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Formation Evaluation: Correlation between Clay Volume and Porosity Based on Well Logging Data

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Abstract

Formation evaluation that includes porosity, clay volume and water saturation estimation is very important stage in prospecting for reservoir characterization and hydrocarbon reserve. The logging data studied comprises of gamma ray, electric (spontaneous potential, micro spherical focused, laterolog deep and shallow, formation density and compensated neutron log. The gamma ray log is used to determine lithology, reservoir and non reservoir rocks, facies and depositional environment. Electric logs analyze fluid rock type such as hydrocarbon or formation water. Porosity is calculated by both density and neutron log. The research has been carried out by qualitative and quantitative analysis based on schlumberger method. Porosity is obtained from density log and then corrected by clay volume and hydrocarbon fluid content. Water saturation is calculated based on the true resistivity (Rt), clay volume (V_{sh}) and corrected porosity (ϕ_c) parameters.

As a result, the hydrocarbon is trapped in ten porous zones that have the reservoir thicknest vary between 10- 140 feet. The highest hydrocarbon saturation occurred in the reservoir-8 that is 71% with water saturation 29%, formation temperature 163.49 °F, clay volume 19 %, and porosity 25.4%. Oil water contact (OWC) encountered at the 2358 feet depth and underneath this OWC form the depletion zone. The correlation between clay volume and porosity showed that the increasing of clay volume result in decreasing porosity. The water saturation is strongly influenced by the value of resistivity log, increasing of resistivity will results in decreasing water saturation.

Key words: formation evaluation, porosity, clay volume.

Introduction

In petroleum exploration and development, formation evaluation that includes porosity, permeability and water saturation measurements is very important stage in prospecting for reservoir characterization and hydrocarbon reserve. Almost all oil and gas produced today comes from accumulations in the pore space of reservoir rocks [1]. The hydrocarbon saturation (Sh) can be obtained from calculation of water saturation. The summation of all saturations in a given formation rock must total to 100%, The existence of water saturation (Sw) less than100%, general implies a hydrocarbon saturation equal to 100% less the water saturation (or 1-Sw)[2]. While, fluid content of a rock formation include water, gas, or oil can be predicted by integrated log, especially resistivity log [3].

When hydrocarbon is present in the rock formation, the mud filtrate will replace the oil and gas immediately around the bore hole. The resistivity profile will show a flush zone with a low to moderate resistivity since filled with mud filtrate and in the virgin formation with an extremely high resistivity because of the high saturation in hydrocarbon [4].

Porosity is define as the ratio of the volume of void or pore space (Vp) to the total of bulk volume (V) of the rock. There are three log-derived porosity measuring tools in common use that are density, neutron and sonic log. Sonic log was less sensitive to borehole and mud cake variations than density and neutron log [5]. In this research we use a single density log which is primarily used as porosity log.

Clay or shale volume (V_{sh}) can be calculated by gamma ray (GR) log since the GR log reflects the proportion of the shale or clay content. By knowing the GR max (shale line), GR min (sand line), and GR value of the log, it can be determined the total volume of shale in the formation [6]. If hydrocarbons fluids and shale or clay in the formation exist in the region investigated by density tool, their presence may affect the density log reading. So, the effect of hydrocarbon fluid and clay content should be considered in the calculation of porosity-derived density log. This study emphasized correlation between clay content and porosity, water saturation and Rt (true resistivity), and porosity calculation effected by clay volume and hydrocarbon fluid.

Data and Methodology

Logging data from well JS # 18 used in this study comprises of Spotaneous Potential Log (SP), Micro Spherical Focused Log (MSFL), Laterolog Shallow (LLS), Laterolog Deep (LLD), Gamma Ray Log (GR) and Formation Density Log (FDL). The study has been carried out by qualitative and quantitative analysis. Qualitative analysis includes determination of porous zone, sand and shale base line, water bearing formation, hydrocarbon depletion zone and oil water contact (OWC). Quantitative analysis includes calculation of formation temperature, mud filtrate resistivity, clay volume, porosity, and water and hydrocarbon saturation [7]. Porosity value is obtained from density log and than corrected by shale volume and hydrocarbon fluid contain. Water saturations estimation is calculated from true resistivity (Rt), clay volume (V_{sh}) and corrected porosity (ϕ_c) parameters [8]. Quantitative analysis is principally based on shally sand interpretation by Darcy and Schlumberger method, include:

