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Petrophysical Interpretation and 3D Geological Modeling of the Nubian Sandstone Formation, Bu Attifel Oil Field, Sirt Basin, Libya

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Abstract

This study evaluates the reservoir quality of the Nubian Sandstone Formation in the Bu Attifel oil field, Sirt Basin, Libya. A comprehensive petrophysical analysis was performed on well log data from four wells (A1-125, A3-125, A4-125, and A88-125) using Techlog software, integrated with 3D geological modeling using Petrel software to delineate the spatial distribution of petrophysical properties. The key findings indicate that the Nubian Sandstone reservoir exhibits fair to good porosity (7-12%), with optimal values in the southwestern area. Water saturation is moderate, varying from 36% (southwest) to 65% (northeast). The structural configuration confirms an anticlinal fold trap hosting two prospective zones (A and B) with superior reservoir qualities. Significantly, Well A88-125 in the southwestern sector represents the optimal drilling target, demonstrating the best combination of reservoir characteristics: 12% porosity, 36% water saturation, and 1.2% shale volume. These parameters establish zone A of well A88-125 as the most favorable prospect for future development. 3D models successfully visualize the spatial heterogeneity and support the identification of high-priority exploration and development opportunities within the field.

Keywords:- Nubian Sandstone, petrophysical properties, 3D Geological Model.

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التفسير البتروفيزيائي والنمذجة الجيولوجية ثلاثية الأبعاد لتكوين الرمل النوبي، حقل أبو الطفل، حوض سرت، ليبيا

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الملخص

يمثّل تكوين الحجر الرملي النوبي أحد أهم المكامن الهيدروكربونية في حوض سرت، ليبيا. يهدف هذا البحث إلى تقييم جودة المكمن وبناء نموذج جيولوجي ثابت ثلاثي الأبعاد للحجر الرملي النوبي في حقل بو عطيفل النفطي، بغرض تتبّع التوزيع الفراغي للخواص البتروفزيائية في المنطقة المدروسة. تم اعتماد منهجية تعتمد على دمج تحليل الخواص البتروفزيائية لسجلات الآبار لأربع آبار (A1-125)، A3-125، A4-125، A88-125باستخدام برنامج Techlog، تلاه إجراء النمذجة الجيولوجية ثلاثية الأبعاد باستخدام برنامج Petrel.

شملت الدراسة حساب وتوزيع أهم المعاملات البتروفزيائية، بما في ذلك حجم الطفل (الطين)، والمسامية، وتشبع الماء، على شبكة تركيبية ثلاثية الأبعاد تمثل بنية المكمن. أظهرت النتائج أن المكمن يتميز بمسامية تتراوح بين 7% و12%، ويمكن تصنيفها بين المتوسطة والجيدة، مع تسجيل قيم أعلى في الجزء الجنوبي الغربي من الحقل. كما بيّنت نماذج تشبع الماء أنه متوسط عموماً، ويزداد من نحو 36% في الجنوب الغربي إلى حوالي 65% في الشمال الشرقي من المنطقة.

أكد النموذج التركيبي وجود فخ تركيبي من نمط الطية المحدّبة، مما يفسّر تجمع الهيدروكربونات في مستويات محددة داخل الحجر الرملي النوبي. كما أظهرت النماذج البتروفزيائية وجود نطاقين محتملين إنتاجياً في المنطقتان (A) (B) يتميزان بخواص خزنيه أفضل نسبياً مقارنة ببقية أجزاء المكمن. توصي الدراسة بأهمية دمج بيانات آبار إضافية وإجراء محاكاة ديناميكية للمكمن للتحقق من دقة النموذج وتحسين استراتيجيات تطوير وإدارة الإنتاج مستقبلاً.

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الكلمات المفتاحية: الحجر الرملي النوبي ،الخواص البتروفيزيائية، النمذجة الجيولوجية ثلاثية الأبعاد.

