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Evaluation of Hydrocarbon Saturation Using Carbon Oxygen (CO) Ratio and Sigma Tool

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Abstract

The main aim of this study is to evaluate the remaining oil in previously produced zones, locate the water productive zone and look for any bypassed oil behind casing in not previously perforated intervals. Initial water saturation was calculated from digitized open hole logs using a cut-off value of 10% for irreducible water saturation. The integrated analysis of the thermal capture cross section, Sigma and Carbon/oxygen ratio was conducted and summarized under well shut-in and flowing conditions. The logging pass zone run through sandstone Zubair formation at north Rumaila oil field. The zones where both the Sigma and the C/O analysis show high remaining oil saturation similar to the open hole oil saturation, could be good oil zones that do not appear to be water flooded. The zones where the Sigma analysis shows high residual oil saturation, which is close to open hole oil saturation and the C/O analysis, show medium residual oil saturation; this could indicate that these zones were fresh water flooded to a certain extent and they still keep some residual oil. If the C/O analysis shows low residual oil saturation, it indicates that these zones were probably fresh water flooded thoroughly. If both Sigma analysis and the C/O analysis show medium residual oil saturation, most probably these zones were saline water flooded to a certain extent and they still keep some residual oil.

Introduction

The Reservoir Monitoring Tool (RMT) is pulsed neutron devices that use induced gamma spectroscopy and decay time measurements to determine primarily oil saturation in reservoirs. For those having low (less than 20,000 ppm NaCl) or unknown salinity-formation water, the inelastic or RMT C/O mode is used [1]. For higher salinities, the capture mode is used to measure the formation Sigma. RMT has applications in determining the presence of water and oil and their saturations behind casing in formations whose waters are fresh or high salinity [2]. The main applications of these RMT on reservoir monitoring include the following: discriminate water/oil, evaluate hydrocarbon zones, locate water and oil zones in water floods, evaluate saturations in formations behind casings when open hole logs are not available and monitor steam and CO2 flood/breakthrough [3].

The water salinity in the North Rumaila field is high with unknown or fresh water injection; therefore, the RMT capture and CO mode were run to evaluate the residual oil and water.

Interpretation (C/O)

Carbon/oxygen (C/O) logging is primarily utilized to determine oil water saturations and reservoir performance in areas with low or unknown formation water salinities. The C/O measurement is based on carbon and oxygen reactions with high energy neutrons producing characteristic gamma rays. From this measurement, one can distinguish between hydrocarbons (C+H) and water (H+O), or different C/O ratio in the oil or water formation [4].

The RMT C/O model mainly measures $R_{C/O}$ and $R_{Ca/Si}$ ratios. What we want to know is oil saturation (S_o) for a given porosity (φ). The following equations were derived from tool characterization based on test pit data and used to solve oil saturation:

$$S_{oil} = 1.53\frac{1-0.35\varphi}{\varphi}\frac{\Delta CO}{\Delta CO+0.19C_{hc}} \quad \ldots(1)$$

Where

$$\Delta CO = COIR - 0.15*LIRI + 0.07\varphi - 0.613 + A \quad \ldots(2)$$

The parameter A is a number near zero that sweeps up all the residual environmental effects (borehole size, casing size, cement type, etc.) which may lead to a ΔCO value that is not zero in a water saturated reservoir [5].

Interpretation (∑)

The thermal capture Cross section, Sigma, is normally used to determine primarily oil saturation in reservoirs in the highly salinity reservoir. The basis for this is the large difference in the capture cross section between saline water and oil. SigmaSat is a model designed for saturation analysis of a single well based on Sigma logs [6]. The practical interpretation model of pulsed neutron log is conceptually simple. The total formation capture cross section, $\sum_{log}$, is the sum of the products of the volume fractions found in the formation and their respective capture cross sections (See Figure 1). Assuming the formation is shaly and contains water and hydrocarbon, thus

$$\Sigma_{log} = \Sigma_{Ma} V_{Ma} + \Sigma_W S_W \varphi_e + \Sigma_{Sh} V_{Sh} + \Sigma_{Hc} S_{Hc} \varphi_e \quad \ldots(3)$$

