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RESERVOIR CHARACTERIZATION OF PLIO-PLEISTOCENE SIENNA CHANNEL, WEST DELTA DEEP MARINE (WDDM), EGYPT

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الخلاصة: كشفت الدراسة عن وجود طبقات من الحجر الرملي الحامل للغاز يتراوح سمكه بين ١ إلى ١٢ متراً، كما أظهر التحليل البتروفيزيائي أن خزان سيينا يمتلك إمكانات هيدروكربونية جيدة من حيث متوسط المسامية (٢٦٪)، وحجم الطين المنخفض (١٦٪) والتشبع بالماء (٦٦٪). وتشير مخططات التعرف على المعادن الطينية إلى أن خزان سيينا قد تم ترسيبه في الغالب في البيئات البحرية الضحلة أو النهرية وفقًا لوجود الغلوكونيت والإيليت والمونتوريلايت والكولينيت كمعادن طينية سائدة. ويهتم تحليل بيانات الضغط بشكل أساسي بتحديد انواع السوائل فى الخزان وتحديد تغيرات الضغط للمنطقة الحاملة للغاز. ومن بيانات الضغط تم حساب معدل التغيير فى ضغط السوائل الموجودة فى الخزان، يتراوح معدل ضغط الغاز من ٠,٠٧٨ إلى ٠,٠٨٤ رطل لكل بوصة مربعة للغاز بينما معدل ضغط الماء ٠,٤٦ رطل / بوصة مربعة تقريبا. ويكشف الرنين النووي المغناطيسي أن الطبقات الحاملة للغاز لديها معاملات بتروفيزيائية جيدة للإنتاج ، سائل حر مع مسامية فعالة ونفاذية جيدة.

ABSTRACT: *In this study, the petrophysical characterizations of the subsurface sandstone Plio-Pleistocene reservoir in the offshore Nile Delta Sienna field has been defined based on the well log data available in three wells. The detailed petrophysical analysis revealed the presence of a gas-bearing sandstone interval ranged from 1 to 12 m of net pay zone with good reservoir characteristics in terms of good porosity (26%), low shale volume (16%) and water saturation (66%). The clay mineral identification plots indicate that, the Sienna reservoir was deposited mostly in fluvial to shallow marine environments according to the presence of glauconite, mica, illite, chlorite and montmorillonite as dominant clay minerals. The analysis of pressure data is concerned mainly with locating the different fluid contacts and determining the pressure gradients of the gas-bearing zone. Very close pressure regimes are detected for the investigated gas anomaly throughout the study area. Pressure gradient of gas ranges from 0.078 to 0.084 psi/ft while, the water gradient is 0.46 psi/ft, also NMR reveals that the pay zones (Sand-1, Sand-2, and Sand-3) have good petrophysical parameters for production, free fluid with good effective porosity and good permeability.*

1. INTRODUCTION

Offshore Nile Delta gas reservoirs are dominated by slope-channel systems of Plio-Pleistocene age. They are largely controlled by episodes of transgressive-regressive events resulted in deposition of fine-grained sediment (sand and shale). Sienna reservoir is one of the major channel systems that makes up the Mid/Late - Pliocene submarine channel complex. Sienna forms a combined stratigraphic/structural trap with up dipping (southern) fault closure. Down dip, the reservoir is a combined dip and stratigraphic closure along the length of the channel. The reservoir pinches out at both eastern and western channels margins. The seal is the Kafr El Sheikh Formation claystone of the Late Pliocene age (Sarhan, et al., 1994).

This study is focused on the Sienna field. it is a gas field in the southern portion of the West Delta Deep Marine (WDDM) concession, approximately 120 km North-East of Alexandria, Egypt (Figure 1).

2. GEOLOGIC SETTING

The West Delta Deep Marine (WDDM) concession covers 6150 km² and lies approximately 50 to 100 km offshore the northwest margin of the Nile cone. It includes the Pliocene Sienna gas field (Figure 1). Sienna Field is believed to be a slope channel complex deposited on the Nile delta slope in the Late- Pliocene within Kafr El Sheikh Package.

Sienna channel complex consists of unconfined channel system with clearly defined development stages. The stages include amalgamated or stacked channels followed by channel abandonment phases and local flooding events. The depositional pattern continued through the Late Pliocene-Pleistocene. The reservoir has been deposited in many stages, starting with a great incision, then followed by depositing amalgamated and laterally extensive system, then, as the slope gets flatter. Sinuous channels begin to develop, then the story ends with channel abandonment with very distal and weak energy deposits on top before the background deposition dominates. The channel complex occupies an area around 54.68 km^2. It consists of 123 m thick of thin shale, interbedded with siltstones, claystones, and thick coarse sandstone beds (EREX, 2002 and Sarhan and Hemdan, 1994).