Introduction

Libya is a major oil producer on the African continent, with its hydrocarbon systems extending across several sedimentary basins (Barr and Wegger, 1972). The Sirt Basin, a Mesozoic-Cenozoic age basin, is the most prolific, accounting for approximately 80-85% of Libya's known recoverable oil reserves (Barr and Wegger, 1972). This basin, covering an area of about 600,000 km² in north-central Libya (Figure 1), is characterized by a complex structural history of rifting, subsidence, and faulting, which has created numerous traps for hydrocarbon accumulation (Giuma H. Swei, 2010). The Bu Attifel oil field (Figure 2), discovered in 1968 and located in the southeastern part of the Sirt Basin, is a significant producer, with the Nubian Sandstone Formation serving as its principal reservoir (Agip Oil Company, 1982; Hallet, 2002).

Effective reservoir management and further exploration in mature fields like Bu Attifel depend heavily on a detailed understanding of reservoir heterogeneity and the spatial distribution of key petrophysical properties such as porosity and water saturation. Traditional 2D mapping methods often fail to capture the full complexity of the subsurface. Therefore, this study aims to build a high-resolution 3D static geological model of the Nubian Sandstone reservoir in the Bu Attifel field.

The primary objective is to integrate petrophysical analysis from well logs with geological data to characterize the reservoir, quantify its properties, and identify prospective zones for future development. The methodology utilizes well log data from four selected wells, analyzed using Techlog software to determine volume of shale, porosity, and water saturation (Schlumberger, 1997). These results are then integrated into Petrel software to construct a structurally sound 3D grid and populate it with petrophysical properties, creating a comprehensive static model that visualizes the reservoir's heterogeneity and quality.

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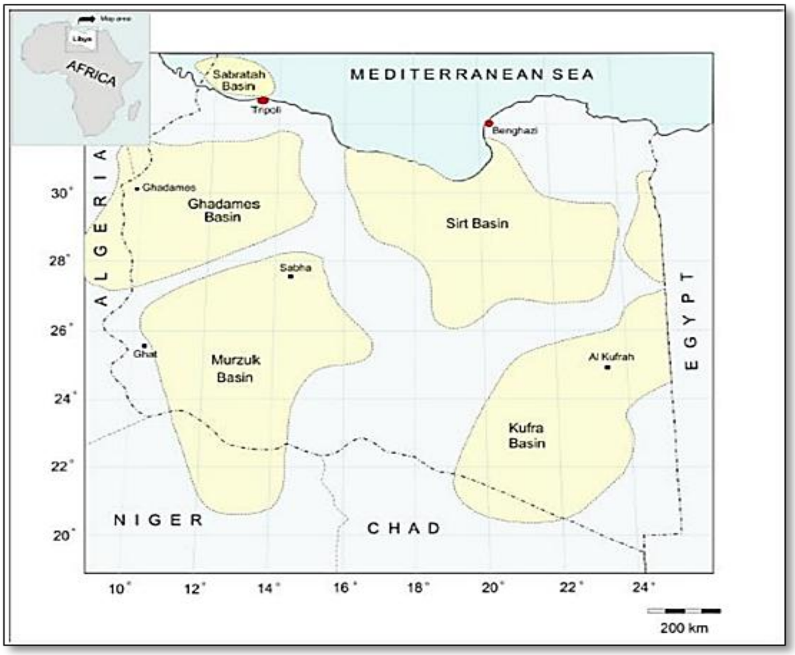

Figure (1). The location map of Sirt Basin (Giuma H. Swei 2010)