Rearranging Equation 3, we can solve for water saturation, Sw

$$S_W = \frac{\Sigma_{log} - \Sigma_{Ma} + V_{sh}(\Sigma_{Ma} - \Sigma_{Hc}) + V_{sh}(\Sigma_{Ma} - \Sigma_{Sh})}{\varphi_e(\Sigma_W - \Sigma_{Hc})} \quad \ldots(4)$$

Where:

Σ_{log}: measured formation Σ.

Σ_{Ma} : Σ Matrix

Σ_{Sh} : Σ shale

Σ_{Hc} : Σ hydrocarbon

Σ_W : Σ water

φ_e : Effective porosity

V_{SH} : Shale volume

S_W : Water saturation

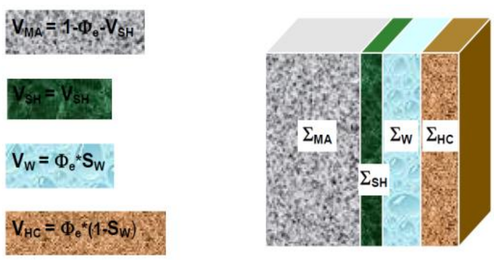

Fig. 1: Volumetric Model [6]

From Equation 4, the water saturation can be calculated in any two-phase combinations, such as water-oil, water-gas even oil-gas under formation condition if the Sigma difference within each combination is big enough to get the accurate saturation [6].

Results and Discussion

The primary objective of running RMT Pulsed Neutron tool in well (R) was to evaluate the remaining oil in previously produced zones, locate the water productive zone and look for any bypassed oil behind casing in not previously perforated intervals.

The current water cut of this well is unknown. Initial water saturation was calculated from digitized openhole logs using a cut-off value of 10% for irreducible water saturation. The RMT tool was run in Capture and CO mode under well shut-in and flowing conditions; the data quality was good. Two passes of CO mode were performed (See Figures 2 and 3) and one pass of Capture mode (See Figures 4 and 5) was used for shut-in and flowing conditions and for the interpretation. The borehole was filled with oil during logging. The log was depth correlated to initial open hole logs. The logging interval is from 3226.0m to 3270.0m covering the 7", 29# casing.

The first two terms on the right hand side of Equation 2 essentially represent what is done on the log when C/O and Ca/ Si curves are scaled and offset to overlay in water zones and then separated in oil zones. It can be illustrated as lithology independent fan chart of ΔCO versus porosity in Figure 6 (Using Microsoft Excel).

