DJS Vol. 46(2) (2023) –pp. 17-33 ISSN: 1012-5965

Delta Journal of Science

Available online at

https://djs.journals.ekb.eg/

Research Article

GEOLOGY

Petrophysical Modeling of Lower Rudeis Sandstone in Shukheir Bay Field, Gulf of Suez, Egypt

Mohammed M. Abdel Wahid[1], Hassan Hassan El-Kadi[1], and Mohammed M. Othman[2]*

[1]Geology Department, Faculty of Science, Al Azhar University, Nasr City, Cairo, Egypt.

[2] Amal Petroleum Company, Nasr City, Cairo, Egypt

Corresponding author: *Mohammed M. Abdel Wahid* *e-mail:* dmohammed@azhar.edu.eg

Received: 3/ 1/2023 **Accepted:** 6/4/2023

KEY WORDS

Property Modeling, Petrophysics, Porosity, Saturation, Well-log Analysis, Shukheir Bay Field, Gulf of Suez.

ABSTRACT

Shukheir Bay Field is part of the Shukheir Marine Concession located in the northern part of the Gulf of Suez. It occupies a total area of 22.5 Km^2. The main reservoir in the Shukheir Bay field is the Rudeis sands of Miocene age, however this study focuses on the lower clastic unit in the formation that usually referred to as Lower Rudeis Sandstone. The petrophysical evaluation of this sand zone was conducted using a complete set of open- hole well-logs in the available wells. The lithologic composition is identified as sand intercalated with shale. Seismic interpretation was deduced to determine the structural geometry for detecting the best localities for drilling developmental wells in the study area. The top and bottom surfaces of Lower Rudeis Sandstone were identified and traced in the whole area of Shukheir Bay Field. Depth structural contour map was constructed and the major faults were detected. 3D static model, using seismic and well log data has been done for proper optimization and development of hydrocarbon potential in Shukheir Bay Field. Seismic data were used to generate the input interpreted horizon grids and fault modeling. Petrophysical parameters (effective porosity, shale volume and hydrocarbon saturation) were distributed and mapped within the constructed 3D grid, using deterministic Kriging algorithms, while facies were distributed and mapped by deterministic facies modeling method. By integrating the results of all available data sets, this study recommends to drill development wells in the central part of the study area.

Introduction

Among the varies studies focused on the petroleum potentialities of the Gulf of Suez, it was hard to find ones that studied in detail the hydrocarbon potentiality in Shukheir Bay field. However, in 1970, the General Petroleum Company ran an exploration programme, where more than 15 wells were drilled along the whole Shukheir Concession **(Ibrahim, M. 1988)**. Starting with Shukheir Bay-l (SHB-1) well where the main targets were the Miocene Belayim and Lower Rudeis Sandstones. However, 94 ft of the Miocene Rudeis Formation were found to be oil bearing. Since then, the exploration efforts have continued but in a very slow rate.

Location of the Study Area

The Gulf of Suez has been the principle petroliferous province in Egypt. It was saving the main energy supply for the country and is still challenging the petroleum companies **(Mostafa *et al*., 2015)**. The gulf itself is about 300 km long. The width reaches about 50 km at its northern end, and about 90 km at its conjunction with the Red Sea **(Robson, 1971) .**

Shukheir Marine Concession is located towards the south of the Gulf where Shukheir Bay Field can be found at the northern part of that concession. It's represented by a shallow offshore water area that covers about 22.5 km^2 (Fig. 1) .

Geologic Setting

The Gulf basin represents a failed rift-system resulted from the relative movements of the African and Arabian plates. As evidenced by the volcanics of Abu Zenima Formation, the rift initiation was in the Late Oligocene, and according to **Dolson *et al*., (2001)**, several unconformities interrupted the sedimentary record as a response to regional tectonic adjustments associated with the different rift phases. Figure (2) summarizes the tectonic factors that affected the Gulf of Suez. Crustal extension and tectonic subsidence of the Gulf's axial trough reached a maximum during the Early Miocene **(Schütz, 1994)**, when the syn-rift Rudeis Formation was deposited. The shoulders of the basin may have risen in the Oligocene and Early Miocene due to thermal effects **(Steckler, 1985)**. **Moretti *et al*., (1986)** concluded that the rift shoulders were formed as a result of advection in the asthenosphere away from the center of the rift combined with regional stretching of the lithosphere. By Middle Miocene (ca. 15 Ma) strike-slip movements began along the Aqaba-Dead Sea Fault System and the Gulf became less active if not inactive as a spreading center center **(Abdel Gawad 1970a, b; Bartov *et al*., 1980)**.

Younes and McClay (2002), Meshref *et al*., (1976) and Moustafa (1996, 1998) concluded that the structural setting of the Gulf is mainly governed by a pattern of complex faulting with two main trends; the Clysmic NW fault trend, and the NE Aqaba trend. The interactions of those trends resulted in a pattern of enechelon faulted blocks. However, the Gulf basin is generally subdivided into three provinces detached by two accommodation zones (Fig. 3); Wadi Araba Province dipping southwest ، Zaafarana Hinge Zone ، Belayim Province dipping northeast, El Morgan Hinge Zone and Amal Province dipping southwest.

The lithostratigraphy in the study area aged from Precambrian to Holocene, and has been divided into three main successions relative to the Miocene rifting, defined as the pre-rift, syn-rift and post-rift successions. These lithostratigraphic units vary in thickness and other facies attributes along the Gulf of Suez. The stratigraphic sequence for Shukheir Bay field is a normal central stratigraphic succession that shows the three major depositional and tectonic stages. Generally, this sequence is described here below in terms of Miocene and Pre-Miocene. The Miocene is unconformably overlained by thin Pliocene - Recent deposits **(Ibrahim, 1988).**

Aim of the Present Study

The main target of this study is to integrate well-log and seismic data to evaluate the clastic part within the Lower Rudeis Formation that may help for diagnosing, analyzing and mitigating the rapid production declination. As well as, locating exploratory drilling opportunities on the Shukheir Bay field, and reduce financial losses by proposing an exploration and development directions for the field.

Materials and Methods

The data authorized and acquired for this study includes:

Seismic Data: Thirty seismic lines were used to reveal and understand the regional structural features affecting the area of interest.

Well-log Data: Logs from four wells were used to evaluate the reservoir parameters. This utilized different types of open-hole well logs for the determination of the included petrophysical parameters (Fig. 4).

Several methods were used to determine the shale content, where the shale volume is important for the correction of the porosity and water saturation values from the effect of shaliness. The porosities were determined using the available porosity tools such as sonic, density and neutron. These porosities were corrected for the effect of shaliness, and then were discriminated into total and effective porosities.

The water saturation models were chosen according to the prevailed shale model. For the clean rocks, Archie's formula was used to calculate the water saturation, while Simandoux equation was used for the shaly formation. These reservoir parameters of Miocene clastics were integrated with the geological modal to show the distribution of these parameters.

Results and Discussion

The seismic reflection and petrophysical interpretations are the focus of this study. The geophysical interpretation was carried out, in parallel, with the petrophysical evaluation, as described in the following paragraphs. Before going in details, the stratigraphic units of the study area are introduced in (Fig. 2).

Seismic to Well Tie

Seismic to Well tie is an essential step in the seismic interpretation process. It relates wellbore data measured in depth with seismic data measured in time. A depth-time relationship is conducted through the slowness function measured at a borehole. According to **Tearpock and Bischke (2003)**, once the well position is annotated, the information from the well data, in the form of geologic tops, must be located and marked on the time sections or loaded into the computer and annotated on the profile (Fig. 5).

