Egyptian Geophysical Society
EGS Journal, Vol. 12, No. 1, 49-64 (2014)

PETROPHYSICAL EVALUATION OF SHALY SAND RESERVOIRS USING CMR TOOL IN OFFSHORE SEQUOIA FIELD, NILE DELTA, EGYPT

N.M.H. Abou Ashour, A. Mahmoud and H.M. Mahmoud

* *Geophysics Dept., Fac. of Sc., Ain Shams University , Egypt.*

التقييم البتروفيزيائى لخزانات الحجر الرملى الطفلى باستخدام تسجيلات الرنين المغناطيسى النووى لحقل سيكويا- دلتا النيل - مصر

الخلاصـة: يختص هذا العمل بدراسة الخصائص البتروفيزيائية وعمل تحليل للمحتوى الهيدروكربوني (الغاز) وبناء نموذج مناسب لخزان سيكويا الحجر الرملى الطفلى لمتكون الوسطانى من البليوسين الواقع فى المنطقة البحرية العميقة لغرب دلتا النيل، مصر. حيث تم حساب المسامية والنفاذية والتشبع بالماء و محتوى الغاز أيضاً اعتماداً على دراسة البيانات المتاحة من التسجيلات البئرية مثل المقاومة الكهربية والكثافة والنيترون وأشعة جاماء، وتسجيل الرنين المغناطيسى النووى الحديث لأربع آبار للتنمية موزعة فى حقل سيكويا . كما شملت الدراسة مقارنة بين النماذج المختلفة (الماء المزدوج و الأندونسية) لحساب التشبع بالماء للخزان واختيار أنسب نموذج مع عمل مقارنة بين نتائج المحسوبة من التسجيلات البئرية التقليدية والأخرى الحديثة (الرنين المغناطيسى النووي) بالإضافة إلى دراسة العلاقة بين البوتاسيوم والتأثير الكهروضوئى و الثوريوم لمعرفة نوع الطفل الموجود داخل خزان سيكويا وتم أيضا دراسة الاتصال الرأسى والأفقى بين الطبقات ومنسوب الماء فى الخزان من خلال دراسة العلاقة بين العمق والضغط لكل الآبار. ولقد أظهرت النتائج أن قيم التشبع بالماء للصخر المحسوبة من نموذج الماء المزدوج هى الأقرب لقيم التشبع بالماءللصخر المحسوبة من الرنين المغناطيسى النووى حيث تتراوح متوسط قيم التشبع بالماء المحسوبة من التسجيلات التقليدية للآبار بين ٣٨% و ٦٨ % والمسامية الفعالة من ٢٨% إلى ٣٢% بينما متوسط قيم التشبع بالماء المحسوبة من التسجيلات الحديثة تتراوح بين ٣٩% إلى ٧٠ % والمسامية الفعالة بين ٢١% إلى ٢٣% والنفاذية بين ٣٠ إلى ٨٩٠ ميلى دارسى وهذا الاختلاف فى القيم يرجع الى أن التسجيلات البئرية التقليدية تعتمد على نوع الصخر والموائع الموجودة داخله بينما الرنين المغناطيسى النووى يعتمد على الموائع فقط. وقد أوصت الدراسة بحفر آبار تنمية جديدة لاستكمال تنمية الحقل على الوجه الأمثل.

ABSTRACT: *This work is devoted to the study of the petrophysical parameters (porosity-permeability- formation water resistivity-hydrocarbon and water saturation-shale content) for Sequoia Pliocene reservoir rocks in Sequoia field in west Nile Delta deep marine concession (WDDM). A suitable model was built for this reservoir using the conventional logging tools (Gamma ray-Density-Neutron-Resistivity) and the new logging tool (Combinable Magnetic Resonance tool "CMR") in 4 development wells.*

Comparisons between the different saturation models (Dual water and Indonesian) to select the best one applicable for this reservoir, plus comparison between CMR and conventional tools results were done.

A study of the lateral, vertical reservoir connectivity and mineralogical identification through pressure plots and Thorium, photo electric effect, and uranium cross plots was done.

The results show that average effective porosity calculated from Neutron-Density varies from 28% to 32%, while average effective porosity calculated from CMR using DMR method ranges from 21 % to 23%. The average water saturation calculated from conventional tools (Dual water and Indonesian) ranges from 38% to 68%, while the average water saturation calculated from CMR ranges from 39 % to 70%. The average calculated permeability from CMR using Timur-Coates model varies from 30 to 890 md. On the other hand, the results show that the water saturation from Dual Water model is the closest model to the water saturation calculated from CMR, and this variation is that conventional tools are fluid and lithology dependent, while CMR is only fluid dependent. The study recommended drilling new wells to develop this field.

INTRODUCTION

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 a new and conventional logging techniques are used to identify 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 with no precise limitations to use certain model than others, so there should be many researches to help log analysts to choose the most suitable and representative shaly sand model for a certain formation sothat CMR is used with conventional tools as CMR is a Schlumberger tool which sends a permanent magnetic field to polarize the hydrogen protons in a preferred orientation. For these protons to generate a measurable signals , they must be at a condition of resonance which can be achieved with an oscillatory magnetic field and once oscillatory magnetic field is removed signals are generated (resonance) as the exponential decay of this signal is represented by T_2 relaxation time which is a function of the petrophysical properties of the fluids and pores that contain them as it is a lithology independent tool.

The Sequoia field is located on the north-western margin of the Nile Delta, approximately 90km offshore. The field lies across the border between the West Delta deep marine concession and the Rosetta concession (Fig 1). The Sequoia block comprises approximately 90 km^2. Gas was encountered in the Pliocene sandstones. The reservoir consists of the succession of sandstone and mudstone in a general upward fining profile (Cross, 2009).

There are 10 wells in Sequoia field,6 development wells and 4 exploratory wells and this study will focus on 4 wells only, namely Sequoia D-1, Sequoia D-3, Sequoia D-4 and Sequoia D-6 wells

General Geology:

A brief summary of the sequence of the major structural and depositional events of the Nile Delta is provided by various authors. The oldest sedimentary rocks are shallow marine carbonates of the Jurassic age.A major eustatic drop in sea level created a significant unconformity. Rifting during the Jurassic as a result of the breakup of the southern NeoTethys continent created a series of east-west growth faults that form the delta hinge line, the boundary between a steady platform to the south and a subsiding basin, the Nile Delta to the north. Early Cretaceous sediments were deposited on the unconformity surface (Aal et al., 1994 &1996). Late Cretaceous interbedded carbonate-clastic sequences are unconformably overlain by Late Eocene-Early Oligocene shalesbeginning in the Late Eocene and continuing to the Recent. The following normal fault trends were formed, the Gulf of Suez NNW trend, the north-south trend of the Baltim area and the Rosetta NNE trend (Aal et al., 1994). Oligocene-Early Miocene sediments consist of sandy and sandy-marlyfacies. Marine conditions were present in the Nile Delta (Palmieri, 1996)

The Middle Miocene Langhian-Serravallian-TortonianSidiSalim Formation was deposited. Sea level rose relatively and delta progradation continued. During the Messinian, the sea level dropped dramatically and extensive erosion occurred. The Qawasim and Abu Madi Formations were deposited as fluvial, estuarine and shallow marine deposits.

The Pliocene rocks in the Nile Delta region are subdivided by (E.G.P.C., 1994) into three formations, from base to top: Abu Madi, Kafr El Sheikh, and El Wastani. The Abu Madi Formation is represented by a thick series of sands, in part pebbly, with interbedded thin shales.

Kafr El Sheikh Formation which incised at the top by low stand and prograding clastics of El Wastani Formation.

The Late Pliocene to Early Pleistocene is represented by El Wastani Formation that was deposited as a regressive sequence after a starvation event of the Kafr El Sheikh Formation, which indicated by a missing time at the base ranging from 0.45 to 1.22 million years. It starts with low stand system tract of channel cut and fills on the top of the Kafr El Sheikh Formation.

The major structures within the concession area are the SW/NE trending Rosetta Fault and the ENE-WSW trending Nile Delta offshore anticline.

Sequoia is a shallow channelized system which extends from the northern part of the Rosetta block through to the western part of the west Delta deep marine (WDDM) concession. The field has an estimated gas in place of 2.0 tcf. A summary of stratigraphic intervals of West Delta marine and Rosetta fields (Fig. 2) which contain Sequoia channel are listed below. The intervals are based on wireline log character, correlated to lithologies

Methodology:

Three types of studies were conducted:

1- Comprehensive well log analysis has been carried out using Interactive Petrophysics (IP) software for Sequoia reservoir in selected wells in the Sequoia field using log data including thecaliper, deep and shallow resistivity tools, porosity tools(density, neutron and sonic), gamma ray (CGR,SGR) and CMR to calculate porosity ,permeability, shale content and water saturation

2- Lithological and mineralogical evaluation of the encounteredreservoir rocks within the Pliocene section (El Wastani Formation.) in the studied wellswas achieved by the graphical technique to identify matrix and porosity in addition to clay type.

