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Petrophysical Characterization for Pliocene Reservoirs in Tao Field, Offshore North Sinai Concession, via Well Logging Interpretation

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Abstract

In the present study, the sandstones of the Pliocene Kafr ElSheikh and ElWastani Formations were evaluated for being promising gas reservoirs in the Offshore North Sinai concession at Tao field in the Nile Delta Basin. The study depended on interpretation of available well log data in four wells (Tao-1, Tao-2, Tao-6 and Tao-8). The well logs data analysis demonstrated that only Tao-1 Well proved to be potential gas reservoir. The favorable zone within El-Wastani Formation is found between depths 670.3m and 681.6m (Zone A). Moreover, the favorable zones in Kafr ElSheikh Formation have depths: 1299–1316.8m (Zone B) and 1430–1477.5m (Zone C). El-Wastani Formation Zone A is the most efficient gas-bearing zone in Tao-1 Well; since it possesses zero VSh, low SW (10%) and low BVW (0.04). Moreover, the sandstones of Kafr ElSheikh Formation in Tao-1 embrace two reservoir zones, (B and C) with total thickness of 17.8m and 47.5m respectively. Furthermore, the achieved results revealed that zones B and C are expected to produce gas free water.

Keywords: *Well log interpretation , Tao field , Offshore North Sinai concession , Kafr-ElSheikh Formation , ElWastani Formation , Nile Delta Basin.*

Abbreviations

Shale Volume (VSh), Neutron-Density (ND), Bulk Volume of Water (BVW), Offshore North Sinai (ONS), Nile Delta Basin (NDB), Tao-1 (T1), Total Porosity (ΦT), Effective Porosity (ΦE), Water Saturation (SW)

Introduction

The Nile Delta basin (NBD) is a passive margin basin extending onshore and offshore. It is a large sedimentary basin developed through thermal subsidence as because of Jurassic - Early Cretaceous rifting of the Tethyan margin (Dixon and Robertson, 1984; Sestini 1989;

Dolson et al., 2005). The NDB is one of the major hydrocarbon-bearing provinces in the eastern Mediterranean region, covering 250,000 square kilometers area (Sestini, 1989; Dolson et al., 2002). It is considered as the most important prolific petroleum province in Egypt, because of the recent explorations that exposed numerous onshore and offshore hydrocarbon discoveries; ranging from the Oligocene to the Quaternary. The hydrocarbon is predominantly a gas, with a few areas producing modest oil (Leila et al., 2017). The Nile Delta's massive gas province basin is of great interest due to its proven gas reserves and undiscovered potentials (Boucher, 2004**).** It is holding 223 trillion cubic feet (TCF) of reserve gas found within nearly about 126 gas fields (Kirschbaum et al., 2010). These gas fields were primarily formed by thermally developed source rocks of the deltaic Neogene sequence, associated with a significant biogenic source of gas (Vandre et al., 2007). Most of the hydrocarbon production in the Nile Delta arises from the Miocene and Pliocene reservoirs (Niazi et al., 2004).

The Offshore North Sinai (ONS) concession is located between 31° 15' & 32° 00' N latitudes and 32° 00' & 33° 00' E longitudes. It lies in the offshore NDB nearly about 65 Km distance northeast from the north coast of Egypt of Port Said City (Ewida and Darwesh 2010). It comprises a total area of 383 km^2 approximately, and it encompasses 3 distinct fields; KAMOSE, TAO and SETI-PLIO as shown in the following map (Fig. 1). The study focuses on TAO Field, which has an area of approximately 144 km^2 and is located between 31° 30' – 32° 00' N latitudes and 32° 30' – 33° 00'E longitudes at ONS Concession.

The sandstones of the Early to Middle Pliocene and the Late Pliocene, Kafr ElSheikh and ElWastani Formations represent the Nile Delta's offshore most primary targets for gas exploration (Othman, et al. 2018; Abd El-Gawad et al. 2019; Sarhan 2021).

The goal of this work is, to conduct formation evaluation using wire-line well log data for the sandstones of Kafr El-Sheikh and ElWastani Formations, to evaluate the well-known gas reservoirs with new promising targets in TAO field, ONS Concession.