1. Determination of Formation Temperature (T_2):

$$T_2 = \frac{D(BHT - T_1)}{TD} + T_1 \qquad (1)$$

Where:

T_2 = Formation temperature (°F)
D = Log depth (feet)
BHT = Borehole temperature (°F)
TD = Total depth (feet)
T_1 = Surface temperature (°F)
T_2 = Formation temperature (°F)

2. Determination of Resistivity of Mud Filtrate (Rmf):

$$Rmf_2 = Rmf_1 \frac{(T_1 + 6.77)}{(T_2 + 6.77)} \quad (2)$$

Where:

Rmf_2 = Resisitivity of mud filtrate at formation (ohm-m)
Rmf_1 = Resisitivity of mud filtrate at surface (ohm-m)

3. Determination of Shale Volume (Vsh):

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (3)$$

Where:

V_{sh} = Clay volume (%)
GR_{log} = Gamma Ray Log (API Unit)
GR_{max} = Gamma Ray maximum (API Unit)
GR_{min} = Gamma Ray minimum (API Unit)

4. Determination of Porosity:

$$\Phi D = \frac{\rho ma - \rho b}{\rho ma - \rho f} \quad (4)$$

Where:

ΦD = Porosity from density log (%)
ρma = matrix density
ρb = bulk density
ρf = fluid density

5. Determination of Porosity, Corrected by V_{sh} Content:

$$\Phi D_{c1} = \Phi - (V_{sh} \times \Phi D_{sh}) \quad (5)$$

Where:

ΦD_{c1} = Corrected porosity by V_{sh} (%)
Φ = Porosity (%)
V_{sh} = Shale volume (%)
ΦD_{sh} = Log density-derived porosity in shale zone (%)

6. Determination of Porosity, Corrected by Hydrocarbon Fluid Content

$$\Phi D_{c2} = \Phi D_{c1} (1 - 0.1\, Shr)$$
$$Shr = 1 - Sxo$$

$$Sxo = \frac{1}{Rxo\sqrt{\frac{V_{sh}^{(1-Vsh/2)}}{R_{sh}} + \frac{\phi D_{c1}}{aR_{mf}}}} \qquad (6)$$

Where:

ΦD_{c2} = Hydrocarbon fluid corrected porosity (%)
ΦD_{c1} = Vsh corrected porosity (%)
Shr = Residual hydrocarbon saturation
Sxo = Water saturation in flush zone
Rxo = Water resistivity in flush zone
V_{sh} = Shale volume
R_{sh} = Resistivity in shale zone
a = Cementation constant
R_{mf} = Resistivity of mud filtrate

7. Determination of Water Resistivity (Rw)

Water resistivity can be obtained from water bearing formation.

$$Rw = \frac{R_{mf}.Rt}{Rxo} \text{ ohm-m} \qquad (7)$$

Where:

Rw = Water resistivity in uninvaded zone
R_{mf} = Resistivity of mud filtrate
Rt = True resistivity
Rxo = Water resistivity in flush zone

8. Determination of Water Saturation (Sw)

$$Sw = \frac{1}{Rt\sqrt{\frac{V_{sh}^{(1-Vsh/2)}}{R_{sh}} + \frac{\phi D_{c2}}{a.Rw}}} \qquad (8)$$

Where:

Sw = Water saturation
Rt = True resistivity
V_{sh} = Shale volume
R_{sh} = Resistivity in shale zone
ΦD_{c2} = Porosity (%), hydrocarbon fluid correction.
a = Cementation constant
Rw = Water resistivity.

9. Determination of Hydrocarbon Saturation (Sh)

$$Sh = 1 - Sw \qquad (9)$$

Where:
Sh = Hydrocarbon saturation (%)
Sw = Water saturation (%)

Results and Discussion

As a result, the hydrocarbon is trapped in ten sandstone porous zones that have the reservoir thicknest vary between 10-140 feet. Oil water contact occurred at the 2358 feet depth characterized by the rapid change in resistivity, and underneath became oil depletion zone. Results of evaluation formation parameters are shown in Table 1, and clay volume, porosity and hydrocarbon saturation estimation can be seen in Table 2 and Table 3.