3- Vertical petrophysical distribution crossplot represented by lithosaturation crossplots and lateral reservoir connectivity represented by pressure-depth plots.

Log Analysis:

The interactive petrophysics (IP) software program has been used to determine petrophysical parameters of Sequoia reservoir. There are different types of log data (resistivity, neutron, density, gamma ray, CMR ,caliper, sonic) 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 (Rm), the mud filtrate (Rmf) and the formation water(Rw) in which resistivities vary considerably with temperature

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

where

(FT) = Formation temperature (F˚)

(ST) = Surface temperature(F˚)

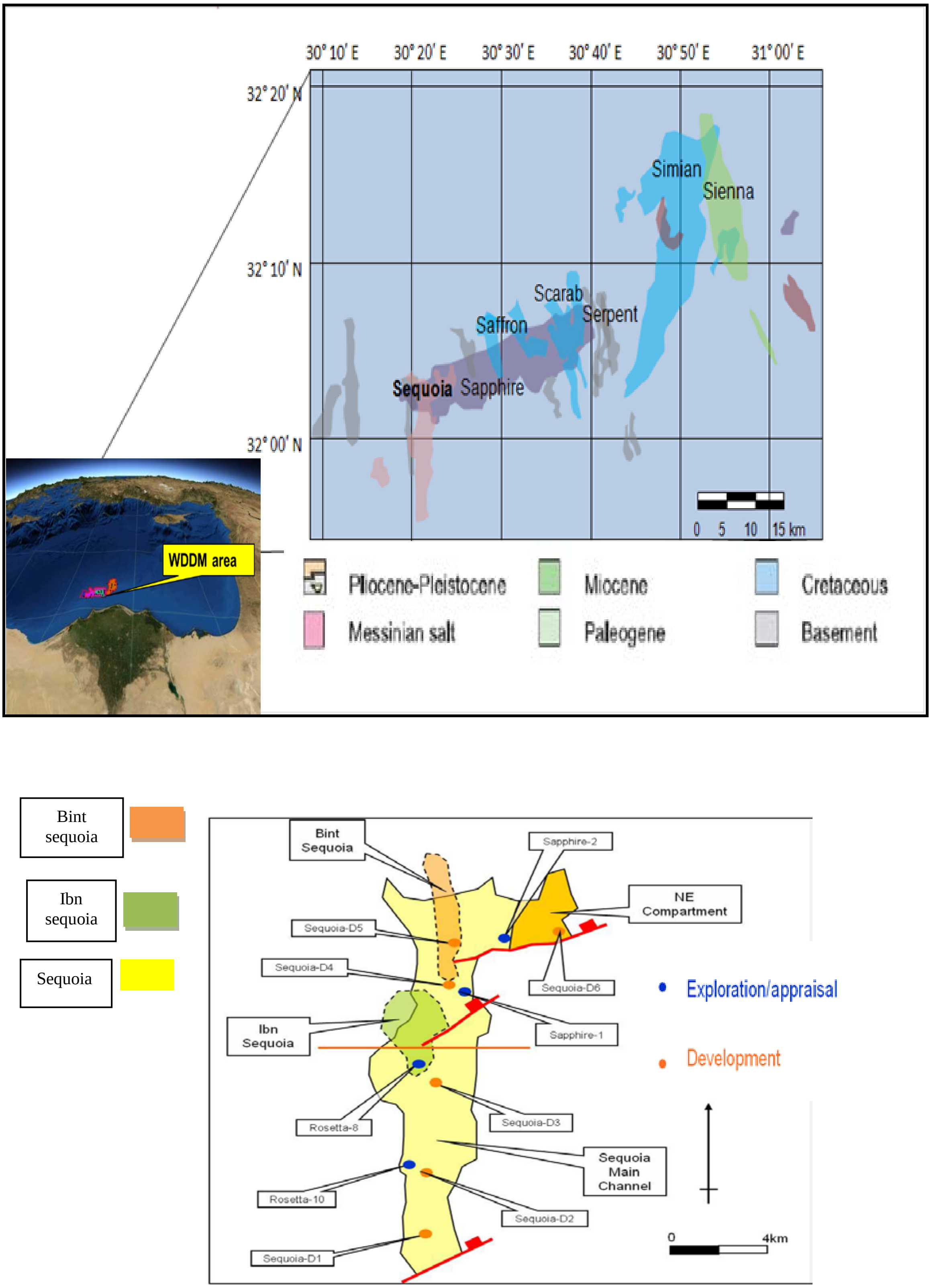

Fig. (1): Sequoia Field Location.

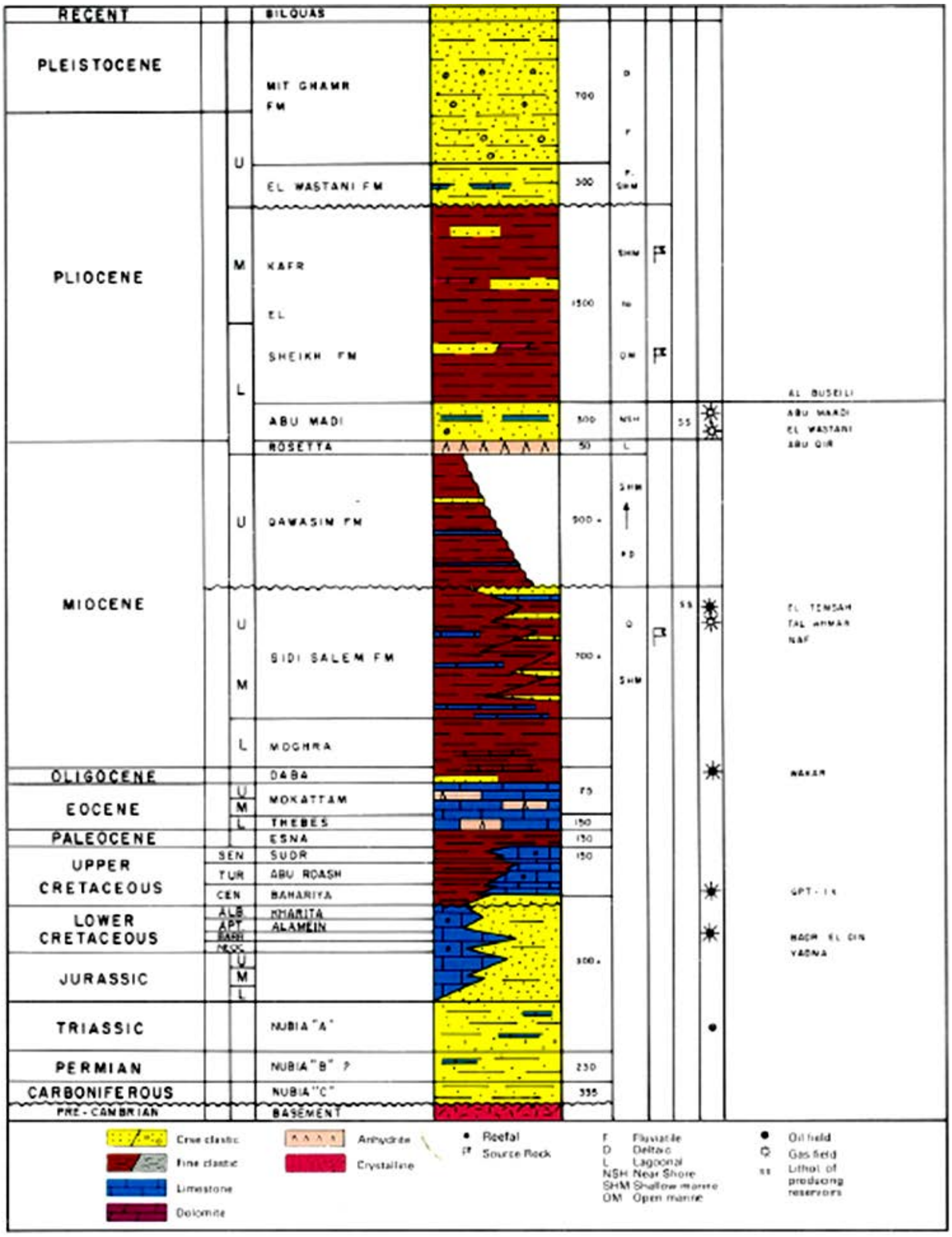

Fig. (2): Generalized lithostratigraphic column of Nile Delta.

(BHC)=Bottom hole temperature (F˚)

(TD)=Total depth (m)

(FD) = Formationdepth (m)

- Determination of Rw was achieved through Water Sample Measurement as it is around 0.08 ohm.m at 140F˚
- Determinationof the shale content (Vsh) was achieved through three indicators, namely the gamma ray log, resistivity log and neutron-density logs and the lowest value of these indicators is likely to close to the actual value.