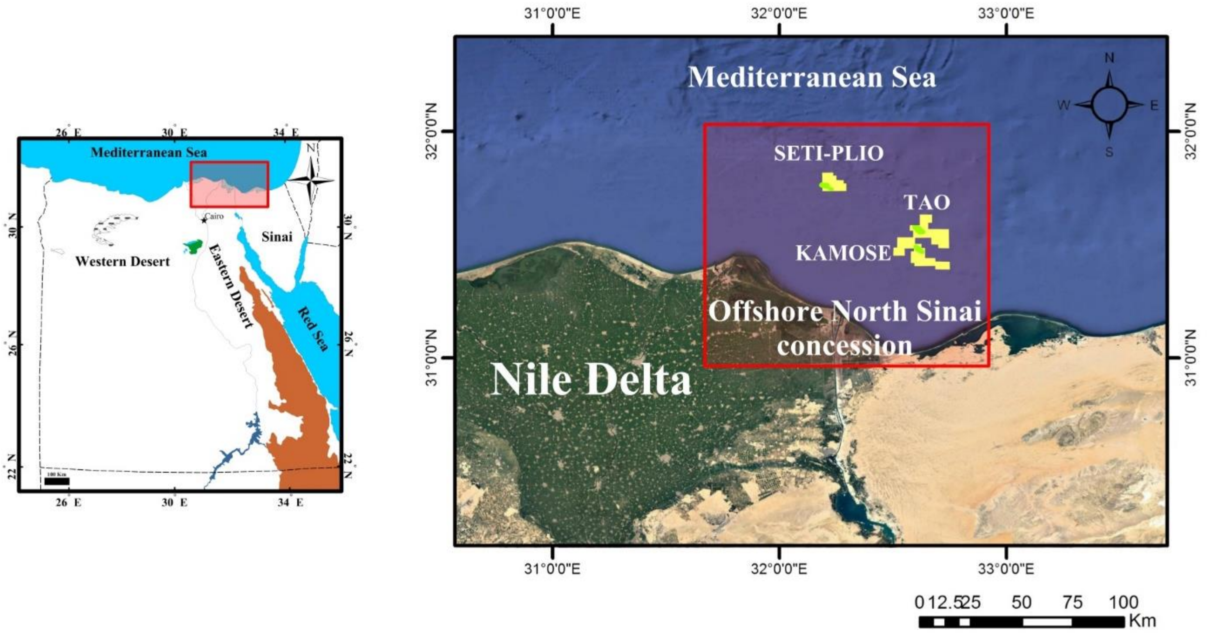

Fig. (1): Location map showing Tao Field at the ONS, NDB, Egypt.

Geological setting

The NDB lies at the northeastern border of the African plate and is considered a part of the Eastern Mediterranean province (Sestini, 1989; Kirschbaum et al., 2010).The NBD passive continental margin is formed by Late Triassic – Early Cretaceous thermal subsidence, following the tectonic extension that separated the African-Arabian plate from the Eurasian plate that was distinguished by the major NW–SE trending basins (Stanley, 1988; May, 1991; Dolson et al., 2001).

A significant E-W trending faulted zone known as the "Hinge Zone" was developed over the northern part of Egypt during the Jurassic-Early Cretaceous time (Said 1962; Sestini 1989; Mosconi et al., 1996). This zone had a significant impact on the general stratigraphic and structural evolution of Egypt's north central basins. The hing zone designates the southern limit of the large Neogene succession north of the Nile Delta (Said, 1981; Harms and Wary, 1990; Arisi et al., 1994).

There are two major provinces in the NDB; the 1 to 1.5 km thick post-Eocene clastics Southern Delta Block, and the 4 to 6 km thick Neogene sediments at the Northern Delta Basin (Sestini 1989; Sarhan et al. 2014).

Throughout the Early Upper Senonian to Early Tertiary period these basins were inverted due to the collision of the African-Arabian and Eurasian plates that resulted in the shortening of Tethys producing the Syrian Arc System NE–SW trending asymmetrical fold series (Moustafa and Khalil 1995; Abd- Allah 2008; Sarhan et al. 2014).

Throughout the Messinian period, the Mediterranean Sea was detached from the Atlantic Ocean, which led to sea level fall that resulted in the development of a wide range of paleocanyons in the Mediterranean region (Sestini 1989; Dolson et al. 2002; Salem et al. 2005). The stage of sea level fall was accompanied by a large marine flooding stage during the Pliocene age due to the new connection of Atlantic Ocean and Mediterranean Sea (Ruggieri and Sprovieri 1976; Lourens et al. 1996). The predominant hydrocarbon reservoirs in the offshore NBD are, represented by the Upper Miocene - Pliocene sediments (Abdel Aal et al., 2000).