Horizon Interpretation

Cannon, (2018) defined the seismic horizon as a set of free points/lines in time that are effectively continuous over large parts of the area of interest. After completing the depth-time conversion, the well-to-seismic tie step has led to define the horizons of interest in the seismic sections. The tops of these horizons were traced and picked in the acquired seismic sections .
Figure (6) shows an example of a picked Lower Rudeis Sandstone horizon.

Fault Interpretation

Picking horizons and interpreting faults are two cooperative processes. However, the following points have been considered during the fault interpretation process:

- Fault planes are interpreted over the same intervals as the horizon interpretations. The planes must be interpreted to their vertical extension and this should be done over the entire fault length.

- Each fault named separately and must be traceable throughout the whole modeling process .
- Fault cut-off lines are used for areas near faults that may be hard to interpret; in complex faulted areas. This can be achieved by linking fault/horizon contact points along fault strike to produce a polygon.
- Also, faults should be given unique names that can be used and referred to in the rest of the modeling process.

Figure (7) displays a structure map where we can clearly distinguish a series of NE-SW trending normal faults affected the tracked horizons. Most of these faults following the Clysmic trend and forming a series of step faults. However, with the presence of other faults trending the opposite direction (Aqaba trend), forming a structure-high block which represents the main reservoir in the study area.

Depth-Structure Map

The data retrieved from both horizon and fault interpretations is used to construct a depth-structure map for the horizon of interest to illustrate and better visualize the structure affecting the area of interest (Fig. 7).

3D Structural Cross-Sections

The majority of reservoir-modeling software programs have different approaches for building a structure model, but almost all of them require the same input of faults and surfaces. However, and as referred, the Petrel software has been used to construct the model in this study. The structural model is built from the depth-converted seismic horizons and fault data, generating a reservoir framework. This is combined with the internal reservoir layering that incorporates the stratigraphic component of the model.

The resulted 3D model comprises both the fault modeled pillar grids and the horizon surfaces, and will be used to identify the proper structure affecting the reservoir.

Facies Modeling

The main reason to build a facies model is to condition the subsequent property model; each facies should have porosity and permeability distribution that is different from the other facies. This could be as simple as good sands, moderate sands and poor sands. If the reservoir quality can be attributed to specific geological bodies or environments, then representative heterogeneity can be introduced into the model. However, before the well data can be used for modeling, it must be scaled up to the vertical resolution of the 3D grid; this applies to both facies and property data.

For facies modeling, Gamma Ray Logs were used as the main discriminators to classify Lower Rudeis Formation into sand and shale levels (Fig. 8). The upscaled facies logs were distributed all over the studied area to create a three-dimensional facies model to incorporate the reservoir heterogeneity represented by the sedimentary geology into the architecture of the geo-cellular grid (Fig. 9).

Four cross-sections were extracted at different directions from the facies model to study the distribution of sand levels in the study area (Fig. 10).

Porosity Modeling

The primary purpose of a 3D property model is to improve the understanding of hydrocarbon distribution-related parameters .

The process of porosity modeling starts with the usual log-data upscaling. The results may be averaged biased to the facies by a weighting approach; this has the effect of smoothing the outcome for all the cells in the well but gives a more representative range for a given facies. Figure (11) displays the upscaled porosity data. Figure (12) also displays the constructed modal, while a number of cross-sections constructed to clarify the distribution of such property in the study area are displayed in Fig. (13).

Saturation Modeling

A log-derived water saturation is another continuous property in a well that is a function of the pore volume. It is a preservative property that can be upscaled using a summation approach like porosity. However, water saturation in the reservoir should be modeled using a saturation height function derived from logs and core analysis data, but the absence of core data in this study has led to a total consistency on the log-derived saturation estimations. Figure (14) displays the upscaled saturation data; and Figure (15) displays intersections taken along that model to track the distribution of such a property.

Discussion

The constructed 3D static modal as well as the distribution maps and the lithosaturation plots are representing a database to track the lateral and the vertical changes in the petrophysical parameters. The sandstone interval referred to as the Lower Rudeis Sandstone is found to be the most prolific and important section in the studied wells and thus is determined as the main target for this study. The Lower Rudeis Sandstone represents a good reservoir with shale volume ranging between 6 and 12%, good effective porosity varying from 18 to 21% and high oil saturation varying from 76 to

94%. Both the lateral and vertical distributions of the petrophysical parameters are presented. The distribution is achieved through the 3D model.

Based on hydrocarbon distribution exhibited from the saturation plots and the iso-parametric maps, the hydrocarbon potentialities of the studied area can be outlined in the following points:

- The hydrocarbon occurrence is represented by the structure- high within the Lower Rudeis Sandstone.
- The observed coincidence between the porosity high and the structural high may be related to post-depositional erosion. Thus, further development efforts that may include the drilling of development wells is highly recommended and would possibly lead to an increment in the production rate for that area.
- The movable hydrocarbon saturation maps show an increase in the central and southwestern direction within the Lower Rudeis Sandstone section of the Rudeis Formation in the studied area.
- Hydrocarbon deficiency at the eastern side may be due to a westward migration from the main basin due to the westward built highly blocks. This urges us to encourage further exploration efforts towards the western part of the studied area for the different possible reservoir layers including Hammam Faraun Mbr., Karim Fm., and Rudeis Fm.

Conclusion

The sand interval of the Lower Rudeis Formation, referred to as Lower Rudeis Sandstone, has been identified and evaluated. This sand interval is found to be an oil reservoir. Based on the evaluation processes and the resulted plots, it’s recommended to drill new development wells in the central and the southeastern parts of the area. We also recommend extending the vicinity of exploration for the study area to include other levels in the Miocene section in Shukheir Bay area.

References

Abdel Gawad, M., (1970a). The Gulf of Suez, a brief review of stratigraphic and structure. Philosophical Transactions Royal Society, London 267 (A), 41-48 .

Abdel Gawad, M., (1970b). Interpretation of satellite photographs of the Red Sea and Gulf of Aden. Philosophical Transactions Royal Society, London 267(A), 23-48.

Bartov, Y., Z. Lewy, G. Streinitz and I.M. Zak, (1980). Mesozoic and Tertiary stratigraphy, paleogeography and structural history of Gebel Arief En Naqa area. *Israel J. Earth Sci.,* 29: 114-139.

Cannon S., (2018), Reservoir Modelling: A Practical Guide. John Wiley & Sons Ltd. Print ISBN: 9781119313465

Dolson, J.C., M.V. Shann, S. Matbouly, C. Harwood, R. Rashed and H. Hammouda, (2001). The petroleum potential of Egypt. In M.W. Downey, J.C. Threet and W.A. Morgan (Eds.), Petroleum provinces of the twenty-first century. *Amer. Assoc. Petro. Geol. Memoir*, 74: 453-482.

Egyptian General Petroleum Corporation (EGPC), (1996). Gulf of Suez oil fields (A comprehensive overview). EGPC, Cairo, Egypt, 736 p.

Farhoud Kh., (2009). Accommodation zones and tectono-stratigraphy of the Gulf of Suez, Egypt: A contribution from aeromagnetic analysis. *Geo-Arabia*, 14(4): 139-162.

Ibrahim, M., (1988). Stratigraphy and Structural Setting of Shukheir area, Egypt. 9^{th} Pet Explor Product Conf, EGPC, Cairo, Egypt, Nov, 1988.

Meshref, W.M., E.M. Refai and S.H. Abdel Baki, (1976). Structural interpretation of the Gulf of Suez and its oil potentialities. 5th Egyptian General Petroleum Corporation Exploration Seminar, Cairo, 21 p.

Moretti, I. and P.Y. Chénet, (1986). The evolution of the Suez rift: A combination of stretching and secondary convection. *Tectonophysics*, 133: 229-234.

Moustafa, A.R., (1996). Internal structure and deformation of an accommodation zone in the northern part of the Suez rift . *J. Structural Geol*., 18: 93-107.