Gamma Ray (GR):

$$Vcl\ Gr = \frac{Gr - Gr\ Clean}{\text{Gr clay} - \text{Gr clean}}$$

Resistivity:

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

Neutron - Density:

$$VclND = \frac{(DenCl2 - DenCl1) * (Neu - NeuCl1)}{(DenCl2 - Dencl1) * (NeuClay - Neucl1)} \frac{- (Den - DenCl1) * (Neucl2 - Neucl1)}{- (DenClay - DenCl1) * (NeuCl2 - NeuCl1)}$$

Where $DenCl_1$& $NeuCl_1$ and $DenCl_2$& $NeuCl_2$ are the density and neutron values for the two ends of the clean line.

- Determinationof porosity from conventional tools was achieved through combining the neutron and density porosities:

  Φ = (ΦD+ ΦN)/2

While the determinationof porosity fromCMR tool based onnew gas equations derived recently by Freedman (1998) and will be referred to as the Density–Magnetic Resonance (DMR) method as itcombines total porosity from the CMR* combinable Magnetic Resonance tool (TCMR) anddensity log-derived porosity (DPHI) to get gas-corrected total formationporosity.

$$DMRP = PHID \times \left(1 - \frac{HIg \times Pgas}{HIf} + \left(\frac{\frac{\lambda + TCMR}{HIF}}{\left(1 - \frac{HIg \times Pgas}{HIf}\right) + \lambda}\right)\right)$$

Where:

DMRP =Total porosity corrected to gas effect.

PHID= (ρma – ρb) / (ρma – ρf)v/v .

λ= (ρf – DG) / (ρma – ρf) .

Pgas = $1 - e^{(-W/T1g)}$.

Pgas:Polarization of gas, W is wait time & T1g is gas longitudinal relaxation time at reservoir conditionsgas (polarization time)HIf: Hydrogen Index of water in flushed zone =1

DG: Density of gas at reservoir conditions (g/cm^3) and it is determined from MDT gradient,

The DMR gas-corrected total porosity (DMRP) is a new formation evaluation parameter. DMRP can be used in volumetric calculations to provide more accurate reservoir volume. Also, more accurate formation gas saturations can be computed when using gas-corrected total porosity in conjunction with deep-reading resistivity tools.

- Determinationof fluid saturations in shaly sand reservoirs is very critical as the shaly sand 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 workwas focused on the Dual Water Model (Fig4) and Indonesian Model and compared their results with CMR results to select the best model suitable for this field

Indonesian (Poupon-Leveaux) :-

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

$$S_w = \frac{S_{wt} - S_{wb}}{1 - S_{wb}}$$

Dual Water Model

$$\frac{1}{Rt} = \frac{\phi T^{m*} * SwT^n}{a} * \left(\frac{1}{Rw} + \frac{Swb}{SwT}\left(\frac{1}{Rwb} - \frac{1}{Rw}\right)\right)$$

Water saturation from CMR tool

SWE = effective water saturation (capillary water saturation) = Cw/PhiE

As Cw is the volume of capillary water = CBP3+CBP4

where:

CBP3: CMR Bin porosity from 3 msec to10 msec

CBP4: CMR Bin porosity from 10msec to 33 msec as shown in (Fig 3)

The hydrocarbon saturations and movable (Shm) and residual hydrocarbons (Shr) were determined as follows

Sh = 1 – Sw, Shr = 1 – Sxo, Shm = Sh – Shr

Permeability determination:

The NMR data is used extensively to estimate permeability. This is because there is a directcorrelation between permeability and the following parameters:

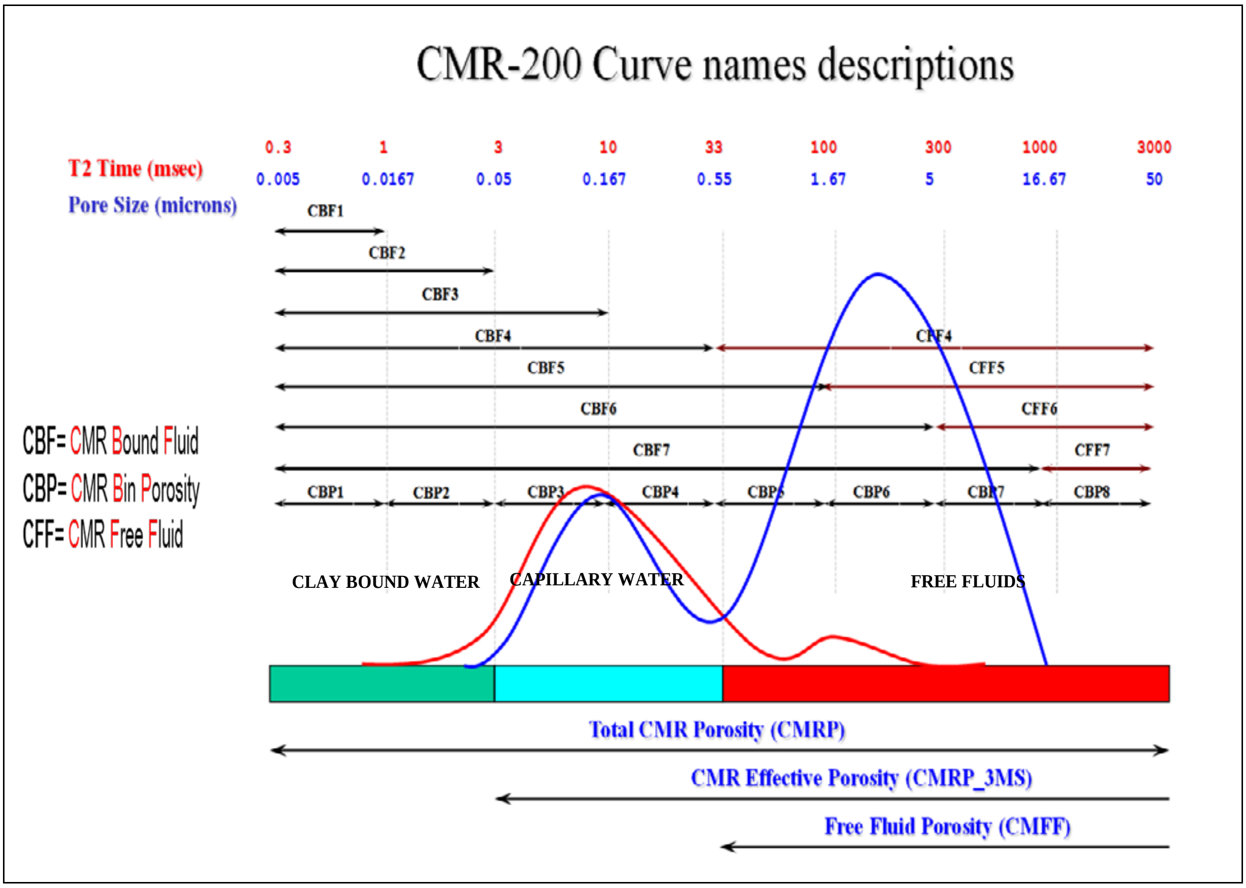

Fig. (3): Distribution of the porosity over T2 values and, hence, over the pore sizes.

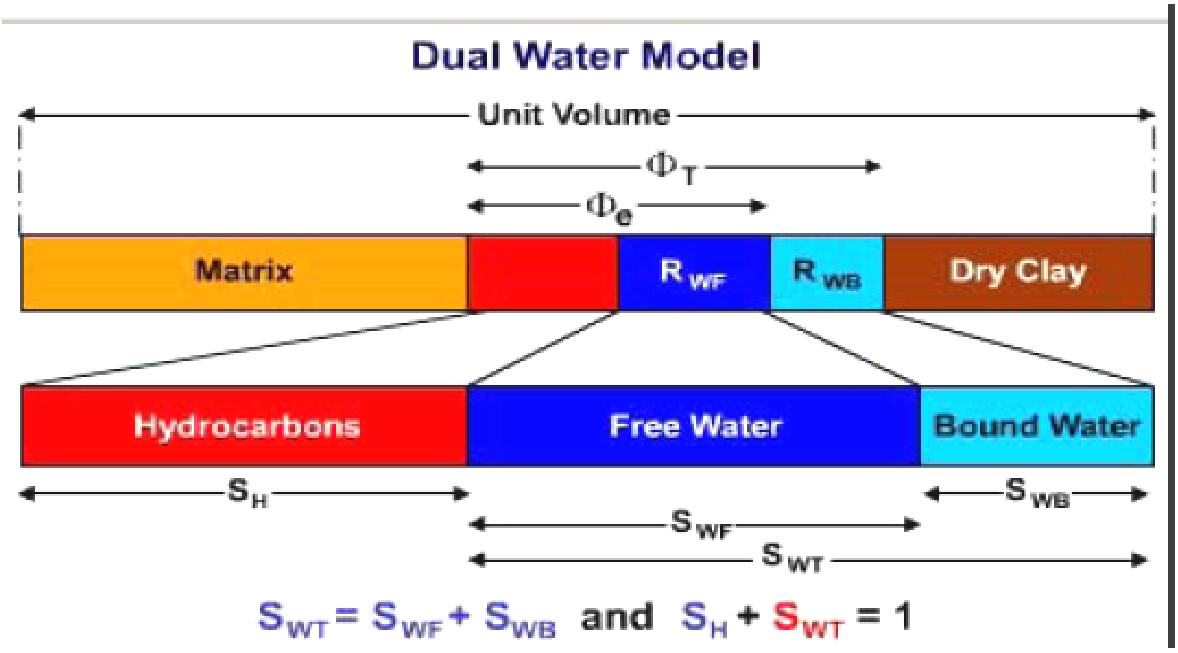

Fig. (4): Dual Water Model.

