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PETROPHYSICAL EVALUATION OF LIMESTONE RESERVOIRS USING WELL LOG INTERPRETATION IN HISWAH FIELD, SAYUN-MASILA BASIN, YEMEN

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تقييم بتروفيزيائى لخزانات الحجر الجيرى باستخدام تأويلات تسجيل الآبار بحقل حسوة، حوض سيئون- المسيلة، اليمن

الخلاصة: يختص هذا العمل بدراسة الخصائص البتروفيزيائية وعمل تحليل للمحتوى الهيدروكربونى وبناء نموذج مناسب لخزان سار-نيفع (الحجر الجيرى) المتكون فى العصر الجوراسى المتأخر الطباشيرى المبكر الواقع فى قطاع مالك (٩) النفطى حوض سيئون- المسيلة، اليمن، حيث تم حساب المسامية ونسبة الطفل ونسبة التشبع بالماء اعتماداً على البيانات المتاحة من التسجيلات البئرية مثل المقاومة الكهربية والكثافة والنيوترون وأشعة جاما بنوعيها لأربع آبار موزعة فى الحقل. أظهرت النتائج أن قيم التشبع بالماء للصخر المحسوبة من سجلات الآبار تتراوح بين ١٢% الى ٤٠% وقيم المسامية الفعالة تتراوح بين ١٠% الى ١٥% بينما قيم حجم الطفلة تتراوح بين ٦% الى ١٧% . تعتبر سجلات الآبار مصدر مهم لمعرفة نوعية الصخر فى وحدات الدراسة من خلال عمل علاقات وحسابات مختلفة. تبين أن خزان سار-نيفع يتكون بشكل أساسى من صخور جيرية طينية مع قليل جداً من الصخور الطينية الثانوية. ومن جانب أخر، تستخدم تسجيلات العناصر المشعة المكونة لأشعة جاما لتحديد مدى ثبات هذه العناصر وتحديد نسبة الطفلة بالإضافة إلى نوعية معادن الطين فى صخور الخزان. تم قياس ثلاثة تسجيلات إشعاعية لمكافئ اليورانيوم ومكافئ الثوريوم ونسبة البوتاسيوم لخزان سار-نيفع فى ٤ آبار فى حقل الحسوة النفطى. عكست نتائج التحليل الإحصائى لعناصر أشعة جاما فى خزان سار-نيفع بأن العنصر المشع الرئيسى هو اليورانيوم مما يدل على احتواء خزان سار-نيفع على مواد عضوية كما عكست نتائج تحليل العناصر المشعة المكونة لأشعة جاما بأن معادن الطين فى صخور الخزان تتمثل فى الكلوريت والمنتمورلونيت والكاولينيت والطين المختلط. أوضح تحليل تسجيلات الآبار بأن خزان سار-نيفع يتكون بصورة رئيسية من صخور كربوناتية (limestone) والقليل من صخور الطفلة وأن خواص الخزان المستنتجة تبين بأن خزان سار-نيفع يعتبر خزاناً ذا كفاءة جيدة. آمكن تقييم الخواص البتروفيزيائية لخزان سار-نيفع وأوصت الدراسة بحفر آبار جديدة لتنمية الحقل على الوجه الأمثل.

ABSTRACT: *This study was carried out to investigate the general geological setting, structure setup and petrophysical characteristics (Φ, R_w, R_t, S_w, S_h, S_{hr}, S_{hm}) for Saar-Naifa reservoir rocks using conventional and advanced logging tools. Several steps were done such as developing lithology saturation and lithologic identification cross plots, introducing the lateral variation of the lithology and the different saturation distribution in the Saar-Naifa reservoir. The porosity analysis of the investigated area indicated that the average effective porosity of the Saar-Naifa reservoir varied from 11 to 15% and the water saturation of the Saar-Naifa reservoir ranged between 12 and 38%. On the other hand, hydrocarbon saturation matches well with water saturation in a reverse relationship. From these results, it could be concluded that the Saar-Naifa reservoir represents the main producing zone in the studied area.*

The gamma ray spectrometry is used to determine the stability of radioactive elements, shale volume and clay type. Three spectrometric variables eU, eTh and K% are recorded in nine wells of Saar-Naifa reservoir in Hiswah oil field. Statistical analysis of the radioactive elements (uranium and thorium) reflects their concentrations in Saar-Naifa reservoir. Spectral gamma ray log analysis results indicate that the clay minerals of Saar-Naifa reservoir are chlorite, montmorillonite, kaolinite and mixed layered clay. Well log analysis reflects that the Saar-Naifa. reservoir is composed mainly of limestone and minor shale and acts as a good reservoir for hydrocarbon accumulation.

INTRODUCTION

The Republic of Yemen lies at the south - west corner of the Arabian Peninsula .Saudia Arabia borders the country to the north , Oman to the east , the Gulf of Aden to the south. and the Red sea to the west.

Sayun-Masila basin is a major hydrocarbon productive sedimentary basin in the Republic of Yemen. This basin was formed as rift during the Late Jurassic (Kimmridgian) due to the Goundwana breakup, when the African-Arabian plate was separated from the Indian-Madagascar plate (Beydoun et al., 1996). The Sayun-Masila basin is bounded from the west and south by the Jahi-Mukalla high, to the east by the Mukalla-Sayhut Tertiary rift basin "Gulf of Aden" and to the northwest by the Fartaq high and North Hadramawt Arch (Fig. 1). The Lower Cretaceous sequence is divided, from base to top, into Naifa, Saar and Qishn Formations. Naifa carbonate and The Saar consists of there members: Upper Saar Clastics,Middle Saar shale and Lower Saar Carbonate. The Lower Saar Carbonate Member and Naifa carbonate contain about 90% of oil reserves. The reservoir is called Saar-Naifa .

Accurate petrophysical evaluation of deep water channels composed of thin bedded sand-shale sequences, is crucial in the economic decision to explore, develop and produce these reservoirs, so that advanced and conventional logging techniques are used to identify the reservoir characteristics accurately and select the best model for this area to determine water saturation, porosity, volume of shale and permeability as there are different saturation models As there is no precise limitations to use certain model than others, so there should be many researches to help log analyst to choose the most suitable and representative shaly sand model for a certain formation. The Hiswah Field is located in the central part of the block 9 The Sayun-Masila basin, (Fig 1). The Hiswah oil field area is approximately ~63 km^2. Oil was encountered in the Lower Cretaceous, Upper Jurassic limestones. The reservoir consists of a succession of limestone and little shale in a general upward fining profile.

There are 26 wells in Hiswah Field : 24 development and exploratory wells and 2 water injection wells . This study will focus on 4 wells only .