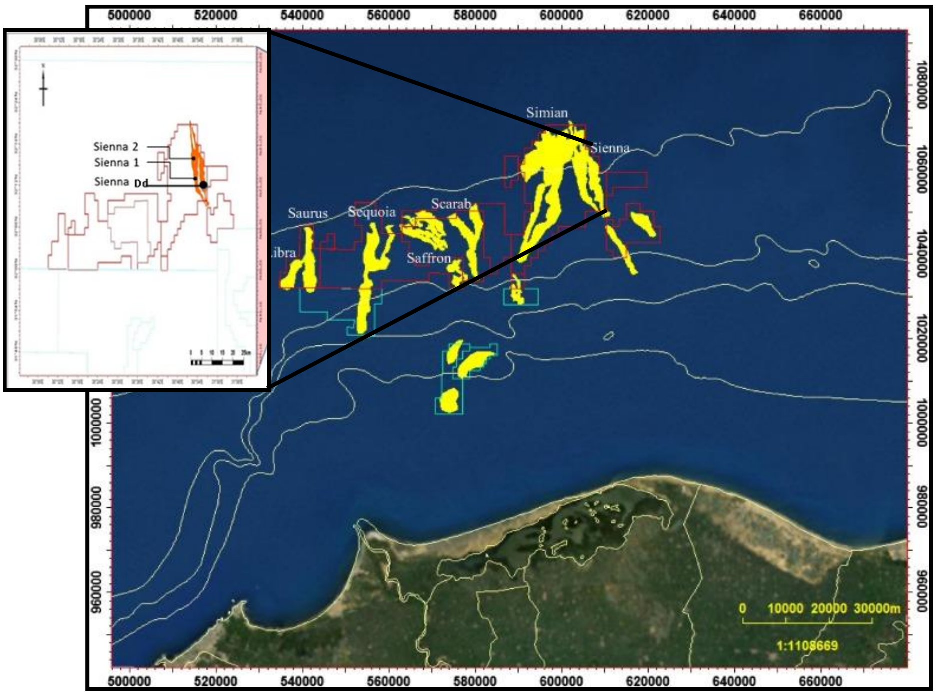

Fig. 1: Map of the study area.

3. MATERIALS AND METHODS

The present study is built up on basic well logs (Gamma-Ray, Density, Neutron and Resistivity), Modular Dynamic Tester (MDT) and NMR log for the Sienna's three wells (Sienna-1, 2, & Dd).

Well logging analysis and Interpretation was achieved for three wells. The wells are nearly vertical and have a full suite of wireline logs over the reservoir interval.

Reservoir Evaluation Workflow:

1- Comprehensive well log analysis has been carried out using Techlog,2013 software for the Sienna reservoir in the selected wells using available data in the form of caliper, deep and shallow resistivity tools, porosity tools (density, neutron and sonic), and gamma ray (CGR, SGR).

2- Lithological and mineralogical evaluation of encountered reservoir rocks within the Pliocene section (Kafr El Sheikh Fm.) in the studied wells. This was achieved by a graphical technique to identify matrix and porosity in addition to clay mineral identification.

3- Vertical petrophysical distribution cross-plot in each well in the form of litho-saturation cross-plot and pressure-depth plots to identify the fluid gradient and contact depth.

Techlog software program has been used to calculate petrophysical parameters of the Sienna reservoir. There are different types of data (resistivity, neutron, density, gamma ray, caliper, and sonic) which were corrected prior to being used in the determination of the petrophysical characteristics of the reservoir.

4- The determination of Rw was achieved by Pickett's Plot. Total porosity and deep resistivity data were plotted in a logarithmic scale paper. The blue line is the line of 100% water saturation zone (S_w=100%) which passes through the plotted data. The intercept of this blue line with x-axis equals (a* R_w). The slope of blue line equals (-1/m), where (m) the cementation factor, (a) electrical tortuosity factor. Besides water resistivity calculation (Rw=0.09 at formation temperature), there are three factors must be available; (m) cementation factor, (n) saturation exponent and (a) electrical tortuosity factor. They are measured in lab as 1.713, 1.86, and 1 respectively (according to SCAL data from Rashid Petroleum Company).