Moustafa, A.R., (1998). Gebel Surf El Dara accommodation zone, southwestern part of the Suez rift. Middle East Research Center, Ain Shams University, *Earth Sci. Series*, 2: 227-239.

Mostafa, A., Sehim, A. and Yousef, M., (2015). Unlocking Subtle Hydrocarbon Plays Through 3D Seismic and Well Control: A Case Study from West Gebel El Zeit District, Southwest Gulf of Suez, Egypt. In Offshore Mediterranean Conference and Exhibition, Jun.2009.

Patton, R.J., Chen, J. and Siew, T.M., (1994), March. Fault diagnosis in nonlinear dynamic systems via neural networks. In IEE Conference Publication (pp. 1346-1346). Institution of Electrical Engineers.

Robson, D.A., (1971). The structure of the Gulf of Suez (clysmic) rift with special reference to the eastern side. *J. the Geol. Soc.*, London, 127: 247-277.

Schütz, K.I., (1994). Structure and stratigraphy of the Gulf of Suez, Egypt. In S.M. London (Ed.), Interior Rift Basins. *AAPG Memoir*. 59: 57-96.

Steckler, M.S., (1985). Uplift and the extension of the Gulf of Suez: Indication of induced mantle convection. *Nature*, 317: 135-139.

Tearpock, D. J. and Bischke, R. E., (2003). "Applied Subsurface Geological Mapping", Pearson Education, inc. Publishing as Prentice Hall PTR, New Jersey 07458, 822 P.

Younes, A.I., and McClay, K.R., (2002). Development of Accommodation Zones in the Gulf of Suez-Red Sea Rift, Egypt. *AAPG Bulletin.* 86(6): 1007-1010.

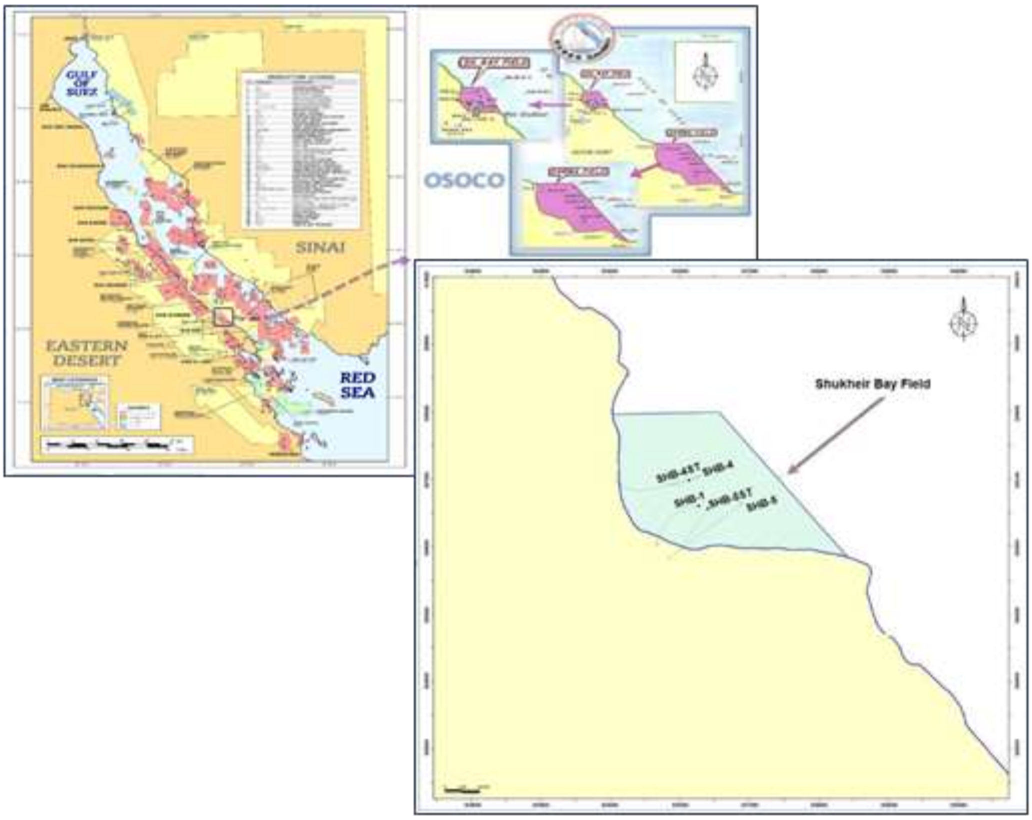

Fig. (1): Base map for the study area (after OSOCO Oil Company).

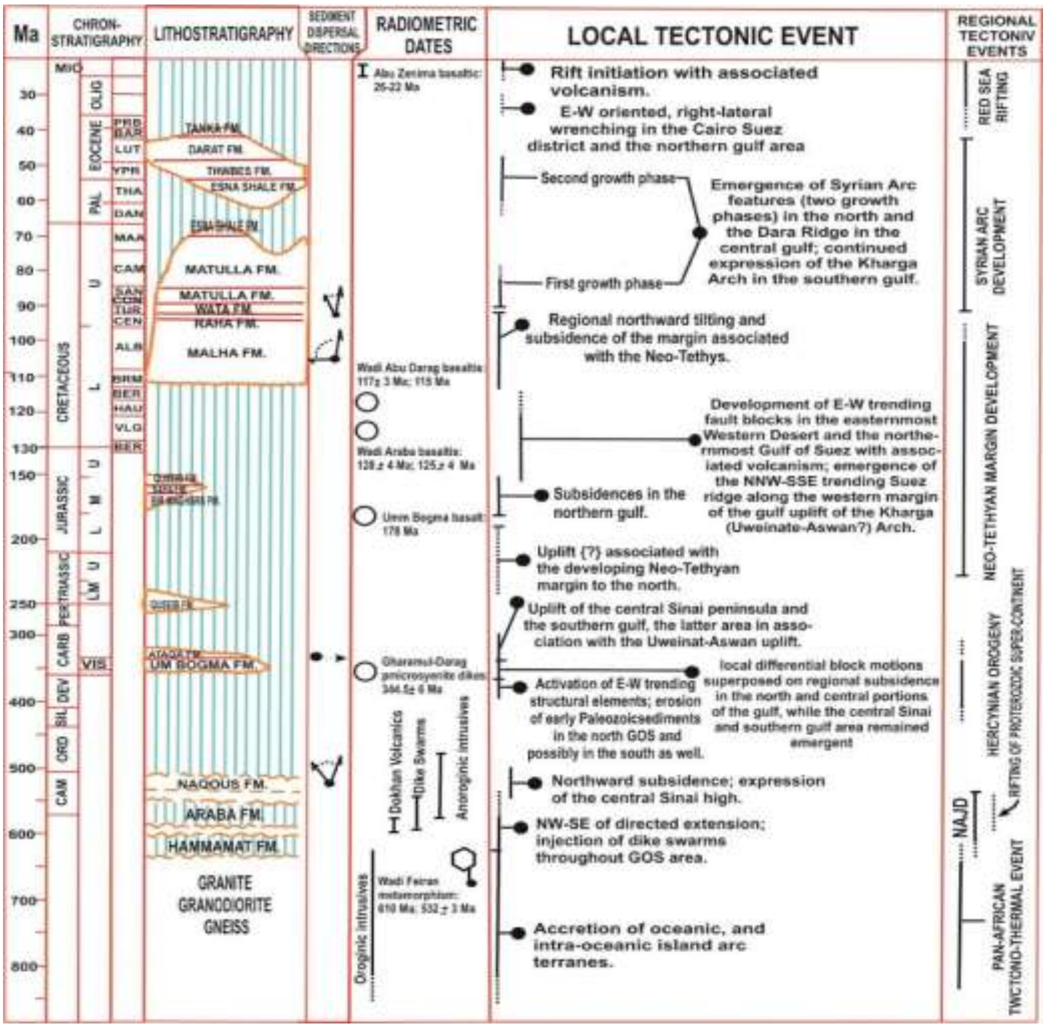

Fig. (2): Pre-Miocene, Tectonostratigraphic Events of the Gulf of Suez after (Patton *et al*., 1994).