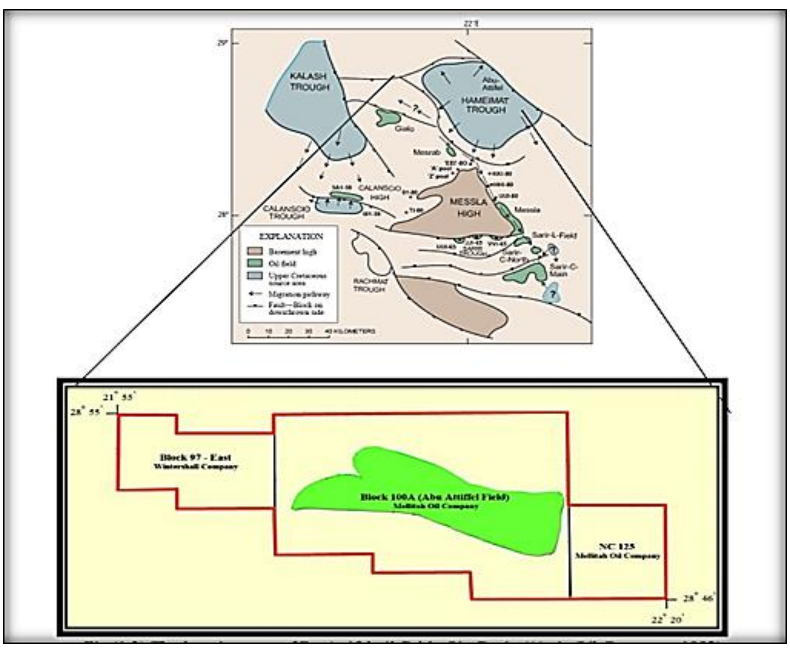

Figure (2). The location map of Bu Attifel oil field - Sirt Basin ((Agip Oil Company, 1982)

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Geological Setting

The Sirt Basin is a rift basin formed during the Early Cretaceous, representing a major extensional event on the North African margin (Figure 3) (Giuma H. Swei, 2010). Its structure is dominated by a series of northwest-southeast trending horsts and grabens, including the Hun Graben, Zallah Trough, and the Zelten Platform, which were instrumental in hydrocarbon entrapment (Barr and Wegger, 1972). The study area, the Bu Attifel field, is situated within a structural high that forms a classic anticlinal fold trap, a common feature in the basin (Agip Oil Company, 1982).

The stratigraphic succession of the Sirt Basin unconformably overlies a Precambrian basement of igneous and metamorphic rocks (Hallet, 2002). The reservoir interval of interest, the Nubian Sandstone Formation, is of Late Jurassic to Early Cretaceous age (Hallet, 2002). This formation consists of poorly to moderately sorted quartzitic sandstones deposited in a fluvial to shallow marine environment during the initial rift phase (Hallet, 2002). It unconformably overlies older Paleozoic or Triassic sediments and is itself overlain by the transgressive marine shales and carbonates of the Upper Cretaceous, including the Sirt Shale and Etel Formation (Barr and Wegger, 1972).

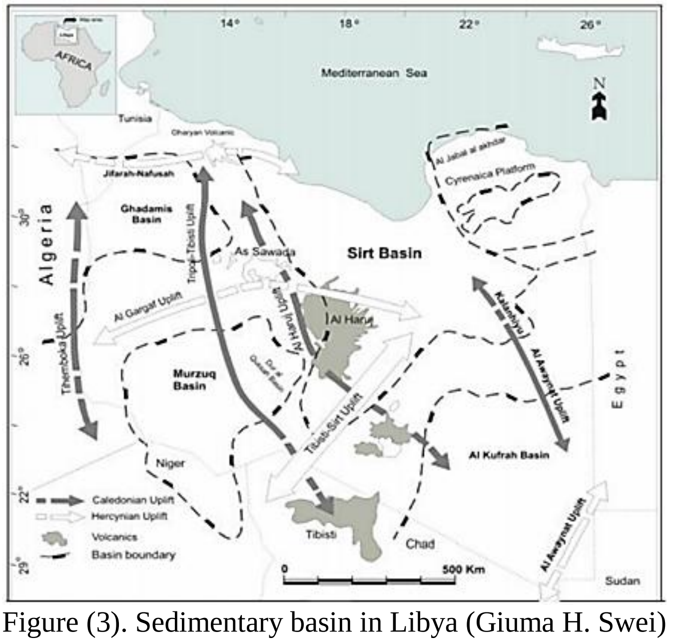

Figure (3). Sedimentary basin in Libya (Giuma H. Swei)

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The Sirt Shale is a prolific source rock across the basin, while the Etel Formation and other interbedded shales act as regional seals (Hallet, 2002). This classic petroleum system configuration—source rock, reservoir rock, and seal—coupled with the structural traps created during rifting, has led to the accumulation of significant hydrocarbon reserves in the Nubian Sandstone and other formations throughout the Sirt Basin (Hallet, 2002).