These electrical components are constant in the field of study through the three wells. Pickett plots over a known water-bearing zone have been constructed in the available wells in the study area for Sienna channel (Figure 2).

5- The determination of shale content (Vsh) was achieved through many indicators, namely Spectrum gamma ray logs (NGS) and neutron-density logs and the lowest value of these indicators is likely to be close to the actual value. The gamma ray has a lower resolution than the density - neutron logs and gives higher shale volume in the thin bed but the neutron-density logs are affected by the gas, this makes a false estimation of the shale volume in shaly sand zone (makes the shaly sand zone appear as a clean zone). So, we used the minimum value of shale volume from them in our interpretation.

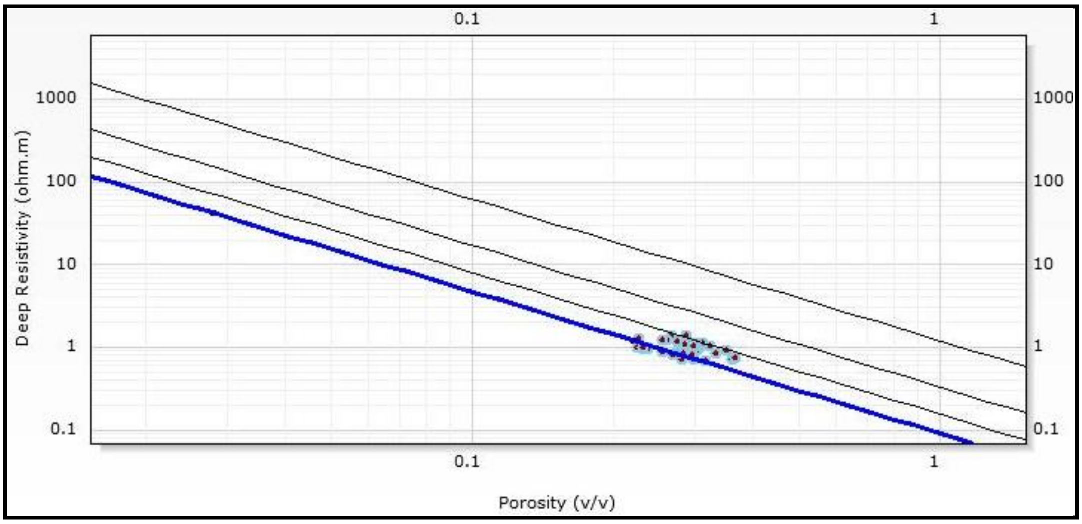

Fig. 2: Pickett's plot for water bearing zones (Rw=0.09 @ 132°F ohm.m).

6- The determination of porosity from conventional tools was achieved using the density (RHOB) and neutron (NPHI) logs to find effective porosity.

7- The effective water saturation (Sw) in clean and shaly zones was computed using the Archie and Indonesia (Poupon and Leveaux (1971) equation. Determination of the hydrocarbon saturation (Shc) was performed.

4. RESULTS AND DISCUSSION

4.1 Lithological Interpretation Using Cross-Plots

The lithology of the Sienna reservoir rock was studied using NPHI – RHOB and PEFZ-RHOB cross-plots. These plots show the reservoir rock is mainly composed of sandstone with considerable amount of shale and silt, the effect of the gas shift points to upward while the effect of the shale shift points downwards.

4.2 Clay Minerals Identification

The clay must be identified due to their great effect on the hydrocarbon reservoir evaluation. The following are Thorium (Th) – Potassium (K), and Photoelectrical effect (PEF) -TH/K cross-plots showing the type of clay minerals in different sand bodies in each of the studied wells. (Figures 8-12).

The mineralogy of the Sienna reservoir rock lies between mixed layer clay, mica, illite, montmorillonite and glauconite. The Sienna reservoir was deposited mostly in fluvial to shallow marine environments according to the presence of these clay minerals.

