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Comparison of Classical Archie's Equation with Indonesian Equation and Use of Crossplots in Formation Evaluation: - A case study

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Summary

In petroleum Exploration and Development Formation Evaluation is done to determine the ability of a borehole to produce hydrocarbon. In other words it is the process of "recognizing a commercial well you drills one". Formation Evaluation of the clean reservoir is easy as compared to the shaly reservoirs as former need the application of simple Archie's Equation[7]. But practically shaly reservoirs are encountered most thus the study of shaly reservoir is extremely important. Number of models has been prepared to study the behavior of shaly reservoirs but no one is proved universal as the petophysical properties of shaly sands depends on number of things like volume, type and distribution of clay minerals. Geological and climatic conditions also have great influence.

Introduction

Formation Evaluation of a well needs the analysis of well log data of both pay and non- pay zones. It is done by examining the trend of various records of geophysical properties like natural gamma decay, porosity, density, permeability, spontaneous potential, etc run on different tracks. Then various geophysical parameters are decided as they for formation evaluation.

In the present case study one of shaly sand model is used which is based on the volume of clay i.e. Indonesian Model.[4] This model expressed by equation 1:-

$$S_w = \frac{1}{\sqrt{R_t}\left[\frac{(V_{clay})^d}{\sqrt{R_{clay}}} + \frac{\Phi^m}{\sqrt{aR_W}}\right]} \quad \text{-------------------- 1} \qquad d = 1 - \frac{Vclay}{2}$$

is compared with Archie's Model[7] expressed by equation 3:-

$$S^n_w = FR_w/R_t \quad \text{----------------------2}$$

where is saturation exponent, accepting n= 2 we will get

$$S_w = \left(\frac{aR_w}{\Phi^m R_t}\right)^{1/2} \quad \text{------------------------3}$$

The trend of water saturation (S_w) calculated from both equations w.r.t V_{cl} (Volume of clay) is also studied. Different crossplots[2&5] i.e. resistivity Vs porosity, gamma ray Vs porosity, gamma ray Vs resistivity, & bulk density Vs porosity found very effective in evaluation of shaly reservoirs and in deciding various petrophysical constants and variables.

Data

Data used for this task is provided by Well Logging Services Mehsana Asset (Gujarat), Oil and Natural Gas Corporation Limited. (figure:-1) .Openhole well log data is used Data which is provided in both Digital and Analog(printed) Format. SP, Resistivity, Natural Gamma, Caliper, Neutron Porosity, Density log data is used .The location and well name and number is not permitted to be disclosed as it is against company's policy.

Results and Discussions

Both from Qualitative and Quantitative analysis of log data different zones identified in particular depth ranges are as follows in Table - 1:-

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Name of Zones	Depth range (m)	Remarks
ZONE-A	(1030m - 1043.5m)	Shale
ZONE-B	(1043.5m- 1044.8m)	Coal
ZONEC	(1044.8m - 1046m)	Shale
ZONE-D	(1046m - 1057m)	Oil Water
ZONE-E	(1057m – 1061.2m)	Coal

Table 1:- Zones observed at different Depths

Zone -D is a permeable zone.Oil is observed between depth range from 1046 m to 1053.5 m. Water is observed between depth range from 1053.5 m to 1056.5 m.

It is also observed that even a small amount of shale can harm the effective porosity. The application of Archie's Model[7] get failed in contminated sands (as it is assumed here that Indonesian Model[4] is the good approximation of shaly reservoir as it is considering the affect presence of shale in terms of volume at least).From the Table-2 it can be observed that the shale volume is varying with depth. Just have a look at some points from (1046 m- 1048 m) the average shale content is 18% and there is appreciable difference in $\mathbf{S_w}$. Similarly at other points (1049 m-1053 m) where amount of shale is less (2%), both models are giving similar results. Same trend can be observed in water bearing zone also. The above discussed results can be easily seen in the plot $\mathbf{S_{w\,Archie}}$ Vs $\mathbf{S_{w\,Ind.}}$ (figure: - 2). From this plot it can be clearly observed that for clean sands all points should lay on the straight line but this is not so in present case. It is also observed that Archie's equation[7] is over estimating $\mathbf{S_w}$ than Indonesian Equation[4] which may results in false estimation of hydrocarbon saturation (S_{hc} = 1- S_w). Moreover two saturation models are also compared w.r.t clay volume (V_{cl}) (figure: - 3) and both curves superimposed at the middle of reservoir where V_{cl} is zero which indicate that the petrophysical parameters should be observed at middle of reservoir rocks as there are least chances of contamination at the middle of bed from alternate beds.[1] Application of crossplots also plays a vital role in formation evaluation. With the help of crossplots (resistivity (R_t) $_{Vs}$ neutron porosity (Φ_n))(Pickett Polt)[5] the estimated value of 'R_w' and cementing exponent 'm' are 0.306 ohm-m and 2.2 respectively (figure:- 4) , for Mehsana field average value of m is 2.15 and R_w = 0.30 ohm-m.