Methodology

This study employs a comprehensive workflow that integrates petrophysical evaluation and 3D geological modeling. The dataset, provided by Mellitah Oil and Gas Company, includes well log data (Gamma Ray, Neutron, Density, and Resistivity) (Figure 4) and formation tops for four wells: A1-125, A3-125, A4-125, and A88-125.

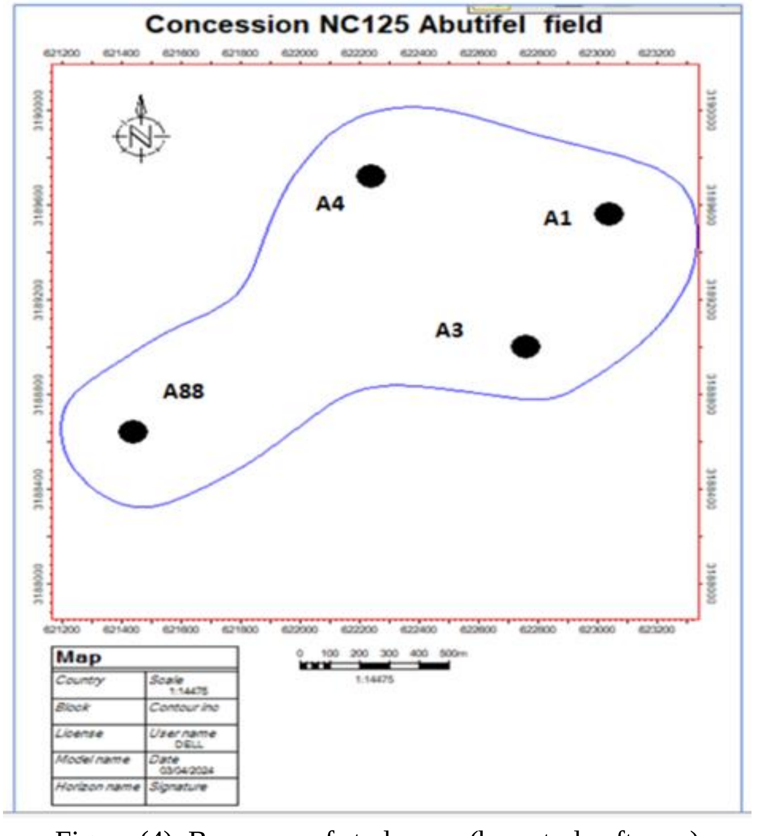

Figure (4). Base map of study area (by petrel software)

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Petrophysical Analysis

Petrophysical evaluation was performed using Techlog software to quantify reservoir properties (Schlumberger, 1997). The Volume of Shale (Vsh) was calculated primarily from the Gamma Ray (GR) log using the Larionov formula for older rocks, which corrects for non-linear clay response (Figure 5) (Schlumberger, 1997). The GR index (IGR) was first determined, and then Vsh was computed.

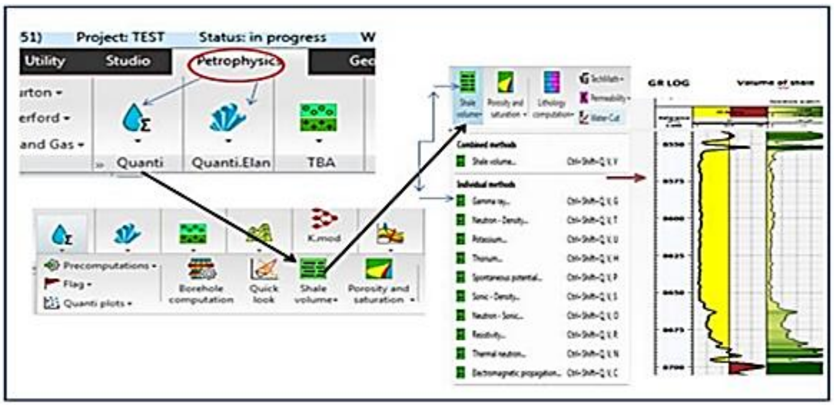

Figure (5). The steps for calculating the volume of shale in Techlog software

Total porosity (φt) was derived by combining the corrected Density (Dc) and Neutron (Nc) porosities (Schlumberger, 1997). The density porosity was calculated using a matrix density of 2.65 g/cm³ and a fluid density of 1.0 g/cm³, then corrected for shale effects. Similarly, neutron porosity was corrected for shale content. The total porosity was then calculated as the root mean square of the corrected density and neutron porosities (Figure 6).

