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Petroleum system modelling and identification of promising oil and gas bearing objects in the eastern part of the Gulf of Suez, Egypt

Ahmed Tarshan[1,2], *Sergey Shimanskiy*[1]

[1]Saint Petersburg State University, St. Petersburg, Russia

[2]Nuclear Materials Authority, Cairo, Egypt

Abstract. The present study aims to identify promising oil and gas bearing objects in the eastern part of the Gulf of Suez. Three-dimensional (3D) modelling of the study area using Petrel software was carried out. The basement layer was created using airborne magnetic data through 3D modelling using GM-SYS-3D software. The sedimentary succession was generated using interpreted seismic sections and well data, and then the data was localised and digitised using Petrel software to be used in the building of the model. The lithology and age of each layer were accurately determined to be used in building the petroleum system model. Data about the temperature gradient and thermal conductivity were obtained for different wells along the Gulf of Suez and the eastern shoulder of the Gulf. In addition to that, heat flow values of the study area have been computed and the heat flow

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map was created to be used in predicting oil and gas accumulation in the study area. Information about hydrocarbon masses and volumes generated and expelled from the source rocks as well as the amount that has migrated and accumulated in reservoirs were computed through running forward simulation using PetroMod software. Accumulations of oil and gas are modelled in the different reservoir layers in the study area. New accumulations of oil and gas were generated within the study area; these accumulations have not been discovered yet. The study area needs more detailed 2D and 3D investigation in the predicted promising locations, where the probability of the existence of hydrocarbon is high. In the southeastern part of the area no activity has been done and according to the results of the petroleum system model, hydrocarbon accumulation area could be discovered in this area in different reservoirs.

1. Introduction

The Gulf of Suez in Egypt has a north-northwest-south-southeast orientation and is located at the junction of the African and Arabian plates where it separates the northeast African continent from the Sinai Peninsula. It has excellent hydrocarbon potential, with the prospective sedimentary basin area, and it is considered as the most prolific oil province rift basin in Africa and the Middle East [*Alsharhan,* 2003].

The eastern margin of the Gulf of Suez displays spectacular interrelationships between rift-border fault systems and sedimentation patterns. The structural and sedimentological evolution over 100 km along the segment of the well of the exposed eastern margin of the Gulf of Suez rift has been studied by detailed field mapping and structural and sedimentological analysis [*McClay et al.,* 1998]. The study area is located in the eastern part of the Gulf of Suez (Figure 1) and lies between latitudes $28^{\circ}28'07.22''$ & $29^{\circ}06'46.05''$ north and longitudes $32^{\circ}54'27.39''$ & $33^{\circ}33'44.13''$ east.

One of the most important tasks in the oil and gas industry is decreasing the risk of exploration through obtaining enough information about the types and volumes of hydrocarbons in a planned structure before starting the drilling. Although there is a very high demand to predict the places of hydrocarbon before drilling, there is no guarantee that oil and gas will be explored even if the drilling is on a closed structure.