Table 1. Results of the evaluation formation parameters

No.	Parameters	Value
1	Sand line (GRmin)	40 API
2	Shale line (GRmax)	145 API
3	Resistivity of shale (R_{sh})	5 ohm-m
4	Density porosity on shale (ΦD_{sh})	0.097 (ρb = 2.5)
5	Fluid density (ρ_f)	1.1g/cm^3
6	Matrix density (ρ_{ma})	2.65 g/cm^3
7	Borehole Temperature (BHT)	168 °F
8	Resistivity of mud filtrate (R_{mf})	3.5 ohm-m @ 85 °F
9	Surface temperature (T_1)	85 °F
10	Total Depth (TD)	2924 feet
11	Cementation constant (a)	0.81

Table 2. Shale volume calculation and Log-derived porosity calculation (ΦD_{c1}), affected by its clay volume (V_{sh}).

No.	Depth (feet)	GR Log (API)	T_2 (°F)	R_{mf} (ohm-m)	V_{sh} (%)	ρB (gram/cc)	ΦD (%)	ΦD_{c1} (%)
1	2235	90	148.44	2.07	48	2.3	23	18
2	2360	70	151.99	2.02	29	2.25	26	23
3	2500	60	155.96	1.97	19	2.2	29	27
4	2550	70	157.38	1.96	29	2.25	26	23
5	2585	90	158.38	1.94	48	2.3	23	18
6	2635	60	159.8	1.93	19	2.3	23	20.7
7	2660	80	160.5	1.92	38	2.3	23	18.9
8	2765	60	163.49	1.89	19	2.2	29	27
9	2810	50	164.76	1.87	9	2.15	32	31
10	2900	45	167.32	1.84	5	2.15	32.3	31.8

Table 3. Water saturation estimation, and log-derived porosity calculation (ΦDc2) affected by residual hydrocarbon fluids (Shr)

No.	Depth (feet)	ΦD_{c1} (%)	Rxo (ohm-m)	Rt (ohm-m)	Sxo	Shr	ΦD_{c2} (%)	Sw (%)	Sh (%)
1	2235	18	10	15	0.87	0.12	18	60	40
2	2360	23	50	60	0.48	0.52	22	36	64
3	2500	27	24	26	0.76	0.24	26	60	40
4	2550	23	12	15	0.97	0.03	23	73	27
5	2585	18	10	12	0.86	0.14	18	67	33
6	2635	20.7	24	22	0.88	0.12	20	77	23
7	2660	18.9	55	60	0.41	0.59	18	34	66
8	2765	27	100	110	0.36	0.64	25	29	71
9	2810	31	35	40	0.66	0.33	30	53	47
10	2900	31.8	28	30	0.8	0.2	31	66	34

The highest water saturation of 77% encountered in the zone no.6 with 40 feet thicknest (depth 2608 – 2648 feet) and formation temperature is 159.8 °F. This zone has 20% porosity, 19% shale volume and 23% hydrocarbon saturation.

The porosity of density log (ΦD) of the tenth sandstone porous zones, as shown in Table 2, are varies range from 23%-32.30%. After corrected by volume of clay (Vsh), the porosity (ΦDc1) decreases into 18%-31.8%. Decreasing level of the porosity, range from 0.5%-5%, is affected by the amount of clay or shale of each zones.

The second correction porosity (ΦDc2) is corrected by hydrocarbon fluids. As demonstrated in Table 3, the results of this correction shows range of this porosity from about 18%-31%, slightly different with the first correction (ΦDc1) that have porosity range from 18%-31.8%. More over some depth of this zone have same porosity that means no changing porosity after corrected by hydrocarbon fluid, such as depth 2235 feet (porosity 18%, Rt 15 ohm-m), depth 2250 feet (porosity 23%, Rt 15 ohm-m), and depth 2585 feet (porosity 18%, Rt 12 ohm-m). This phenomenon is caused by the value of resistivity in those zones is to small, range from 12 ohm-m- 15 ohm-m, that indicated as water zones, so no effect for the hydrocarbon fluids correction.

