Effect of Archie's constants on water saturation Estimation, Nubian Sandstone (Case Study)

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Abstract—**Estimation of water saturation (Sw) is an important stage of reservoir reserve assessment. Geophysical data recorded of select four wells over studied reservoir depth intervals are processed for presenting this work. Shaly studied reservoir (lower Cretaceous) located Southeast Sirte Basin, has about 410-650 feet thickness, with 30% volume of shale (Vsh) cut off value. It has average total porosity 10%. The reservoir divided into two main units (A and B) according to fluid content (gas and Oil). However, using Archie's standard Tortuosity factor (a=1), Cementation factor (m=2), and Saturation exponent (n=2) parameters effect on water saturation especially shaly reservoir. Therefore, factual parameters of a, m, and n from special core analysis of studied reservoir clarified and comprised water saturation by using different shaly models (Archie, Indonesian and Simandoux) is the main intent. Free and forced fit line technique are used to estimate a and m values. The Simandoux formula gives lowest values of water saturation whether use free or forced Archie's parameters, while the Indonesian has values lower than Archie. Therefore, Shale content (30%) plays performance of various shaly sand saturation equations, which is clearly present by different value between water saturation degrees of average Sw values (ΔSw) where it reach to 3%.**

Index Terms: **Water saturation, Archie's constant, shaly rock, Nubian Sandstone.**

I. INTRODUCTION

Hydrocarbon reserve evaluation depend on water saturation, which is the most fluid associated with hydrocarbon in reservoir pore spaces. Therefore, evaluation water saturation and use corrected reservoir and/or lithology parameters, such as porosity, and resistivity in saturation selected models, especially constant values (a, m and n). It's playing very important effecting as will showing.

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However, in this study reservoir rock of Lower Cretaceous is used to illustrate effect of Archie's constants on water saturation content. However, the viability of a reservoir depends upon three critical parameters. The first two of these are the porosity of the reservoir rock, which defines the total volume available for hydrocarbon saturation, and the permeability, which defines how easy it is to extract any hydrocarbons that are present. The final critical parameter is the hydrocarbon saturation, or how much of the porosity is occupied by hydrocarbons. This paper presents the results of the application of three formulas to determine water saturation content cross shaly reservoir (Nubian Sandstone), which is based on the already results determining Archie's parameters by the core technique values.

The Nubian reservoir contain two main reservoir units (A and B), the unit B is lies immediately below the unit A. It has an average thickness about 410-650 feet. The upper unit is described as fine- to medium-grained Quartzitic sandstone with shale interbeds. Lower of this unit present a proportion of clay increases and the sandstone becomes argillaceous with a red colour. While, lower unit is consists of medium- to coarse-grained sandstone with some siltstone beds. The sandstone is cross bedded at low angles and has occasional mud intraclasts (confidential reports).

II. MATERIAL AND METHODS

Archie introduced an equation, which relates resistivity index (RI) and formation resistivity factor (F) in order to calculate water saturation (Archie, 1942). The formation resistivity factor, F is related to porosity, and the resistivity index, RI, is related to resistivity. Archie's equation requires the values of cementation exponent, m, saturation exponent, n and the rock consolidation factor, a. The equation was not a precise one, as he pointed out, and was only an approximate relationship. The conventional procedure to determine m and n parameters is by the cross plot techniques. However, the equation was empirical in origin and therefore needs modification in rock–fluid combinations different from Archie's experiments. Modifications need to be made in rocks with the following characteristics; Non-Archie pore geometries (i.e., Pore systems), Conductive minerals such as clays and pyrite, and very fresh (i.e., nonsaline) formation waters. The shaly reservoirs have different models applied to water saturation. These models were derived, over the years to account for the presence of shale in the formation and its effect on resistivity measurement (Hilchie, 1982; Schlumberger, 1989). Equations (1), (2) and (3) includes the used common shaly models for water saturation estimation (Archie, Simandoux and Indonesian respectively), which are ability to permutation Archie's parameters (a, m and n). In addition to, available log data such as; Gamma Ray, porosity and resistivity. Then, comparisons between water saturation results according on Forced or Free Archie's parameters are used as will be explained in next paragraph, where formation water resistivity (Rw) equal to 0.015 Ohm.m at reservoir temperature.