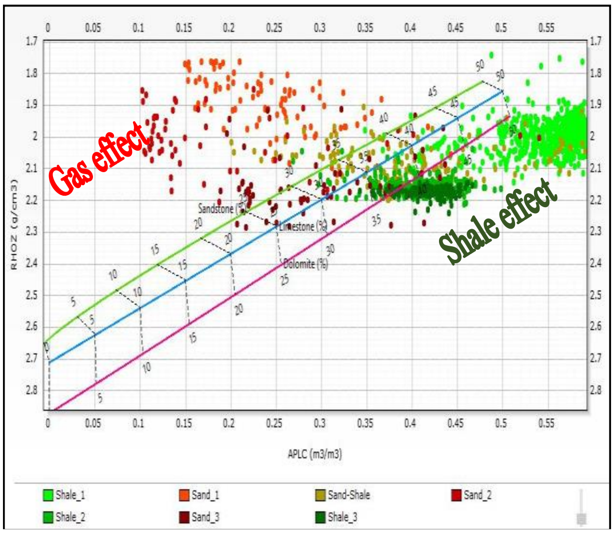

Fig. 3: RHOB-NPHI cross-plot for Sienna-1 well.

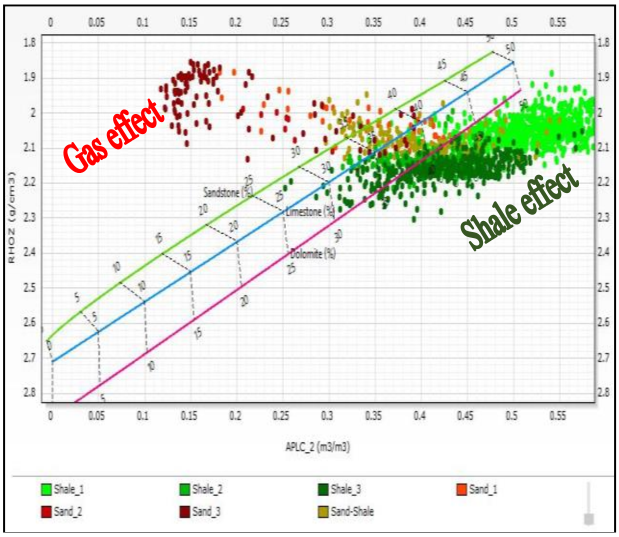

Fig. 4: RHOB-NPHI cross-plot for Sienna-2 well.

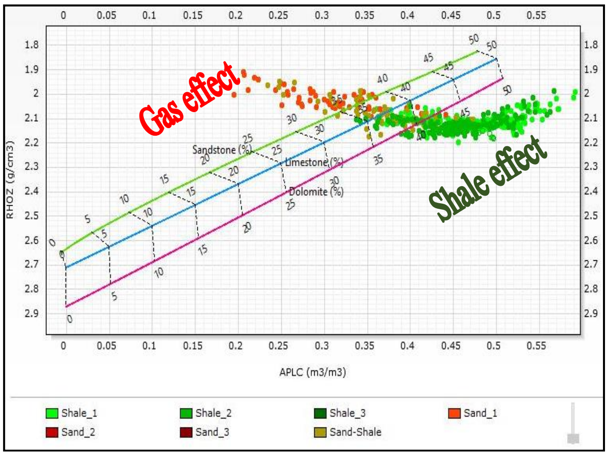

Fig. 5: RHOB-NPHI cross-plot for Sienna-Dd well.

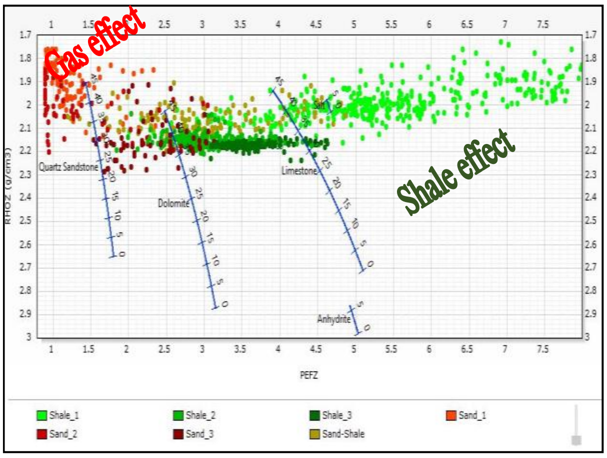

Fig. 6: PEFZ-RHOB cross-plot for Sienna-1 well.