General geology:

Malik Block-9 occupies the western part of the Sayun-Masila basin, a Jurassic-age rift containing important source-reservoir-seal combinations that make them world-class hydrocarbon systems. A rich Jurassic marine source rock called the Madbi shale is present in the deeper basin and is responsible for charging all the potential reservoirs. The source and reservoir intervals for Block-9 are shown on the stratigraphic column in Figure 2. The reservoirs can be charged laterally where the Madbi is in fault contact with porous sands and carbonates, or via faulting. The faults are responsible for the numerous structural culminations and closures within the basin. Fault reactivation occurred locally during the Cretaceous time with some additional movement occurring during Oligo-Miocene time. At Hiswah, this recent fault movement has manifested itself as a strike-slip along the Hiswah Field Bounding Fault that has resulted in alternating compressive and extensional features. The latter may be part of the antithetic fault generation. As shown in Figure (2), the succession at South Daysah begins with basement rocks of metamorphic sediments. The Arabian craton was transgressed in mid-Jurassic Callovian time, prior to the rifting episode. The Kohlan and Shuqra Formations were deposited during this pre-rift event. Following the onset of extensional tectonics and rifting in the Upper-Jurassic Oxfordian to Tithonian time, syn-rift marine deposits of the Madbi and Lower Naifa Formations were deposited (Figure 2). Post-rift, sub-basin, marine carbonate deposits of the upper Naifa and Saar Formations record an overall regressive event and were abruptly terminated by the lower Cretaceous Valanginian unconformity. The sub-basin is best expressed by the Qishn and Saar package of reflectors, and is displayed by the regional seismic line in Figure 3.

The Valanginian unconformity was transgressed in the Lower Cretaceous Barremian time, as a result of rise of the sea level, depositing the important Qishn Formation clastics sands, silts and shales. Continued transgression resulted in the clastics being capped and sealed by carbonate and shale deposits of the Qishn Carbonates Member. Carbonate deposition was terminated by the Lower Cretaceous Aptian unconformity (Figure 2). The Aptian unconformity was transgressed in Albian time and deposits dominated by fluvial sandstones continued until the Upper Cretaceous Maastrichtian unconformity. This dominant sandstone interval comprises the Harshiyat and Mukalla Formations (PEPA, 2004).

METHODOLOGY

1- Comprehensive well logging analysis has been carried out using IP software for Saar-Naifa reservoirs in selected wells in Hiswah field using logging data in the form of caliper, deep and shallow resistivity tools, porosity tools (density, neutron and sonic), gamma ray (CGR,SGR)

2- Lithological and mineralogical evaluation use made of encountered reservoir rocks encoutered within the Tithonian,Berriasian section (Saar and Naifa Fm.) in the studied wells. This has been achieved by graphical techniques to identify matrix and porosity in addition to the clay type.

3- Vertical petrophysical distribution cross-plot has be made in each well in the form of litho-saturation cross-plot and lateral distribution of petrophysical parameters in the form of isoparametric maps.

Log Analysis:

The Interactive Petrophysics (IP) software program has been used to calculate the petrophysical parameters of Saar-Naifa reservoir. There are different types of data (resistivity, neutron, density, sonic, gamma ray (CGR-SGR), caliper, Photoelectric Absorption (PE)) which are corrected prior of being used in the determination of the petrophysical characteristics of the reservoir.

The formation temperature is an important parameter in formation evaluation. It has a great effect on the resistivities of the drilling mud (R_w), the mud filtrate (R_{mf}) and the formation water(R_W) in which resistivities vary considerably with temperature. Formation Temperature Equation [Asquith 1980].

$$FT = ST + [((BHT-ST)/TD)] * FD \quad (1)$$

where

(FT) = formation temperature (C)

(ST) = surface temperature (C)

(BHC) = bottom hole temperature (C)

(TD) = total depth (M)

The determination of R_W was achieved through two methods:

A) Water Sample Measurement

B) Pickett’s Plot.

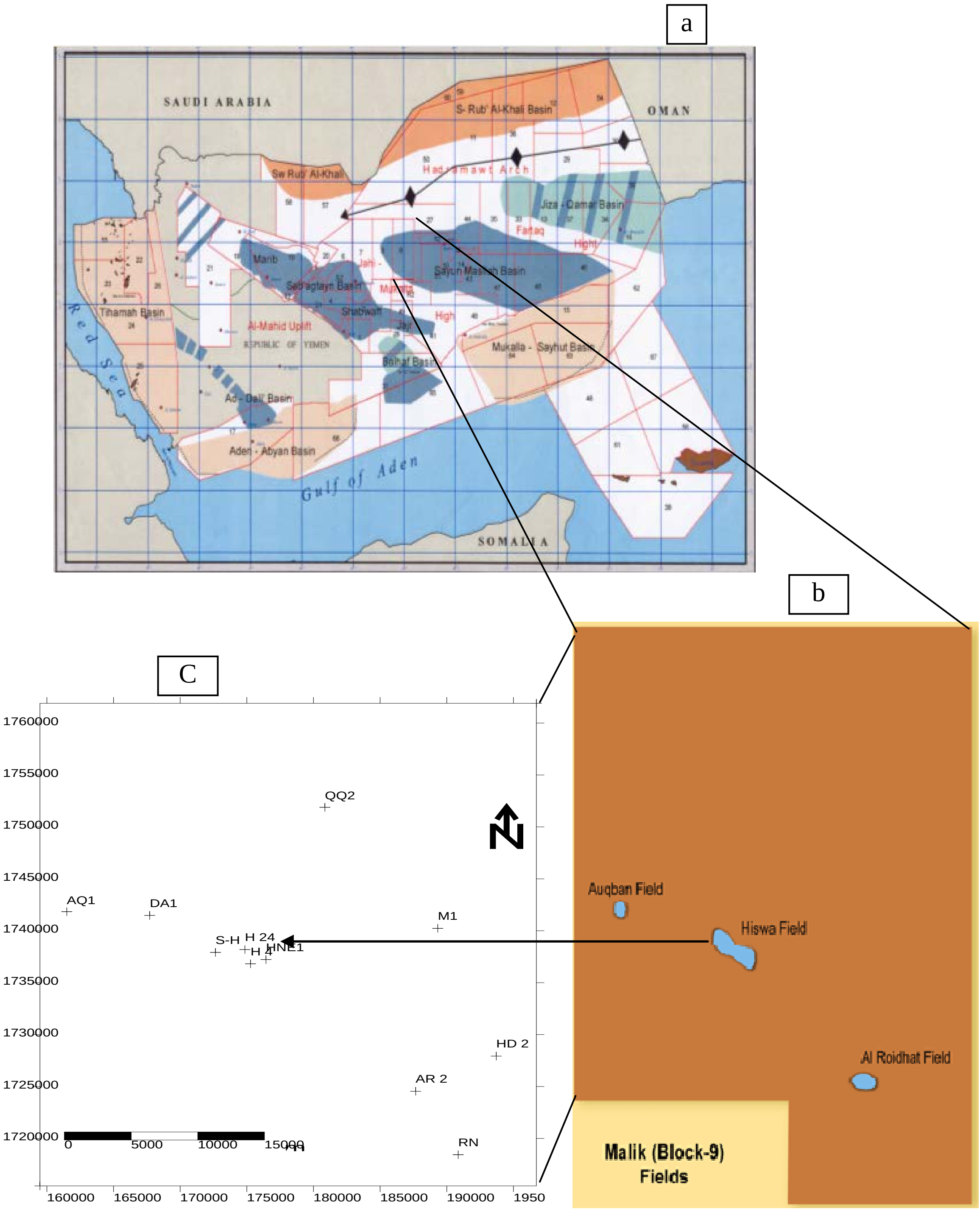

Figure (1): Location map showing the geology of Yemen (a), oil fields (b) and the locations of the wells (c).