Archie, 1942: (1)

$$S_{wa} = \left(\frac{a \times R_w}{\phi^m \times R_t} \right)^{1/n}$$

Simandoux: (2)

$$S_{ws} = \left[\sqrt{(D^2 + E)} - D \right]^{2/n}$$

$$C = \frac{(1 - V_{sh}) a R_w}{\phi^m}$$

$$D = C \frac{V_{sh}}{2 R_{sh}} \qquad E = \frac{C}{R_t}$$

Indonesian (3)

$$S_{wi}^{n/2} = \left[\frac{\frac{1}{\sqrt{R_t}}}{\frac{V_{sh}^{(1 - Vsh/2)}}{\sqrt{R_{sh}}} + \frac{\phi^{m/2}}{\sqrt{a R_w}}} \right]$$

Where: n = saturation exponent, a = tortuosity factor m = cementation exponent, Φ = porosity R_t = formation / true resistivity, R_w = formation water resistivity, V_{sh} = Volume of shale, R_{sh} = resistivity of the shale (Ω.m) and Sw = water saturation.

III. DETERMINATION OF ARCHIE'S PARAMETERS

The exponent m has been observed near 1.3 for unconsolidated sands, and is believed to increase with cementation. Common values for this cementation exponent for consolidated sandstones are 1.8 < m < 2.0. The constant a, called Tortuosity factor, cementation intercept, lithology factor and/or lithology coefficient is sometimes used. It is meant to correct for variation in compaction, pore structure and grain size. The saturation exponent n usually is fixed to values close to 2. This parameter is dependency on the presence of non-conductive fluid (hydrocarbons) in the pore-space, and to the wettability of the rock. However, Plot of log Formation Factor (FF) versus log Ø is used to determine the coefficients "a" and "m" for 34 core samples measurements (Fig.1). The m is slope of the Forced and Free fit straight line of the plotted points, while the a factor is given from the intercept of the lines. The same technique treats to determine Archie's parameter n by plotting log Sw and log Resistivity Index (RI) for 80 core samples, which value as a slope (Fig.2). Table (1) includes the result values of these parameters, which are used to calculate the saturation content. It is noted the free fit line results are very close (or equal) to the standard values.

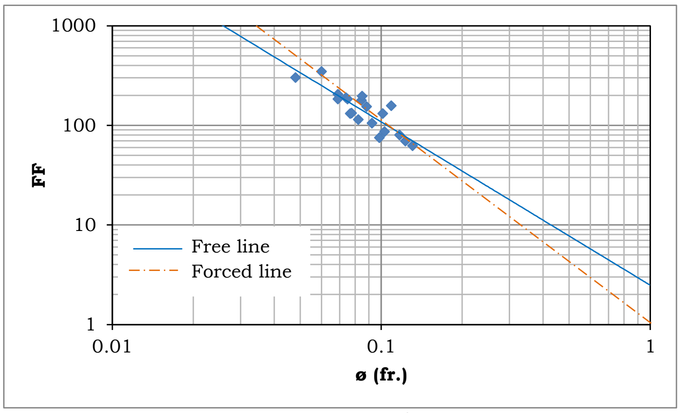

Figure 1. Porosity and Formation Factor for 34core Samples.

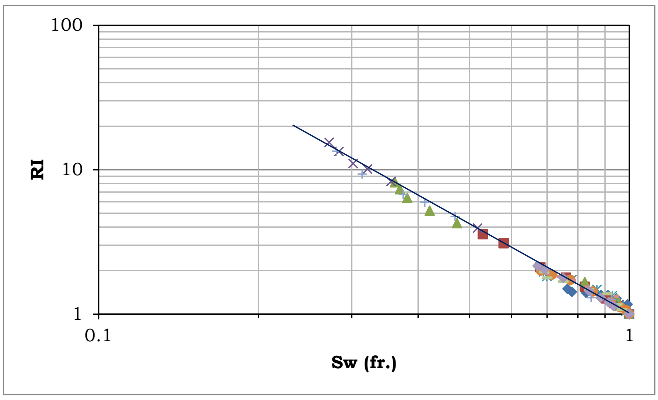

Figure 2. Water Saturation Versus Resistivity Index for 80 core Samples

Table 1. Archie's parameter values of studied reservoir.