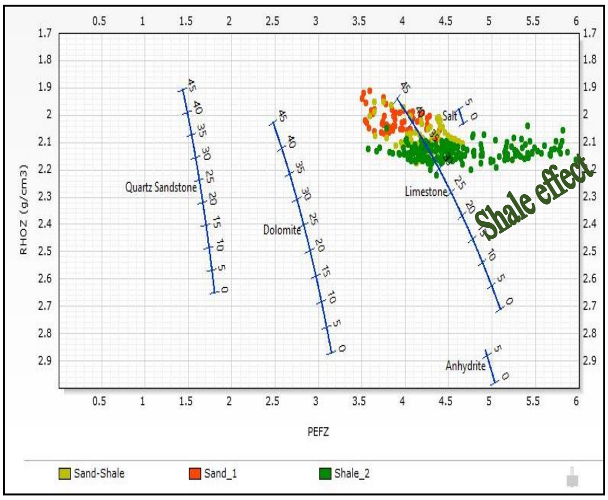

Fig. 7: PEFZ-RHOB cross-plot for Sienna-Dd well.

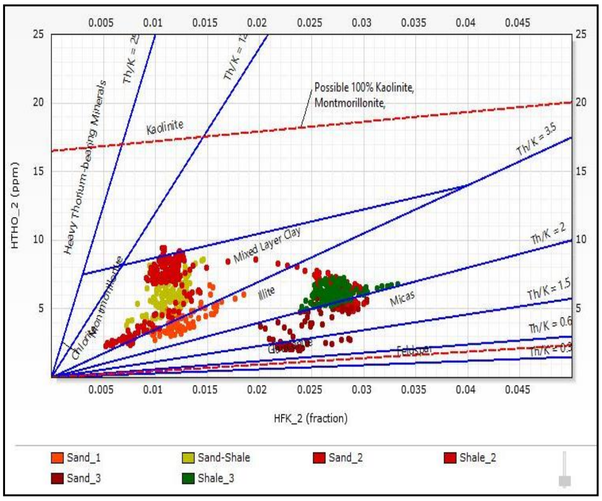

Fig. 8: TH-K cross-plot for Sienna-1well.

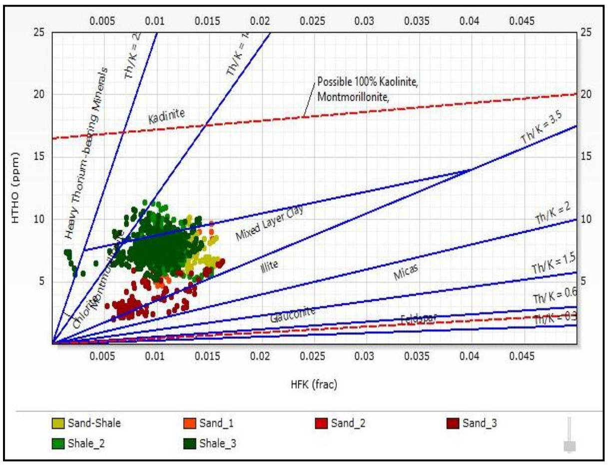

Fig. 9: TH-K cross-plot for Sienna-2 well.

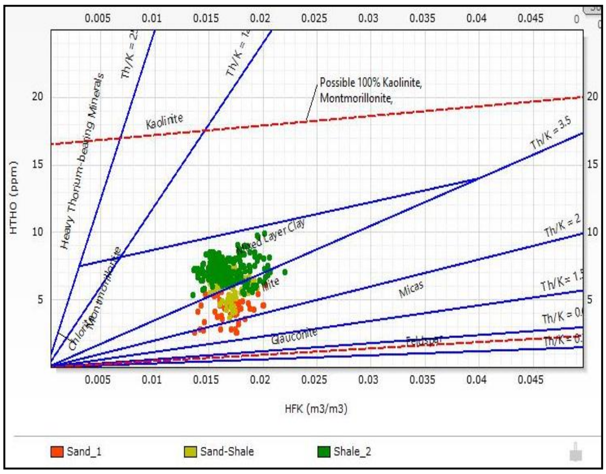

Fig. 10: TH-K cross-plot for Sienna-Dd well.

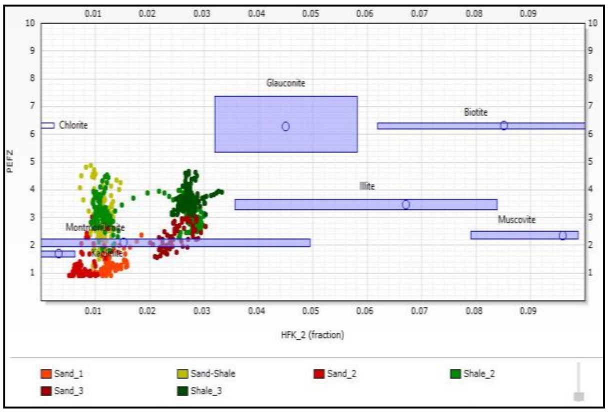

Fig. 11: TH\K-PEF cross-plot for Sienna-1 well.