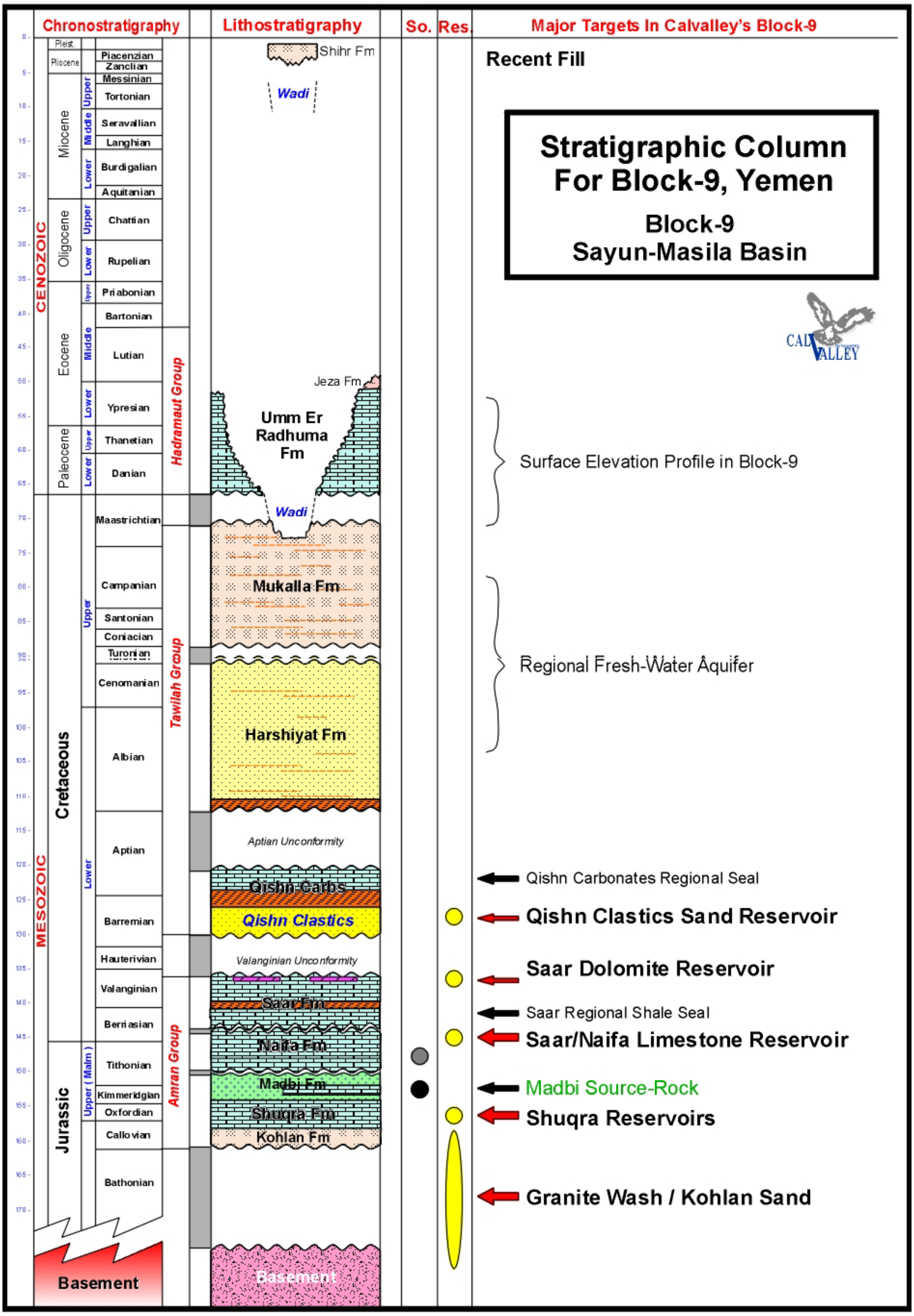

Figure (2): Stratigraphic Column of the Sayun-Masila Basin and Block-9 (Calvalley, 2007).

The determination of shale content (V_{sh}) was achieved through three indicators, namely gamma ray log, resistivity log and neutron-density logs and the lowest value of these indicators is likely to be close to the actual value.

Gamma Ray :

$$VclGr = \frac{Gr - GrClean}{Grclay - GrClean}$$

Resistivity :

The volume of shale was estimated from resistivity logs [PGL 2008].

$$Z = \frac{Rclay}{Rt} * \frac{(Rclean - Rt)}{(Rclean - Rclay)}$$

Neutron / Density :

Shale volume estimated from Neutron/Density logs as a double shale indicator from Equation(3-10) (PGL 2008):

$$V_{s\ (n\ )h} = \frac{[(D_{cl-2} - D_{cl-1})(N - N_{cl-1}) - (D - D_{cl-1})(N_{cl-2} - N_{cl-1})]}{[(D_{cl-2} - D_{cl-1})(N_{clay} - N_{cl-1}) - (D_{clay} - D_{cl-1})(N_{cl-2} N_{cl-1})]}$$

where

Dcl1&Ncl1 and Dcl2 & Ncl2 are the density and neutron values for the two ends of the clean line .

The determination of porosity from conventional tools was achieved through Combining the neutron and density porosities:

$$\Phi=(\Phi_D+ \Phi_N)/2$$

$$\phi_e = \frac{2\phi Nc - 7\phi Dc}{9}$$

(in gas, Schlumberger, 1972)

The determination of fluid saturations in shaly limestone reservoirs is very critical as the shaly limestone models are classified into empirical and theoretical models. The empirical models are those models that were developed by modifying Archie's equation due to the presence of shale and this work will focus on the Indonesian Model .

Indonesian (Poupon-Leveaux) :

$$\frac{1}{\sqrt{Rt}} = \left(\sqrt{\frac{\phi^m}{a * Rw}} + \frac{Vcl^{\left(1-\frac{Vcl}{2}\right)}}{\sqrt{Rcl}}\right) * Sw^{\frac{n}{2}}$$

The hydrocarbon saturations and movable (S_{hm}) and residual hydrocarbons (S_{hr}) were determined as follows:

$$Sh = 1 – Sw \ \& \ Shr = 1 – Sxo \ \& \ Shm = Sh – Shr$$

Lithological and Mineralogical Identification:

In this study density – neutron (RHOB-CNC) (M – N)cross plots will be used for lithology identification of the Saar-Naifa reservoir in the studied well, while the clay minerals identification were achieved by different cross - plots Th-K, PE-K and PE-Th/K.