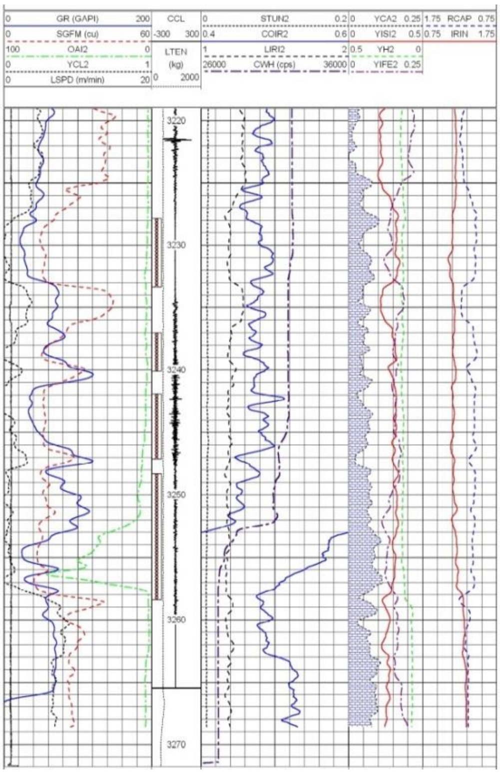

Fig. 2: CO mode log under well flowing

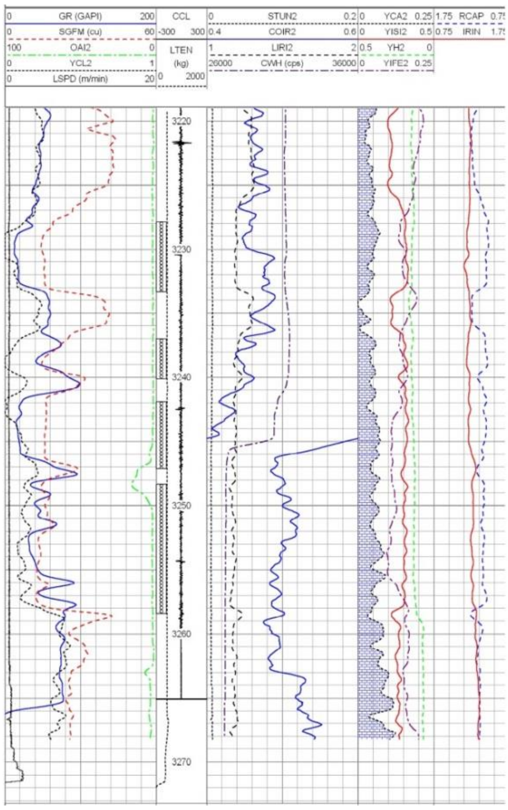

Fig. 3: CO mode log under well Shut in

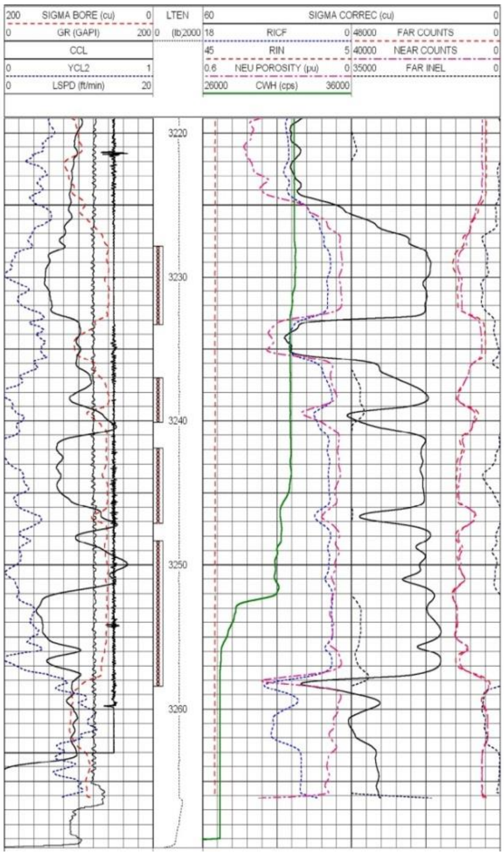

Fig. 4: Sigma mode log under well flowing

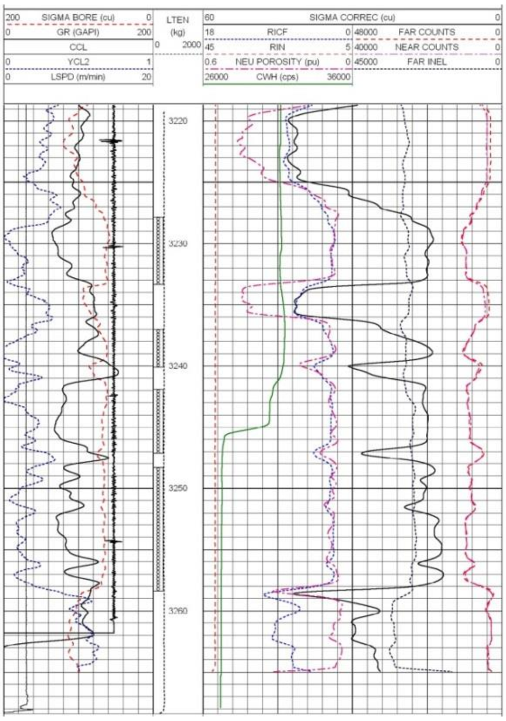

Fig. 5: Sigma mode log under well shut in

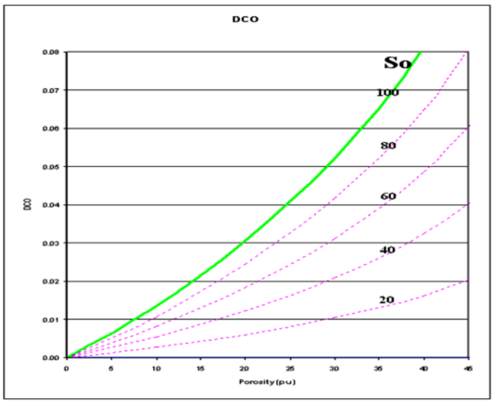

Fig. 6: Lithology Independent ΔCO Fan Chart (Using Microsoft Excel)

CarbOxSat is a model designed for saturation analysis of a single well based on C/O logs. The model uses either the ΔCO (mostly used) or normalized C/O calculation, and a volumetric model to determine effective and total hydrocarbon saturation [4].

The CarbOxSat analysis relies on a total porosity or effective porosity, shale volume and an environmental corrected CORI and LIRI as its basic inputs [3]. The total porosity is corrected to an effective porosity using the shale volume. They can be from the openhole logs or the calculated products if there had been openhole logs .Otherwise, the casedhole logs measured from RMT can be used. In this case, the total porosity from openhole is used to calculate the effective porosity. The CarbOxSat analysis is illustrated in Figure 7 (Using PetroSite Software).

Track 1 indicates the amount of matrix and shale by volume, along with the effective porosity from openhole logs open calliper was showed in depth track. Track 2 shows the open hole and cased hole Gamma ray and formation Sigma for correlation. Track 3 shows