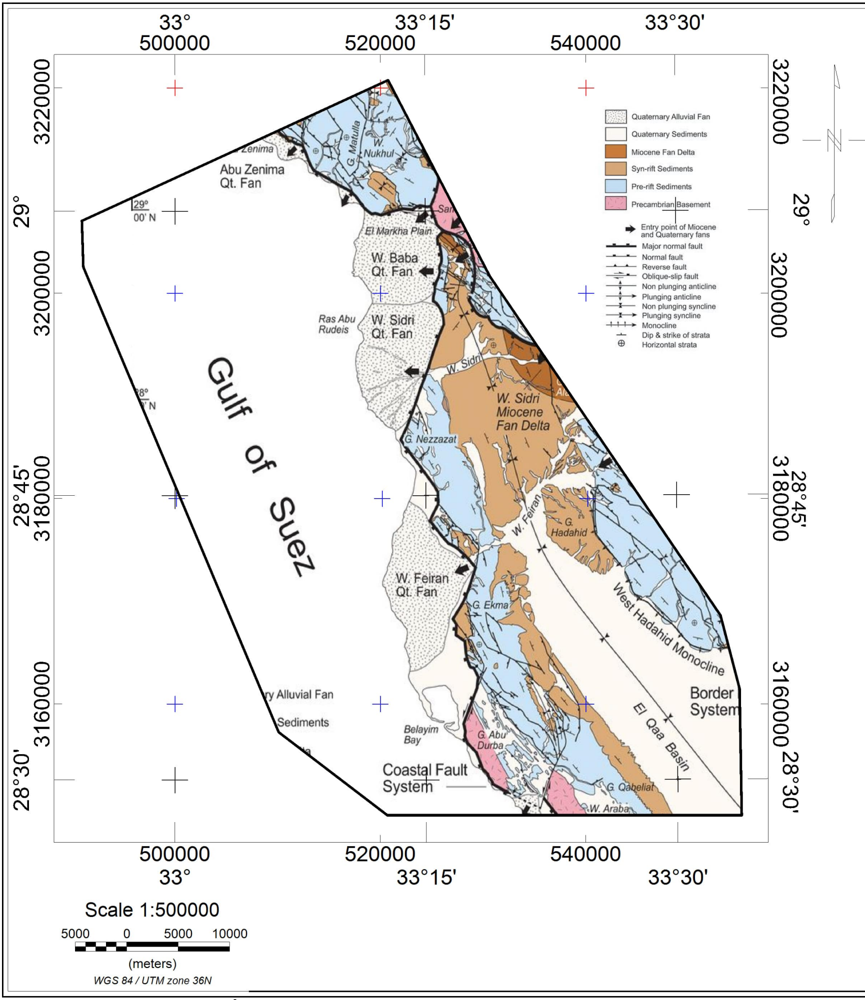

Figure 1. Geological map of the central eastern part of the Gulf of Suez, Egypt [*Moustafa and Khalil,* 2016].

Over 50 years back, geologists started assembling the idea that has since developed into such a predictive approach. This idea connects the past to the present. The past considers a basin, fluids and sediments fill this basin, in addition to dynamic processes working on them. The present considers hydrocarbon discoveries. Early attempts were made to describe how the basins formed, filled and distorted, focusing mainly on the pressure of sediments and the resulting rock structures [*Al-Hajeri et al.,* 2009; *Knebel and Rodriguez-Eraso,* 1956; *Weeks,* 1952].

During the building of the model, a great deal of information is required to generate a reasonable model that simulates the accumulations of the hydrocarbon in a specific area. Geological, geophysical and geochemical information contributes to the building of the model. Information about the sedimentary succession of layers, organic matter, fluids, ages and heat flow is necessary in the building of the petroleum system model.

Applying basin and petroleum system modelling requires two main steps, the first step is building the model and the second step is the forward modelling process. Building the model includes building a structural model and identifying the age of deposition and the physical properties of each layer in the model. The workflow of building the petroleum system model is illustrated in Figure 2.

2. Model Building

2.1. Construction of the Basement Layer

In March 1998, the Airborne Geophysics Department of the Nuclear Materials Authority (NMA) of Egypt led a high-resolution aeromagnetic survey covering 2745 km^2 over the eastern part of the Gulf of Suez. Data was gained along primary (essential) lines spaced at 1000 m, and along control lines spaced at 10,000 m, (normal to the primary lines). The nominal flying elevation was about 100 m (330 ft) above the ground surface (terrain clearance). The direction of the survey was $125^\circ - 305^\circ$ azimuth degrees for primary lines and $35^\circ - 215^\circ$ azimuth degrees for control lines.

Using the GM-SYS-3D inversion code, the presumed sedimentary section-basement complex magnetic susceptibility contrast Δk for several inversion trials was gradually set between 0.035 and 0.08 SI during the inversion run. The inverted basement relief images, corresponding to the used susceptibility contrasts, were