– Surface area/Pore volume ratio(S/V)
– Pore throat diameter and hence pore size
– Porosity

These parametersare measured directly and indirectly by the NMR.

NMR permeability is arguably the best log-derived approach for estimating permeability.Two related kinds of permeability models have been developed (George R. Coates, Lizhi Xiao, and Prammer,1999).

(1) The free-fluid or Timur- Coates model which can be applied in formations containing water and/or hydrocarbons.

(2) The mean-T_2 or SDR model which can be applied on pore systems containing only water as it depend on T_2 which is affected by hydrocarbons so that this model will not be accurate in hydrocarbon intervals.

1) Timur-Coates model:

KTC = a . Φ 4(FFV / BVF)2

Where

Timur-Coates permeability (KTC) md

Porosity (Φ) v/v

Free Fluid Volume (FFV) v/v

Bound Fluid Volume (BFV) v/v

a is constant that isobtained empirically from crossplots ideally using core data.

2) The mean-T_2 or SDR model:

KSDR = 4 x DMRP4 x T2LM2

where

KSDR : SDR permeability md .

DMRP: Total porosity corrected to gas effectv/v.

T2LM: Transverse Relaxation Time Distribution msec.

Lithological and Mineralogical Identification:

In this study density – neutron (RHOB-APLC) crossplots were used for lithology identification of El Wastani reservoir (Pliocene) in the studied wells while The clay minerals identification were achieved by different crossplots; Th-K, PE-K and PE-Th/K.

RESULTS

The evaluation of Sequoia reservoir is illustrated through the mineral identification crossplots, lithosaturation crossplots , and reservoir connectivity using pressure plots.

A) Themineral identification crossplots (Th-K, PE-K and PE-Th/K) of Sequoia D-1, Sequoia D-3, Sequoia D-4 and Sequoia D-6 wells show that clay minerals lie between montmorillonite, gluconite, illite, biotite and moderate percentage of mica as shown in Figures 5, 6, 7 and 8.

B) Lithosaturation crossplots of Sequoia reservoir: The rock units of main Sequoia reservoir intervals in Sequoia D-1, Sequoia D-3, Sequoia D-4 and Sequoia D-6 wells are composed mainly of sandstone with shale streaks, the averageeffective porosity calculated from Neutron –Density ranges from 28% to 32%, while averageeffective porosity calculated from CMR using DMR method ranges from 21% to 23%. Theaverage water saturation calculated from conventional tools ranges from 38% to 68%, while the average water saturation calculated from CMR ranges from 39 % to 70%.Theaverage calculatedpermeability from CMR using Timur – Coates model ranges from 30 to 890 md. All results are listed in table 1.

The highest values of water saturation and lowest values of permeability are due to existence of thin bed layers as they considered as Thin Beds reservoirs and can be detected clearly on CMR tool .

When we focus on porosity track and water saturation tracks in figures 9,10,11 and 12we can conclude that, the effective porosityvalues calculated from conventional tools are higher than effective porosity values from CMR. This is because the CMR is only a fluid dependent, while conventional tools (neutron & density) are fluid and lithology dependent.For water saturation tracks it appears that water saturation calculated from Dual water model (SwDW) is different from that calculated from Indonesian model (SwInd). The water saturation from Dual water model is close to the water saturation calculated from CMR(SWE) because Dual water model is based on two major water kinds as shown in (Fig4);the first kind is called clay water and is closely associated with clay particles, and the second kind of water is called free water, which is the bulk of the water found in the pore space (Dawood ,1999).This is similar to CMR principle which separates the fluids in the pores into three categories (clay bound water, capillary water and free fluids) as shown in (Fig 3).

C) ***MDT pressure data analysis***

MDT pressure data is taken for 4wells to several compartments in the Sequoia field Sequoia D1, D4,D6and D5 instead of D3 as there is no pressure data in D3 but it looks similar to D5. Pressure data analysis is performed for this data as shown in (Fig 13).It can be concluded that:

1- The D6 area has already been modelled as a separate compartment (pressure gradient 0.0526 psi/ft) but the rest of the field has been treated as one interconnected reservoir but there is a slight pressure difference between the south (pressure gradient 0.0593 psi/ft) and north (pressure gradient 0.0566 psi/ft) of the field.

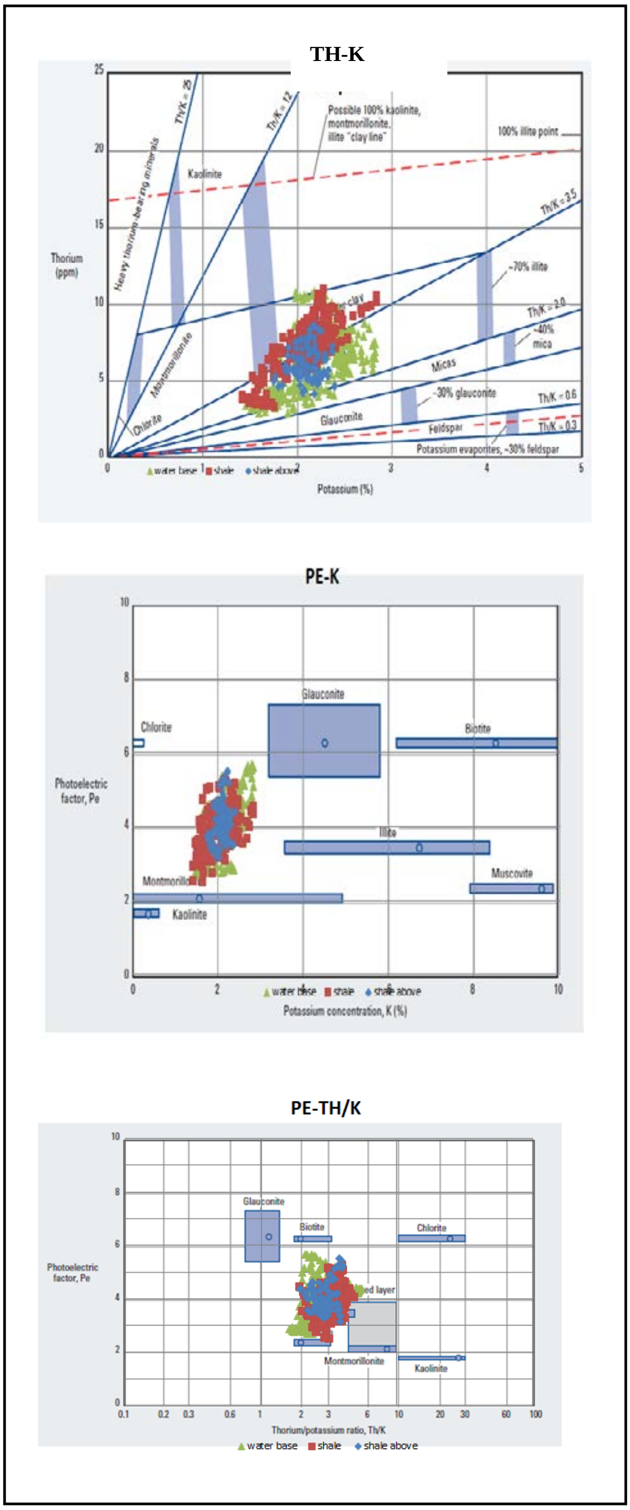

Fig. (5):Th-K,PE-K&PE-Th/K crossplot for clay intervals in SequoiaD1 well.