In the NDB, the Pliocene-Quaternary succession is a post-rift megasequence known as Post-Messinian Megasequence (Sarhan et al., 2014, Sarhan and Safa 2019). The Post-Messinian Megasequence formed in an active progradation coming from the terrigenous charge, from the southern River Nile's distal fluvial system (El-Fawal et al. 2016). It is lithologically comprises the Early to Middle Pliocene Kafr El-Sheikh Formation, the Late Pliocene El-Wastani and Mit Ghamr Formations, the Quaternary Bilqas Fm (EGPC 1994) (Fig. 2).

Kafr El-Sheikh Formation represents an outer part of marine shelf depositional setting, while El-Wastani Formation characterizes the delta front sequence (El- Fawal et al. 2016). Kafr El-Sheikh Formation comprises different sandy intervals that indicate the main gas reservoirs for considerable newly discovered gas in NDB (Mohamed 2004). The most of such reservoirs have one or more buried channels (Sarhan and Safa, 2017).

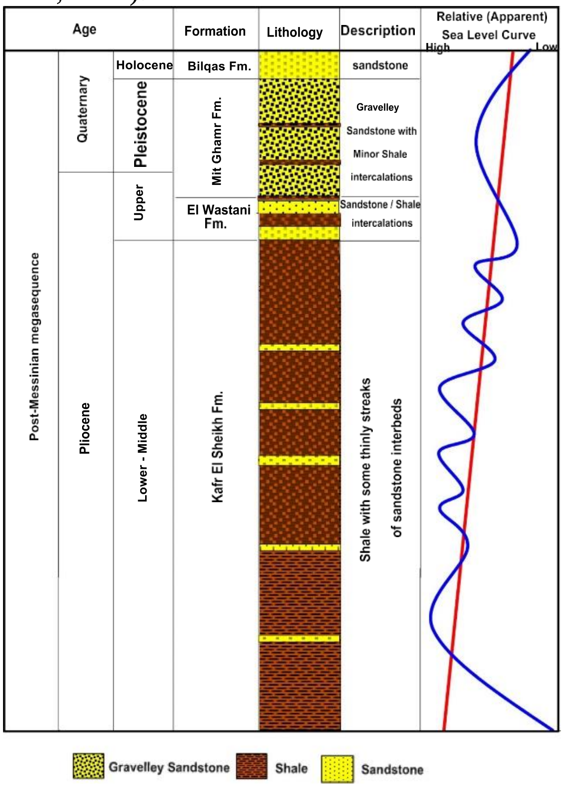

Fig. (2): TAO Field lithostratigraphic column, ONS Concession, NDB (from Sarhan 2021).

Available seismic data and methods

The available geophysical data encompasses wire-line logs for four drilled wells in Tao field, offshore North Sinai. These wells are: Tao-1 (T1), Tao-2, Tao-6 and Tao-8. The mud logs for Tao-6 and Tao-8 wells are also available.

The present study correlates mud records to electric log data for the Kafr El-Sheikh and El-wastani Formations, in the study wells. The mud logs were first evaluated qualitatively in order to identify potential zones of hydrocarbon within the Kafr El-Sheikh and El-wastani Formations. The wire-line logs were provided in digital forms (LAS files) which were imported into TECHLOG software, to identify the major petrophysical parameters in the form of VSh, Φ_T, Φ_E, SW and BVW. The following sections represent the technique used to calculate each parameter.

Shale Volume (Vsh)

VSh has been calculated using Gamma Ray minimum through a linear response. It is displayed in track eight (Figs. 3.4, 3.5 and 3.6). The shale amount in the examined zones has been calculated according to (Schlumberger, 1972; Fertl and Frost 1980) as shown in equation 1:

$$V_{sh} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}} \qquad (1)$$

Where;

GR_{log} reading of fm Gamma Ray Log
GR_{min} Clay free zone Gamma Ray Matrix
GR_{max} Gamma Ray (100%) Shale

Total Porosity (ϕ_T)

Total Porosity (Φ_T) shown in track six (Figs. 3.4, 3.5 and 3.6) was calculated from ND combination as shown in the following relationship, (Asquith and Gibson 1982):

$$\phi_T = \frac{\phi_N + \phi_D}{2} \qquad (2)$$

Where;

ϕ_N Neutron porosity read on log
ϕ_D density porosity

Effective porosity (ϕe)

The following equation was used to calculate effective porosity (Asquith and Gibson 1982) and displayed in track seven (Figs. 3.4, 3.5 and 3.6).