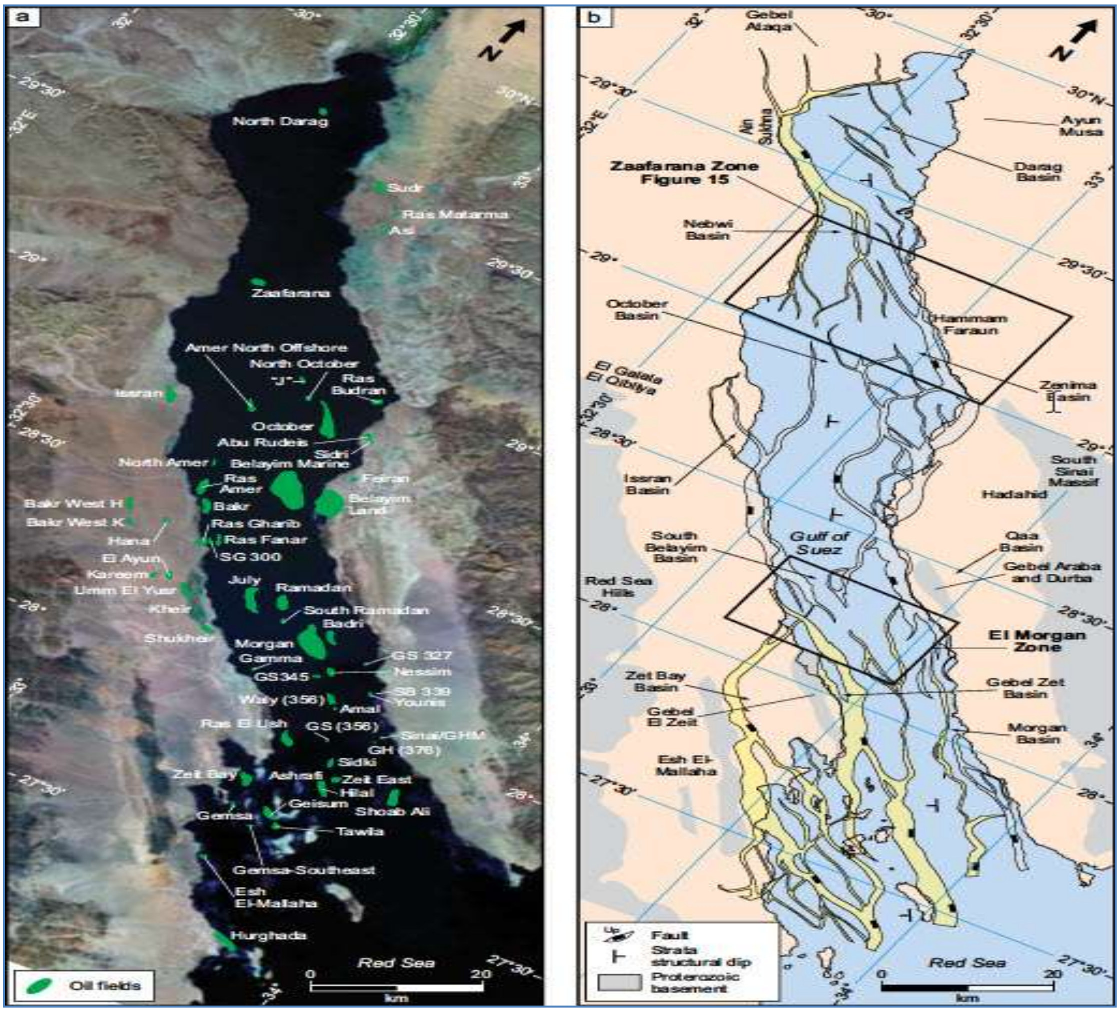

Fig. (3): (a) Landsat Thematic Mapper Image Showing the Basement Outcrops and Oil Fields Around the Gulf of Suez Region (After Farhoud Kh., 2009). **(b)** Basins and Major Faults in the Gulf (modified after EGPC, 1996; Younes and McClay, 2002).

