Scientific Journal for Damietta Faculty of Science **13**(1) 2023, 83-89
ISSN Print 2314-8594
ISSN Online 2314-8616

*https://sjdfs.journals.ekb.eg/*

# Well Logging Analysis of the Devonian Awaynat Wanin Formation (F3) "B" in A37-NC169a well, Al Wafa field, Ghadames Basin, Libya

Ahmad M. K. Basal[1], Mohammad A. Sarhan[*1], Mostafa Gumaa Alfarog[1], Esraa El-Twargy[1] and Ahmed Elbahrawy[1]

[1]Geology Department, Faculty of Science, Damietta University, New Damietta City, Egypt.

Received: 19 April 2023 /Accepted: 31 May 2023

[*] Corresponding author's E-mail: msarhan@du.edu.eg

## Abstract

The Ghadames basin represents the second main basin in oil production in Libya. Al Wafa Field is one of the oil and gas producer in Ghadames basin. This work aims to evaluate the sandstone of Aouinet Uennin Formation (F3) "B" in A37-NC169a well, Al Wafa field, Ghadames Basin, Libya. The applied methods in this research encompasses the qualitative and quantitative well logging evaluation for the entire sandstone (F3) "B"-sand level) of the Awaynat Wanin Formation in A37-NC169a well. The analysis of the well logging data, the examined sandstones exhibit high potentiality for hydrocarbon production in its topmost part (level 1) with 54 ft thick. This reservoir displays high hydrocarbon saturation values fluctuates between 80-90%, porosity ranges between 5-15%, low Bulk Volume of Water 0.01and 0.02, irreducible water saturation equals 22 %, and permeability nearly 7 MD. Accordingly, this study highlights the oil potentiality of the sandstones of the Awaynat Wanin Formation (F3) "B" for further exploration purposes in Al Wafa field and the surrounding fields within the Ghadames Basin.

***Keywords:*** Awaynat Wanin Formation; Ghadames Basin; Well Logging; Al Wafa field.

## Introduction

The Ghadames basin is the second most significant basin in oil and gas production in Libya (Underdown & Redfern, 2008). Ghadames basin covers about 212,000 km$^2$ and represents an intracratonic basin extending across the eastern part of Algeria and southern Tunisia and the northwestern Libya (Saadi et al., 2011). The Nafusah Uplift to the north, the Tihemboka and Gargaf Arches and Hoggar Shield bound the Libya Ghadames Basin to south and Sirte Basin to the east (Saadi et al., 2011). Ghadames basin contains up to 6000 m of Palaeozoic as well as Mesozoic sedimentary section (Bora and Dubey, 2015).

The Ghadames basin was affected by four major tectonic episodes. The first stage includes the deformation of the north African platform and the formation of a huge subsiding sag basins before the Hercynian orogeny (Van de Weerd and Ware, 1994). However, the second event encompasses the Late Carboniferous-Permian Hercynian orogeny which changed the basin architecture considerably. The third phase is the Triassic-Liassic extensional episode, forming a re-newed subsidence and the sedimentation of a thick continental clastic succession (Yahi et al., 2001; Boudjema, 1987). A large Mesozoic extensional sag basin was superimposed over the eroded remains of the previous Palaeozoic basin as a result of the subsequent thermal subsidence that caused NW tilting (Echikh, 1998). The Oligocene - Eocene Africa-Arabian plate collision is the fourth stage; this event led to the Alpine orogenic tectonic, which improved erosion and uplift in eastward (Guiraud et al., 1987; Boote et al., 1998).

Al Wafa Field is located about 100 kilometers south of the city of Ghadames (Fig. 1) and situated along the Libyan-Algerian boundary in the southwestern region of the Libyan side of the Ghadames Basin. The field produces both oil and gas from the main Reservoir F3-Sandstone only, and the average per day production is 10,290 BOPD. The first discovery well, D1-52, was drilling by Shell Libya in 1964. This field produces 7600 BB of crude oil and condensate as well as 601 MMSCF of gas per day (Hlal et al., 2022).