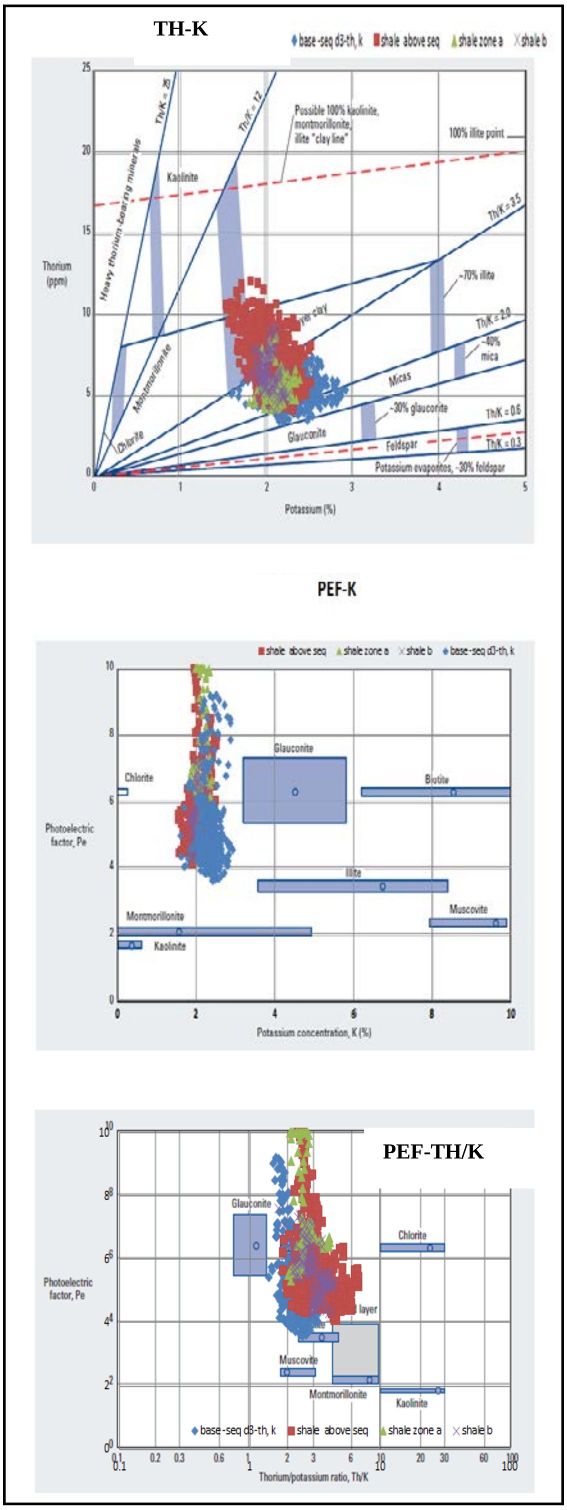

Fig. (6):Th-K,PE-K&PE-Th/Kcrossplot for clay intervals in SequoiaD3 well.

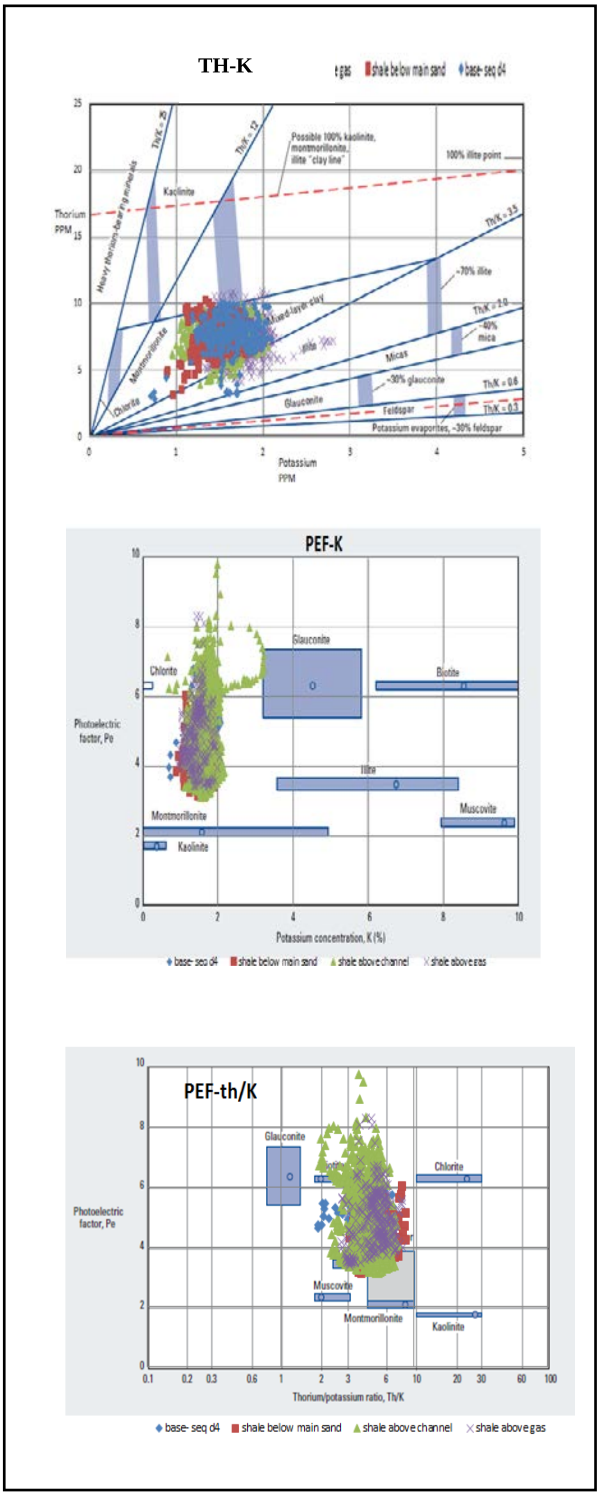

Fig. (7): Th-K ,PE-K&PE-Th/K crossplot for clay intervals in SequoiaD4 well.

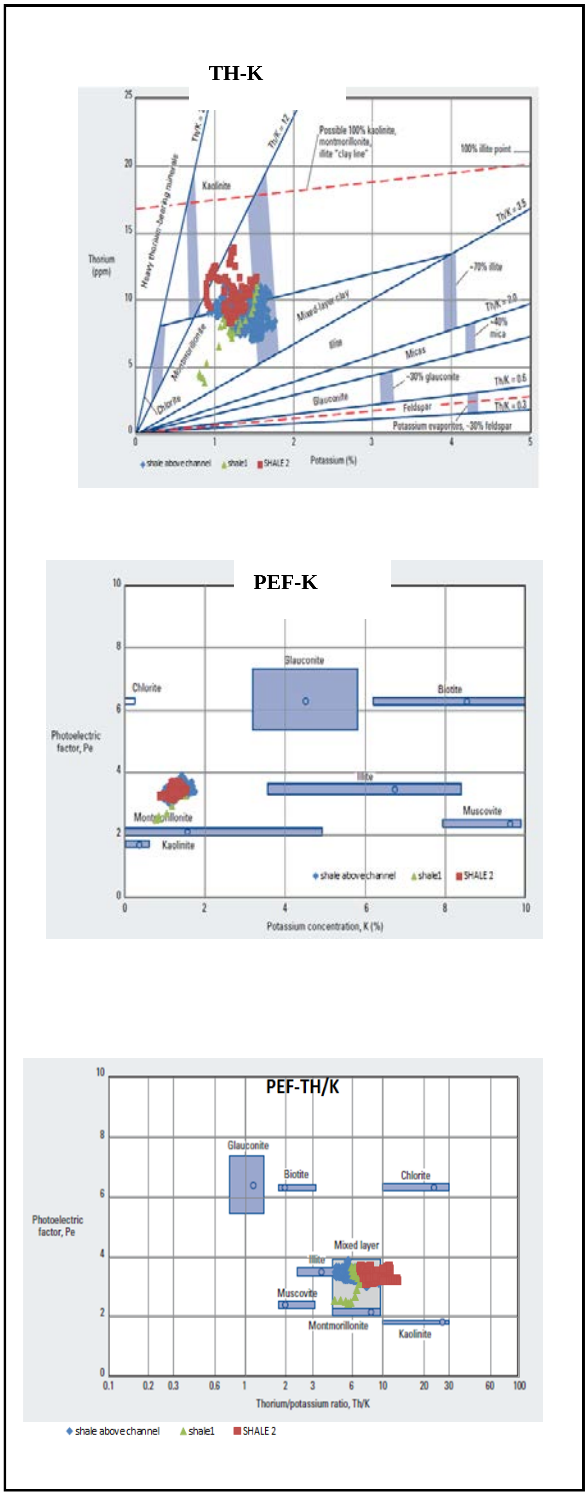

Fig. (8): Th-K, PE-K&PE-Th/K crossplot for clay intervals in SequoiaD6 well.