The crossplot between Natural Gamma Ray (GR) and Neutron Porosity (Φ_n) [5] (figure:-5), shows satisfactory results by separating shale and sands points. A good boundary can be marked between shale and sand.

Similarly crossplot between Natural Gamma Ray (GR) and Resistivity (R_t)[5] not only separate out sand and shale but fluids(oil and water) contributing the total resistivity of sand are also separated out (figure:-6)

The figure:-7 is also showing the relation between Neutron porosity (Φ_n) and Bulk density(ρ_b)[5] which is separately showing the shale and sand point in case if sands are radioactive (e.g. Arkose).The clean sand line connects the quartz point and water point .The shale line is passing through the quartz point and shale point. The typical shaly sands response will be a cluster of data vertical between shale point and clean sand line with cleanest sand obviously nearer to the clean sand line. The effect of gas or rough borehole will shift the data to the left on the crossplot. The presence of heavy minerals can be inferred in term of high density.

An exercise is also done to evaluate the same well using ELANPlus Program of GEOFRAME[3]. Four response equations corresponding RHOB, NPHI, CUDC_IND and GR used for inversion and synthesis of logs. Volumes of various formation components have been computed using multimineral models of rock consisting of Quartz, Carbonaceous shale, Coal, siderite as heavy mineral, Oil and water as fluids. The saturation of fluid is calculated with the help of Indonesian equation. Other parameters are chosen same as were used in Quick look interpretation. The result is displayed as "Paralog" as shown in figure:-8. It is also showing the same results as discussed above.

It should be noted that the parameters estimated above are purely log data based and log data has been analyzed without much of external information like core analyses, lab study, etc.

Conclusion

In the present case study oil is observed at the depth between 1046 m to 1053.5 m.and water at depth between 1053.5 m to 1056.5 m.

The perophysical quantities to be chosen should observed at the middle of bed as there are least chances of contamination at the middle of bed from alternate beds.[1]
It can also be concluded that evaluation of shaly sand is more challenging as compared to clean sand. Moreover it is also observed that no shaly sand model is universal hence the choice of appropriate Model and geophysical parameter can drastically affect the results.

It is also suggested that use of crossplots is extremely beneficial in formation evaluation. Moreover in case of complex lithologies the advance software tools are really helpful.

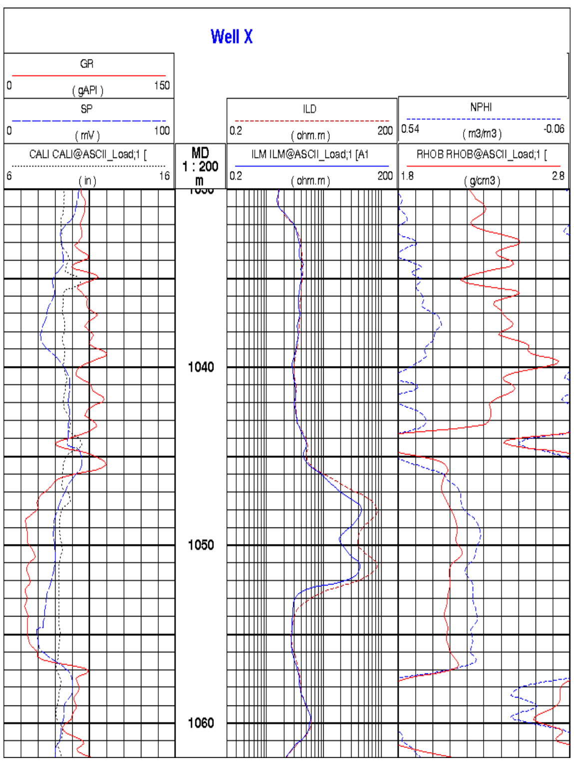

Figure 1 Well log used for case study (Well – X).