$$\phi_e = \phi_t * (1 - V_{sh}) \qquad (3)$$

Water Saturation (SW)

Indonesian model (Poupon and Leveaux 1971) was used to calculate water saturation (SW) as follows:

$$S_w = \left\{ \left[\left(\frac{V_{sh}^{2-V_{sh}}}{R_{sh}} \right)^{1/2} + \left(\frac{\phi_e^{\,m}}{R_w} \right)^{1/2} \right]^2 Rt \right\}^{-1/n} \qquad (4)$$

Where;

R_{sh} resistivity of shale, (log reading opposite thick shale zone) (Ωm2/m),
R_t deep resistivity (Ωm^2/m),
R_w Connate water resistivity (Ωm^2/m),
m exponent of cementation(=2),
n exponent of saturation(=2),
a factor of tortuosity(=1).

Track nine displays the calculated SW values (Figs. 3.4, 3.5 and 3.6), which are shaded with blue color, whereas the saturation value of hydrocarbon (gas) is represented by the red color in the same track.

Bulk volume of water (BVW)

The values of porosity and SW which are calculated from well los are multiplied to obtain BVW. The low and nearly equal for BVW opposite a particular zone, indicate that it is at irreducible state (i.e produce hydrocarbon free water). The calculated BVW values are presented in track ten (Figs. 3.4, 3.5 and 3.6) and are shaded with blue color. BVW has been determined by using the equation of Buckles (1965):

$$BVW = \emptyset e * Sw \qquad (5)$$

Results

The well log analysis study was performed through the qualitative investigation for the available mud log of T1 well to identify the possible zones of hydrocarbon within the Pliocene sequence. This process indicated three sandstone intervals, exhibiting promising signs for being potential gas zones. In the T1 Well, these zones are designated as A, B, and C.

Zone (A) (670.3 and 681.6 meters) in the sandstones of El-wastani Formation (Fig. 5). Nevertheless, the sandstones of Kafr El-Sheikh Formation possess two major promising gas-bearing zones, B and C. Zone B lies within depth intervals between: 1299–1316.8 meters and 1430–1477.5 meters for zone C as shown in Figs. 6 and 7.

The presence of gas shows as well as high chromatograph analysis values, particularly for methane, Ethan, and propane content, are positive signs for the recommended zones, which supports the presence of gas not oil.

The sands of the A, B, and C zones within the ElWastani and Kafr ElSheikh Formations are almost identical in description, according to the composite log of T1. The sandstones of the interpreted zones have been defined as loose, translucent, colorless, white, grey; medium grained and sometimes coarse; sub-rounded to sub-angular; moderately sorted; with argillaceous matrix to glauconitic sometimes and has with no oil shows (Figs. 3 and 4).