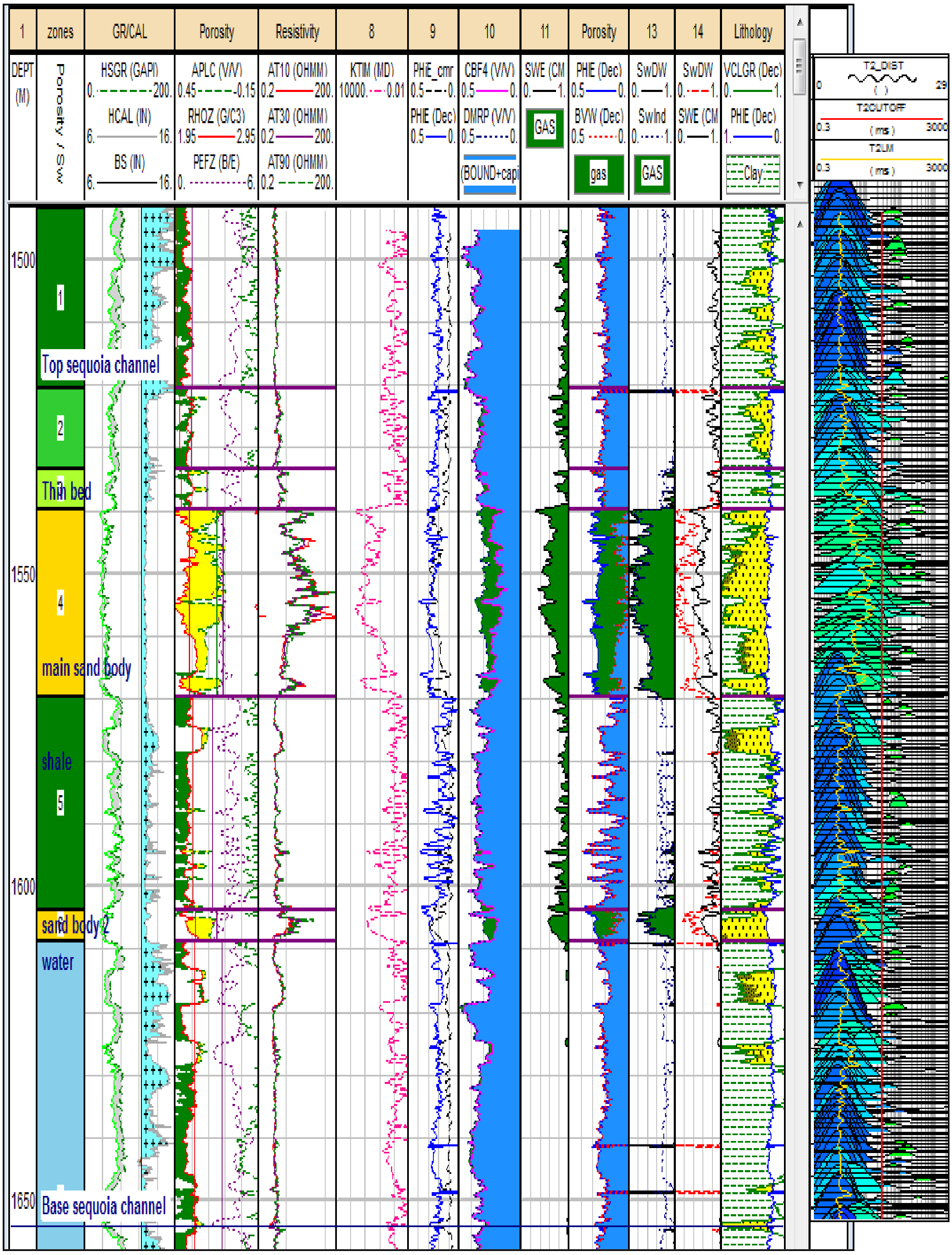

Fig. (9): Lithosaturation CrossPlot for Sequoia channel in well sequoia D-1.

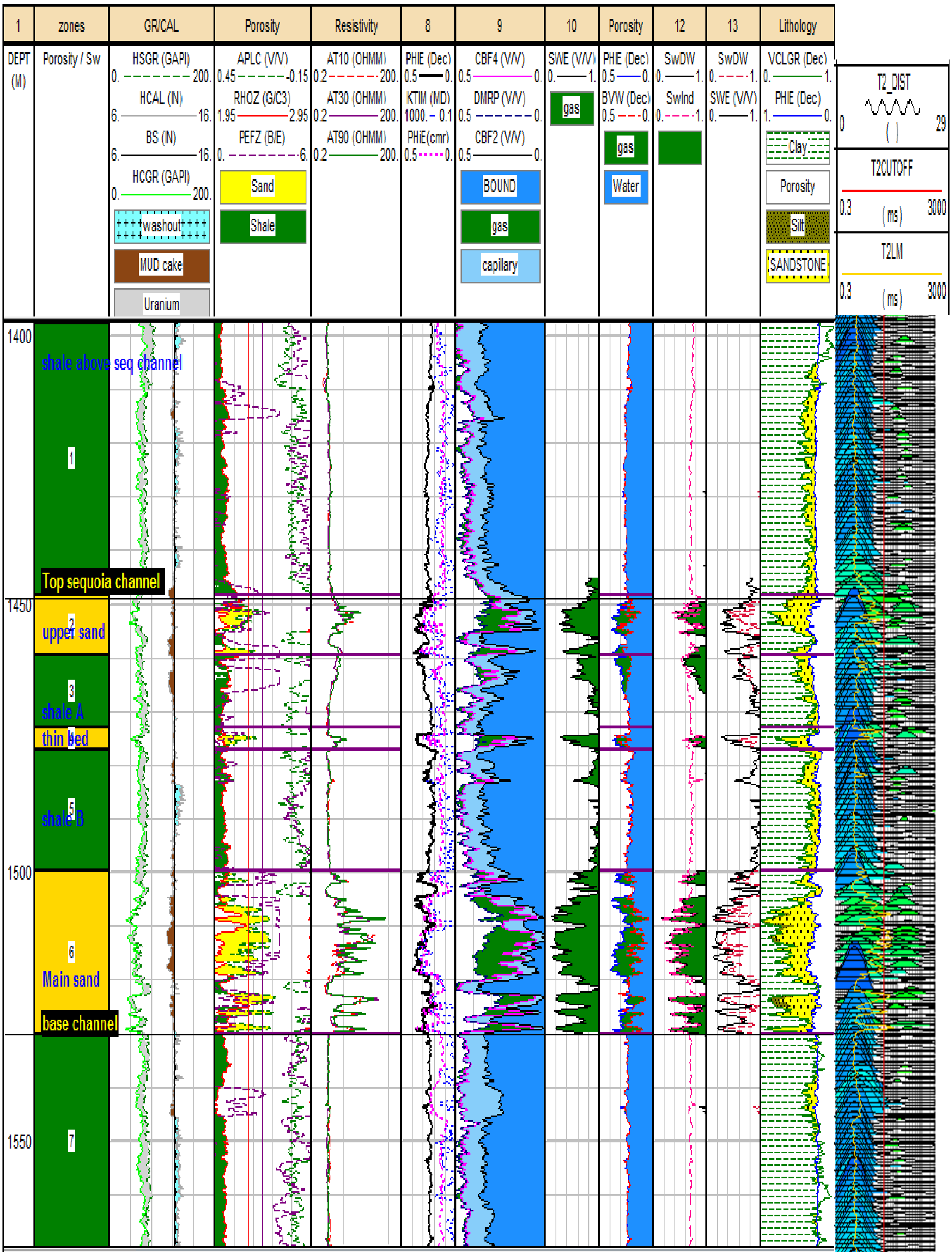

Fig. (10): Lithosaturation Cross Plot for Sequoia channel in well sequoia D3.