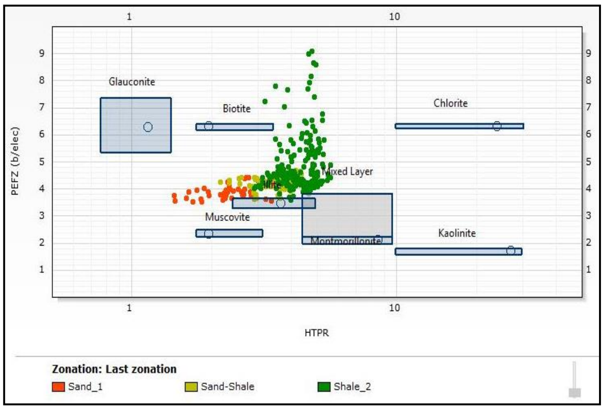

Fig. 12: TH\K-PEF cross-plot for Sienna-Dd well.

The vertical distribution in the form of litho-saturation cross-plots shows the vertical variation of lithology, water saturation and gas content for each zone of the Sienna channel. Density, neutron porosity and resistivity were adopted to evaluate various reservoir intervals. Figure 13 shows the vertical distribution of the formation evaluation results are displayed in a number of tracks and the horizontal distribution of zones. Four tracks represent the input data and two tracks represent the output data. Description of the different tracks in the litho-saturation cross-plot is shown in Table 1.

Table 1: Description of the tracks in the litho-saturation plot.

Track Number	Description
1	Total vertical depth (m)
2	CGR, Caliper and bit size
3	RHOB and NPHI
4	Different Resistivity (shallow, medium, deep)
5	Effective porosity and water bulk volume
6	Amplitude distribution (NMR)
7	litho-saturation
Zone name is in one track for 3 well	

4.4 Formation Evaluation

Sienna channel units which evaluated at three wells are composed of sandstone with shale for reservoir intervals, Effective Porosity average is 22%, Water saturation average is 66 % and the results for the main pay zones in the 3 wells are listed in Table 2.

5. MODULAR FORMATION DYNAMICS TESTER (MDT) ANALYSIS

MDT pressure data is taken for three wells in the Sienna field, namely Sienna-1, -2 and Dd. Pressure data analysis is performed on this data as shown in Figure 14. It can be concluded that:

1- Two wells (Sienna-1 and -2) have been treated as one interconnected reservoir with a slight pressure difference between the south and north of the field, but Sienna-Dd area has been modeled as a separate compartment.

2- 2- MDT plot shows two types of fluid (pressure data make two segment), first is gas at shallower depth with density 0.181 g/cc at Sienna-1 and -2 while, gas density is 0.194 g/cc at Sienna-Dd.

3- 3- For Sienna-2 well there is no free water level (FWL) detected so, it is recommended to drill deeper as there is a probability of finding another pay interval at deeper levels.

4- 4- The free water level for Sienna-1well is located at –2444m TVDSS with water density equals 1.05 g/cc while the free water level for Sienna-Dd well is located at –2424m TVDSS with water density equals 1.056 g/cc.

6. QUALITATIVE INTERPRETATION FOR NUCLEAR MAGNETIC RESONANCE NMR DATA

NMR logging, a subcategory of electromagnetic logging, measures the induced magnet moment of hydrogen nuclei (protons) contained within the fluid-filled pore space of porous media. NMR logs provide information about the quantities of fluids present, the properties of these fluids, reservoir permeability and the sizes of the pores containing these fluids.

Table 2: Reservoir parameters of Sienna pay zones.

Well	Zones	Top (M)	Bottom (M)	Net Pay Thickness	Eff. Porosity (%)	Sw (%)
Sienna-1	Sand_1	2384	2397.5	10.35	30	25
Sienna-1	Sand-Shale	2397.5	2418	1.5	27	43
Sienna-1	Sand_2	2418	2426.5	6.5	27	17
Sienna-2	Sand_1	2420	2427.5	1.05	29	33
Sienna-2	Sand_3	2486.9	2502	12	29	21
Sienna-Dd	Sand_1	2419.8	2428	3.048	29	37