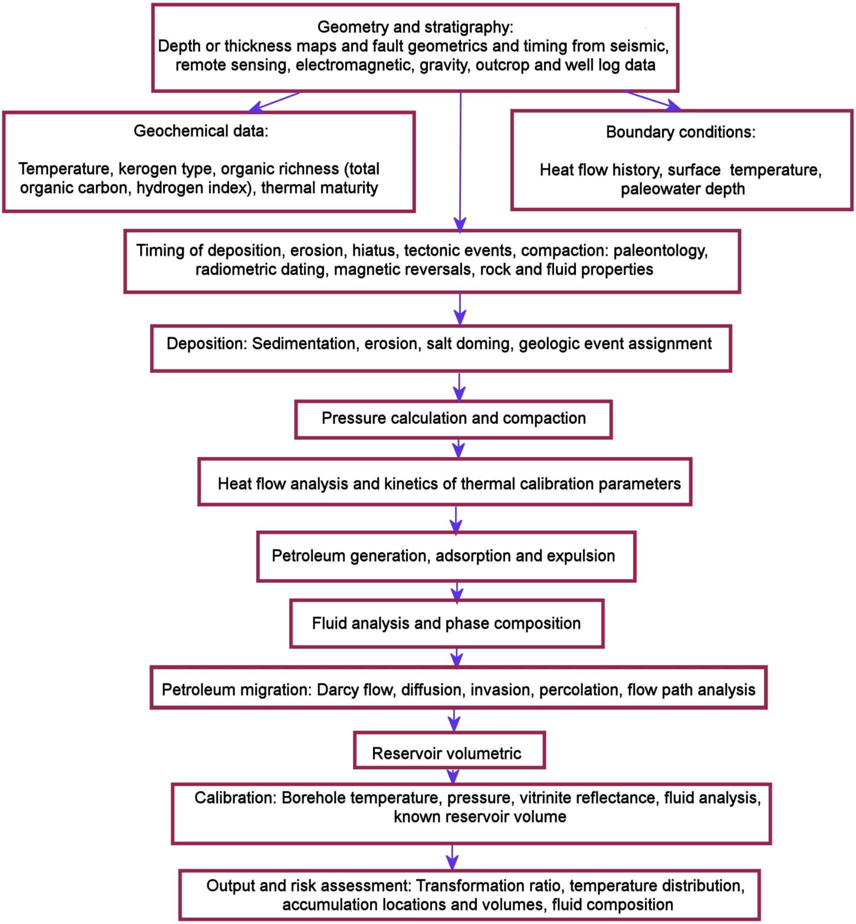

Figure 2. Workflow chart illustrating the steps of BPSM (Basin and Petroleum System Modelling) [*Al-Hajeri et al.*, 2009].

consistently inspected. The overall calculated 3D response fit the observed geomagnetic data (Figure 3a) to better than ± 50.0 nT. Other model parameters are set to be constant for all trails (convergence limit: 10 nT, Z0: 0m and regional offset: 0.0), where Z0 is the nominal top of the basement surface. Estimates of the depth to the basement varied reliably between 500 and 4700 m (Figure 3b). The basement relief encountered at the study area was shown up with three major basin structures. These basins are located at the north western, central western and south eastern part of the area [*Shimanskiy and Tarshan,* 2019].

2.2. Model Building Using Petrel Software

The available interpreted seismic sections and well data in the area under study were collected from different published sources [e.g. *Mokhles et al.,* 2003; *Zahra et al.,* 2015, 2016]. Sixteen seismic sections were obtained covering the northern, central and southern parts of the study area in addition to a single geologic cross section for the southeastern part of the area. Seismic lines GS-370, in-line 195, in-line 215, in-line 215, cross-line 360, cross-line 280 and cross-line 330 are published by *Zahra et al.* [2015]. Seismic lines RG-12-82, RG-14-82, RS-27-83, R6-05-82, and R6-07-83 are published by *Zahra et al.* [2016]. Seismic lines 1330, 1150, 1570 and ARB are published by *Mokhles et al.* [2003]. The geologic cross section for the southeastern part of the study area is obtained from *Rabeh et al.* [2009]. The locations of these lines were traced accurately from the location map of the area. Depth of each formation was gathered from 24 wells in the area under study from different published sources [e.g. *Abou Shagar,* 2006; *Atia,* 2014; *Abu Al-Atta,* 2015]. The locations of the all seismic sections and wells are illustrated (Figure 4). These data were gathered and used in producing a depth-structure map for each formation in the area under study using Petrel software. Finally, a 3D depth model was created as shown in Figure 5.

3. Lithology, Depositional Environment and Age Determination

Determination of the lithology and the depositional environment of each formation are critical. For example, classifying the environment of deposition, and thus the properties, such as permeability and porosity, of coarse-grained sediments helps to identify their potential as