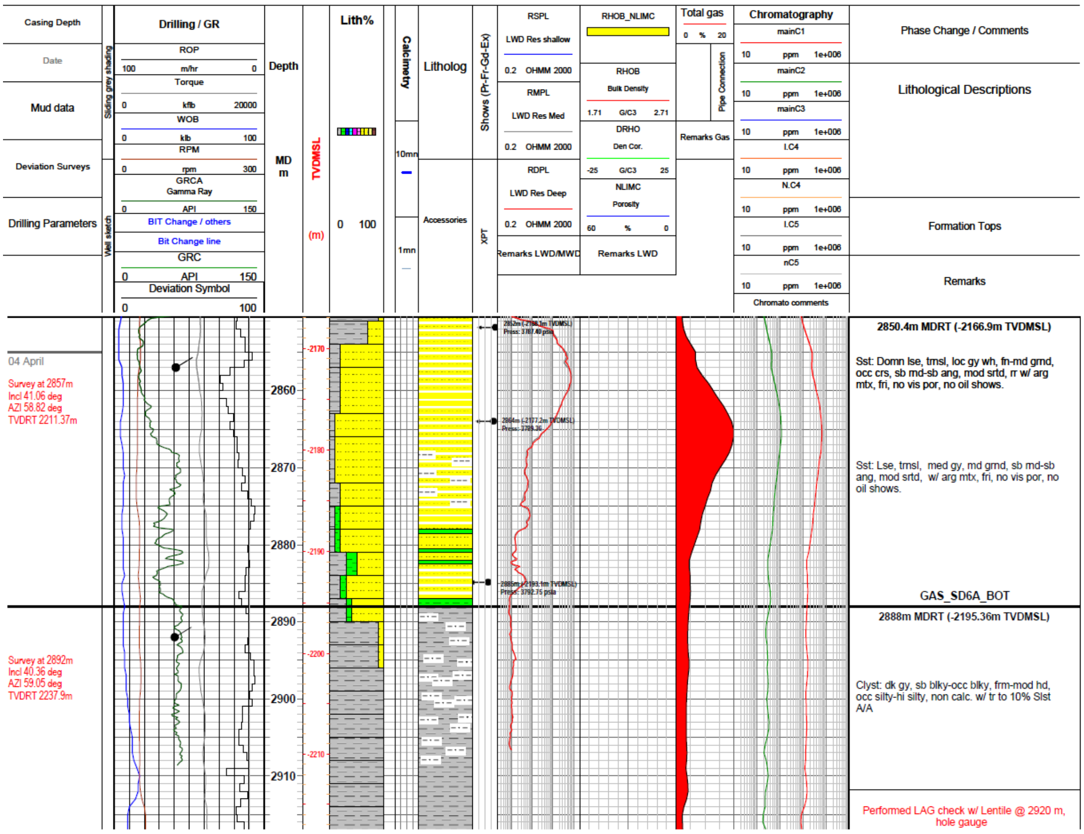

Fig. (3): Tao-8 well composite log between depths; 2860 and 2910m.

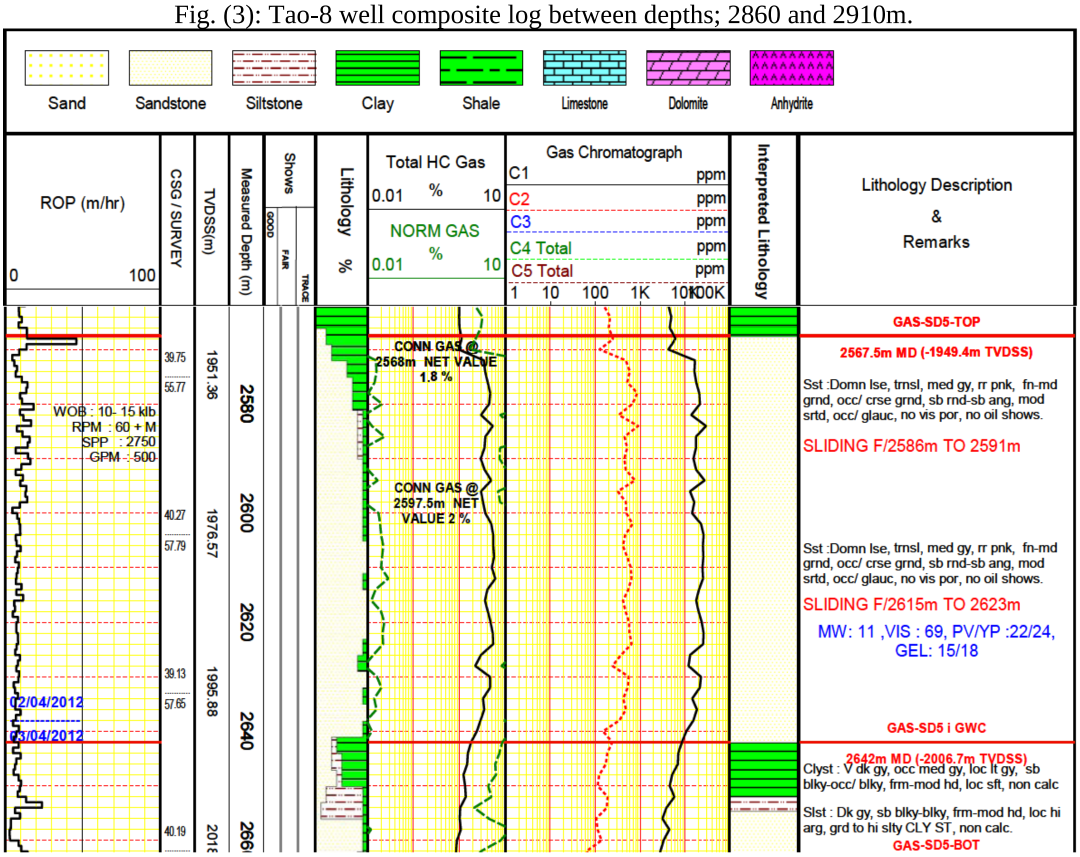

Fig. (4): Tao-6 well composite log between depths 2580 and 2660m.