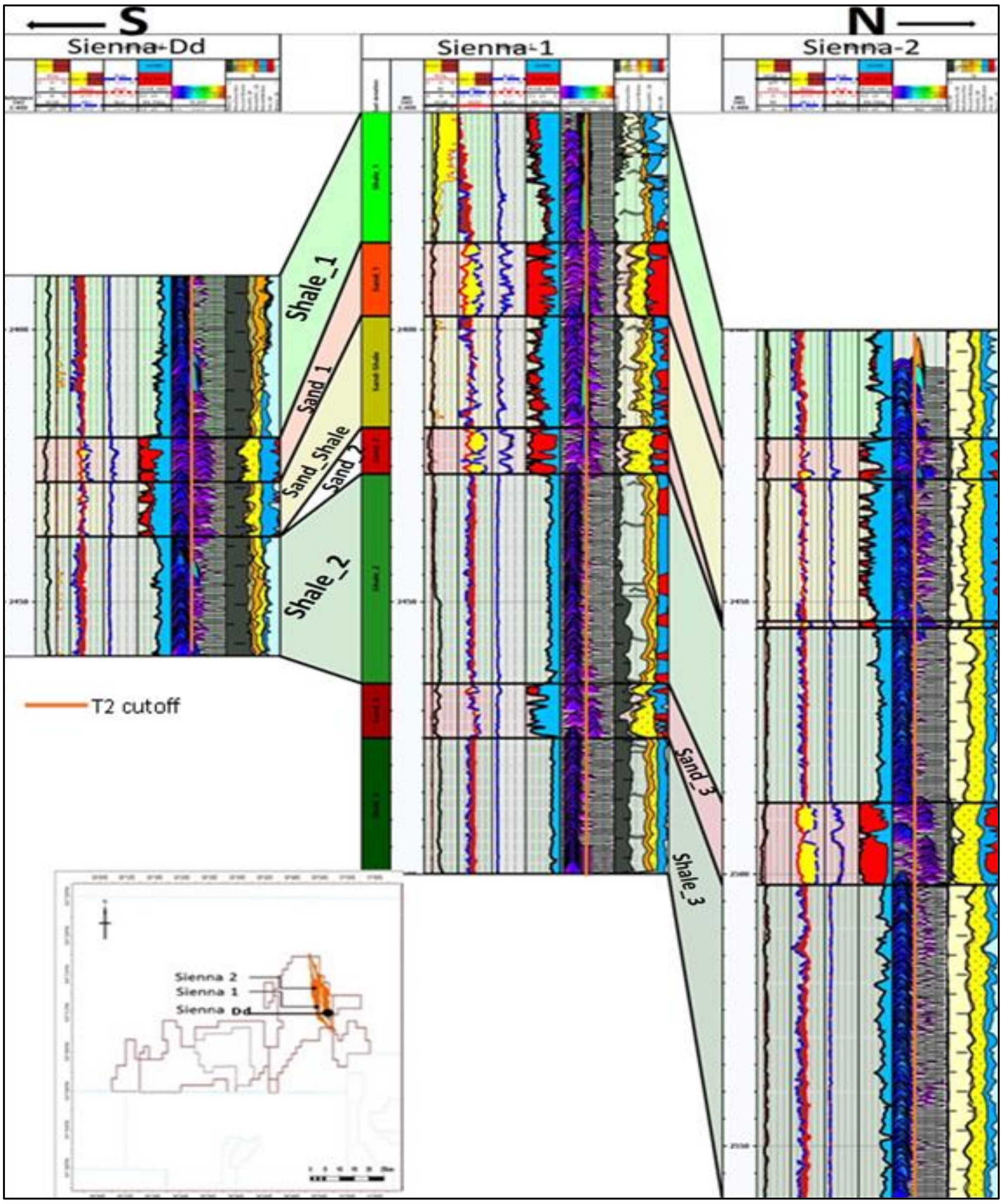

Fig. 13: litho-saturation plot for Sienna-1, Sienna-2 and Sienna-Dd.