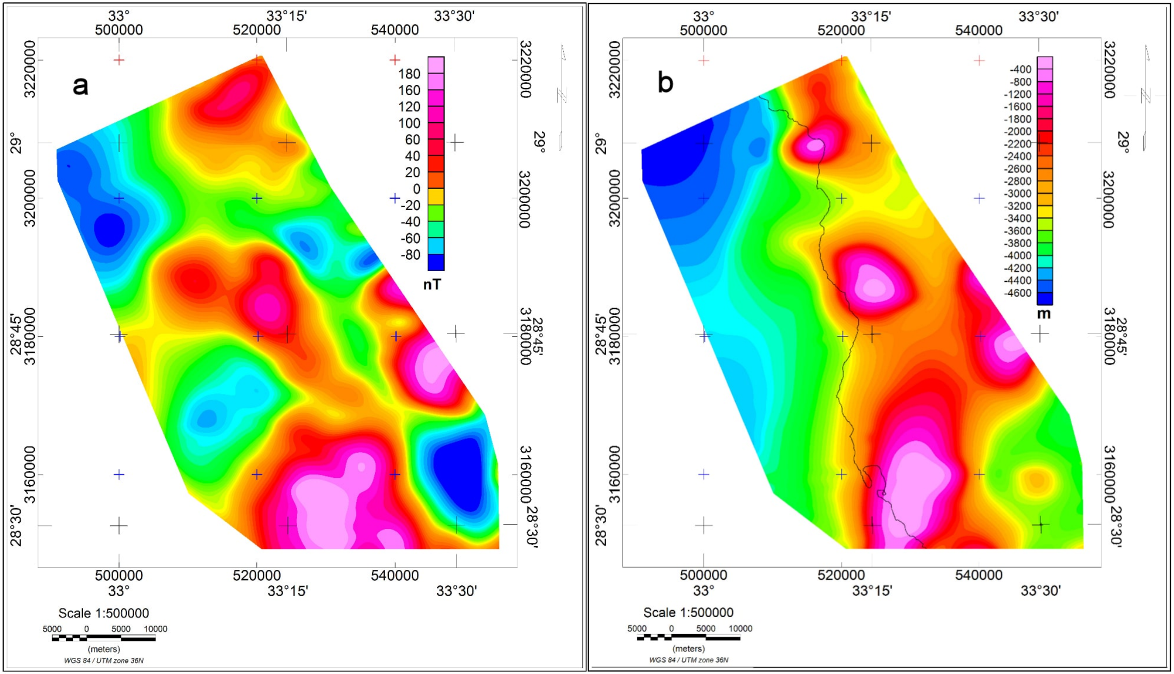

Figure 3. a) Reduced-To-the Pole (RTP) aeromagnetic anomaly map, b) Basement relief contour map after performing the 3D layered-earth inversion of the subsurface magnetic susceptibility distributions, eastern part of the Gulf of Suez, Egypt.

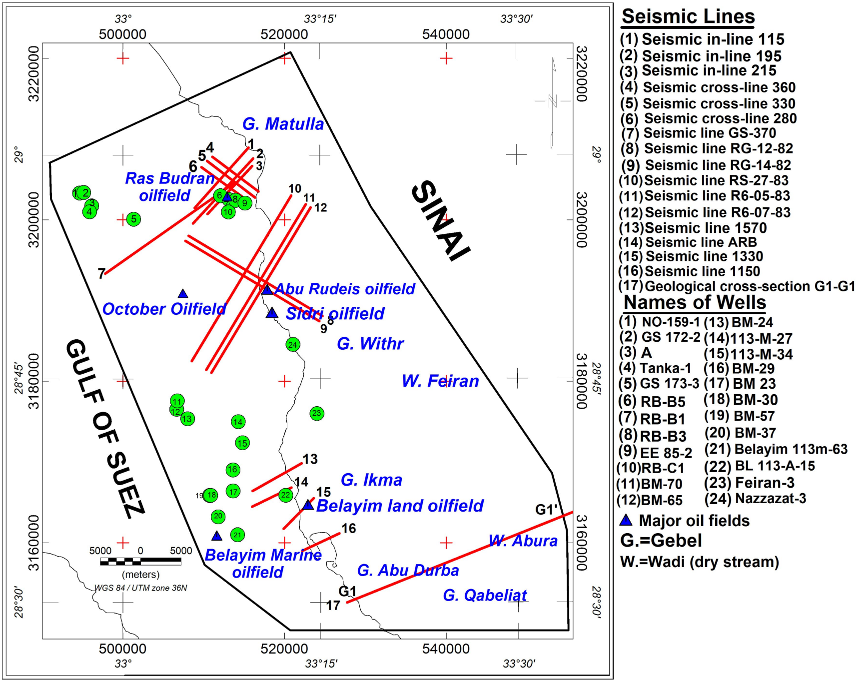

Figure 4. Location map of wells and seismic sections used in the model building, eastern part of the Gulf of Suez.

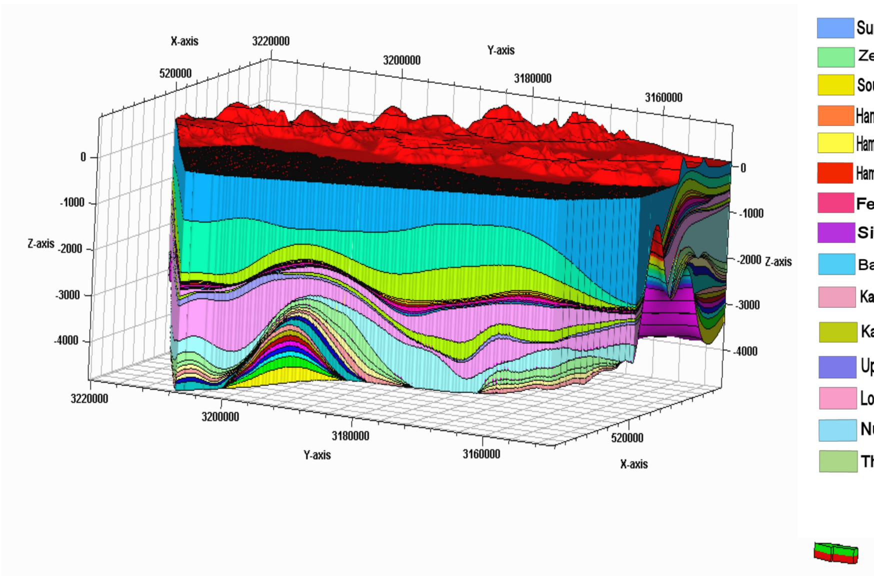

Figure 5. 3D-based structure modelling using Petrel software, eastern part of the Gulf of Suez, Egypt.