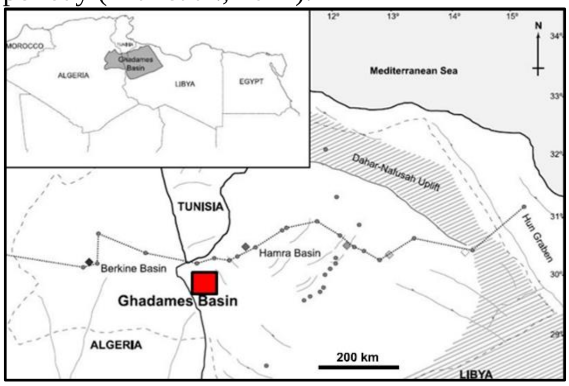


Fig. 1. Regional map displays the location of Al Wafa field in Ghadames Basin, Libya (After, Underdown and Redfern, 2007).

The main reservoir in Al Wafa Field is the F3-sand level of the Devonian Aouinet Ouenine Formation (Fig. 2). This formation has a thickness varies from 134 to 184 ft and is mainly composed of shale with interbedded sandstone. The shale is soft to weakly hard, sub-flacky, non-calcareous, and gray to light grey in colour. However, the sandstones display hard to moderately hard, colourless, light brown to light grey, fine to medium grained, sub-angular to sub-rounded, poorly to moderately sorted, and siliceous cement with oil shows (Hlal et al., 2022).

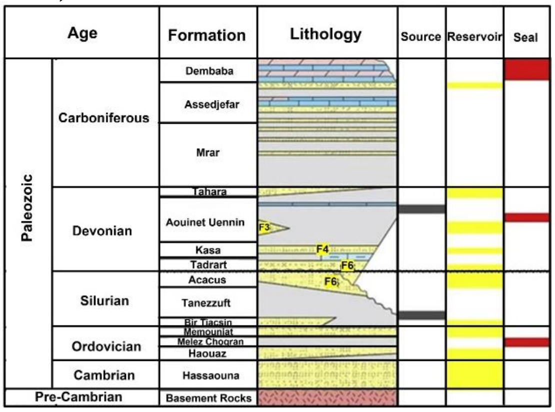


Fig. 2. Stratigraphic column and petroleum system of Ghadames Basin (modified after Bora and Dubey, 2015; Rusk, 2001).

The current work aims to evaluate the (F3) "B" sand level of the Aouinet Ouenine Formation as a potential oil-bearing reservoir in A37-NC169a well, Al Wafa Field, Ghadames Basin. The studied area is located within Al Wafa Field, Ghadames basin, SW of Libya. The available A37-NC169a well locates in the intersection of latitude 28° 55′ 33.193″ N and longitude10° 03′ 38.668″ E. The composite and conventional well logs data for A37-NC169a well are available. The core data report for A37-NC169a well is also accessible (Fig. 3).

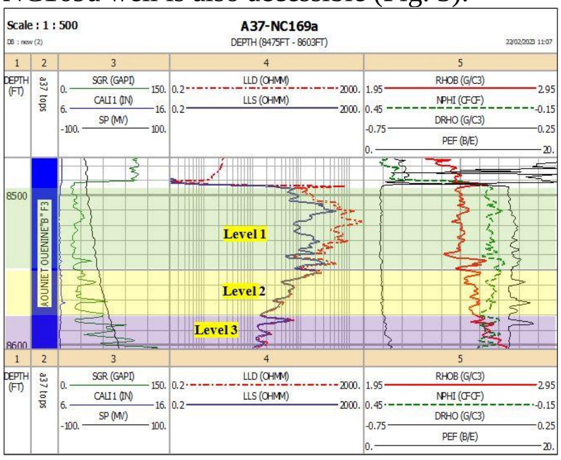


Fig. 3. Available well logging data of A37-NC169a well in Al Wafa field, Ghadames Basin.

## Methods and Results

The applied methods in this research encompasses the well logging evaluation for the entire sandstone (F3) "B"-sand level) of the Awaynat Wanin Formation in A37-NC169a well. This assessment was qualitatively and quantitatively performed using IP Software of Schlumberger to examine its reservoir characteristics as a hydrocarbon-bearing interval in Al Wafa Field.