	Cementation Exponent (m)	Tortuosity Factor (a)	Saturation Exponent (n)
Forced fit line	2.006	1	1.96
Free fit line	1.64	2.48	1.96

IV. RESULTS AND DISCUSSION

Accuracy in water saturation values relies on the uncertainty of Archie's parameters used either in Archie saturation equation for clean formations or in a shaly-sand Archie water saturation model for shaly formations (Hamada, AlMajed Okasha, and AlGathe, 2010; Atkins and Smith, 1961; Kennedy, Herrick, and Yao, 2001; Dernaika, Efnik, Koronful, Mansoori, Hafez, and Kalam, 2007; Sweeney, and Jenning, 1960). Well 1 and 3 are selected to illustrate the variation and comparison between water saturation shaly models overall studied reservoir units (A and B). Figure 3 and 4 show the water saturation and the main wire line recorded through the studied reservoir through different wells. It is clearly the well 1 is less shale content cross the reservoir units rather the well 3. From the Neutron and Bulk density logs overlay, the A unit is occupied by gas content. Figure 5 and 6 show results of different models over shaly studied reservoir depths and effect of Forced and Free fit line values of Archie's parameters. Generally, both reservoir units demonstrated the lowest values of water saturation by Simandoux, Indonesian, and Archie formula respectively, even using Forced or Free fit line Archie's values. Thence, both units A and B are selected from the wells 1 and 3 to explain and show effect of Archie's parameters and shale content (Figures 5 and 6). It recognized both Archie and Indonesian formulas have closed values of water saturation while the Simandoux results less than them. Therefore, Archie formula known for clean reservoir water saturation estimation could be used instead of Simandoux formula in shaly intervals if used the factual parameters of a, m, and n of a reservoir. Table (2) includes average values of water saturation of whole and each studied reservoir units of different wells with Shale content. Increasing of avaerage water with increasing average shale content, furthermore it as high values estimated by forced Archie's parameters comparied with free Archie's. core measured water saturation for the same depth may be useful for verifecation of these water satuartion models.

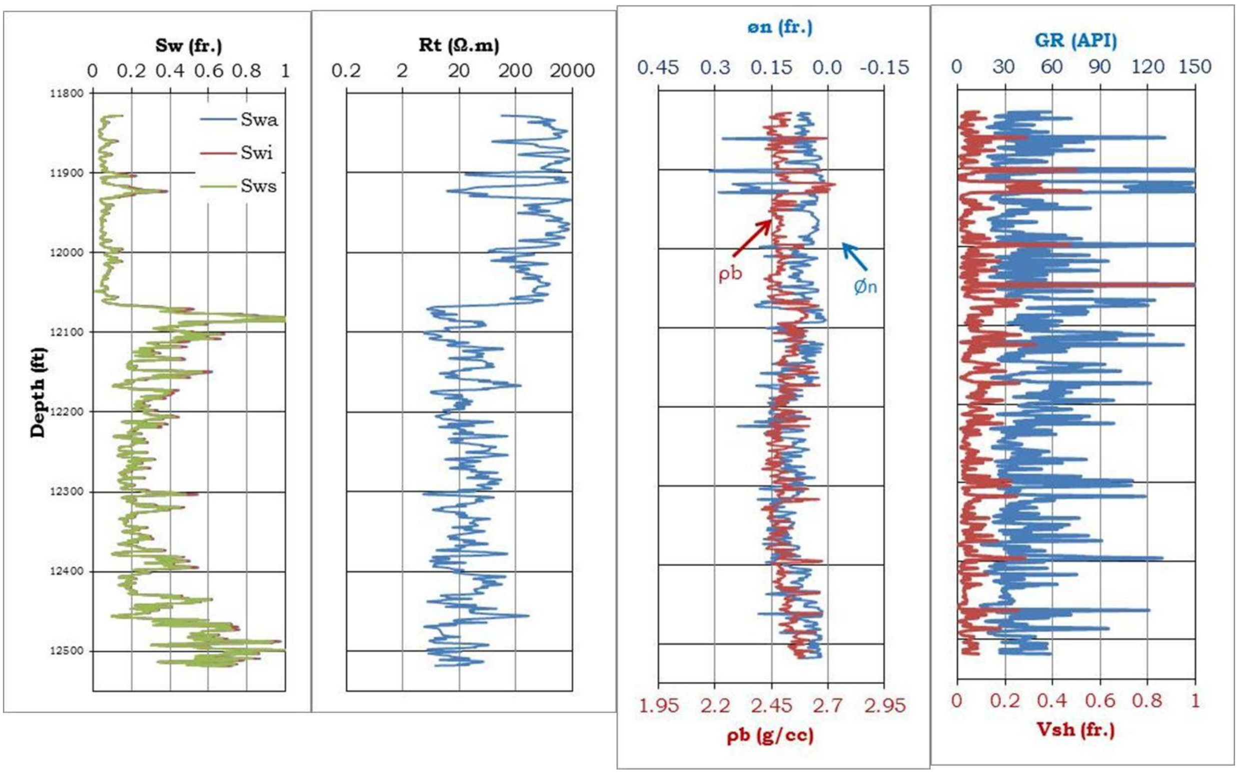

Figure 3. Water Saturation Results and Main Wire Line Logs of Well 1.