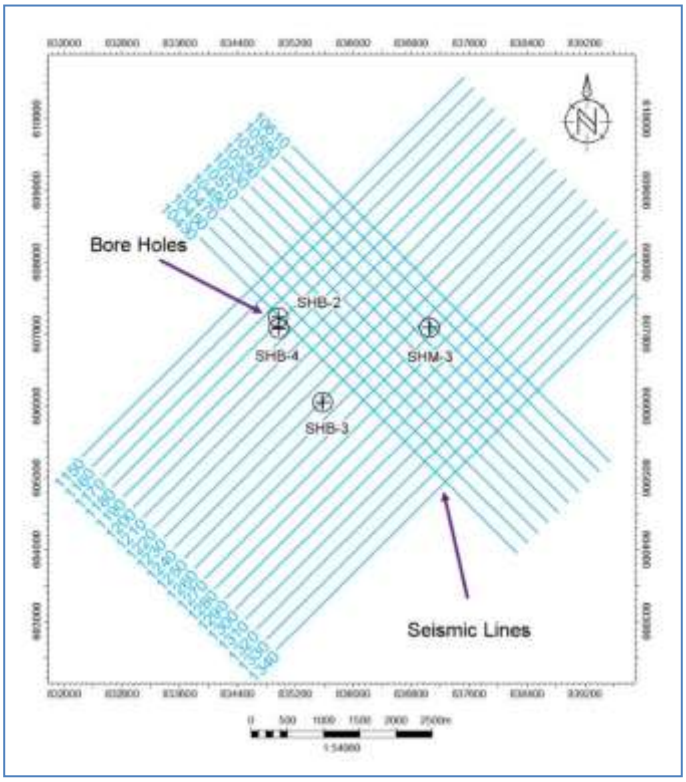

Fig. (4): Location Map for the Available Datasets

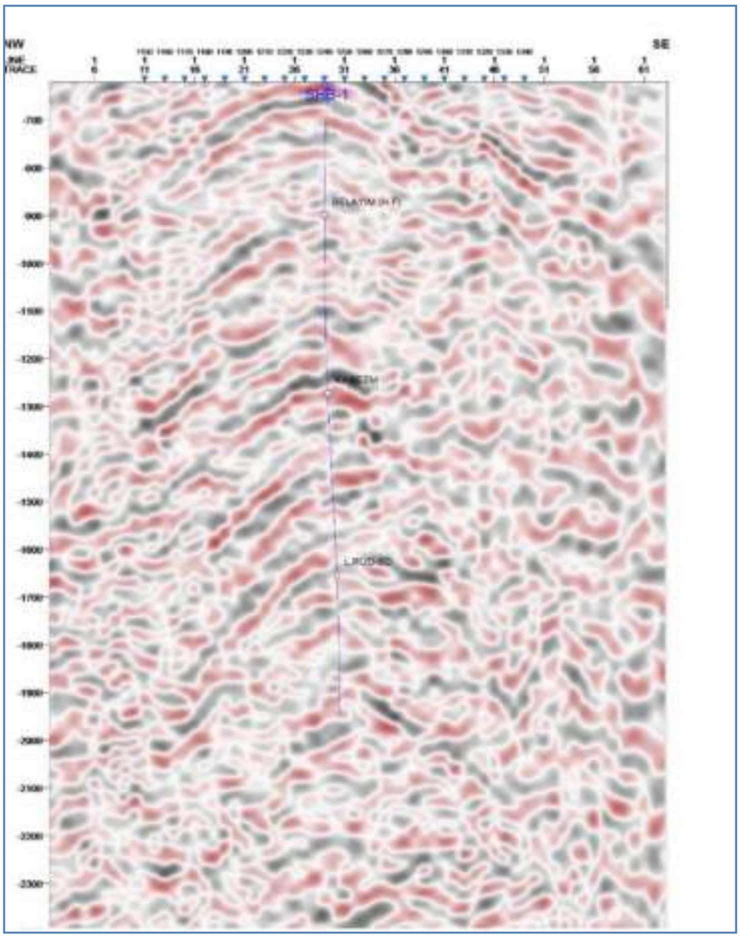

Fig. (5): A Seismic Section Tied to a Well

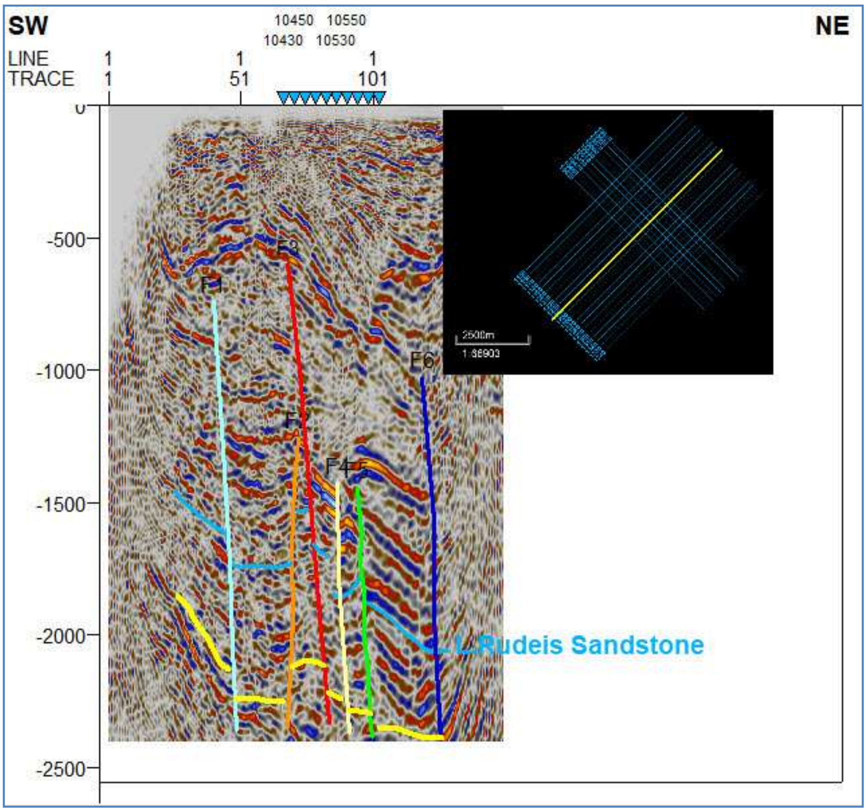

Fig. (6): A Seismic Section Shows the Picked Lower Rudeis Sandstone Horizon

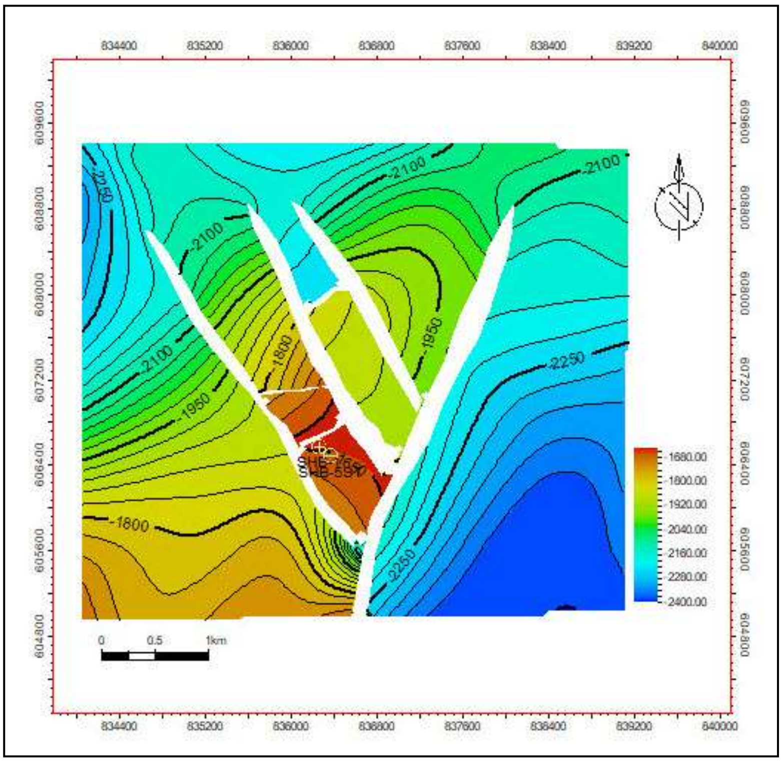