The well log data is graphically represented in five tracks comprising; depth in track one, stratigraphic unit in track two, gamma ray (the green colour) and calliper (the blue colour) in addition to spontaneous potential of black colour in track three. However, track four contains the shallow (with purple colour) and deep resistivity (with red colour). The last track comprises; neutron log (green colour), density log (red colour), density correction (black colour) and photo electric (pink colour).

The visual examination indicates low calliper curve reflecting good bore hole conditions which mean high quality log record interval between depths; 8496 to 8600ft. Based on the log responses, the Awaynat Wanin Formation (F3) “B” in A37-NC169a well was classified into three levels; Level 1, Level 2 and Level 3.

Level 1 is the topmost interval occupies the zone between depths of 8496-8550 ft and characterized by lowest observed gamma ray reflecting the clean nature of the entire sandstone. This interval is characterized by; PEF value equals 1.98, high separation between the Neutron (NPHI) and density (RHOB) curves which indicating the presence of gas in this zone, neutron curve shifted to right relative to density log which lies on the left side, resistivity logs reveal high values of deep resistivity log, positive separation between the three recorded resistivity loges (i.e. LLD<LLS<MSFL) which probably indicates the presence permeability in this interval.

Level 2 represents the middle zone and occupies the interval between depths; 8550 and 8580 ft. It is characterized by gradual increase gamma ray values and gradual decrease in resistivity logs. Also, neutron curve shifted to right relative to density log and the separation between the neutron and density curves decreases gradually and PEF value equals about 2 b/e confirm the slightly shaly matrix.

Level 3 is the lowermost zone representing the interval between the depths of 8580 -8600 ft and characterized by the gradual more increase in gamma ray values. The resistivity logs track each other and more observed decrease of the three-resistivity logs. The NPHI and RHOB logs are intersect of each other due to the shale effect more than the gas effect. PEF value is about 2.3 b/e confirms the intercalation between sand and shale.

Accordingly, the water saturation for only level 1 has been performed due to it represents the promising reservoir zone in the examined succession using Archi equation (Archie, 1942) as follow:-

$$Sw = \sqrt{Rw/RT} * \varnothing 2 \qquad (1)$$

Where; Sw is water saturation, Rw is water resistivity from core data, RT is the deep resistivity from well logs, ø is the porosity value from well logs.

Since; Ø= 0.10, RW = 0.06, RT = 600

$$So;\ Sw = \sqrt{\frac{0.06}{150*0.102}} = 0.2$$

The density -neutron cross plot for the examined zone of A37-NC169a well displays that the clustering of points on sandstone line with moderate to high porosity values between 5 -15 % (Fig. 4). The porosity-water saturation plot for the reservoir interval shows that most of sand grains in this zone display medium to course grained in size (Fig. 5).

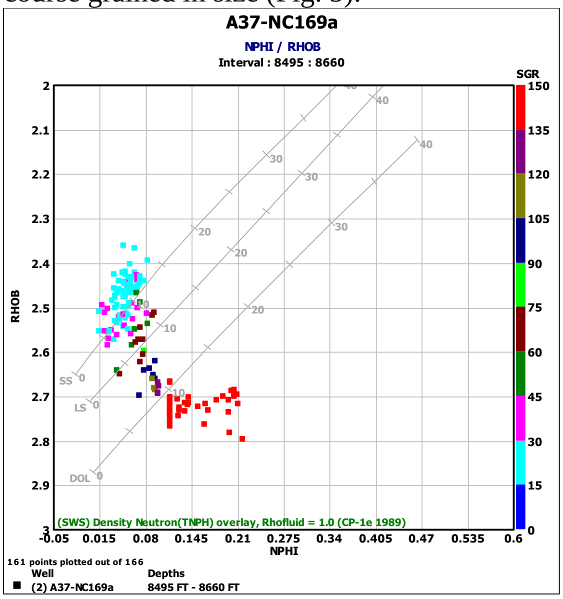


Fig. 4. Density (RHOB)-Neutron (NPHI) cross plot (after Schlumberger, 1972b) for the examined zone of A37-NC169a well in Al Wafa field, Ghadames Basin.

According to Asquith & Gibson, 1982), the water saturation of flushed zone (Sxo) can be calculated from the following equation:

$$Sxo = Sw^{1/5} \qquad (2)$$

Where; Sw is water saturation, Sxo: water saturation of flushed zone.