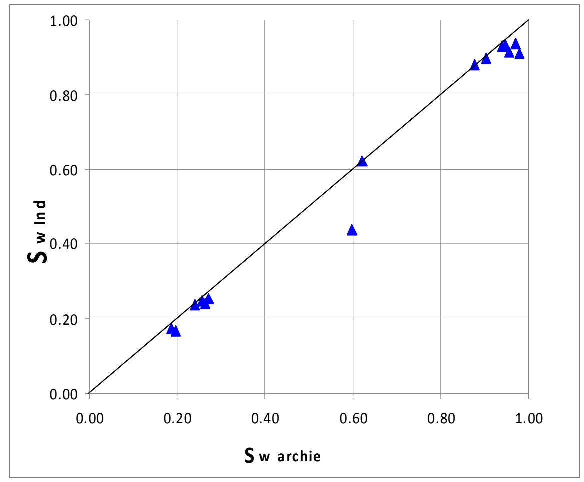

Figure:-2 Comparing results of Archie's and Indonesian model

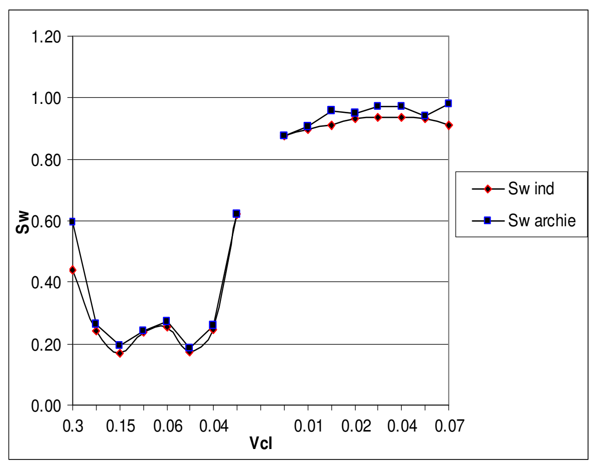

Figure:-3 Showing variation in S_w w.r.t. Vcl

Depth	R_t	GR	ρ_b	Φ_n	Φ_d	$V_{sh\,gr}$	$V_{sh\,ND}$	V_{sh}	Φ_e	$S_{w\,Ind}$	$S_{w\,Archie}$
1046	9.0	63	2.07	0.41	0.31	0.68	0.3	0.3	0.27	**0.44**	**0.60**
1047	35.0	53	2.06	0.35	0.32	0.52	0.1	0.1	0.30	**0.24**	**0.26**
1048	82.0	30	2.11	0.34	0.29	0.19	0.15	0.15	0.27	**0.17**	**0.20**
1049	49.0	18	2.13	0.29	0.28	0.01	0.03	0.01	0.28	**0.24**	**0.24**
1050	40.0	21	2.13	0.31	0.28	0.06	0.09	0.06	0.28	**0.26**	**0.27**
1051	80.0	22	2.11	0.32	0.29	0.07	0.09	0.07	0.28	**0.17**	**0.19**
1052	40.0	23	2.1	0.31	0.30	0.09	0.04	0.04	0.29	**0.25**	**0.26**
1053	6.0	21	2.08	0.31	0.31	0.06	0	0	0.31	**0.62**	**0.62**
1054	3.0	21	2.06	0.30	0.30	0.06	0	0	0.31	**0.88**	**0.88**
1054.3	2.9	21	2.08	0.31	0.31	0.06	0.01	0.01	0.31	**0.90**	**0.90**
1054.6	2.8	21	2.09	0.32	0.30	0.06	0.05	0.05	0.30	**0.91**	**0.96**
1055	2.8	20	2.09	0.31	0.30	0.04	0.02	0.02	0.30	**0.93**	**0.95**
1055.3	2.6	22	2.08	0.32	0.31	0.07	0.04	0.04	0.30	**0.94**	**0.97**
1055.6	2.8	25	2.1	0.31	0.30	0.12	0.04	0.04	0.29	**0.94**	**0.97**
1056	2.9	30	2.1	0.30	0.30	0.19	0.01	0.01	0.30	**0.93**	**0.94**
1056.3	3.1	30	2.12	0.31	0.29	0.19	0.07	0.07	0.28	**0.91**	**0.98**

