to petrophysical interpretation on a Triple Combo display for well ND-2 that presents a suit of input log data set and the interpreted reservoir characteristics. Pay analysis in Abo Madi Formation indicated the presence one pay zone in ND-2 well extending from 9968.5 ft to 10080 ft and one pay zone in ND-3 well extending between 9921ft to 10054 ft. The pay results showed match-able in the porosity and water saturation (phi: 23% and sw: 36%) (Table 1). Alternatively, the clay content showed slight increase in ND-3 well (12%) and ND-2 well about (8%).

Table 1: Summary of measured average petrophysical characteristics (pay zone results) in all well.

well	Top (ft)	Bottom, ft	Net pay (ft)	Net/ Gross	$Ø_{AVG}$	SW_{AVG}	VCL_{AVG}
ND-1	8266	8401.5	126	0.93	0.211	0.164	0.098
ND-2	9968.5	10080	94.5	0.848	0.229	0.365	0.081
ND-3	9921	10054	113	0.85	0.232	0.362	0.124
ND-4	9154	9234	56.5	0.706	0.212	0.246	0.091

Conclusions

The GAs technique has been applied to overcome the conventional methods in addressing PM of pump problems with various degrees of success. Many studies have used many techniques and assumptions to find which method is most appropriate for PM of pump problems. The success of a method is based on many aspects such as the size and composition of the power system, the targets, applications and constraints that should be taken into account. GA techniques are not perfect to determine the optimum solutions, but they may achieve appropriate solutions to complex pieces of equipment.

Based on a case study associated with applying GA in the PM of pump problems was demonstrated. Optimum solutions can be identified if appropriate problem encoding, evaluation function and GA parameters were predetermined. The use of integer encoding to represent PM of pump problem variables in a genetic structure can be implicitly considered some of the problem constraints and greatly reduced the PM of pump search space. The results presented above give the integer GA was a robust technique for PM of pump problems and can determine optimum solutions with a wide range of variations in GA parameters. The application of KBS, the formulation of the evaluation function and the design of the GA operators can help in optimizing the GA technique to solve genuine large-scale PM of a pump.