the environmental corrected Carbon/Oxygen ratio (COIR2C) and lithology ratio (LIRI2C); the overlay of these two curves in the proper scales is the quick indicator of oil or water zones. Track 4 shows an envelope of C/O 100% wet and C/O 100% hydrocarbon with corrected C/O in between, indicating the hydrocarbon saturation. Track 5 indicates the hydrocarbon saturation from C/O and open hole logs. The swept oil was shaded in between. Track 6 shows effective porosity, the volume of water, and the volume of hydrocarbons present.

The calculated saturation accuracy depends not only on the Sigma difference between liquids or liquid and gas in the reservoir, but also the porosity. Higher porosity makes it easier to identify each component and usually produces more accurate saturation than the lower porosity reservoir. The SigmaSat analysis relies on a total porosity or effective porosity, shale volume and a measured Sigma as its basic inputs [2]. The total porosity is corrected to an effective porosity using the shale volume. They can be from the openhole logs or the calculated products if there had been open hole logs .Otherwise, the cased hole logs measured from RMT can be used. In this case, the total porosity from open hole is used to calculate the effective porosity [6]. The SigmaSat analysis is illustrated in Figure 8 (Using Petrosite Software).

The parameters were used to process are as follows:
Sigma Hydrocarbon = 20.5c.u.
Sigma Water = 105 c.u.
Sigma Matrix = 6 c.u.
Sigma Shale = 36 c.u.