In consequence, the wire-line logs for the interesting zones A, B and C have been quantitatively evaluated. This evaluation includes the calculations of the decisive petrophysical parameters necessary for determining the potentiality of hydrocarbon reservoirs. VSh, Φ_T, Φ_E, SW, and BVW are all calculated. The results of these parameters for zone A within Elwastani Fm and the calculations for zones B and C have been shown in Kafr ElSheikh Fm at T1 Well (Figs. 5, 6 and 7).

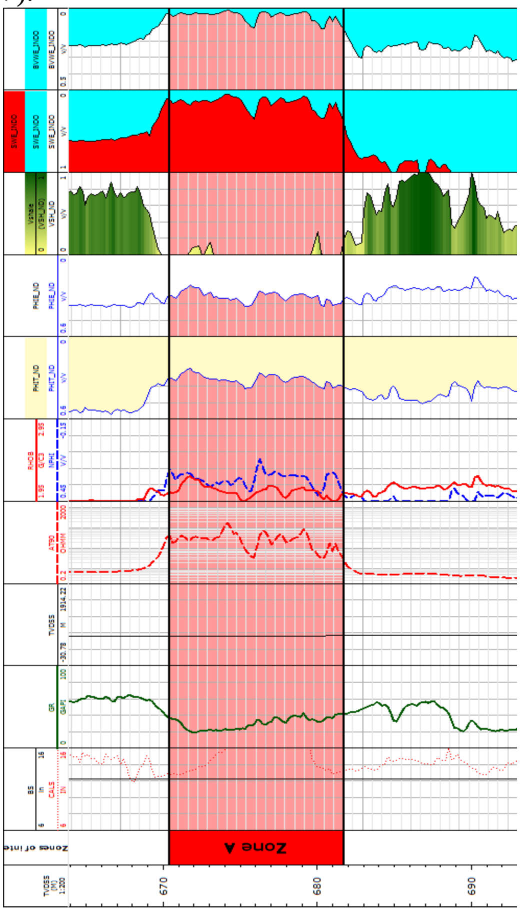

Fig. (5): Input well log data and output interpretation results for zone A.

The ND cross-plots (Schlumberger, 1972) for the interpreted zone A, B and C illustrate the high values of porosity ranging from 32 to 37% and the effect of the gas on the plotted point's distribution (Fig. 9).

The calculated VSh, in the interpreted zones reveals that it is nearly zero. Also, the calculated Φ_T reveals that the lowest value (32%) is observed in Zone C, while the highest value of the Φ_T (37%) was noted in Zone A. The highest value of measured Φ_E is 37%, which was recorded in Zone A, whereas the lowest value (32%) was found in Zone C.

The calculated SW has been displayed in track nine (Figs. 5, 6 and 7). It is shaded with blue color, whiles the hydrocarbon saturation in the same track, and has the red color. The maximum SW is 10%, so the saturation of the hydrocarbon corresponds for 90%, was observed in Zone A, while SW was low in Zone C (7%).

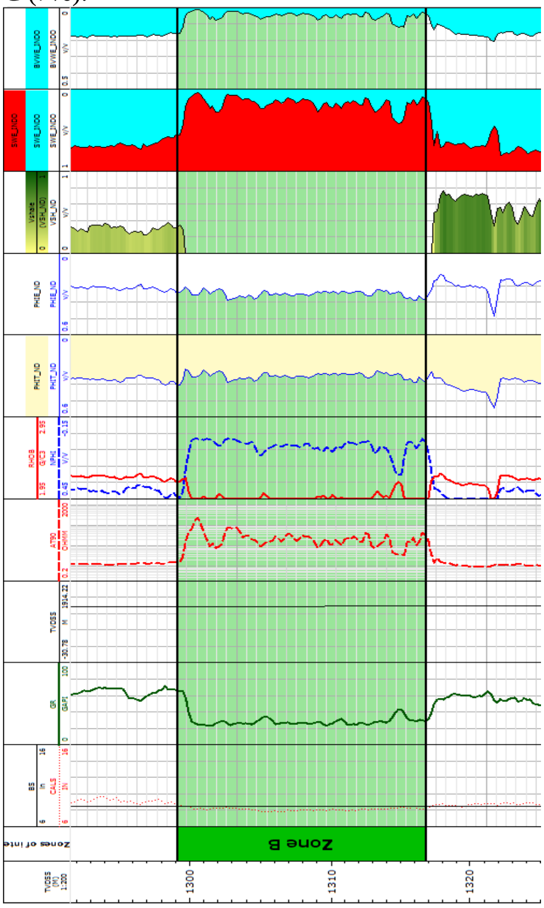

Fig. (6): Input well log data and output interpretation results for zone B.