Table:-2 Quantitative interpretation of permeable Zone

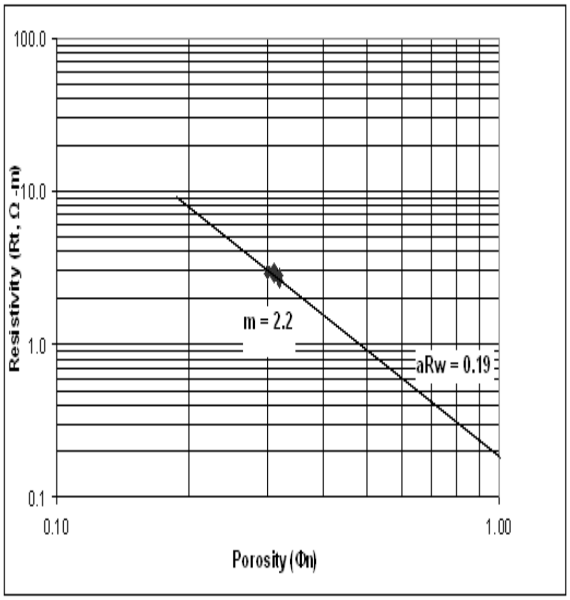

Figure:-4 Pickett plot to estimate 'R_w' and cementing exponent 'm'.