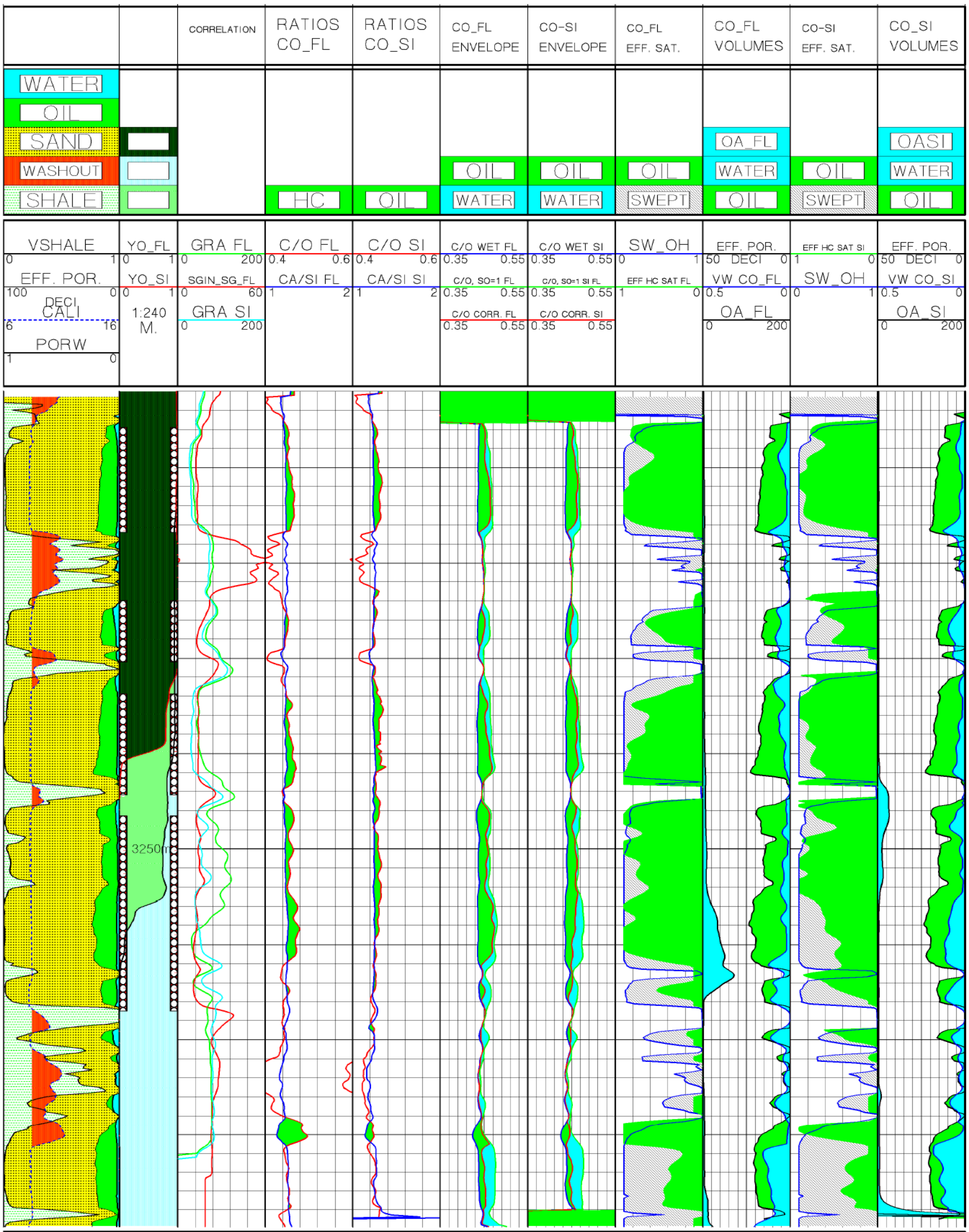

Fig. 7: CarbOxSat Analysis Results Log (Using Petrosite Software)

Track 1 indicates the amount of matrix and shale by volume, along with the effective porosity. Open Calliper was showed in depth track. Track 2 displays openhole and cased hole gamma ray and formation Sigma for correlation. Track 3 is RMT Capture Ratio (RNF), and Inelastic Ratio (RINC). The RNF and RINC curves behave somewhat like a neutron-density log and will crossover in the presence of gas. Track 4 shows an envelope of Sigma 100% wet and Sigma 100% hydrocarbon with Sigma intrinsic in between, indicating the hydrocarbon saturation before shale correction. Track 5 indicates the hydrocarbon saturation from Sigma and openhole logs. The swept oil was shaded in between. Track 6 shows effective porosity, the effective volume of water, and the volume of hydrocarbons present.