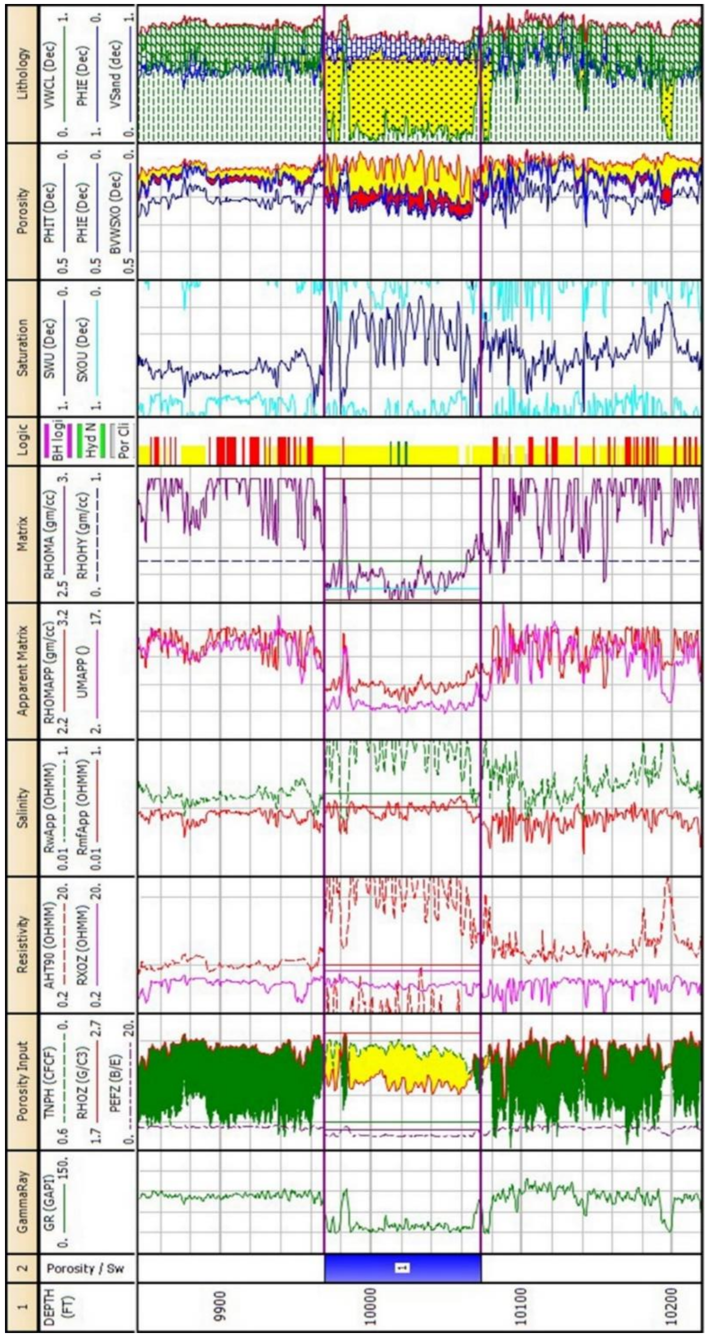

Figure 4: A sample of log analysis ND-2 well.

For each pay zone or reservoir interval in any well, the statistical analysis provides a set of outputs including tabulated values, histograms, and cross plot for each property involved in reservoir characterization. In addition, an example of histograms constructed for average porosity (ϕavg), average water saturation (Swavg), and average volume of clay (Vclavg) in all reservoir intervals of ND-1well is shown in Figure 5. Results of uncertainty analysis (P10, P50 and P90) in all wells showed consistence values in most petrophysical parameters of reservoir results Table 2. Among various reservoir parameters, average porosity and clay volume showed relatively consistent values calculated under different probability (Table 2). Among the items encompassed in uncertainty analysis, N/G showed an obvious instability in calculations of the net pay result in Qawasim zone in ND-1and ND-4 wells. For example in the Qawasim zone of ND-1 well, the N/G calculation varied between 83% at P10 and 95.6% at P90, whereas in Qawasim zone of ND-4 well the N/G calculated values varied between 50% at P10 and 80.9% at P90 (Table 2).

Porosity calculations under uncertainty showed a slightly less estimates in the average porosity compared to the corresponding average calculated by conventional log analysis. These discrepancies in the mean porosity values typically fall within 0.8% in Qawasim pay zone but report approximately 0.3 % in Abu Madi Formation, and in Baharyia formation reported 0.8%. The uncertainty analysis of all pay zone results at P10, P50, and P90 percentiles (Table 2) provides a relatively consistent average porosity values that typically fall between 15 and 24 %. Compared to the conventional log analysis, Sw calculations under uncertainty showed different trends in the calculated average water saturation. The variations in the average value between uncertainty analysis and log analysis do not exceed 0.9% as reported in Abu Madi pay zone but the common change typically falls below 0.1% as seen in both Qawasim and Bahariya .The discrepancy in pay saturation among the various percentiles report its minimal value in Qawasim and Abu Madi formation (3-4%) but in Bahariya formation falls close to 4% (Table 2). The uncertainty in shale content represents a proficient bench mark to indicate the stability of depositional environment of a specific formation. Generally, the discrepancies within Qawasim formation report 7% but report approximately 5 % in Abu Madi formation, but Bahariya formation report 9%. A Tornado plot presents a powerful tool to determine the impact of the input parameters on the output result. Average porosity calculations in pay zone are strongly affected by Gamma ray clean, Gamma ray records, but secondary effect goes Neutron and Density log measurements, Gamma ray and Vclay cut off (Figure 6). Average water saturation calculations have been significantly affected by Archie parameters (m and n), deep resistivity measurements, and Gamma ray clean but an intermediate influence are attributed to Sw cutoff and Vcaly cut off.

Table 2: Reservoir parameter derived from Monte Carlo simulation for all well zones at different probabilities.