reservoir or carrier rocks that facilitate petroleum migration from source to carrier rock. Characterization of the depositional environment of source rocks helps to predict the potential petroleum product resulting from the maturation of kerogen. Fine-grained sediments deposited in deep sea basins, and in anoxic lakes and continental shelf all contain various types of kerogen, leading to different petroleum products [*Peters et al.,* 2005; *Al-Hajeri et al.,* 2009]. Determination of the age of each layer is a very essential parameter in creating a petroleum system model for detecting the time of each process. Data about the age of each layer in the Gulf of Suez is summarised in Table 1.

4. Determination of Petroleum System Element

The petroleum system comprises source rock, migration, carrier rock, cap rock and trap. Carrier or reservoir rock is a rock which carries petroleum in the subsurface and should have a good degree of permeability and porosity, while source rock is sedimentary rock that contains organic matter but at a smaller scale. The majority of source rocks are considered as sedimentary rocks. The most common types of sedimentary rocks in the oil fields are sandstone, shale and carbonates. The type of the petroleum system element for each layer used in the model should be determined. Source rock, reservoir rock and seal are determined for each layer in the sedimentary succession of the study area as shown in Table 1.

5. Total Organic Carbon and Hydrogen Index

Information about the properties of source rocks is necessary as inputs in the simulation. These properties control the organic matter degradation that produces petroleum. These properties are the total organic carbon, the hydrogen index, and the kinetic parameters for the thermal conversion of the source-rock kerogen to petroleum. Many studies were conducted in the area that showed that it contains several source rocks. Many studies are published [e.g. *Atia,* 2014; *El Atfy et al.,* 2014; *Afife et al.,* 2016] about the values of the total organic matter and hydrogen index of each source rock in different wells. The average value for each formation is calculated and used in the building of the petroleum

Table 1. Chronostratigraphic conceptual model of the basin fill in terms of geologic processes operating at a specific time for eastern part of Gulf of Suez, Egypt

Layer Name	Lithology	PSE	Deposition Age/From	To	Erosion/ From	To	TOC	HI	Kinetics
Sediment surface	Sandstone	Overburden	4	0					
Zeit	Sand and Shale	Seal	7.1	5.2	5.2	4			
South Gharib	Salt	Seal	10.7	7.1					
Belayim-H. Faroun_Seal	Shale	Seal	11.6	11.4	11.4	10.7			
Belayim-H. Faroun_P	Sandstone	Reservoir	11.7	11.6					
Belayim-H. Faroun_S	Shale	Source	11.9	11.7			1.5	380	Pepper&Corvi(1995)_TII(B)
Belayim-Feiran	Anhydrite	Seal	12.5	11.9					
Belayim-Sidri	Shale and Sand	Seal	13.4	12.5					
Belayim-Baba	Salt	Seal	14	13.4					
Kareem-Sh	Shale	Seal	14.8	14.2	14.2	14			
Kareem-Ma	Anhydrite	Seal	15.3	15	15	14.8			
Upper Rudeis	Sandstone	Reservoir	16.8	15.6	15.6	15.3			
Lower Rudeis	Shale	Source	20	17.2	17.2	16.8	2.13	255	Pepper&Corvi(1995)_TII(B)
Nukhul	Sandstone	Reservoir	23	21.5	21.5	20			
Thebes	Limestone (organic rich)	Source	56.5	42.1	42.1	23	2.71	421	Pepper&Corvi(1995)_TII(B)
Esna	Shale	Seal	65	56.5					
Sudr	Limestone (chalk, typical)	Source	74	69.1	69.1	65	1.22	588.8	Pepper&Corvi (1995)_TII-S(A)
Dawi	Limestone (organic rich)	Source	84	74			3.1	483	Pepper&Corvi (1995)_TII-S(A)
Matulla	Sand and Shale	Source	88.5	86.5	86.5	84	0.88	638.7	Pepper&Corvi (1995)_TII-S(A)
Wata/Qada	Limestone (Shaly)	Source	94.8	89.5	89.5	88.5	4.7	741	Pepper&Corvi (1995)_TII-S(A)
Raha	Shale and Sand	Seal	97	94.8					
Nubia A-P1	Sandstone	Reservoir	106	99.6	99.6	97			
Nubia A-S1	Shale (organic rich, typical)	Source	110	106			0.6	265	Pepper&Corvi(1995)_TII(B)
Nubia A-P2	Sandstone	Reservoir	119	110					
Nubia A-S2	Shale (organic rich, typical)	Source	124	119			0.69	244	Pepper&Corvi(1995)_TII(B)
Nubia A-P3	Sandstone	Reservoir	145.6	124					
Nubia A-S3	Shale (organic rich, typical)	Source	260.4	245	245	145.6	1.03	167	Pepper&Corvi(1995)_TII(B)
Nubia B	Sandstone	Reservoir	336.3	299	299	260.4			
Nubia C+D	Sandstone	Underburden	570	443.7	443.7	336.3			
Basement	Granite (500 Ma old)	Seal	620	580 620	580	570			