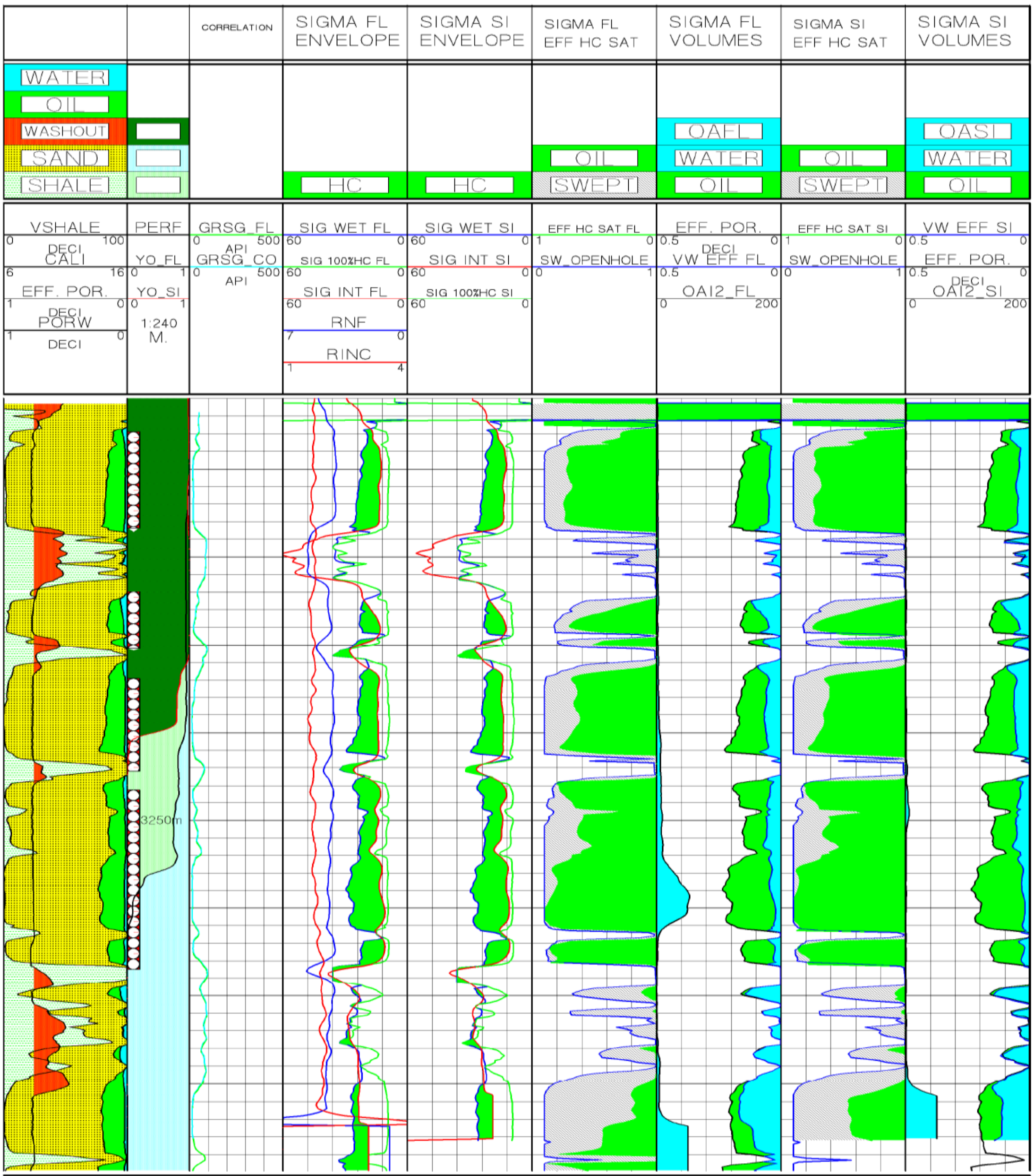

Fig. 8: SigmaSat Analysis Results Log(Using Petrosite Software)