RESULTS

The evaluation of Saar-Naifa reservoir is illustrated through the mineral identification cross- plots and litho-saturation cross - plots .

A) The mineral identification cross- plots (Th-K, PE-K and PE-Th/K) of Hiswah-4, S-Hiswah, HNE-1v, Hiswah-24 wells show that clay minerals vary between montmorillonite, gluconite, illite, biotite and moderate percentage of mica as shown in Figures (1), (2) and (3).

B) Litho-saturation crossplots of Saar-naifa reservoir. The rock units of Sequoia channel in Hiswah-4, S-Hiswah, HNE-1, Hiswah-24 wells the composed mainly of limestone with shale streaks for reservoir intervals (figures 7, 8, 9, 10). The effective porosity calculated from neutron–density ranges from 10% to 15% and the water saturation calculated from conventional tools ranges from 12% to 40 % .

The highest values of water saturation 38.2 % from Hiswah-24 well and lowest values of water saturation 12 % from HNE-1 well .while the highest values of Porosity 14.9 % from Hiswah -4 well and lowest values of porosity 11.4 % from S-Hiswah well. The highest values of clay volume 16.6 % from S-Hiswah well and lowest values of 5.8 % from HNE well, Table (1). The conventional tools (neutron & density) are fluid and lithology dependent while for water saturation tracks it is apparent that water saturation calculated from Indonesian model (Sw_{ind}).

From the statistical analysis of the radioactive elements in the Saar-Naifa reservoir, it is clear that the main radioactive elements in this Formation are potassium, uranium and thorium respectively (Table 2-5).

The mean value of Potassium is 0.52% and the mean value of uranium is 3.50 ppm while the mean value of thorium 1.54 ppm. These values lead to the assumption of the concentration of organic matter in the Saar-Naifa reservoir and support the low value of shale volume in Saar-Naifa reservoir.

Table (1): Petrophysical results for reservoir intervals for Hiswah-4, S-Hiswah, HNE and Hiswah-24 wells.

Name	**Top m**	**Bottom m**	**Grrose m**	**Net pay m**	**Net/Grros m**	**Av $V_{CL\ \%}$**	**Av Ø %**	**Av Sw %**
Hiswah 4	1113	1272	159	66	0.420	0.145	0.149	0.166
Hiswah24	1163	1484	321	8.84	0.028	0.090	0.121	0.382
HNE	1114	1324	210	36.77	0.175	0.058	0.116	0.122
S-HIS	1240	1360	120	11.96	0.100	0.166	0.114	0.370
average						0.114	0.125	0.26

Table (2): Analysis of radioactive elements of Saar-Naifa reservoir in Hiswah oil field.

K(potassium)%	**Mean**	**S.D.**	**Min**	**Max**
S-Hiswah	1.02	0.50	0.52	4.98
HNE	0.34	0.32	0.14	3.64
Hiswah-24	0.25	0.18	0.001	2.01

Table (3): Analysis of radioactive elements of Saar-Naifa reservoir in Hiswah oil field.

Th (thorium) ppm	**mean**	**S.D.**	**min**	**max**
S-Hiswah	1.54	1.65	0.45	11.99
HNE	1.49	0.70	0.59	9.77
Hiswah-24	1.57	1.08	0.09	14.52

Table (4): Analysis of radioactive elements of Saar-Naifa reservoir in Hiswah oil field.

U (uranium) ppm	**Mean**	**S.D.**	**Min**	**Max**
S-Hiswah	3.45	2.07	0.73	13.43
HNE	4.30	2.09	1.17	18.81
Hiswah-24	2.77	1.58	0.02	10.31

Table (5): Analysis of radioactive elements of Saar-Naifa reservoir in Hiswah oil field.

K-Th (potassium-Thorium) GAPI	**Mean**	**S.D.**	**Min**	**Max**
S-Hiswah	17.59	12.54	8.17	93.55
HNE	7.21	5.49	3.07	66.46
Hiswah-24	8.34	4.92	0.26	69.13