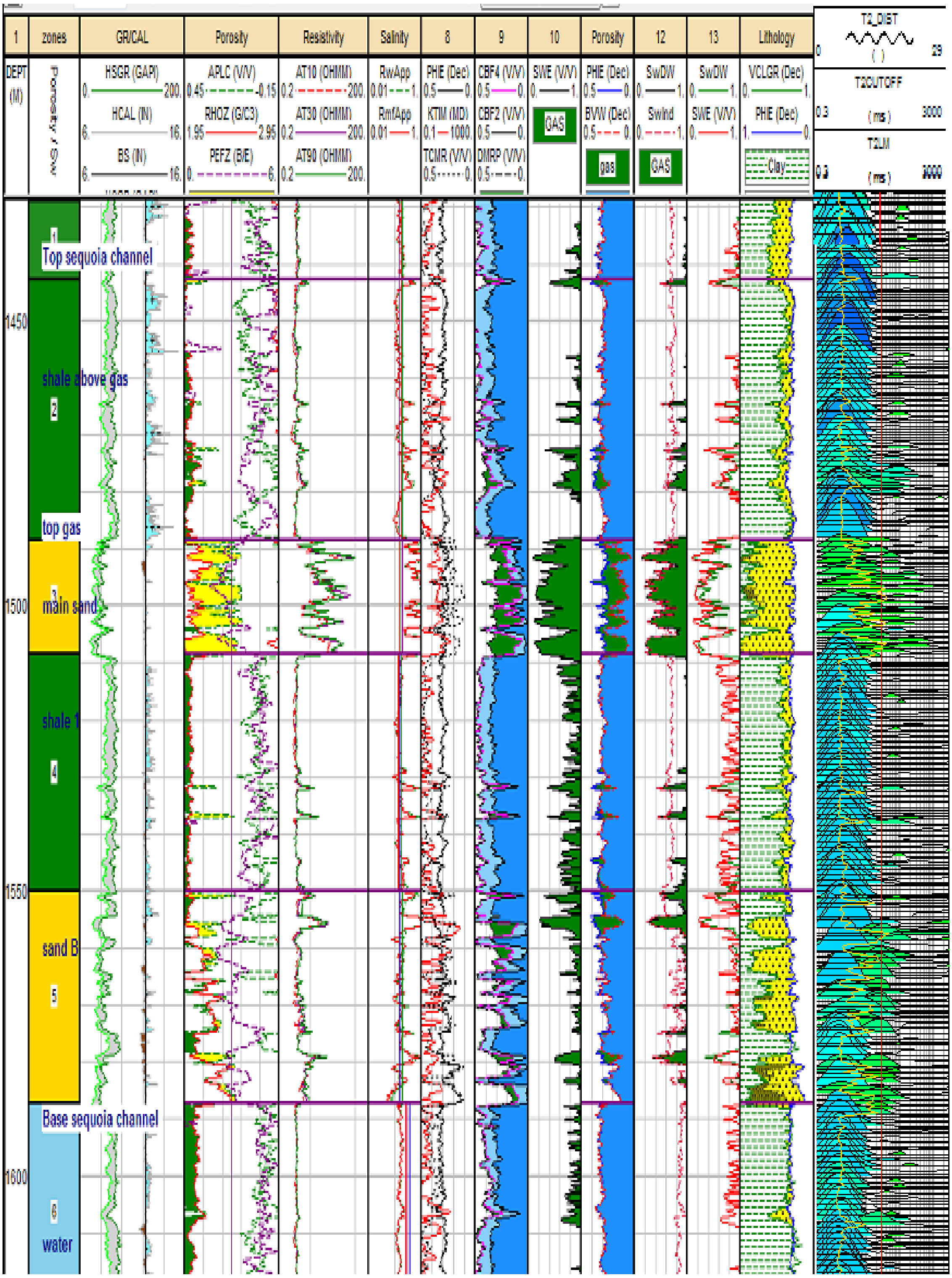

Fig. (11): Lithosaturation CrossPlot for Sequoia channel in well Sequoia D4.

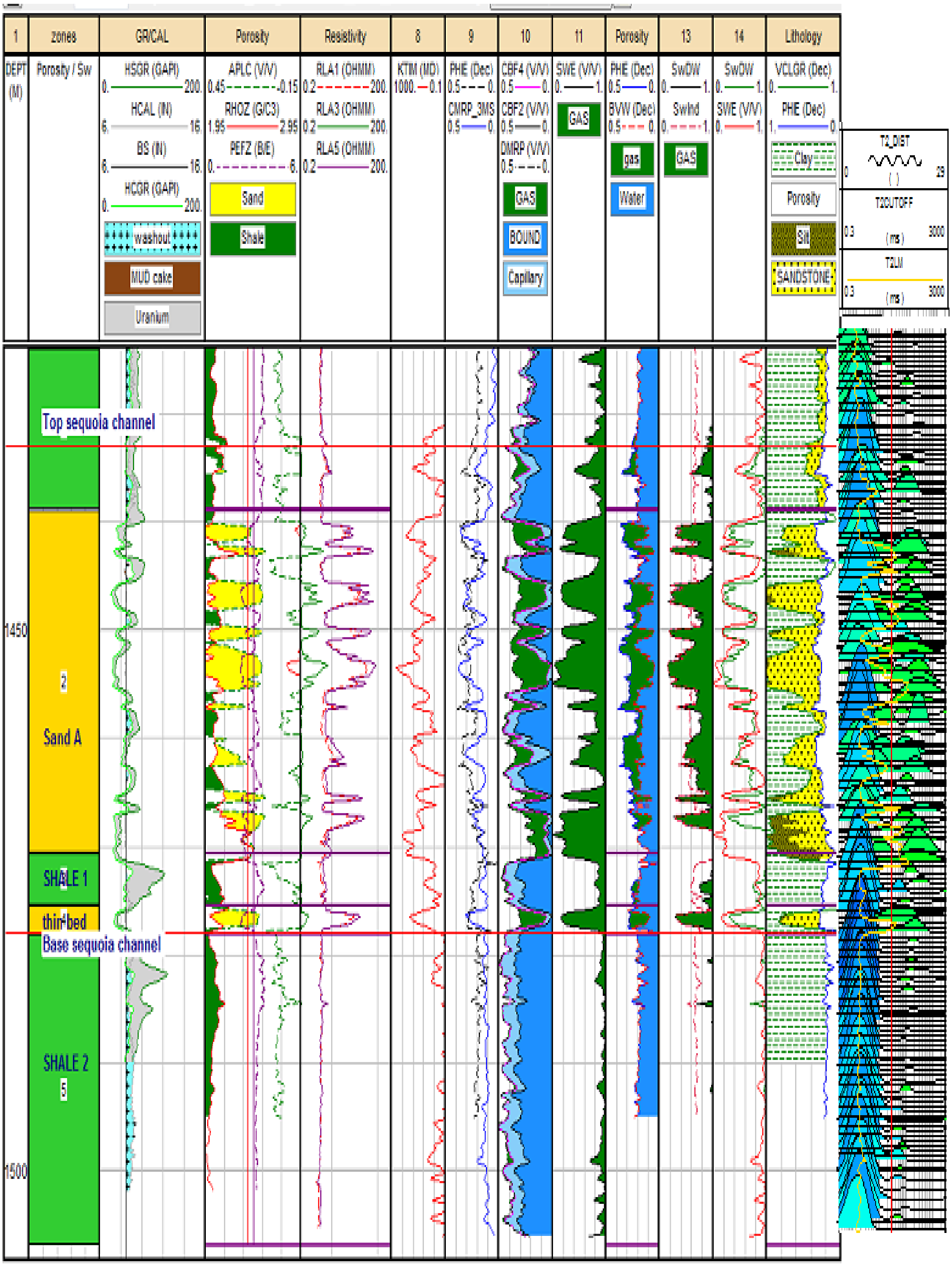

Fig. (12): LithoSaturation CrossPlot for Sequoia channel in well Sequoia D6.

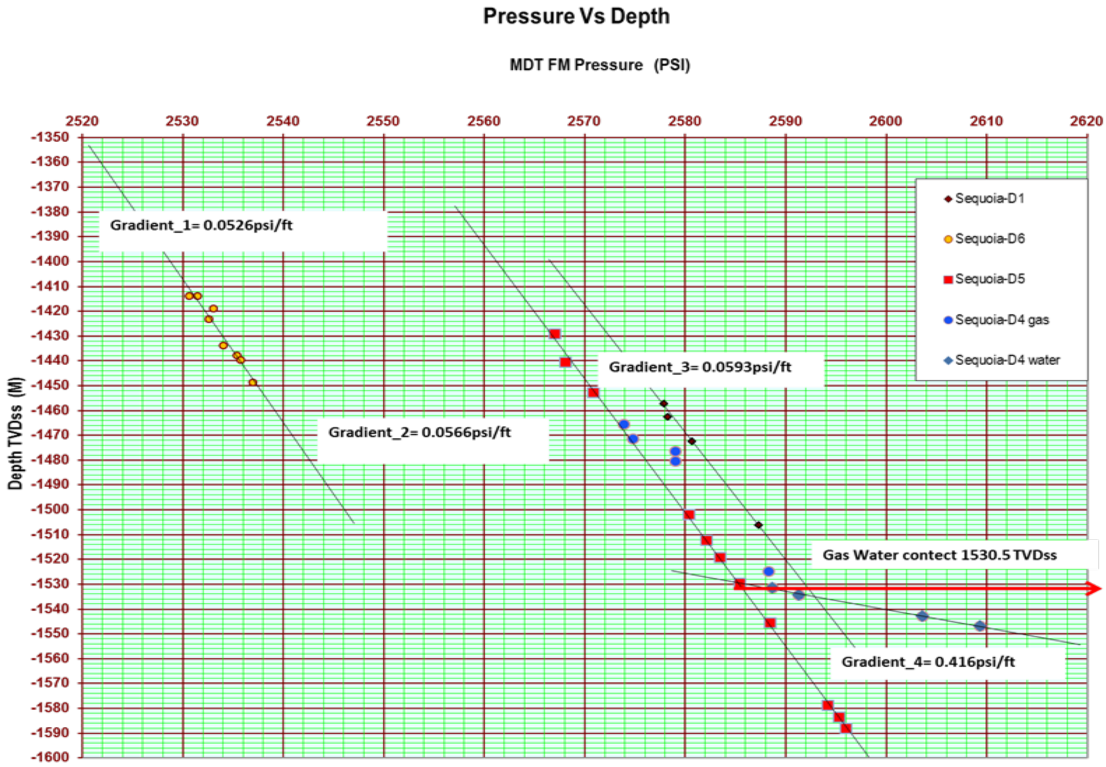

Fig. (13): MDT data for Sequoia reservoir.