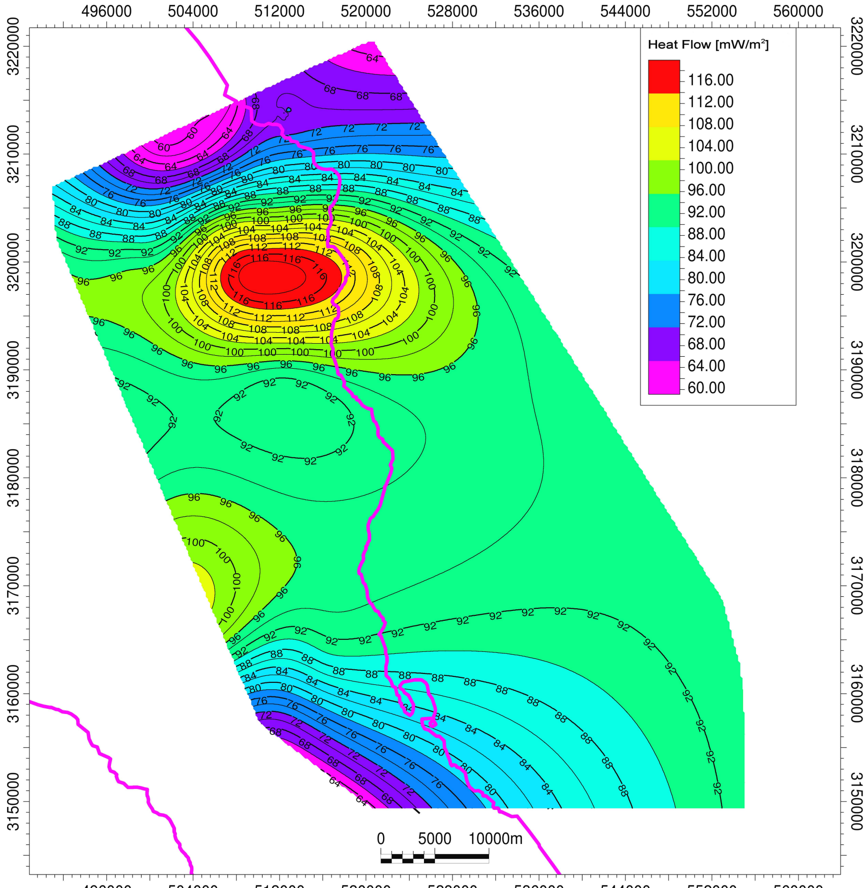

Figure 6. Heat flow map of the eastern part of the Gulf of Suez, Egypt.

system model as shown in Table 1.

6. Heat Flow Map

The history of the burial of basin sediments contains information about the preservation of organic matter, which is related to the temperature and pressure of sediments that affected on them. Temperature is the main variable in converting kerogen to petroleum. While the pressure is essential for the migration of fluids, there is a relation between the thermal history of the basin and the history of the crust in which the basin was formed. Crustal behavior controls basin subsidence or uplifting and heat flow. Evaluation of the past condition is very important while building a petroleum system model because the model requires the rebuilding of the temperature during the geological time across the basin. These conditions are considered to be boundary conditions. The boundary conditions include sediment/water interface temperature and paleoheat-flow estimates which are required to calculate the temperature history of the basin, [*Al-Hajeri et al.,* 2009].

The data about temperature gradient and thermal conductivity were collected for 48 wells along the Gulf of Suez and the eastern shoulder of the Gulf [*Abdel*

Zaher et al., 2011, 2014]. Thermal Heat flow values of the study area have been computed using the formula $Q = K(dt/dz)$, where Q is heat flow, K is thermal conductivity, and t is the temperature at depth z. The heat flow map of the area under study is generated as shown in Figure 6.

7. Forward Modelling

After the boundary conditions, ages and properties of all layers have been defined, the simulation can be run forward, starting with sedimentation of the oldest layer and progressing to the present. The following steps summarize the workflow of the PetroMod modelling software, [*Hantschel et al.,* 2009].