Water Saturation (Sw) was determined using Archie's equation, with assumed parameters of a tortuosity factor (a) of 0.81, a cementation exponent (m) of 2, a saturation exponent (n) of 2, and a formation water resistivity (Rw) of 0.016 Ω.m. (Figure 7) ,Net pay thickness was identified using cut-off values of porosity greater than 9%, water saturation less than 50%, and volume of shale less than 20% (Figure 8).

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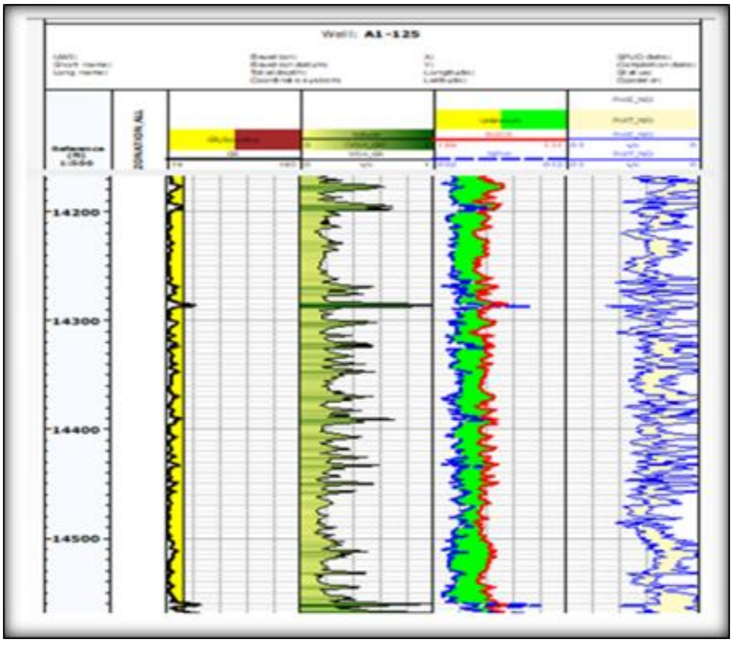

Figure (6). Total and effective porosity in well A1-125

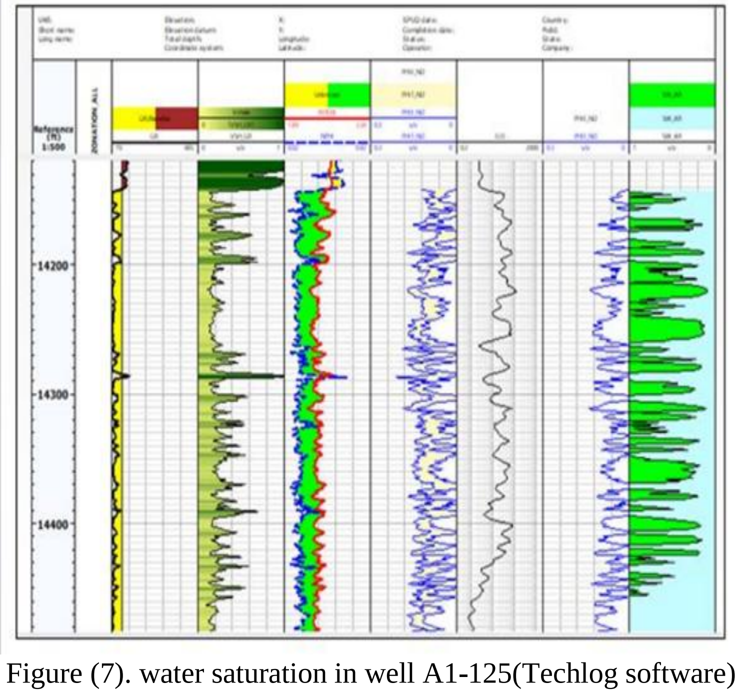

Figure (7). water saturation in well A1-125(Techlog software)