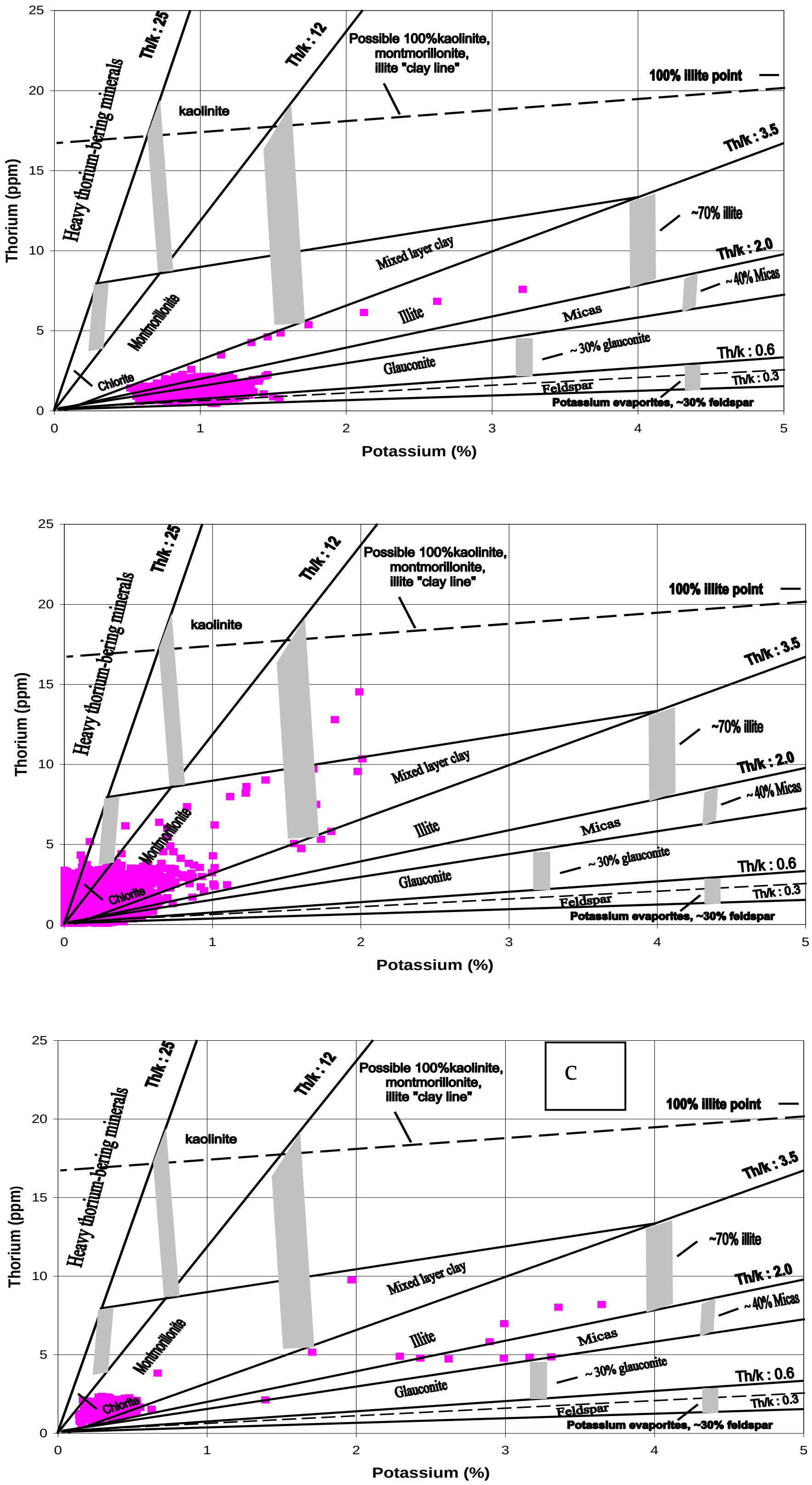

Figure (4): Thorium-potassium cross-plot to identify clay type of Saar-Naifa reservoir in: a) S-Hiswah well, b) Hiswah-24 well and c) HNE well.

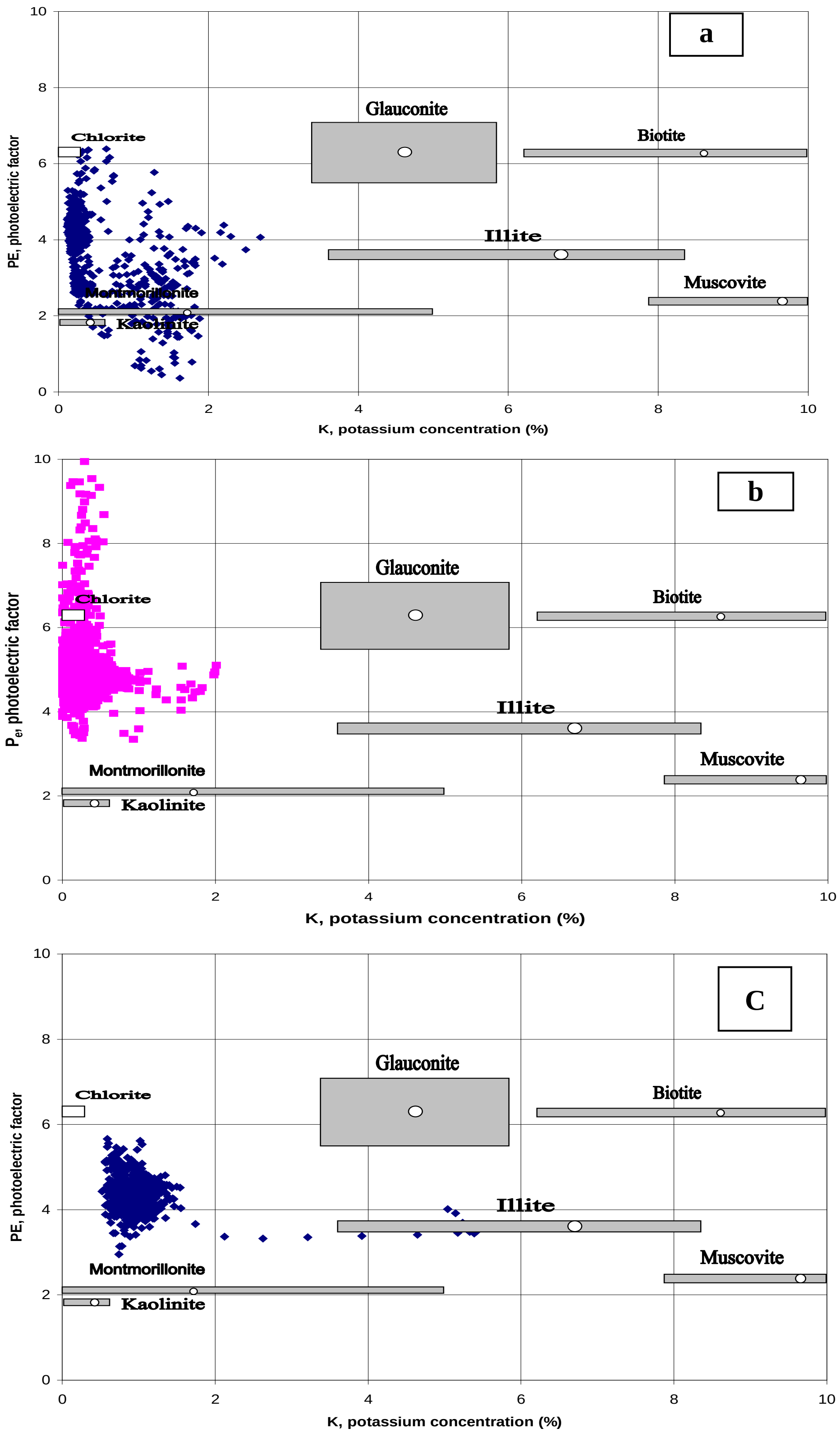

Figure (5): Photoelectric potassium cross- plot to identify clay type of Saar-Naifa reservoir in HNE-1V (a), Hiswah-24 well (b) and S-HISAH well (c).