The PetroMod forward modelling deals firstly with the deposition and layers that are created on the top surface during deposition or may be removed during erosion. Several methods such as estimation from sedimentation rate and the depositional environment can be used to calculate the depositional thickness which may be greater than the current thickness. Secondly, PetroMod calculates the pressure and compaction. Pressure calculation and compaction should be applied before heat flow analysis because the compaction may cause changes in density elasticity and porosity. Thirdly, PetroMod performs heat flow analysis. This step aims to calculate the temperature which is the main condition for determining geochemical reaction rates. Thermal conduction and convection should be considered from the bottom as well as generating heat from naturally occurring radioactive emissions.

Moreover, PetroMod uses an interactive kinetic databas for the prediction of the phases and properties of hydrocarbons generated from different types of rocks. The stage of the fluid analysis involves the fluid phases which are usually liquid, vapour, supercritical or unsaturated phases. The fluid analysis step examines temperature- and pressure-dependent dissolution of the hydrocarbon components in the fluid phases to determine fluid properties, such as density and viscosity, for use in fluid flow calculations. These properties are also necessary for migration modelling and calculation of reservoir volumetrics. Fluids can be designed using a black-oil model, consisting of two components or a multi-component model.

There are some methods that can be used to model the petroleum migrating from the source to the trap. The method used in our model is a hybrid method. This method involves two methods: the flow path and

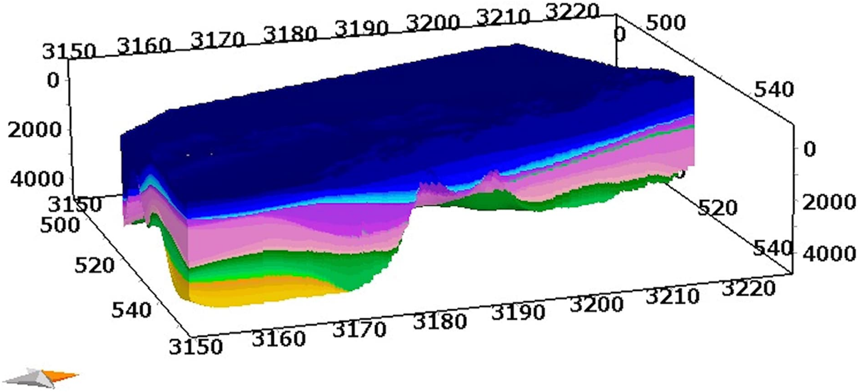

Figure 7. 3D layering using PetroMod software, eastern part of Gulf of Suez, Egypt.

the Darcy flow. The flow path method is based on the geometric analysis of source-carrier-reservoir rock system. In this method, the petroleum generated in the source rock is expelled upward only into a carrier bed where fluid migrates by buoyancy to a geometric high below a seal rock. The Darcy flow method is based on equations of flow through porous media where flow velocities are controlled by permeability and fluid velocity. Upward and downward expulsion from source rock is modelled using the Darcy equation.

Also, PetroMod is taking into consideration the height of petroleum accumulation which is controlled by capillary pressure of the sealing rocks which overlies the reservoirs and the spill point at the base of the structure. The 3D depth-based structural model and the layers of the study area are illustrated in Figure 7.

8. Results and Forecast of Oil and Gas Fields Within the Area Under Study

After running the simulation forward, beginning with the deposition of the oldest layer and progressing to the present, ten source rocks have accumulated in several reservoir layers and created multiple petroleum systems. Here we will show the accumulation of petroleum in each reservoir formation within the study area and the amount of oil and gas in each one. The study area includes five concessions as shown in Figure 8. In Figure 9, Figure 10a and Figure 10b the resulting accumulations and path along which hydrocarbon has migrated are illustrated in 3D using PetroMod software. Oil accumulations are modelled in green and gas accumulations are modelled in red. The proven locations of hydrocarbon, already discovered, and the newer locations of hydrocarbon accumulations which probably exist will be indicated in each reservoir.

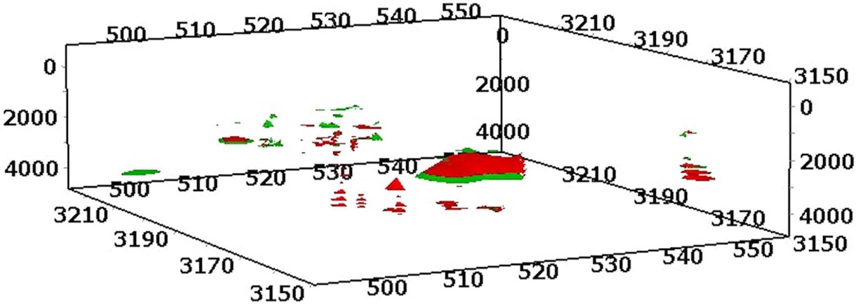

Figure 8. Location map of concessions of the eastern part of Gulf of Suez, Egypt.