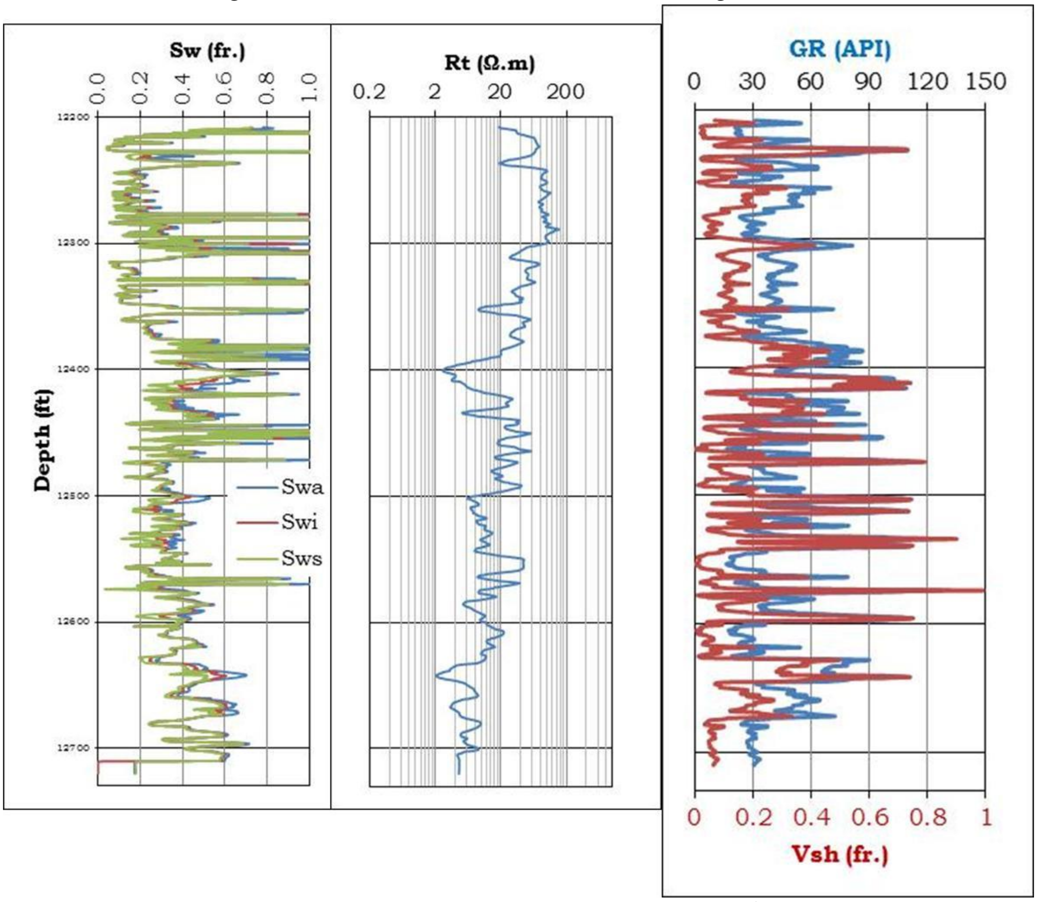

Figure 4. Water Saturation Results and Main Wire Line Logs of Well 3.