Well	Zone	Depth From	Depth TO	Output %	Pay thickness(ft)	NET/GROSS	$Ø_{AVG}$	Sw_{AVG}	VCL_{AVG}
ND-1	Qawasim	8266	8401.5	10	112.5	0.83	0.168	0.194	0.175
				50	125	0.923	0.211	0.164	0.098
				90	129.5	0.956	0.245	0.134	0.025
ND-2	Abu Madi	9968.5	10080	10	75.75	0.679	0.212	0.396	0.139
				50	93.5	0.839	0.23	0.357	0.075
				90	102.5	0.919	0.243	0.309	0.032
ND-3	Abu Madi	9921	10054	10	91	0.684	0.22	0.397	0.176
				50	113	0.85	0.234	0.354	0.122
				90	122.5	0.921	0.246	0.315	0.067
ND-4	Qawasim	9154	9234	10	40	0.5	0.159	0.279	0.142
				50	55.5	0.694	0.215	0.238	0.086
				90	64.75	0.809	0.238	0.202	0.04
WD-1	Zone1	6361.5	6375	10	2.25	0.167	0.164	0.279	0.288
				50	7.25	0.537	0.197	0.237	0.174
				90	11.75	0.87	0.225	0.198	0.053
	Zone 2	6390	6405	10	1	0.067	0.122	0.376	0.297
				50	3	0.2	0.197	0.295	0.169
				90	6	0.4	0.233	0.23	0.019
	Zone3	6561	6620.5	10	6	0.101	0.162	0.46	0.259
				50	16.75	0.282	0.193	0.394	0.131
				90	26.25	0.441	0.216	0.343	0.033
	Zone 4	6793	6857.5	10	37.5	0.581	0.194	0.117	0.212
				50	56	0.868	0.208	0.091	0.164
				90	62.75	0.973	0.223	0.06	0.101
	Zone 5	6959.5	7105.5	10	20.5	0.14	0.178	0.192	0.268
				50	50	0.342	0.2	0.151	0.175
				90	68	0.466	0.221	0.113	0.08
WD-2	Zone 1	6739.5	6752.5	10	10.5	0.808	0.185	0.236	0.208
				50	12.75	0.981	0.208	0.205	0.123
				90	12.75	0.981	0.228	0.174	0.052
	Zone 2	6771.5	6791.5	10	2	0.1	0.141	0.213	0.316
				50	8.5	0.425	0.216	0.171	0.134
				90	11	0.55	0.249	0.142	0.026
	Zone 3	6951.5	6962	10	8.5	0.81	0.209	0.256	0.143
				50	9.5	0.905	0.224	0.224	0.083
				90	10.25	0.976	0.239	0.195	0.037
	Zone 5	7006	7028.5	10	10.5	0.467	0.151	0.39	0.184
				50	19.5	0.867	0.169	0.341	0.112
				90	22.25	0.989	0.188	0.299	0.043
	Zone 6	7055	7061.5	10	1	0.3	0.16	1	0.119
				50	4.5	0.692	0.184	0.419	0.049

				90	4.5	0.846	0.203	0.37	0
	Zone 7	7132	7143	10	0.1	0.02	0.15	1	0.192
				50	0.5	0.045	0.152	0.505	0.104
				90	6.5	0.591	0.201	0.417	0
	Zone 8	7217.5	7278	10	44.5	0.736	0.197	0.144	0.166
				50	49.5	0.818	0.211	0.122	0.114
				90	54.25	0.897	0.224	0.099	0.069
	Zone 9	7404.5	7514	10	35	0.32	0.193	0.31	0.154
				50	47.25	0.432	0.205	0.268	0.106
				90	53.25	0.486	0.219	0.231	0.066

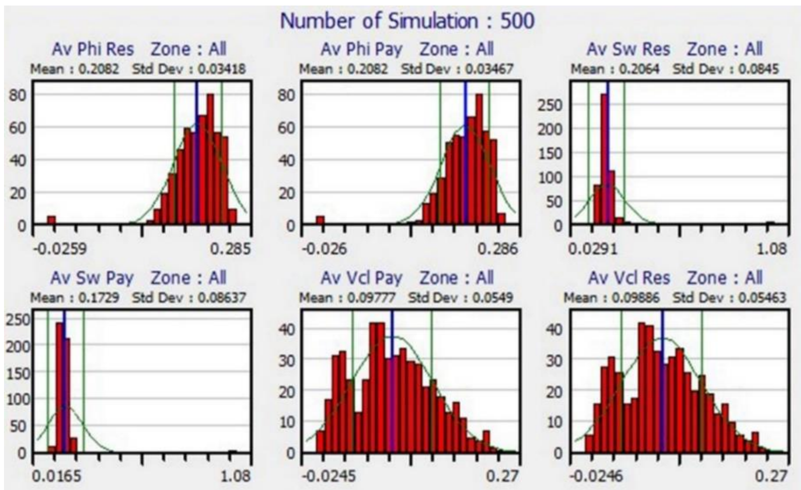

Figure 5: The histograms developed by Monte Carlo simulation for ND-1 well.