So, $Sxo = Sw^{1/5} = 0.72$

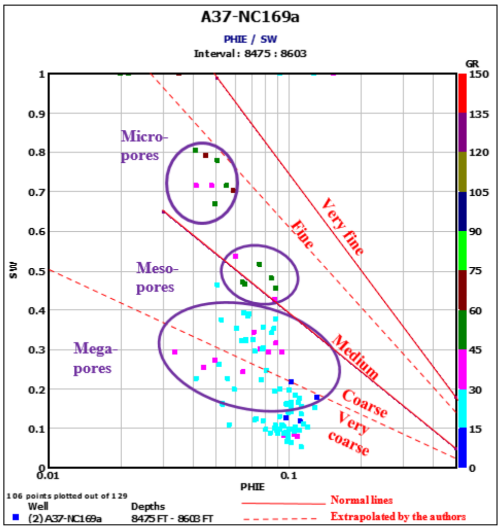


Fig. 5. Water saturation (Sw)-effective porosity (PHIE) cross plot (modified after Asquith and Gibson, 1982) shows the grain size distribution for the reservoir zone in A37-NC169a well, Al Wafa field, Ghadames Basin.

The Movable Hydrocarbon Index (MHI) which reflects the oil movability in hydrocarbon reservoirs. MHI is the ratio between water saturation in the un-invaded zone ($S_w$) and water saturation in the flushed zone ($S_{xo}$). If Sw/Sxo equals or greater than 1.0 then oil will not move during invasion (i.e. residual oil). However, when the ratio is less than 0.7 in sandstone reservoirs, this reflects the presence of movable oil (Asquith and Gibson, 1982; Schlumberger 1972a).

From equations 1 and 2, so the calculated MHI value in the zone of interest equals 0.27 (i.e. less than 0.7) reflecting movable hydrocarbon in this interval.

Bulk Volume Water (Buckels, 1965) is calculated as follow:

$$BVW = \Phi * S_w \quad (3)$$

Where; BVW is Bulk Volume Water, Φ is porosity, $S_w$ is water saturation.

If the calculated values for BVW are constant or nearly constant, this reflects that the reservoir zone is at irreducible case. Since, the calculated BVW for the investigated zone range between 0.01-0.02 (Fig. 6). This indicates that the water in the un-invaded zone will not move through production and causing water-free hydrocarbon. Asquith and Gibson (1982) reported that the value of the irreducible water saturation in a specific reservoir is based on the formation factor which is a function of porosity **($F = 1/\Phi^2$)**. Therefore, it can be calculated from the next equation:

$$S_{wirr} = (F/2000)^{0.5} \quad (4)$$

Where; $S_{wirr}$ is irreducible water saturation, F is Formation Factor.

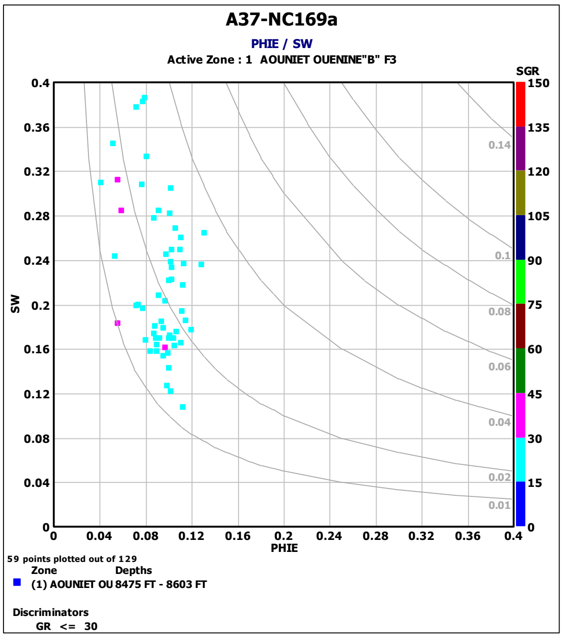


Fig. 6. Buckells plot (PHIE versus Sw) for the reservoir zone showing points followed 0.02 hyperbola bulk volume of water (BVW) indicate the reservoir at irreducible state (i.e. producing free water oil)

The calculated $S_{wirr}$ for the inspected zone equals 0.22 (Table 1).