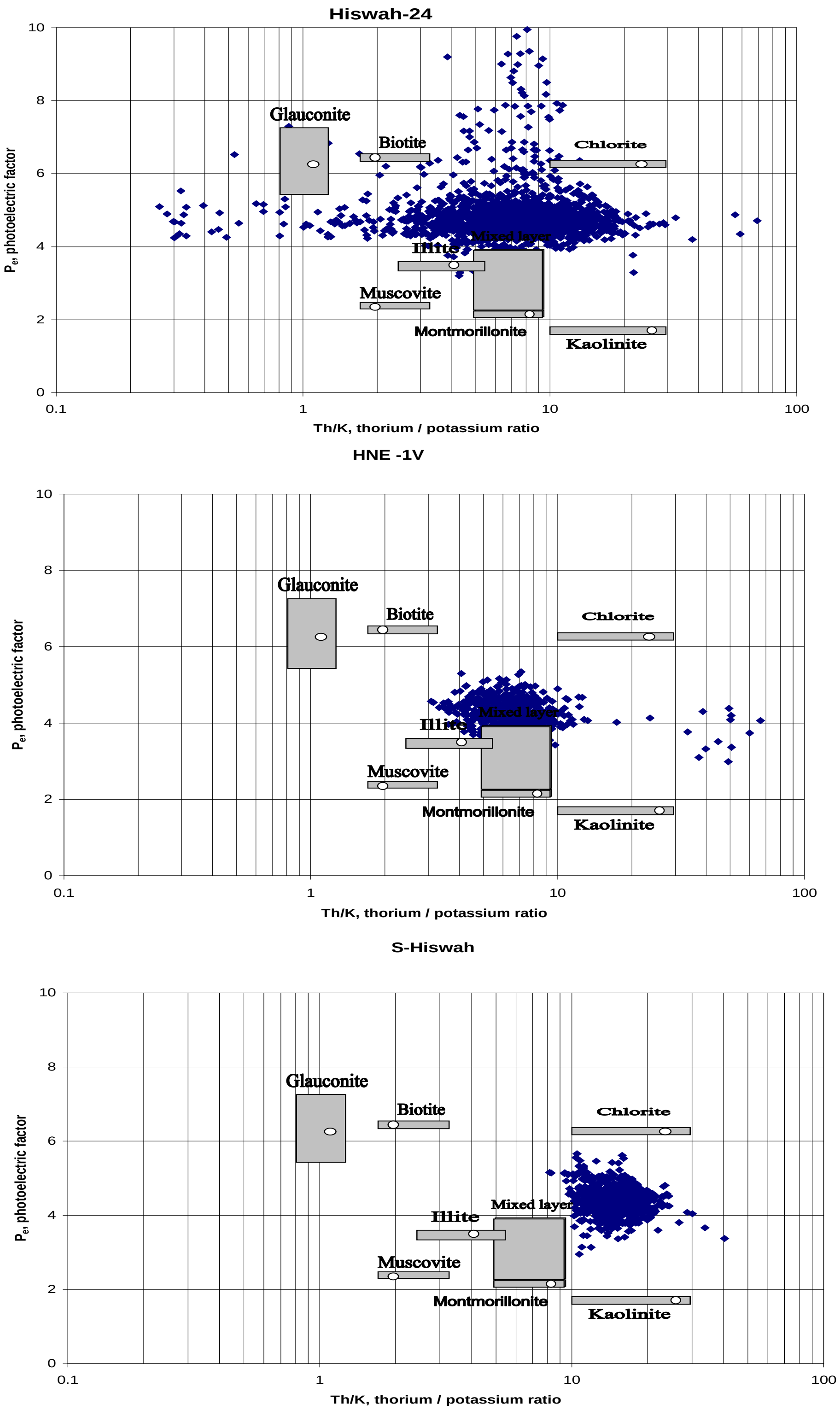

Figure (6): Thorium-potassium with photoelectric cross-plot to identify clay type of Saar-Naifa reservoir in: a) S-Hiswah well, b) Hiswah-24 well and c) HNE well.

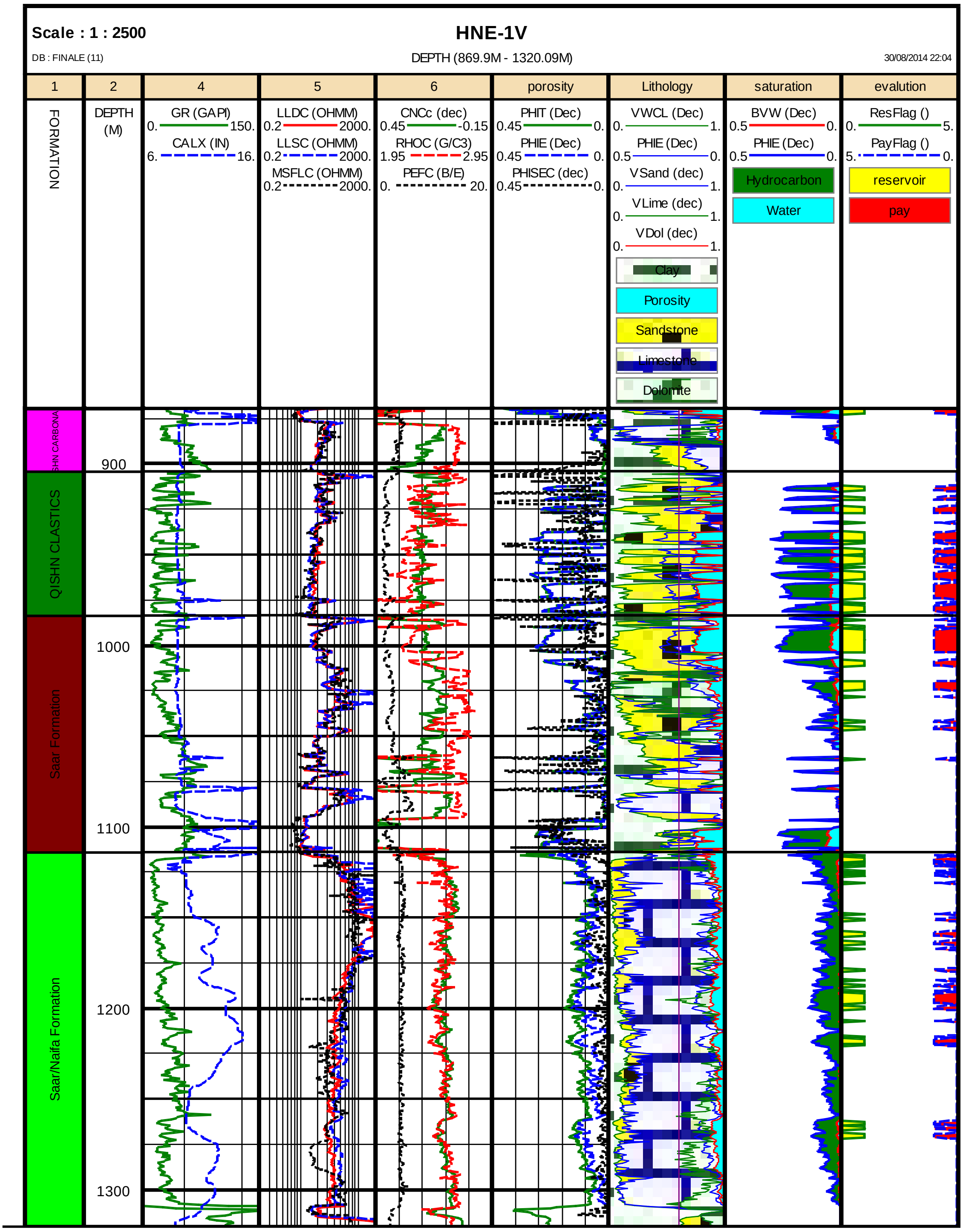

Figure (7): Litho-saturation cross-plot of the HNE well (Schlumberger, 2008).