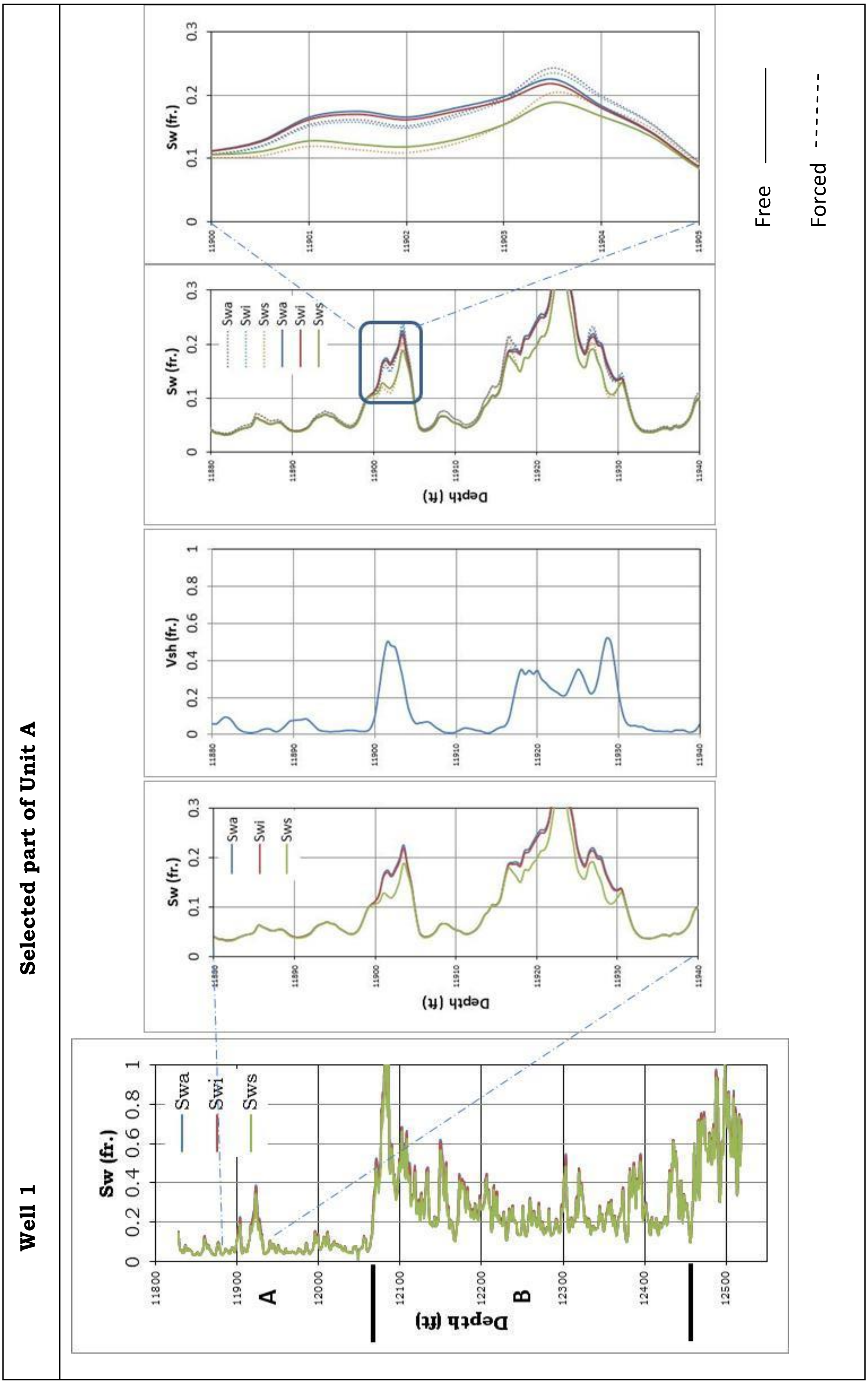

Figure 5. Water Saturation Estimation Results of Well 1 Using Forced and Free Archie's Parameters.