The zones where both the Sigma and the C/O analysis show high remaining oil saturation similar to the open hole oil saturation could be good oil zones that do not appear to be water flooded (See Figure 9). The zones where the Sigma analysis shows high residual oil saturation, which is close to open hole oil saturation and the C/O analysis, show medium residual oil saturation; this could indicate that these zones were fresh water flooded to a certain extent and they still keep some residual oil If the C/O analysis shows low residual oil saturation, it indicate as that these zones were probably fresh water flooded thoroughly. If both the Sigma analysis and the C/O analysis show medium residual oil saturation, it is most probably that these zones were saline water flooded to a certain extent and they still keep some residual oil. If both the Sigma analysis and the C/O analysis show low residual oil saturation, the implication is that these zones were fully flooded with saline water.

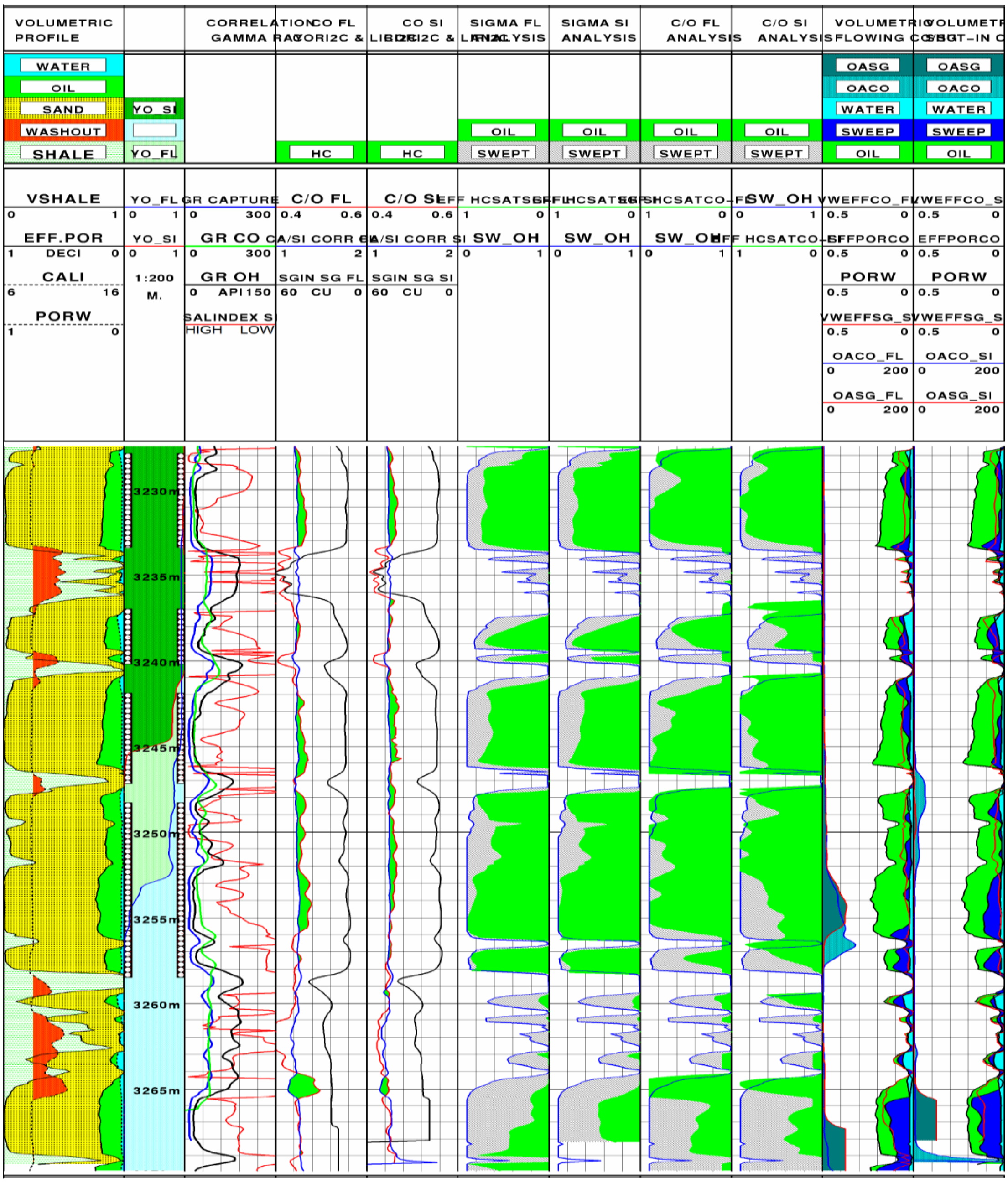

Fig. 9 SigmaSat and CarbOxSat Analysis Results Composite Log (Using Petrosite Software)

The integrated analysis of the thermal capture cross section, Sigma and Carbon/oxygen ratio was conducted and summarized (See Table1).

Table 1: Analysis results interpretation summary

Zone	Interval (m)	Possible Interpretation
1	3227.0-3233.5	Oil Saturated
2	3237.0-3240.5	Oil Saturated / Slightly flooded fresh water
3	3242.0-3247.0	Oil Saturated / Slightly flooded saline water (CO-SI affected by water Re-invasion at bottom part)
4	3247.5-3256.5	Oil Saturated / Slightly flooded saline water (CO-SI affected by water Re-invasion at bottom part)