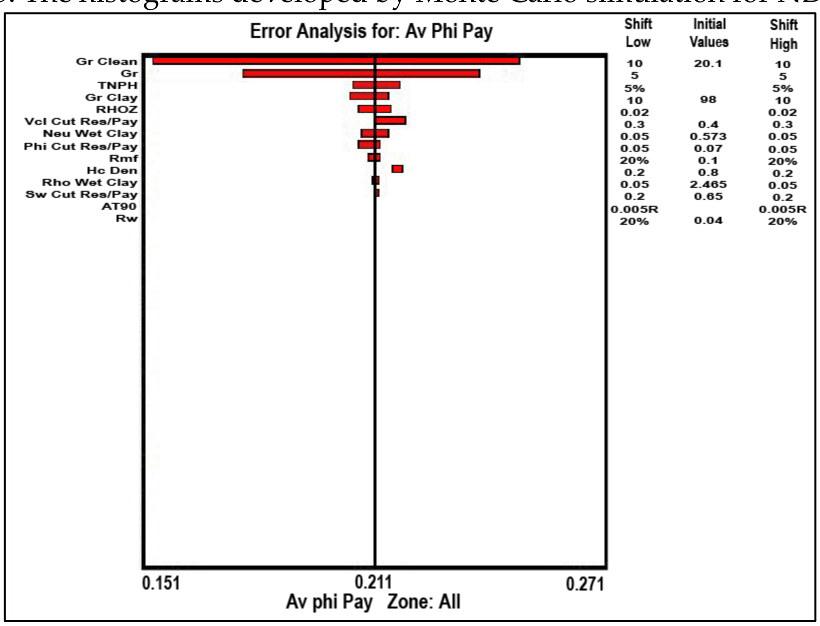

Figure 6: Error Analysis for Average porosity for ND-1.

Conclusions

Petrophysical analysis showed good porosity (22%-23.2%) in the pay zone of Qawasium formation and Abo Madhi formation about (21%). In Bahariya varied between (16% and 22%). The N/G calculated by uncertainty analysis has markedly decreased in the corresponding conventional log interpretation values. Uncertainty analysis of porosity calculation trend to provide a slightly higher estimate in the average porosity value compared to the corresponding average values derived by conventional log analysis. Sw value change in various probabilities (P10, P50, and P90) and fall between (3 and 4%) in Qawasim and Abu Madi formation but in Bahariya formation fall close to 4%. Average clay volume calculations indicated that conventional log analysis inclines towards overestimation compared to the values obtained from uncertainty analysis.Sensitivity analysis showed that the average porosity calculations are strongly affected by Gamma ray clean, Gamma ray records Neutron and Density log measurements. Water saturation calculations showed a major influence by Archie parameters (m and n), deep resistivity measurements, Gamma ray clean, Sw cutoff and Vcaly cut off. Alternatively, for N/G calculation; the Vcaly cutoffs showed the major influence on the output calculated values but intermediate influences are attributed to Gamma ray clean and Sw cutoffs. Limited effects on N/G calculation can be related to porosity cutoffs, and Archie parameters (m). Calculations of average clay volume are, as expected, strongly sensitive to the clean Gamma ray, Gamma ray and Vclay cutoff.

References

[1] Rider, M.H. (1996), The Geological Interpretation of Well Logs. 2nd Ed, Gulf Pub Corp, Houston, ISBN-10: 0884153541, p. 280.

[2] Serra, O. (1984), Fundamentals of Well Log Interpretation: 1, The Acquisition of Logging Data, Elsevier, Amsterdam, ISBN 0-444-42132-7 (U.S.: V. 1), p.423.

[3] Adams, S.J. (2005), Quantifying Petrophysical Uncertainties. Society of Petroleum Engineers. https://doi.org/10.2118/93125-MS

[4] Moore, W.R., Ma, Y.Z., Urdea, J. and Bratton, T. (2011), Uncertainty analysis in well-log and petrophysical interpretations, in Y. Z. Ma and P. R. La Pointe, eds., Uncertainty analysis and reservoir modeling: AAPG Memoir 96, P. 17–28. https://doi.org/10.1306/13301405M963478.

[5] Hertz, D.B. (1964). Risk Analysis in Capital Investment, Harvard Business Review, 42, No.1, p. 95-106

[6] Synergy web site (June 2010), http:// ipdownloads.lr-senergy.com/

[7] Schlumberger (2010), "Interactive Petrophysics Version 3.6 User's Manual", Synergy Ltd., Ternan House, North Deeside Road, Banchory, Kincardineshire AB31 5YR, Scotland

[8] John T. Dewan (1986), Open-Hole Nuclear Logging - State of the Art, SPWLA Twenty Seventh Annual Logging Symposium

[9] Bertozzi, W., Ellis, D.V., and Wahl, J.S. (1981), the Physical Foundations of Formation Lithology

Logging with Gamma Rays, Geophysics 46 (10), pp-1439-1455. https://doi.org/10.1190/1.1441151

[10] *Dewan, J.T. (1983), Essentials of modern open-hole log interpretation, PennWell Books, Tulsa, 361p. ISBN-10: 0878142339*

[11] *Theys, P. (1997), Accuracy – Essential information for a log measurement, SPWLA 38th Annual Logging Symposium, Paper V.*