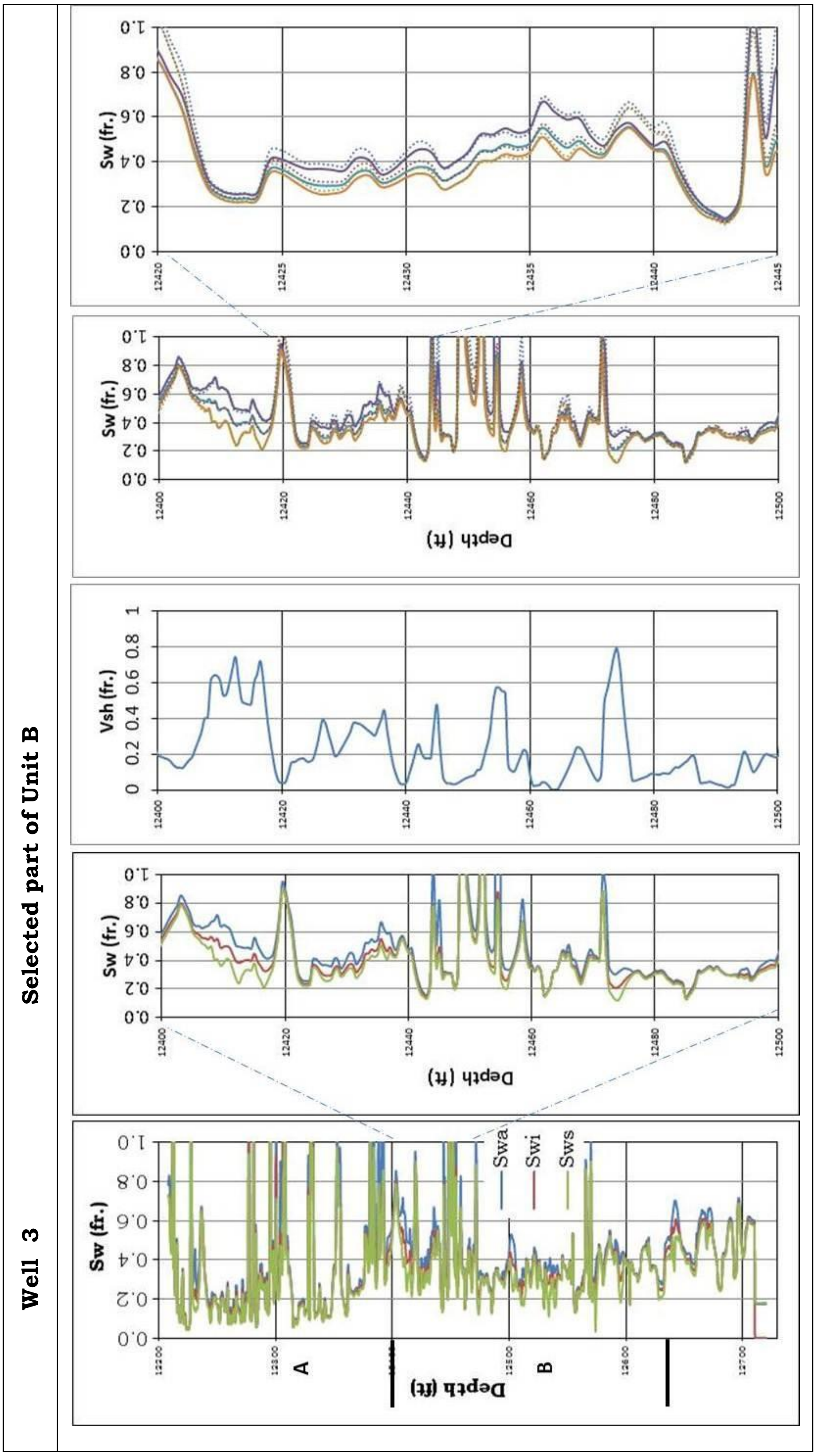

Figure 6. Water Saturation Estimation Results of Well 3 Using Forced and Free Archie's Parameters.

Table 2. Summarized Average Water Saturation of Studied Reservoir.

Units		Average Sw (%)					
		Well 1		Well 2		Well 3	
		A	B	A	B	A	B
Swa	Free	7.56	29.28	13.82	32.95	66.15	42.99
	Forced	7.87	29.93	14.52	33.30	138.4	45.79
	Free	24.78		29.09		52.36	
	Forced	25.82		30.30		80.49	
Swi	Free	7.49	29.05	13.11	30.61	34.23	37.72
	Forced	7.79	29.67	14.54	32.46	38.88	38.95
	Free	24.59		26.97		37.91	
	Forced	25.60		29.55		40.06	
Sws	Free	7.02	27.97	12.14	28.85	30.76	35.02
	Forced	7.33	28.61	12.96	29.04	34.64	36.25
	Free	23.68		25.57		34.68	
	Forced	24.70		26.56		36.86	
Vsh (%)		7.44		14.7		18.01	

V. CONCLUSION

Implication of research and practice of such this study has provided a viable solution to enhance and enclosed water saturation model in this reservoir rock type "shaly sand" according to the basic wire line and core data measured. Additional to site-specific values of Archie's parameters will facilitate computation of a more accurate water (hydrocarbon) saturation; thereby enhancing management economic decisions. Using free Fit line technique was better than Forced to determine Archie's parameters. Whereas, presence varied percentage of shale over the studied reservoir is also an impact factor. Therefore, in like this studied reservoir cored samples which used to defined a, m and n could be taken in such shaly interval, not in clean ones only. These parameters have been validated against reservoir bearing zones and used in the study to select and develop water Saturation interpretation model or Formula for shaly formations. The water saturations for A and B reservoir units have decreased by about 5 to 10 % as compared with the earlier estimated values using conventional parameters. The study will help in evolving strategy for the development of the shaly reservoir and realistic estimation of oil in place.

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