Bulk Volume Water at irreducible state is controlled by the grain size (Asquith and Gibson, 1982 & Asquith, 1985). Since the sand grains of the reservoir zone are medium to coarse in size, so it is predictable that points that track 0.02 BVW hyperbole will yield oil without water.

Absolute permeability for the reservoir zone was calculated using Timur model of (Timur, 1968) as follow:-

$$K^{0.5} = 100 * [(\Phi^{2.25} / S_{wirr})] \quad (5)$$

Where; K is absolute permeability, Φ is porosity, $S_{wirr}$ is irreducible water saturation.

The results reflect that the values of permeability for the examined interval is 6.53 MD approving the high quality for this zone to produce hydrocarbon (Table 1).

The constructed Picket crossplot (Pickett, 1972) for the studied zone with the Awaynat Wanin Formation (F3) “B” in A37-NC169a well shows that the majority of the plotted points are below 50 % $S_w$ line representing hydrocarbon-bearing zone confirming the calculated water saturation values using Archi model. It is of worth mentioning that the Picket plot was constructed using the value of n-exponent equals 3.3 and the water resistivity equals 0.06 based to the available core data for the examined well (Fig. 7).

Table (1): The calculated petrophysocal parameters for the examined interval within Awaynat Wanin Formation (F3) “B” in A37-NC169a well.

| DEPTH Ft | Ø | RT (Ωm2/m) | SXO | SW | SW/SXO | BVW | Swirr | K (MD) |
|---|---|---|---|---|---|---|---|---|
| **8496** | 0.10 | 150 | 0.72 | 0.2 | 0.27 | 0.02 | 0.22 | 6.53 |
| **8510** | 0.10 | 600 | 0.63 | 0.1 | 0.16 | 0.01 | 0.22 | 6.53 |
| **8520** | 0.10 | 1000 | 0.59 | 0.077 | 0.13 | 0.01 | 0.22 | 6.53 |
| **8530** | 0.10 | 800 | 0.61 | 0.086 | 0.14 | 0.01 | 0.22 | 6.53 |

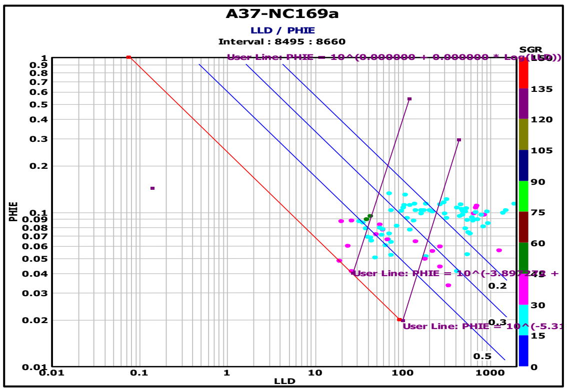


Fig. 7. Pickett plot for the reservoir zone in A37-NC169a well, Al Wafa field, Ghadames Basin.

The performed quantitative analysis using IP Software exposed that the interval between depths; 8496-8550 ft which represents the aforementioned level 1 is the most promising hydrocarbon-bearing interval in A37-NC169a well (Fig. 8).

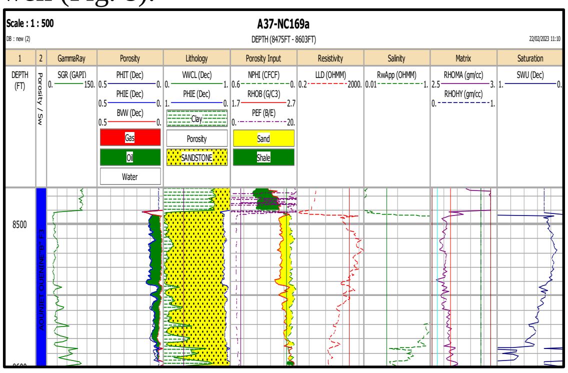

Fig. 8. Output results of well logging analysis of the investigated interval within A37-NC169a well, Al Wafa field, Ghadames Basin.