The Pickett plot (Pickett, 1972), constructed for the studied zones shows that the majority of the points plotted are grouped below the SW 50% line, which confirms the hydrocarbon potentiality of these zones. This indicates that saturation of the hydrocarbon in the investigated zones is expected to be greater than fifty percent (Fig. 8). The results reveal that the calculations for the SW values were correct, also the high importance of the interpreted zones as gas-bearing zones.

The values of BVW were showed in track ten (Figs. 5–8). It is shaded with blue color. The highest value of BVW is 0.10; it was noted in Zone C, while the lowest value (0.03) was noted in Zone A. The BVW in sandstone reservoirs in the irreducible case (i.e.

expected to yield gas free of water). If the sand grains in the investigated zones are fine-grained and graded to siltstones; the values of BVW should range from 0.035 to 0.09 (Asquith 1985). Consequently, because the values of BVW in A, B and C Zones; range between 0.02 and 0.04. These zones are expected to produce gas without water.

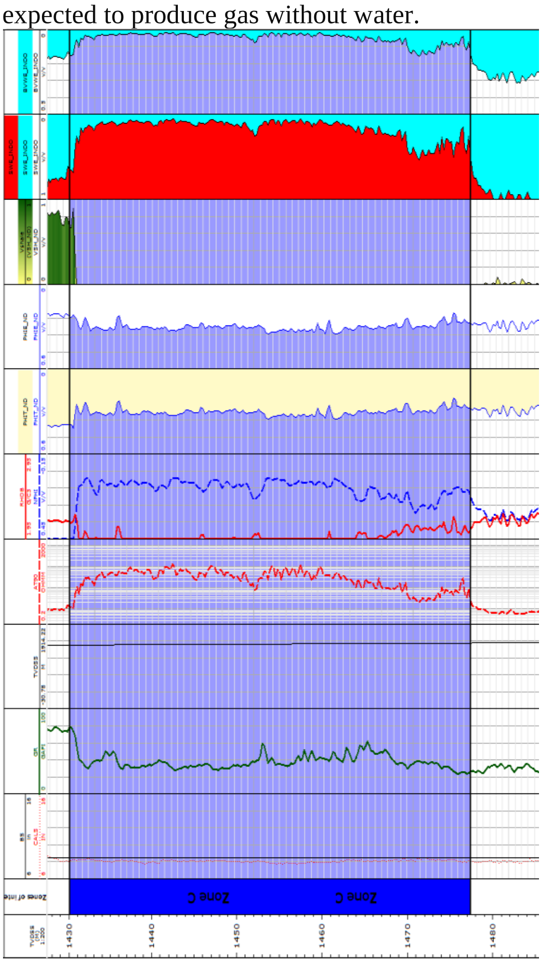

Fig. (7): Input well log data and output interpretation results for zone C.

Discussion

This investigation discussed the evaluation potentiality for the undiscovered gas resources in the offshore North Sinai Concession. The procedures include delineation of the seismic bright spots correspond the Pliocene sand-intervals in the study area. Using petrophysical evaluation for the sand intervals in Tao field in order to know how far these intervals are promising in adding new economic reserves for the natural gas resources existing at North Sinai Concession, offshore Nile Delta Basin.
The interpretation of wire-line log data for the Kafr ElSheikh and Elwastani Formations sandstones in TAO Field; indicated that these formations are preferable gas reservoirs. The detailed petrophysical analysis of the T1 Well, well log data revealed three gas-bearing zones A, B, and C. These favourable intervals correspond to a total net pay thickness of 76.6m and have a very low VSh (near zero), a high E (0.32-0.37), a low SW (below 0.10), and a low BVW (0.04–0.02). Zone A, with a thickness of 11.3m, represents the promising sandstones interval of El-wastani Fm. Zones B (17.8m thick) and C (17.8m thick) represent the sandstone reservoir zones within the Kafr El-Sheikh Fm in T1 Well (47.5m thick).
Pickett plots (Pickett, 1972) for the investigated zones show that the majority of the plotted points characterising the gas zones in the investigated wells are clustered and located below the Sw = 50% line, indicating the gas potential of these intervals. The constructed plots match the calculated water saturation values, confirming the accuracy of mathematical petrophysical calculations and the significance of the examined intervals as gas-bearing zones. The remarkably converging values of the calculated petrophysical parameters describing the investigated intervals suggest reservoir similarity between the Tao gas field and the offshore North Sinai Basin.