Figure 1 shows the relationship between clay volume and porosity, generally showed the increasing of clay volume result in decreasing porosity. It relate to rock texture and depositional environment process where course-grained size in the high porosity rock was deposited in high energy environment which lack of clay material. The water saturation is also vary in the range of 29%-77% and strongly influenced by the value of resistivity log, increasing of resistivity will results in decreasing water saturation (Figure 2).

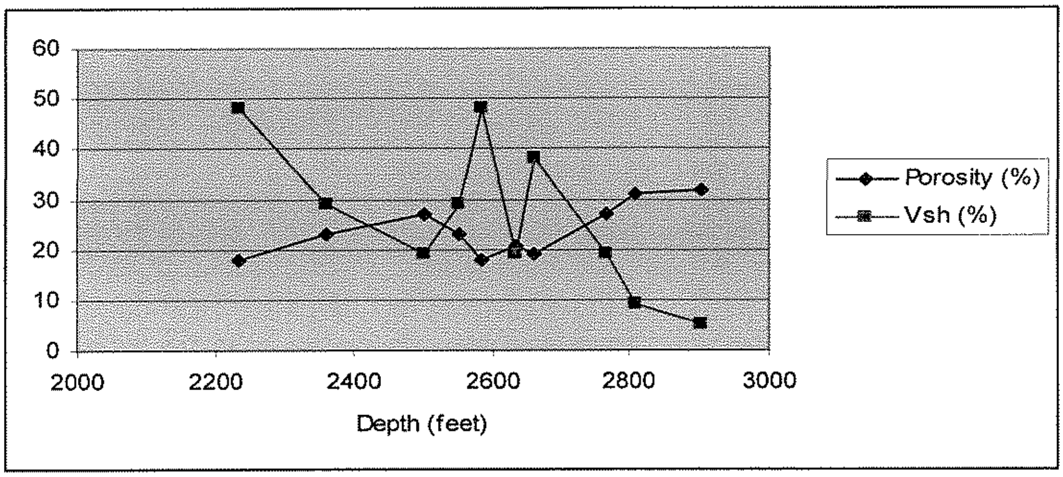

Figure 1. Cross plot of depth vs. porosity and clay content (V*sh*).

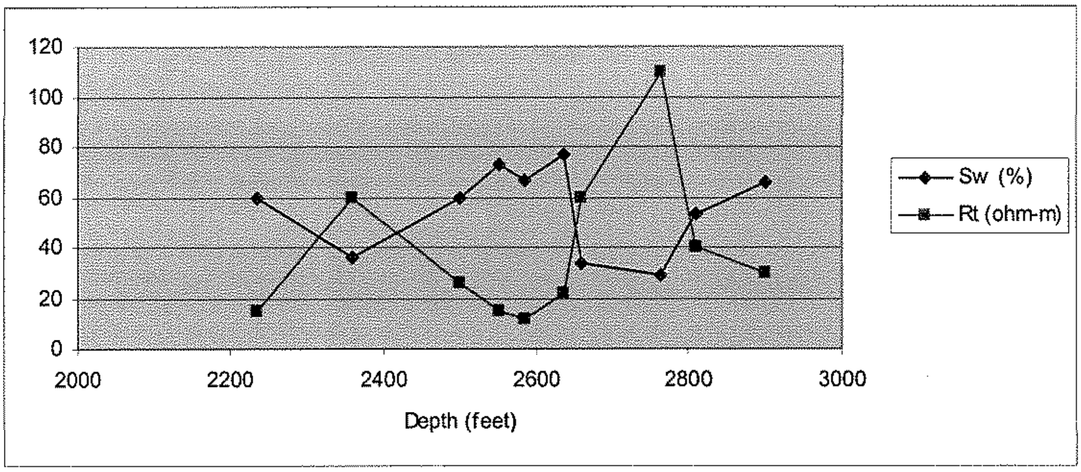

Figure 2. Cross plot of Depth vs. Water saturation (Sw) and Resistivity (Rt)

Conclusion

Determination of clay or shale volume, porosity and water saturation is very important in the formation evaluation. The porosity values are strongly affected by clay volume, but less influenced by hydrocarbon fluids content. The increasing of clay volume will result in decreasing porosity. The water saturation is strongly influenced by the value of resistivity log, increasing of resistivity will results in decreasing water saturation.

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