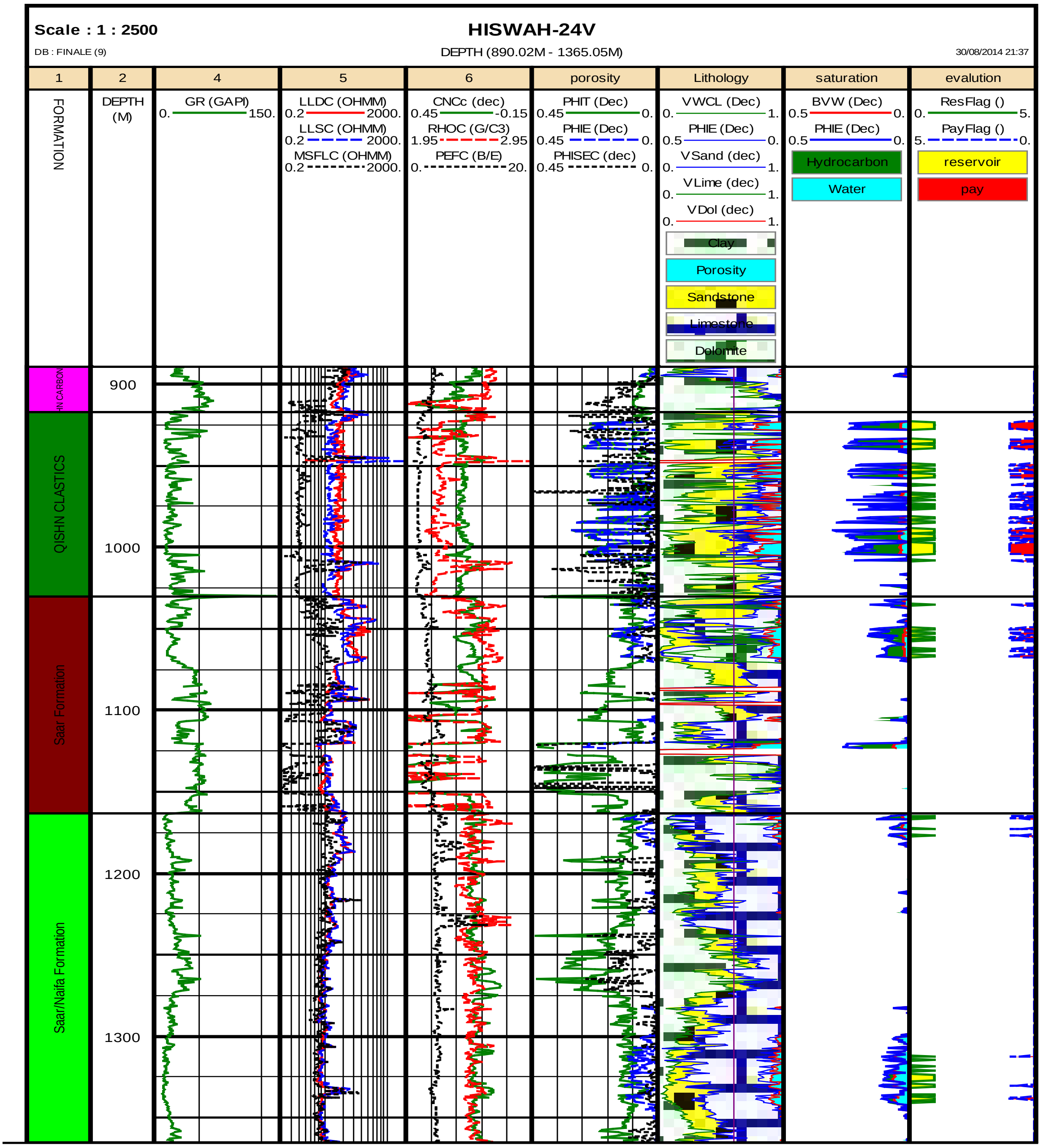

Figure (8): Litho-saturation cross-plot of the Hiswah-24 well.

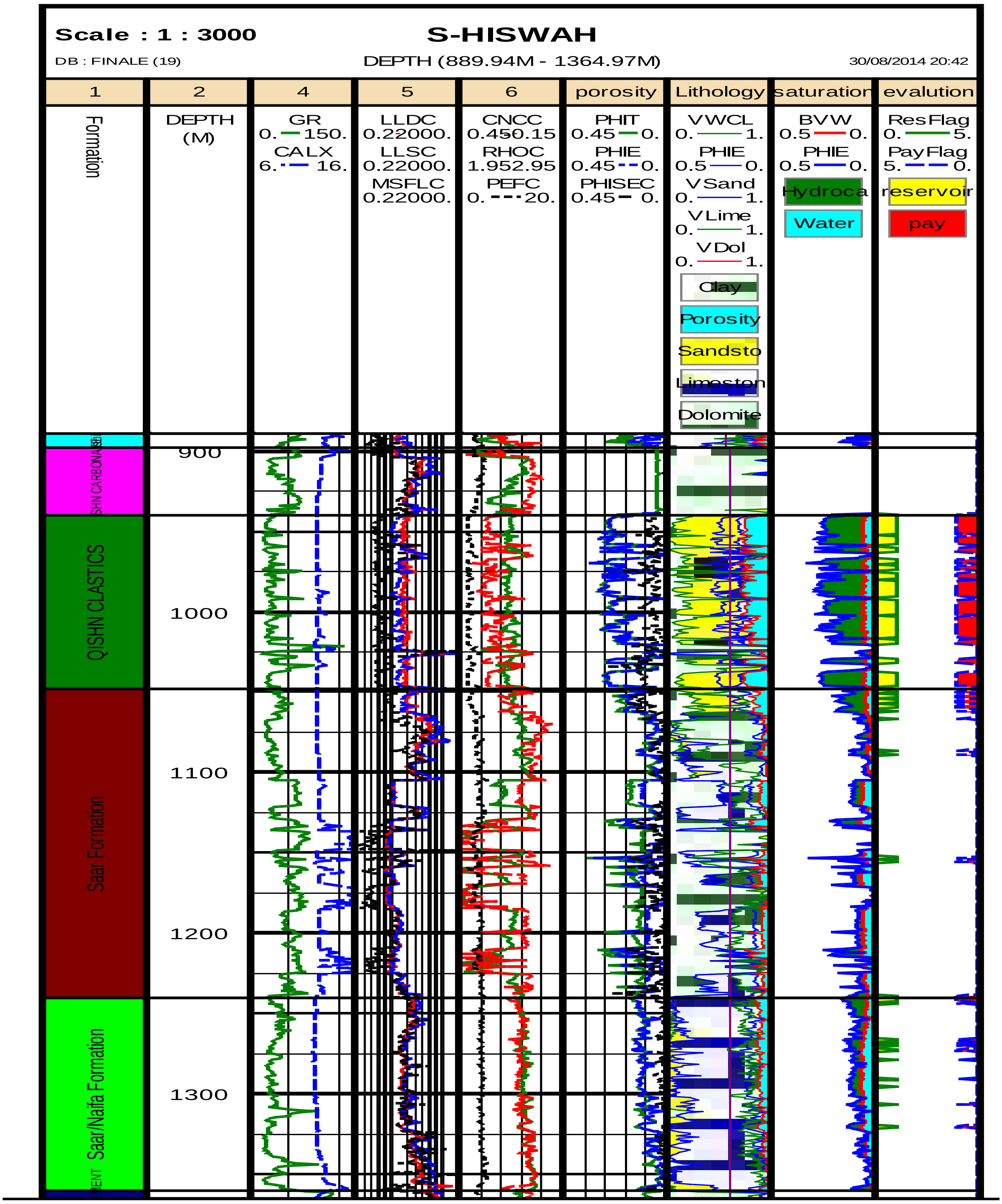

Figure (9): Litho-saturation cross-plot of the S-Hiswah well.