## Discussion and Conclusions

In the Ghadames basin, the hydrocarbon produced from the Tanezzuft Formation (Early Silurian) and the shales of the Aouinet Ouenine (Late Devonian) throughout the Late Carboniferous age. The subsidence rate increased through the Middle - Late Cretaceous interval as well as the high heat flow in the Cenozoic time had the maximum effect on the hydrocarbon generation from source rocks. However, the extensive uplifting and erosional processes in the Alpine orogeny has a significant influence on the accumulation and migration of the hydrocarbon in the Ghadames basin and the nearby basins. The greatest hydrocarbon expulsion was in the Oligocene time for both the Aouinet Ouenine and the Tanezzuft source rocks (Bora and Dubey, 2015).

The sandstones of the Devonian Awaynat Wanin Formation (F3) “B” in Ghadames Basin are potential oil reservoir. In Al Wafa field, the porosity varies between 0.05 and 0.15, water saturation is 10 up to 20% and the total net pay zones thickness is 54 feet. Accordingly, the current study emphasised the oil potentiality of the Awaynat Wanin Formation (F3) “B” sandstones for future development and exploration processes in Ghadames basin.

The interpretation of the accessible well log data for Awaynat Wanin Formation (F3) “B” in A37-NC169a well reveals good reservoir quality for oil production in level 1 which is located between depths of 8496 and 8550 ft. The Awaynat Wanin Formation in level 1 possesses low water saturation values ranging from 20 to 10 %; thus, its hydrocarbon saturation values range from 80 to 90%. Based on the density-neutron cross plot, this zone exhibits moderate to high porosity ranges from 5 to 15%. The sandstone within level 1 shows relatively high permeability (about 7 MD) over and above the movability of the preserved hydrocarbon, as the movable hydrocarbon index equals 0.27 (i.e. lower than 0.7). The calculated values for BVW are constant or close to constant ranging between 0.01and 0.02, which reflects that the reservoir zone is at irreducible case. According to these findings, future explorations in the Ghadames basin are recommended and should focus on the sandstones of the Awaynat Wanin Formation (F3) “B” especially in Al Wafa field.

## Acknowledgment

The authors are grateful to the National Oil

Corporation Petroleum of Libya and the Mellitah Oil & Gas B.V. Company for providing the geophysical data presented in this work.

**Conflict of interest**

Here we authorize that there is no conflict of interests for the current study.

**References**

Archie, G. E. (1942). The electrical resistivity log as an aid in determining some reservoir characteristics: Petroleum Technology, v. 5, pp. 54-62.

Asquith, G. B. (1985). Handbook of log evaluation techniques for carbonate reservoirs. Methods in exploration series, Member 5, AAPG, Oklahoma, USA.

Asquith, G., and Gibson, C. (1982). Basic well log analysis for geologists: methods in Exploration series. AAPG, Tulsa, Oklahoma.

Boote, D. R., Clark-Lowes, D. D., & Traut, M. W. (1998). Palaeozoic petroleum systems of North Africa. Geological Society, London, Special Publications, 132(1), 7-68.

Bora, D. and Dubey, S. (2015). New insight on petroleum system modeling of Ghadames basin, Libya. Journal of African Earth Sciences, 112, pp.111-128.

Boudjema, A. (1987). Evolution structurale du bassin petrolier Triasique du Sahara Nord-Oriental (Algerie). PhD thesis. Universite Paris-Sud.

Buckles, R. S. (1965). Correlating and averaging connate water saturation data. Journal of Canadian Petroleum Technology, v. 4, no. 1, pp. 42-52.

Buckles, R. S. (1965): Correlating and averaging connate water saturation data. Journal of Canadian Petroleum Technology, v. 4, no. 1, pp. 42-52.

Echikh, K. (1998). Geology and hydrocarbon occurrences in the Ghadames basin, Algeria, Tunisia, Libya. Geological Society, London, Special Publications, 132(1), 109-129.

Guiraud, R. (1998). Mesozoic rifting and basin inversion along the northern African Tethyan margin: an overview. Geological Society, London, Special Publications, 132(1), 217-229.

Guiraud, R., Bellion, Y., Benkhelil, J., & Moreau, C. (1987). Post-Hercynian tectonics in northern and western Africa. Geological Journal, 22(S2), 433-466.