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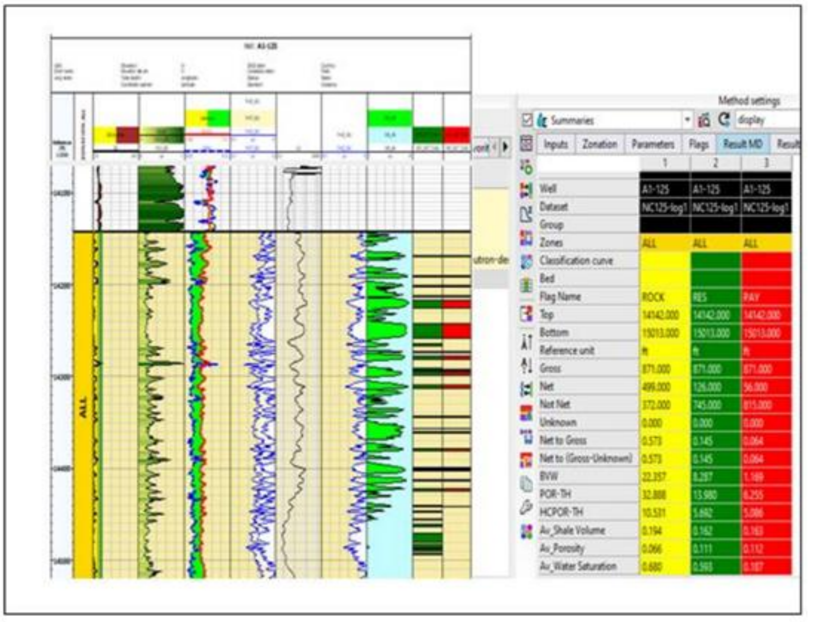

Figure (8). Net pay thickness of the reservoir in well A1-125

3D Geological Modeling

A 3D static model was constructed using Petrel 2017 software to visualize the spatial distribution of reservoir properties (Figure 9). The workflow involved several key steps: first, well data (well heads, formation tops, and upscaled log curves for porosity, Vsh, and Sw) were imported into the project (Figure 10). Second, structural modeling was performed to create the reservoir framework. This involved building a structural grid based on the interpreted top and bottom surfaces of the Nubian Sandstone, defining the anticlinal geometry of the Bu Attifel field.

A 3D grid was then constructed with a cell size of 200m x 200m and vertical layering to capture reservoir heterogeneity(Figure 11) (Figure 12). Finally, petrophysical modeling was carried out using geostatistical algorithms (e.g., sequential Gaussian simulation) to distribute the well log-derived properties (porosity, water saturation, and volume of shale) throughout the 3D grid, generating continuous property models that honor the well data and reflect the geological trends.

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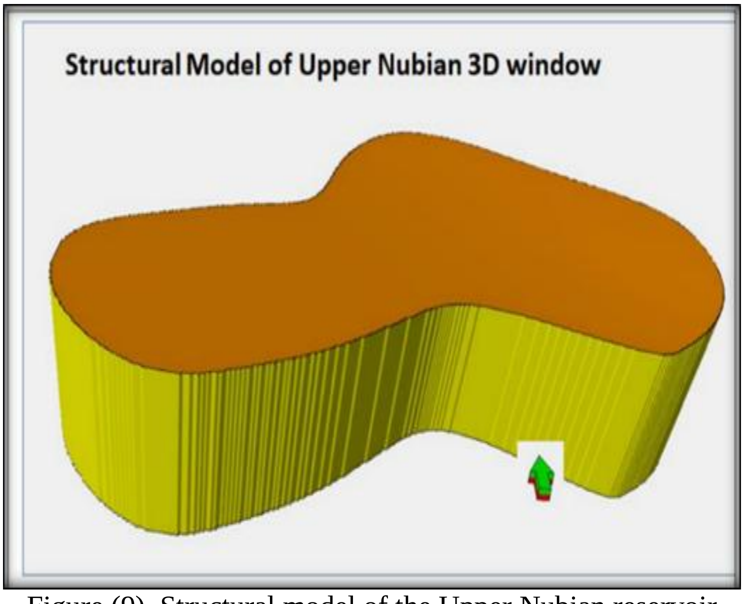