Fig. (7): Depth-Structure Contour Map for the Lower Rudeis Sandstone

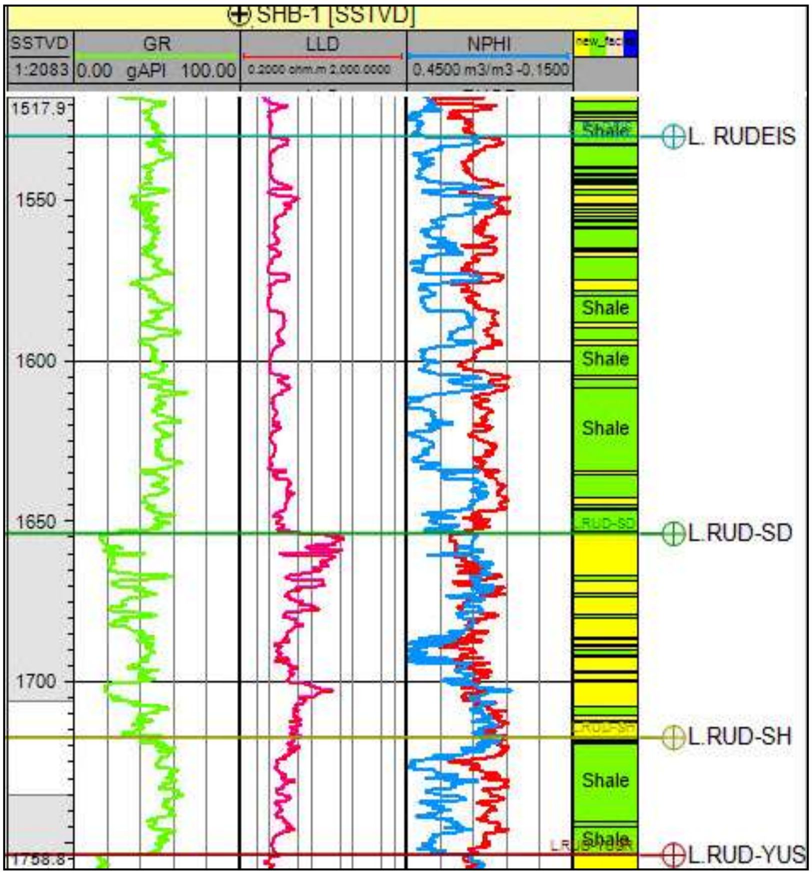

Fig. (8): Upscaled Facies Log in Well SHB-1

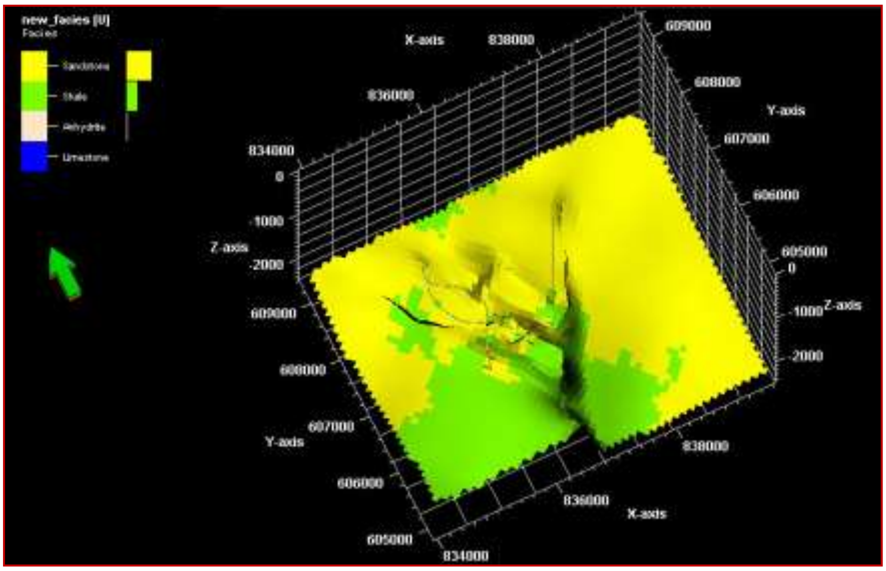

Fig. (9): Lower Rudeis Sandstone Facies Model for the Study Area

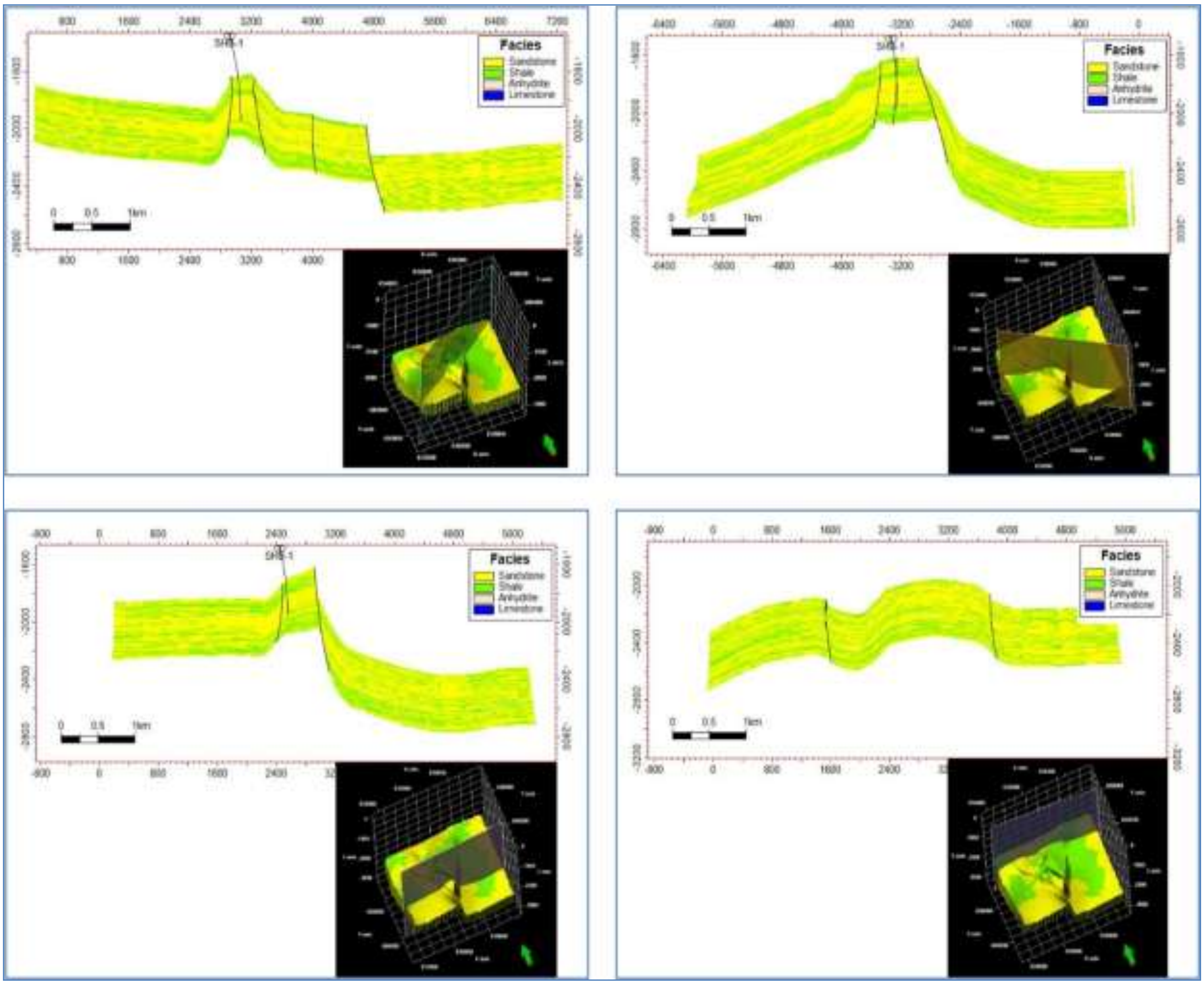

Fig. (10): Four Cross Sections Along the Facies Model for the Lower Rudeis Sandstone