Hlal, O., El Zarorg, R., Targhi, M. H., & Sultan, M. A. (2022). Using Reservoir Saturation Test (RST) With Repeat Formation Test (RFT) For Improve Well Production In Wafa Field Case Study Ghadames Basin West, Libya. Special Issue of the 6th Annual conference on Theories and Applications of Basic and Biosciences, PP 348 -358.

Pickett, G.R. (1972). Practical formation evaluation. Golden, Colorado, G.R. Pickett, Inc.

Rusk, D.C. (1999). Libya: Petroleum Potential of the Under-Explored Basin Centers--A 21st Century Challenge. AAPG Bulletin, 83(12).

Saadi, N. M., Zaher, M. A., El-Baz, F., & Watanabe, K. (2011). Integrated remote sensing data utilization for investigating structural and tectonic history of the Ghadames Basin, Libya. International Journal of Applied Earth Observation and Geoinformation, 13(5), 778-791.

Schlumberger (1972a). Log interpretation manual/principles, vol. I: Houston, Schlumberger Well Services, Inc.

Schlumberger (1972b). Log interpretation/charts, Houston, Schlumberger Well Services, Inc.

Timur, A. (1968). An investigation of permeability, porosity, and residual water saturation relationships. In SPWLA 9th annual logging symposium. Society of Petrophysicists and Well-Log Analysts.

Underdown, R. H. (2006). An integrated basin modelling study of the Ghadames Basin, North Africa (Doctoral dissertation, University of Manchester).

Underdown, R., & Redfern, J. (2007). The importance of constraining regional exhumation in basin modelling: a hydrocarbon maturation history of the Ghadames Basin, North Africa. Petroleum Geoscience, 13(3), 253-270.

Underdown, R., & Redfern, J. (2008). Petroleum generation and migration in the Ghadames Basin, North Africa: A two-dimensional basin-modeling study. AAPG bulletin, 92(1), 53-76.

Van de Weerd, A. A., & Ware, P. L. G. (1994). A review of the east Algerian Sahara oil and gas province (Triassic, Ghadames and Illizi basins). First Break, 12(7), 363–373.

Yahi, N., Schaefer, R. G., & Littke, R. (2001). Petroleum generation and accumulation in the Berkine basin, eastern Algeria. AAPG bulletin, 85(8), 1439-1467.

## الملخص العربي

**عنوان البحث: تحليل تسجيلات الآبار لمتكون عوينات وانن "B"(F3) الديفوني لبئر NC169a -37 A، حقل الوفا، حوض غرامس، ليبيا**

**أحمد محمد كمال بصل[١]، محمد عبد الفتاح سرحان، مصطفى جمعة الفروج[١]، إسراء التوارجي[١]، أحمد البحراوي[١]**
**[١] قسم الجيولوجيا كليه العلوم جامعة دمياط دمياط الجديدة مصر**

يمثل حوض غدامس ثاني أكبر حوض لإنتاج النفط في ليبيا. حقل الوفاء هو أحد منتجي النفط والغاز في حوض غدامس. حقل الوفاء هو أحد منتجي النفط والغاز في حوض غدامس. يهدف هذا العمل إلى تقييم الحجر الرملي لتكوين عوينات وانن في حقل الوفاء ، حوض غدامس ، ليبيا. عند تحليل بيانات تسجيل البئر ، تُظهر الأحجار الرملية التي تم فحصها إمكانية عالية لإنتاج الهيدروكربون في الجزء العلوي (المستوى ١) بسماكة ٥٤ قدمًا. يعرض هذا الخزان قيم عالية للتشبع الهيدروكربوني تتأرجح بين ٨٠-٩٠٪ ، وتتراوح المسامية بين ٥-١٥٪ ، وانخفاض حجم الكتلة المائية ٠,٠١ و ٠,٠٢ ،
تساوي نسبة تشبع الماء غير القابل للاختزال ٢٢٪ ، والنفاذية حوالي ٧ ملي دارسي. وبناءً على ذلك ، تسلط هذه الدراسة الضوء على الإمكانات النفطية للحجر الرملي لتكوين عوينات أوينين لأغراض استكشافية أخرى في حقل الوفاء والحقول المحيطة داخل حوض غدامس.