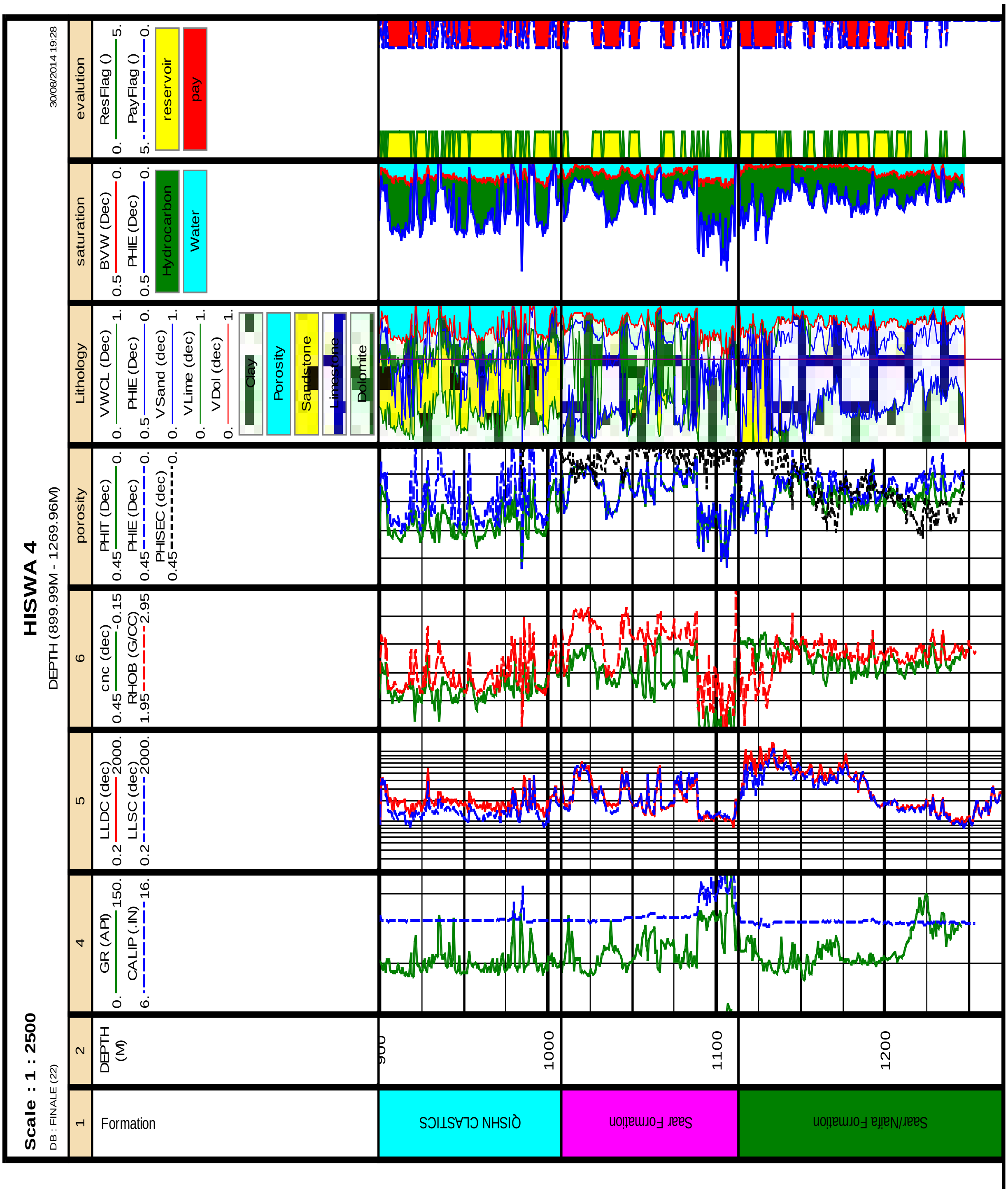

Figure (10): Litho-saturation cross-plot of the Hiswah-4 well.

SUMMARY AND CONCLUSION

Four wells are selected in the studied area from Hiswah Field to perform pretrophysical analysis of the reservoirs rocks through calculation of petrophysical parameters. Porosity analyses of the investigated area indicate that the average effective porosity of the Saar-Naifa reservoir ranges from 11 to 15%. Water saturation of the reservoir ranges from 12 to 38%. On the other hand, hydrocarbon saturation matches well with water saturation in a reverse relationship. Hydrocarbon occurrence decreases, where the water saturation increases. From these results we conclude that the Saar-Naifa reservoir represents the main producing zone in the studied area because the reservoir has good a petrophysicl quality, (porosity, permeability, and water saturation). Lithological identification, wireline logs are the best sources of more information about lithology. Log parameters, such as density, sonic, neutron, natural gamma ray spectrometry, and photoelectric factor enable the determination of sediment components such as limestone, dolomite, sandstone, and clay. Type of each lithologic component was determined through different cross plots. From these cross plots, it could be concluded that the lithology of the Saar-Naifa reservoir is composed mainly of carbonates (limestone) with shale and dolomite. Hydrocarbon potential of the studied area is achieved based on integration of the lithological, petrophysical parameters, fluid parameters, which are obtained from comprehensive analyses processes. It was evaluated through the vertical and horizontal distribution of the hydrocarbon potential. Vertical distribution of hydrocarbon potential is presented and explained through the litho-saturation cross plots. These plots show changes in lithology content of the Saar-Naifa reservoir. It shows porosities (total and effective) and fluid saturations (water and hydrocarbon saturations). On the ether hand, the gamma ray spectrometry is used to determine the stability of radioactive elements, shale volume and clay type. Three spectrometric variables eU, eTh and K% are recorded in nine wells of Saar-Naifa reservoir in Hiswah oil Field. Statistical analysis of the radioactive elements (uranium and thorium) reflects their concentrations in the study reservoir. The reflects from the spectral gamma ray log analysis results, the clay minerals of Saar-Naifa reservoir are chlorite, montmorillonite, kaolinite and mixed layered clay. Well log analysis reveals that the Saar-Naifa. reservoir is composed mainly of limestone with minor shale and acts as a good reservoir for accumulation hydrocarbon. For field development it is recommended according to all the previous analysis to drill a new well in the all field area .

Recommendations :

There is one recommendation to develop this field.

1- By overlaying the results of the reservoir petrophysical parameters of the Saar-Naifa reservoir it was found that southern part of Hiswah field it the best place for the further exploration and development of the Saar-Naifa reservoir.

2- Drill more well in the field and make the 3-D seismic for the whole area .

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