Figure (9). Structural model of the Upper Nubian reservoir

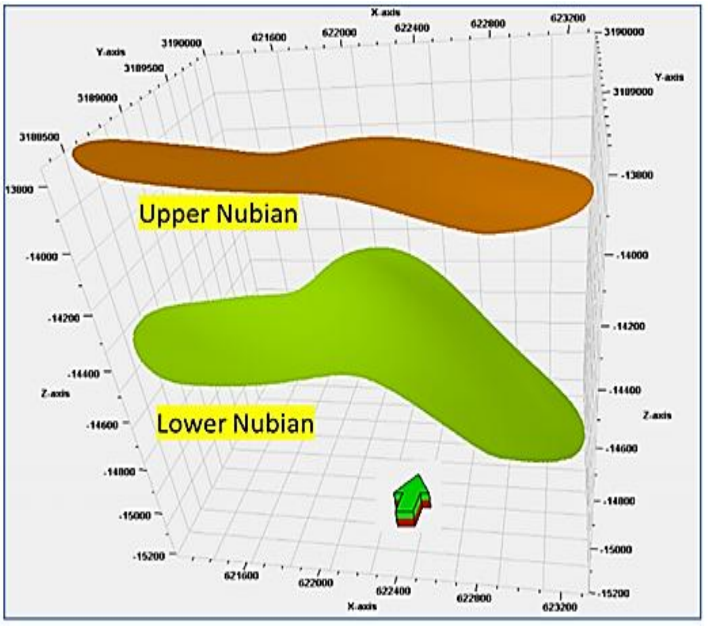

Figure (10). The3D grid skeletons for Nubian Reservoir

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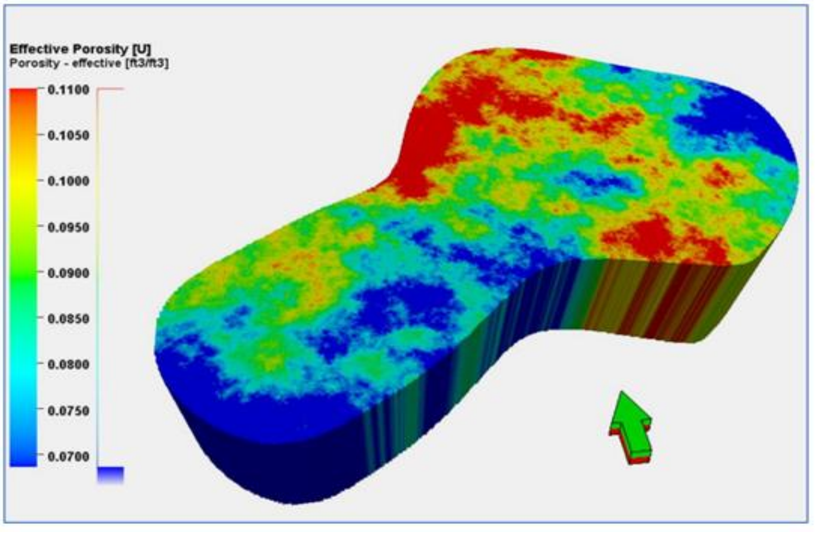

Figure (11). An effective porosity model for zone 1 of the Nubian reservoir

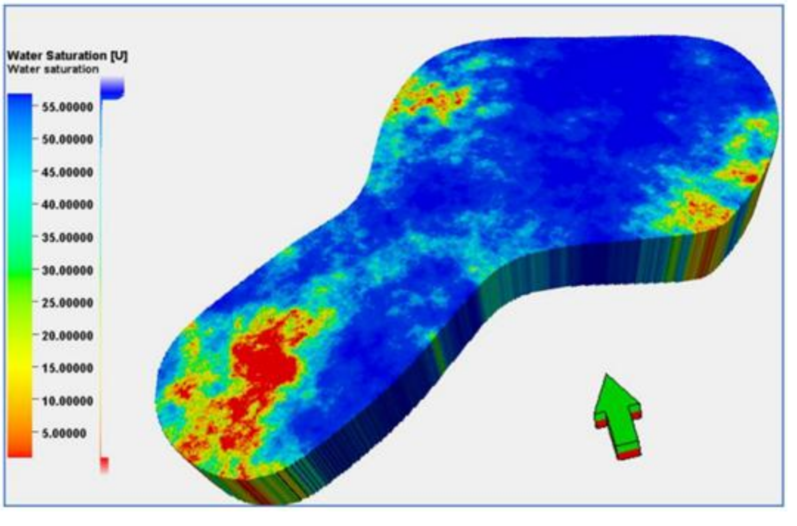

Figure (12). Water saturation models (Petrel software).