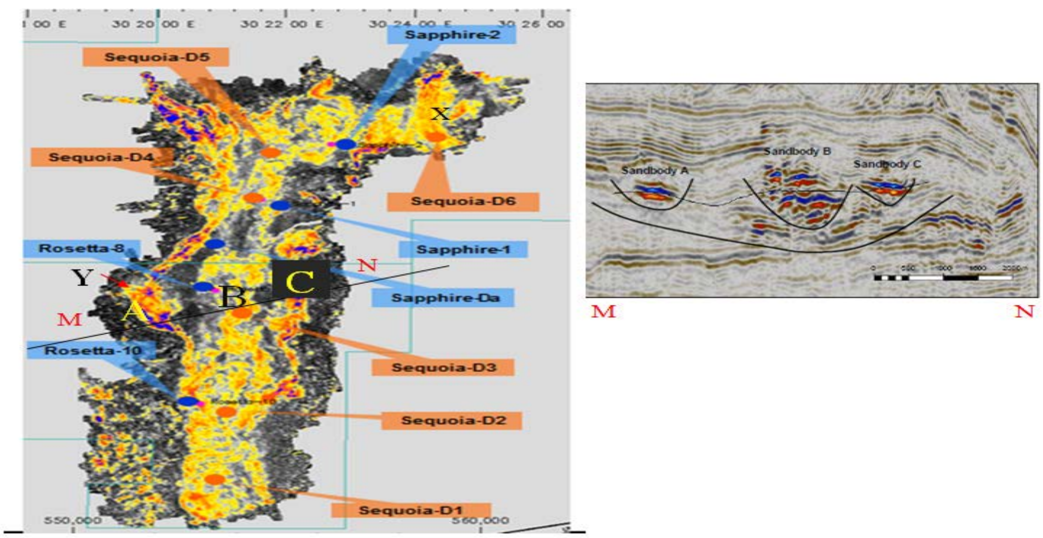

Fig. (14): RMS amplitude map along a slice 80ms below top channel horizon. Inline cross section (M-N) demonstrates 3 channel complexes in the centre of the field. Sandbody A is the western channel, which the block diagram depicts singing round the tip of the fault. Sandbody B is the central channel and Sandbody C is a late stage splaying channel which ponds on the footwall of the fault X and Y location of recommended wells.

Table (1): Petrophysical results for Reservoir intervals:Sequoia D1, Sequoia D3, Sequoia D4 and Sequoia D6.

					CONVENTIONAL			CMR		
Well Name	***Res-Zones***	***thick***	***Top***	***Bottom***	***Av vclay***	***Av effective por***	***Av sw***	***Av eff por (cmr)***	***Av swe***	***Av ktim***
Sequoia D1	Thin Bed	6.3	1533.4	1539.7	0.119	0.277	0.872	0.149	0.787	2.137
	Main sand body	30.1	1539.7	1569.8	0.046	0.275	0.264	0.229	0.605	39.647
	Sand body 2	4.9	1603.6	1608.5	0.038	0.287	0.466	0.22	0.696	10.67
Weighted Average					0.06	0.28	0.38	0.22	0.64	30.49
Sequoia D3	Upper sand	11.3	1448.2	1459.5	0.164	0.305	0.78	0.204	0.572	116
	Thin Bed	4.2	1473	1477.2	0.175	0.316	0.83	0.189	0.577	200
	Main sand	30.5	1499.5	1530	0.114	0.295	0.595	0.23	0.412	660
Weighted Average					0.13	0.30	0.66	0.22	0.47	484.37
Sequoia D4	Main sand	20	1488.4	1508.4	0.022	0.291	0.354	0.244	0.454	716
	Sand B	32.9	1554.4	1587.3	0.116	0.281	0.886	0.19	0.843	31
Weighted Average					0.08	0.28	0.68	0.21	0.70	289.98
Sequoia D6	Sand A	31.6	1438.9	1470.5	0.1	0.32	0.534	0.23	0.391	930
	Thin Bed	2.56	1475.5	1478.06	0.075	0.28	0.612	0.22	0.369	443
Weighted Average					0.10	0.32	0.54	0.23	0.39	893.50

2- Sequoia D4 and Sequoia D5 wells in the north part have the same pressure trend (pressure gradient 0.0566 psi/ft) but for Sequoia D4 There is another trend parallel to the main pressure trend which indicate the presence of thin beds

3- For Sequoia D5 well, there is no F.W.L detected so it is recommended to drill deeper as there is a probability of finding another pay interval below the total depth especially a flat spot is detected on the seismic section indicating the free water level which may be at 1624 TVDss .

4- The free water level for Sequoia D4well is located at 1530.5 TVDss where pressure gradient=0.416 psi/ft indicating a water zone.

SUMMARY AND CONCLUSION

The Wastani Formation can be interpreted in terms of aPliocene deep-water canyon fill deposited on a delta-front slope. It lies along strike from a number of analogous canyon systems which constitute the reservoirs of the WDDM succession. Four wells were selected in the study area fromSequoia field to perform pretrophysical analysis of the reservoir rocks through calculation of petrophysical parameters and comparison between Dual water model and Indonesian Model for water saturation calculation and also comparing between conventional tools results and advanced tools results (CMR)to select the most suitable model for the Sequoia reservoir. Study of the reservoir connectivity and water levels was done through the pressure-depth plots.The Dual water model and Indonesian model are applied and the results are compared to water saturation calculated from CMR tool .The closest results to CMR results are those from theDual water model. The close difference between SWE calculated from CMR and SW calculated from conventional tools is due to the fact that the conventional tools are fluid and lithology dependent, while CMR is only fluid dependent, especially resistivity tools which are affected by the fluids and matrix which play an important role in Dual Water saturation calculation as they have approximately the same trends of increase or decrease.

Timur-Coates permeability model was used to calculate permeability as it is the best method for gas reservoirs. For field development it is recommended according to all the previous analysis (MDT-lithosaturationcrossplots) that :

To drill a new well in the northern part around Sequoia-D6 at location X to delineate the channel in the north of the Sequoia field and to detect the aquifer level of the field, and to drill a new well in the western channel at location Y to explore this part of the Sequoia field .

To increase the depth of the drilled well Sequoia-D5 until reaching the water level as it wasn't detected on the MDT or lithosaturation crossplots.

REFERENCE

Abdel Aal, A., Price, R. J, Vaitl, J. D. and Shrallow, J. A., 1994, "Tectonic evolutionof the Nile Delta, its impact on sedimentation and hydrocarbon potential,". Proceedings of the 12th Petroleum Conference of EGPC, Cairo, 12(I), pp.19-34.

Abdel Aal, A., J. A. Shrallow., H. Nada., and O., Shaarawy., (1996), "Geological Evolution of the Nile Delta, Egypt, using REGL, Regional Seismic Line Interpretation," 13^{th}., Exploration and Production Conference EGPC, Cairo, Egypt. Vol.1, PP.242-255.

Cross. E, Alan Cunningham, Robert J. Cook, Amal Taha, Eslam Esmaie, Nasar El SwidanNigel, 2009, "Three-dimensional seismic geomorphology of a deep-water slope-channel system, The Sequoia field, offshore west Nile Delta, Egypt,"AAPG May 4, v. 93, no. 8, pp. 1063–1086.

Dawood, A.M, 1999, "Estimation of Hydrocarbon Saturation in Shaly Formations," M.Sc, Cairo University, Egypt, P 61-122

Egyptian General Petroleum Corporation, EGPC, 1994, Nile Delta and North Sinai Fields, Discoveries and Hydrocarbon Potentials (a comprehensive overview) Cairo, Egypt, 387pp.

Freedman, R., Chanh Cao Minh, and Greg Gubelin, Schlumberger Oilfield Services; J.J. Freeman Shell E&P Technology Co.; Thai McGinness and Bob Terry, Amoco Production Co.; and David Rawlence, Woodside Offshore Petroleum, 1998", Combining NMR And Density Logs For Petrophysical Analysis In Gas-Bearing Formations". Society of Petrophysicists& Well Log Analysts, SPWLA 39.

Coates, G.R., Lizhi Xiao, and Manfred, G. Prammer, 1999 "NMR Logging Principles and Applications,", Halliburton Energy Services, Paper 253

Palmieri, G., H. Harby, J.A. Marini, S. Dalla, F. Hashem and M. Shash, 1996. Baltim fields complex: an outstanding example of hydrocarbon accumulations in a fluvial Messinian incised valley. Proceedings of the 13th Petroleum Conference, Cairo, 1996. Egyptian General Petroleum Corporation, v. 1, PP. 256-269

Poupon, A., Holye, W. R. and Schmidt, A. W., 1971, Log Analysis In Formation with Complex lithologies," J. Pet. Tech.), Paper 2925.

Samuel, A., B. Kneller, S. Raslan, A. Sharp, and C. Parsons, 2003, Prolithic deep-marine slope channels of the NileDelta, Egypt: AAPG Bulletin, v. 87, P. 541-56.