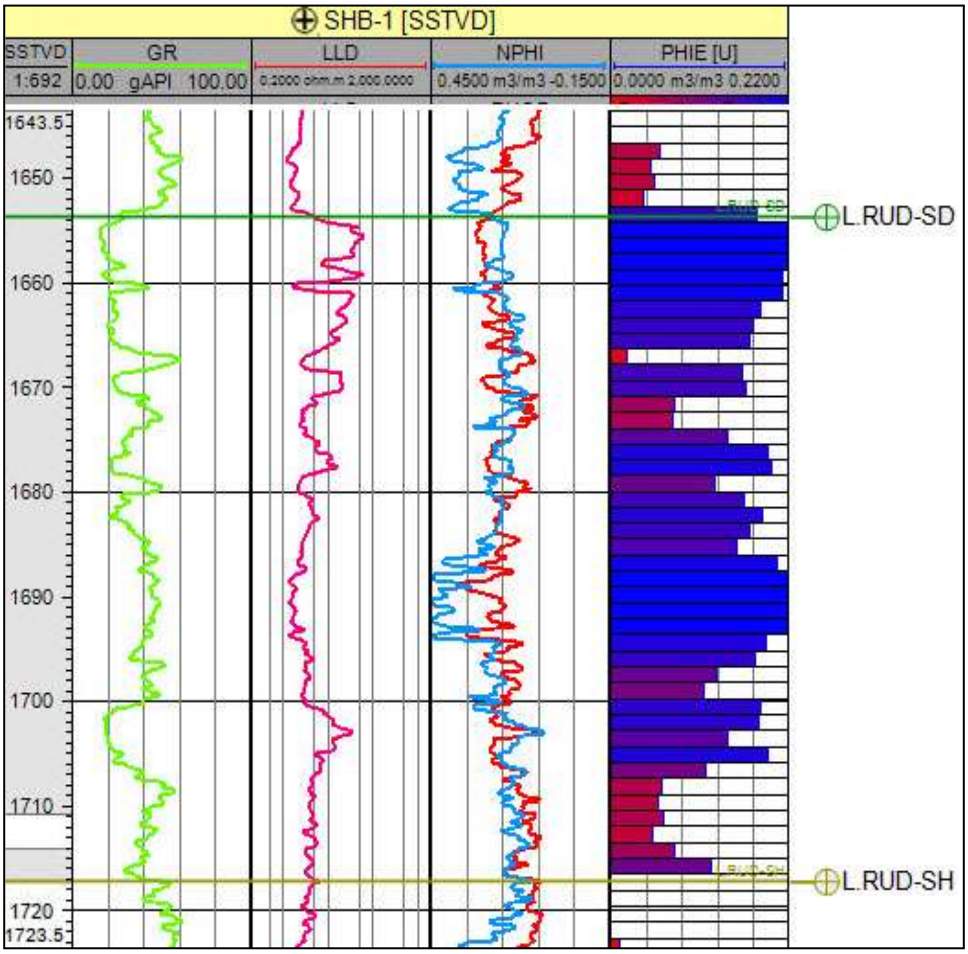

Fig. (11): Porosity Discrimination Log in Well SHB-1

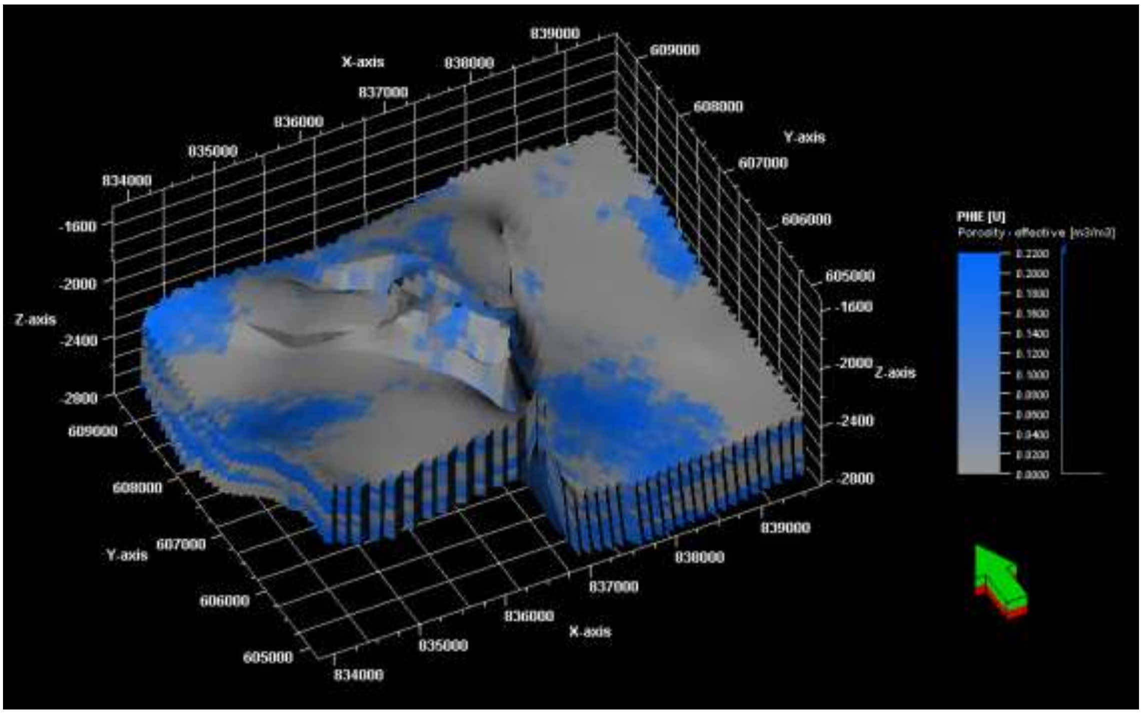

Fig. (12): Porosity Model for Lower Rudeis Sandstone in the Study Area

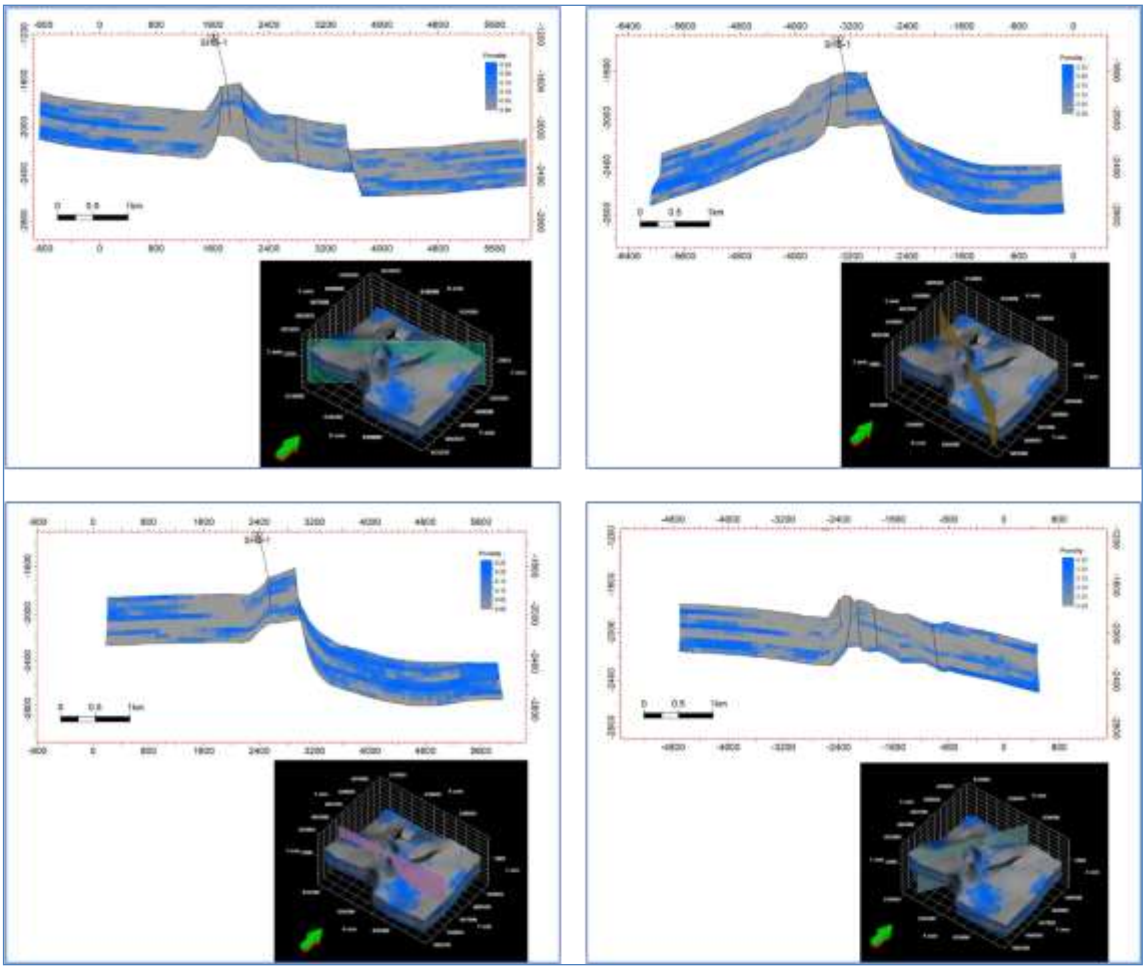

Fig. (13): Cross Sections Along the Porosity Model for Lower Rudeis Formation

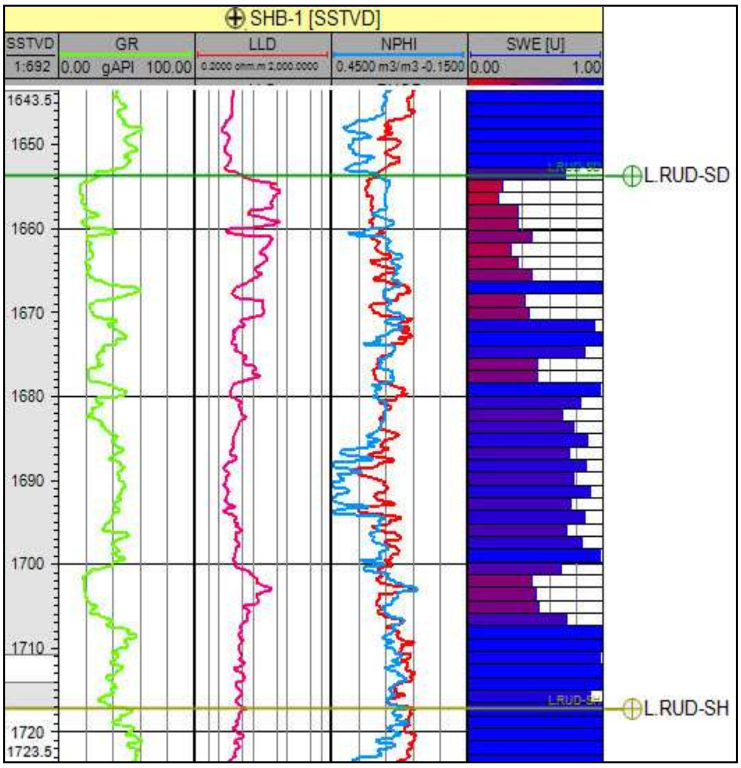

Fig. (14): Saturation Discrimination Log in Well SHB-1

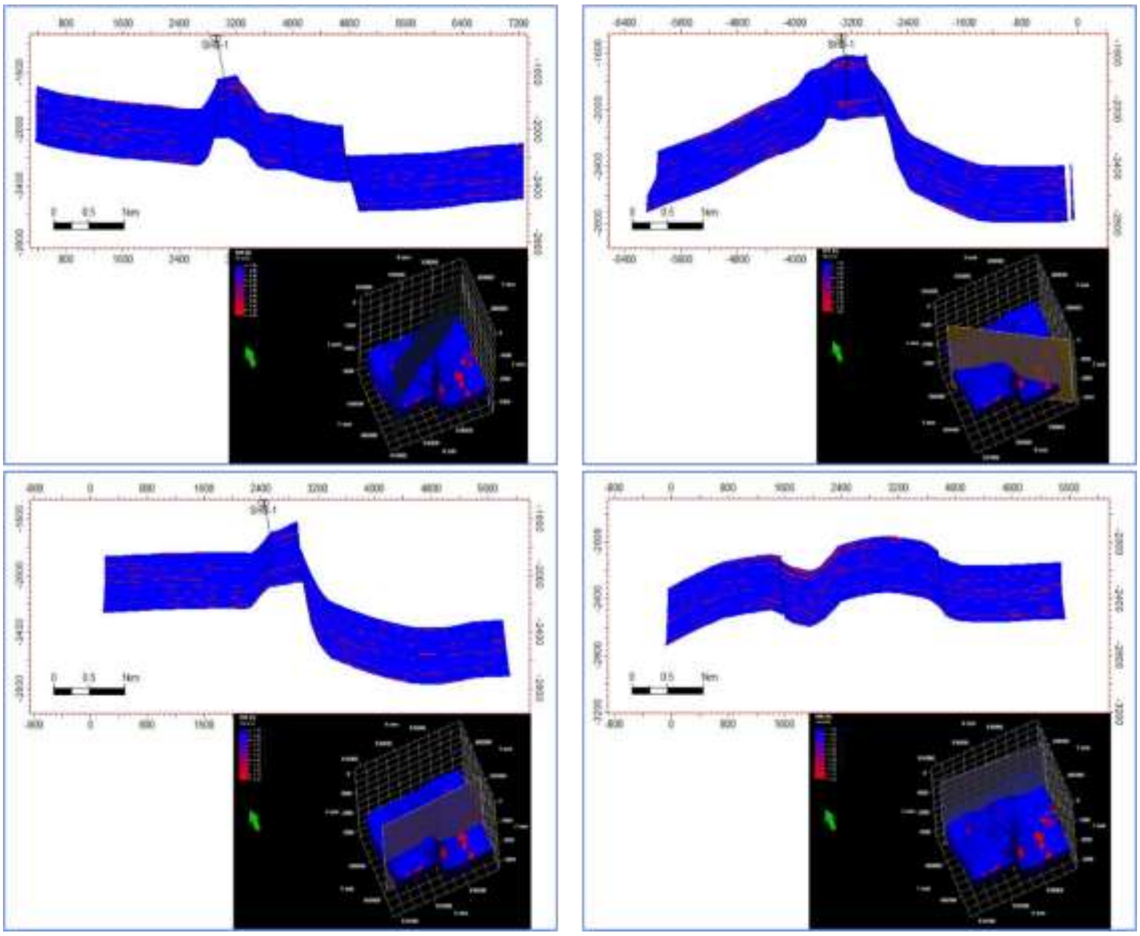

Fig. (15): Intersections Along the Saturation Model in Lower Rudeis Sandstone

النمذجة البتروفيزيائية لحجر روديس السفلي الرملي في حقل خليج شقير ، خليج السويس ، مصر

محمد محمود عبد الواحد[١]، أ.د/ حسن حسن القاضي[١]، د. محمد محمود عثمان[٢]

١- قسم الجيولوجيا – كلية العلوم – جامعة الأزهر – القاهرة – مصر
٢- شركة أمل للبترول – مدينة نصر – القاهرة – مصر

حقل خليج شقير هو جزء من امتياز شقير البحري الواقع في الجزء الشمالي من خليج السويس. تشغل مساحة إجمالية قدرها ٢٢.