Results and Discussion

The integrated petrophysical and 3D modeling approach yielded a detailed characterization of the Nubian Sandstone reservoir in the Bu Attifel field. The results highlight significant lateral and vertical heterogeneity in key reservoir properties.

http://www.doi.org/10.62341/idui5214

Petrophysical Properties

The analysis of well log data revealed distinct variations in reservoir quality across the field. The calculated Volume of Shale (Vsh) was generally low, averaging between 1.2% and 7%, indicating a clean sandstone reservoir with minimal clay content that could impede flow.

The porosity values, as shown in Table 1, ranged from fair to good, with an average of 7% in well A4-125 (northeast) and up to 12% in well A88-125 (southwest). This trend suggests a deterioration in reservoir quality towards the northeast, which is consistent with the depositional model and potential diagenetic effects.

Water saturation (Sw) showed a clear inverse relationship with porosity. As shown in Table 2, average Sw values were lowest in the southwest (36% in well A88-125) and highest in the northeast (60% in well A1-125), which is located closest to the interpreted oil-water contact. The net pay thickness was successfully mapped based on the defined cut-offs, confirming the presence of commercially viable hydrocarbon-bearing intervals in all studied wells, with the thickest net pay associated with the zones of highest porosity and lowest water saturation.

Table 1: Average Volume of Shale and Porosity of the Upper Nubian Sandstone Reservoir:

Well Name	Average Vsh (%)	Average Porosity (%)
A1-125	7.0	10.0
A3-125	4.4	11.0
A4-125	5.2	7.0
A88-125	1.2	12.0

Table 2: Average Water Saturation of the Upper Nubian Sandstone Reservoir:

Well Name	Average Water Saturation (%)
A1-125	60.0
A3-125	41.0
A4-125	37.0
A88-125	36.0

3D Geological Model

The 3D structural model successfully delineated the Bu Attifel field as a four-way dip-closed anticlinal fold, confirming the primary

http://www.doi.org/10.62341/idui5214

trapping mechanism. The structural framework provided the basis for distributing petrophysical properties.
The 3D porosity model visually confirmed the well-log analysis, clearly showing a high-porosity corridor (greater than 11%) trending from the southwest to the central part of the field. The water saturation model corroborated this, with low saturation zones (less than 40%) coinciding with the high-porosity areas.
The model of shale volume showed a generally clean reservoir, with minor increases in shale content in the northeastern periphery. The integration of these models led to the identification of two distinct zones, labeled A and B, located in the southwestern and central parts of the concession. These zones exhibit the most favorable combination of high porosity, low water saturation, and low shale volume, making them prime candidates for infill drilling, workover opportunities, and further exploration activities to target untapped hydrocarbon resources.

Conclusions

The study successfully achieved its objective of characterizing the Nubian Sandstone reservoir in the Bu Attifel oil field through integrated petrophysical analysis and 3D geological modeling. The most important findings are:
The Nubian Sandstone reservoir in the Bu Attifel field is a structurally trapped, high-quality anticlinal accumulation with fair to good reservoir properties.
Petrophysical analysis reveals a clear trend of decreasing reservoir quality from southwest to northeast, with porosity values ranging from 12% to 7% and water saturation increasing from 36% to 65% along this trend.
The constructed 3D static model provides a robust representation of the reservoir's structural framework and property distribution, effectively capturing its heterogeneity.
The model identified two specific zones (A & B) in the southwestern and central parts of the field that possess the most favorable petrophysical characteristics (high porosity, low water saturation) and are recommended as high-priority targets for future development and exploration.
Future studies should focus on integrating dynamic data (e.g., pressure and production history) into the model for history matching

http://www.doi.org/10.62341/idui5214

and to predict future reservoir performance under different production scenarios.

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