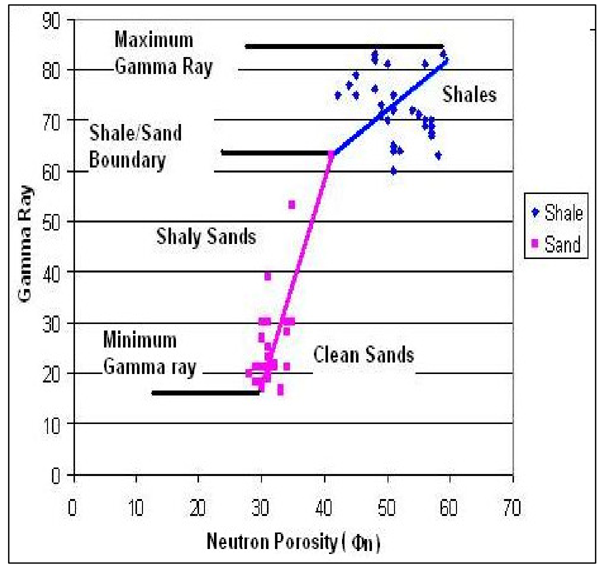

Figure:-5 Cross plot Gamma Ray Vs Neutron Porosity

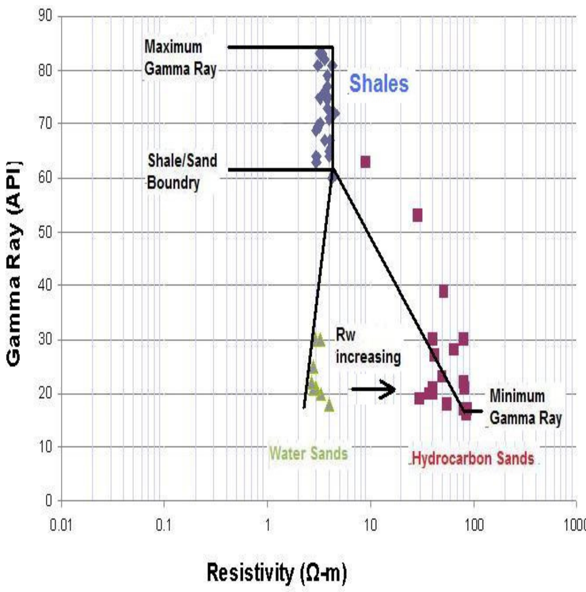

Figure:-6 Cross plot of Gamma Ray Vs Resistivity

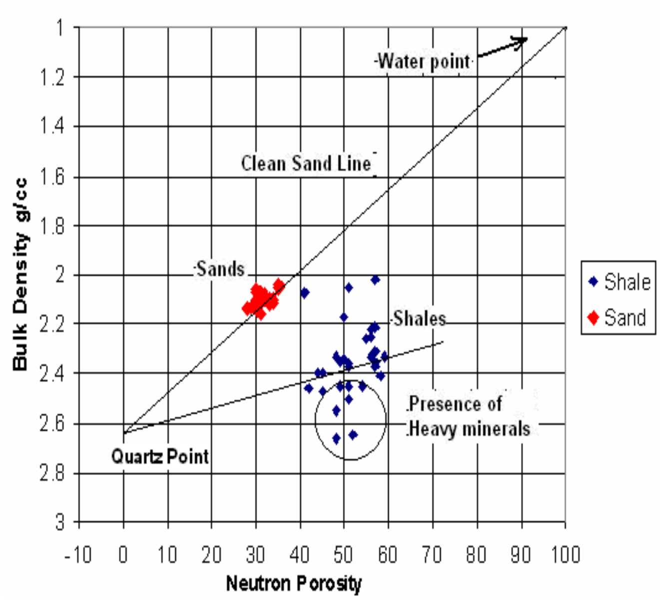

Figure:-7 Cross plot of Bulk Density Vs Neutron Porosity

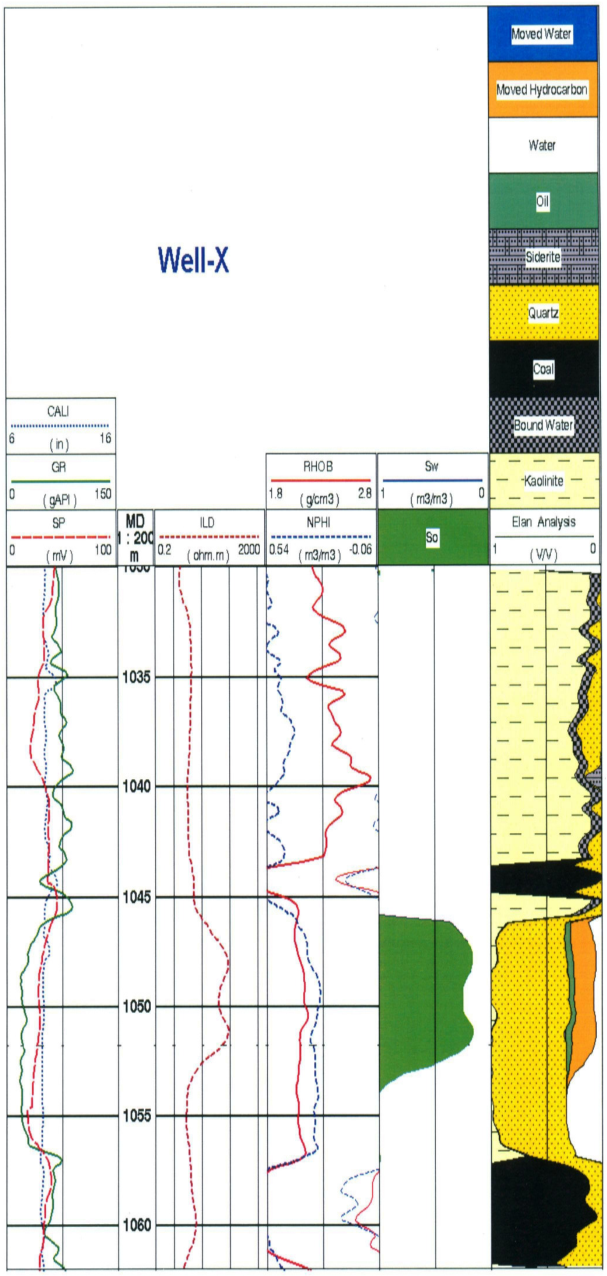

Figure 8: - Paralog of Well – X generated using ELANPlus Program

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References

Edwid S. Robinson, "Basic Exploration Geophysics", page no. 519, John Willy & Sons 1988

Vaish, J.P.; "Geophysical Well Logging – Principles and Practices", 1995, pages 511-517.

Schlumberger; "GEOFRAME 4.0 - ELANPlus Theory" (Manual).

Bateman, R.M; "Open-Hole Log Analysis and Formation Evaluation", 1985.

Schlumberger; Inc. "Log Interpretation – Principles", Schlumberger Education Services, Houston, TX, 1972.

Rider, M.; "The Geological Interpretation of Well Logs". 1996, Second Edition, pages 151-165.

Archie, G.E; "The Electrical Resistivity Log as an Aid in Determining some Reservoir Characteristics", 1942 Transactions AIME, v.146, pages 54-62.