Conclusion

The interpretation of the wire-line log data for the sandstones of the Kafr ElSheikh and Elwastani Formations in TAO Field at ONS concession; indicated that these formations are preferable gas reservoirs. The detailed petrophysical evaluation for the well log data of T1 Well revealed three gas-bearing zones A, B and C. These favorable intervals correspond to total net pay thickness of 76.6m and display relatively very low VSh (nearly zero), high Φ_E (0.32-0.37), low SW (below 0.10) and low BVW (0.04–0.02). The promising sandstones interval of Elwastani Fm is represented by Zone A, with 11.3m thick. The sandstone reservoir zones within the Kafr ElSheikh Fm in T1 Well, are represented by zones B (17.8m thick) and C (47.5m thick). Consequently, it is strongly recommended to drill new wells near to the T1 Well in TAO Field to investigate the Kafr ElSheikh and Elwastani Formations as supplementary gas reservoirs.

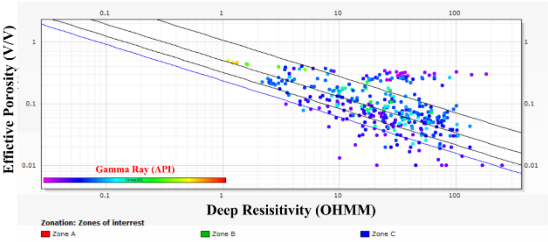

Fig. (8): Pickett plot for zones A, B and C in T1 Well.

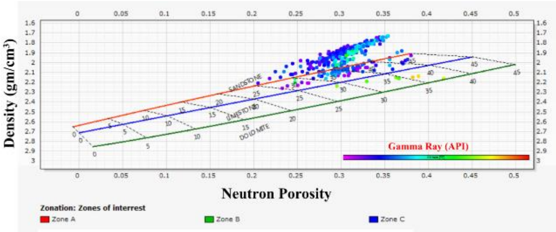

Fig. (9): ΦN-ΦD cross-plot for zones A, B and C in T1Well.

Acknowledgments

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الملخص العربي

عنوان البحث: التوصيف البتروفيزيائي لخزانات البليوسين في حقل تاو، امتياز شمال سيناء البحرى من خلال تفسير تسجيلات الآبار

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[١] قسم الجيولوجيا كليه العلوم جامعة دمياط الجديدة مصر
[٢] شركة شمال سيناء للبترول

في هذه الدراسة ، تم تقييم الحجر الرملي لتكوينات كفر الشيخ والوسطاني لكونها مكامن غازية جديدة واعدة في امتياز شمال سيناء البحري في حقل تاو بحوض دلتا النيل. تم الانتهاء من الدراسة عن طريق التقييم البتروفيزيائي لأربعة آبار (تاو١ و تاو٢ و تاو٦ و تاو٨). أظهر تحليل بيانات سجلات الآبار أن بئر تاو١ هي الوحيدة التي أثبتت أن المعايير الإيجابية في ثلاث مناطق رئيسية لتكون خزانات غاز محتملة. تم العثور على المنطقة المفضلة داخل تكوين الوسطاني بين الأعماق ٦٧٠,٣ م و ٦٨١,٦ م (المنطقة أ). علاوة على ذلك ، فإن المناطق المفضلة في تكوين كفر الشيخ لها أعماق: ١٢٩٩ - ١٣١٦,٨ م (المنطقة ب) و ١٤٣٠ - ١٤٧٧,٥ م (المنطقة ج). بالنظر إلى معايير جودة المكمن ، كشفت الحسابات الكمية أن منطقة تكوين الوسطاني أ هي أكثر المناطق الحاملة للغاز كفاءة في بئر تاو ١ ؛ لأنها تمتلك صفر حجم الصخر الطيني و تشبع الماء منخفض (٠,١) و الحجم الكلي للماء منخفض (٠,٠٤). علاوة على ذلك ، فإن الحجر الرملي لتكوين كفر الشيخ في تاو ١ يحتضن منطقتين مكمنين (B و C)بسماكة إجمالية ١٧,٨ م و ٤٧,٥ م على التوالي. علاوة على ذلك ، أظهرت النتائج المحققة أنه من المتوقع أن تنتج المناطق B و C غازًا بدون ماء.