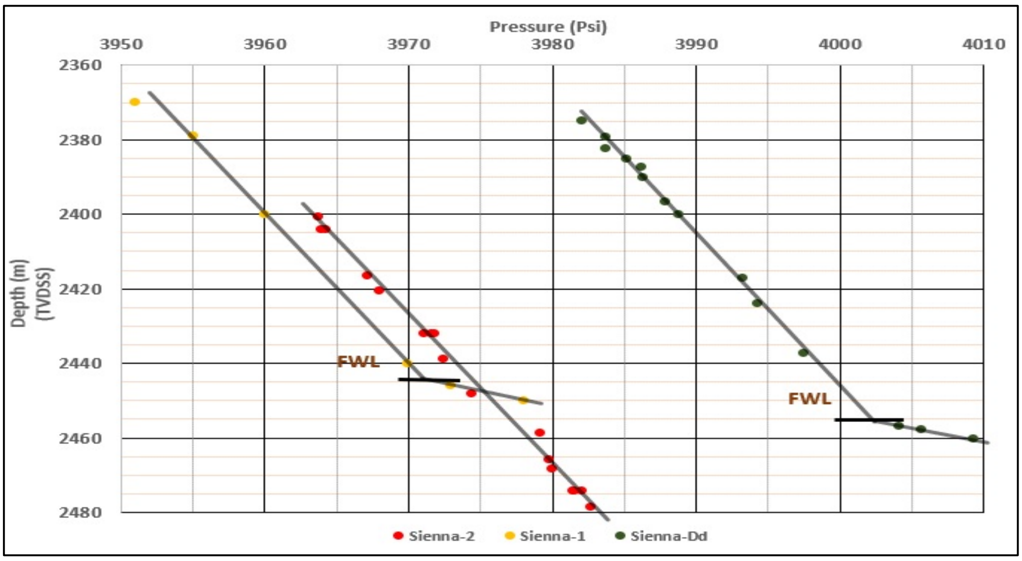

Fig. 14: MDT plot for studied three wells.

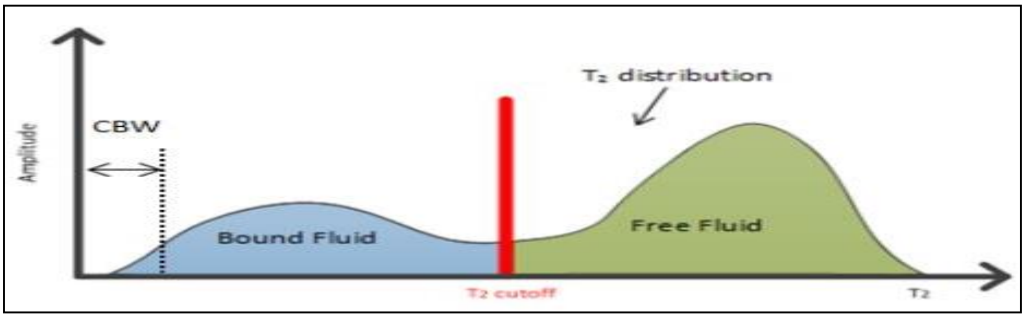

Fig. 15: NMR T2 time distributions identifying free fluid, clay-bound and capillary bound water components.

The decay rate of the induced magnet moment reflects the rate of relaxation, which is related to the pore size distribution and fluid type and viscosity in the pore spaces. The amplitude of decay rate curve depends on the volume of each fluid component, and therefore is directly proportional to porosity (Figure 15) (Dunn et al, 2002).

NMR T2 distribution is shown in figure 13 (track 6) with T2 cutoff line to separate between bound and free fluids. From NMR data, effective porosity and BWV data (Track 5), Pay zones appeared with free fluid with T2 values more than T2 cutoff and low Sw values which indicate the good permeability zone. T2 values in front of shale layers are less than T2 cutoff due to clay bounded water but in shale-1 zones, it has high values due to wash out opposite these zones, according to caliper reading.

7. CONCLUSIONS

1- The different cross-plots which are constructed to display the reservoir mineralogy as the neutron-bulk density cross-plot and bulk density-PEF cross-plot indicated that, the lithology of the Sienna reservoir is sandstone intercalated, mainly with shale layers. The petrophysical evaluation for the studied interval reflected a gas-bearing sandstone reservoir with average value of effective porosity = 22%, Vsh = 13%, and Sw = 66%. The analysis of pressure data (MDT) helped in delineating the free water level and determined the reservoir pressure gradient which reflected a connected and homogenous reservoir.

2- Differences in relaxation times of NMR data are used to differentiate between irreducible water, and movable water, gas depending on the T2 cutoff value. NMR-log data also provide indication about porosity according to the amplitude of the decay curve.

3- For field development it is recommended according to all the previous analysis (MDT-litho-saturation crossplots, to drill a new well around Sienna-Dd to delineate the channel in the eastern part of the study area and to delineate the aquifer level of the field, and to increase the depth of the drilled well Sienna-2 until reaching the water level as it isn't seen by the MDT plot.

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