٥ كيلومتر مربع. الخزان الرئيسي في حقل خليج شقير هو رمال روديس من العصر الميوسيني ، ومع ذلك تركز هذه الدراسة على الوحدة الرملية السفلية في التكوين الذي يُشار إليه عادةً بالحجر الرملي السفلي. يتم إجراء التقييم البتروفيزيائي لهذه المنطقة الرملية باستخدام مجموعة كاملة من جذوع الآبار المفتوحة في الآبار المتاحة. تم تحديد التركيب الصخري على أنه رمل مقحم مع الصخر الزيتي. تم استنتاج التفسير الزلزالي لتوضيح سمة هيكلية مفصلة ولتحديد الهندسة الإنشائية لكشف أفضل المواقع لحفر الآبار التنموية في منطقة الدراسة. تم تحديد وتتبع الأسطح العلوية والسفلية من الحجر الرملي السفلي في منطقة حقل خليج شقير بالكامل. تم عمل نموذج ثابت ثلاثي الأبعاد ، باستخدام البيانات الزلزالية وسجل الآبار لتحسين وتطوير إمكانات الهيدروكربون في حقل خليج شقير. تم استخدام البيانات الزلزالية لإنشاء شبكات الأفق المفسرة للمدخلات ونمذجة الخطأ. تم توزيع العناصر البتروفيزيائية (المسامية الفعالة ، حجم الصخر الزيتي والتشبع الهيدروكربوني) داخل الشبكة ثلاثية الأبعاد المنشأة ، باستخدام الخوارزميات المناسبة ، كذلك تم توزيع السمات ورسم خرائطها باستخدام الطرق المناسبة. من خلال دمج نتائج جميع مجموعات البيانات المتاحة ، يوصى بهذه الدراسة العلمية لحفر آبار تطوير في الجزء المركزي من منطقة الدراسة لزيادة جهود الاستكشاف نحو الجزء الجنوبي الغربي.