5	3257.0-3258.5	Fresh Water flooded / Residual Oil
6	3264.5-3269.0	Saline Water Sweeped

Conclusions

1. Workover operations should be focused on the zones 3, 4 and 5 in order to extract the residual oil.
2. There are no bypassed oil zones in this well as shown from the CO and Sigma analyses.
3. Productivity test will help how each zone pay leading to increase oil production overall in this well.

Nomenclature

Symbol	Unit	Definition
GR	api	Natural Gamma
SGIN	cu	Foramtion Sigma
VSHALESG	deci	Volume of shale
TOTPORSG	deci	Total porosity
EFFPORSG	deci	Effective porosity
SIGMAWET	deci	SIGMA wet
SIGMOILY	deci	SIGMA at SHC=1
SHCTOTSG	deci	Tot. HydroCarbon saturation
SHCEFFSG	deci	Eff. HydroCarbon saturation
VHCSG	deci	Volume of hydrocarbon
VWTOTSG	deci	Volume of water in TPOR
VWEFFSG	deci	Volume of water in EPOR
VSHALECO	deci	Volume of shale
TOTPORCO	deci	Total porosity
EFFPORCO	deci	Effective porosity
CORWET		C/O at So=0
COROILY		C/O at So=1
SHCEFFCO	deci	Eff. HydroCarbon saturation
SHCTOTCO	deci	Tot. HydroCarbon saturation
VHCCO	deci	Volume of hydrocarbon
VWEFFCO	deci	Volume of water in EPOR
VWTOTCO	deci	Volume of water in TPOR
LIRI2		Far lithology index inelastic
COIR2		Far CO Ratio inelastic
LIRI2C		Far lithology index inelastic - Environmental corrected
COIR2C		Far CO Ratio inelastic-Environmental corrected
LIRI1		Near lithology index inelastic
COIR1		Near CO Ratio inelastic
LIRI21C		Near lithology index inelastic - Environmental corrected
COIR1C		Near CO Ratio inelastic-Environmental

		corrected
SGIN	cu	Sigma Intrinsic
SALIN		Natural Gamma

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