9. Results and Discussion

The Gulf of Suez is known for its multi reservoir character, in that each field contains several productive reservoirs. The reservoirs can be classified into pre-rift reservoirs and synrift reservoirs [*Alsharhan,* 2003; *Alsharhan and Salah,* 1994, 1995; *Khalil and Meshref,* 1988; *Meshref et al.,* 1988; *Tewfik et al.,* 1992].

PetroReport provides detailed information on hydrocarbon masses and volumes generated and expelled from the source rocks as well as the amount that has migrated to and accumulated in reservoirs. The mass and volume of hydrocarbon losses are also displayed in detail. Values can be displayed and combined for all paleo events or shown for individual paleo times only,

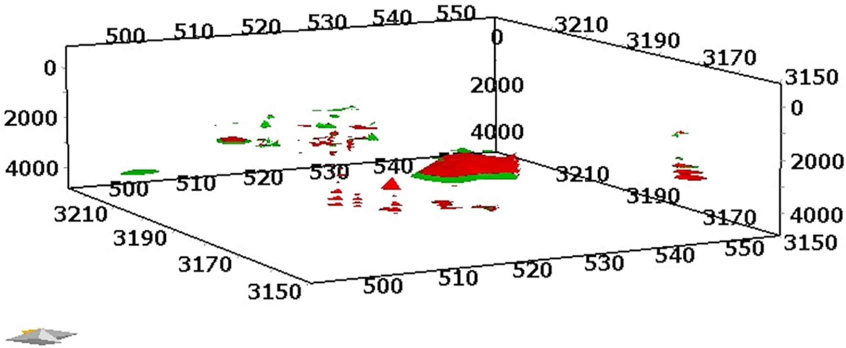

Figure 9. 3D modelled oil and gas accumulations. According to BPSM, oil (green) and gas (red) have migrated from multiple source rocks and accumulated in reservoirs, eastern part of the Gulf of Suez, Egypt.

layers and components can be selected and de-selected as required (PetroMod online help, Petroleum System Modelling, Petro Report User Guide, 34 pp., Schlumberger, 2012). An overview of timing and total volumes of the generated, expelled and accumulated hydrocarbons over time for the entire digital model is illustrated in Figure 11.

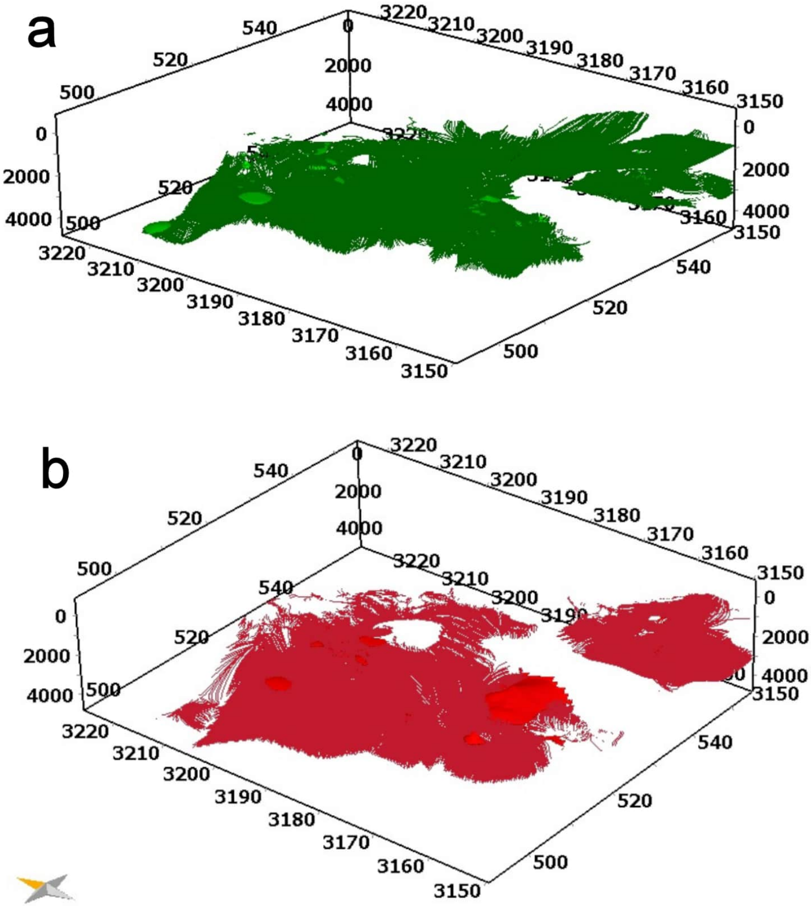

Figure 10. a) The paths along which liquid (in green) and b) vapour (in red) hydrocarbon phases migrated from areas where they were generated to their accumulation locations, eastern part of the Gulf of Suez, Egypt.

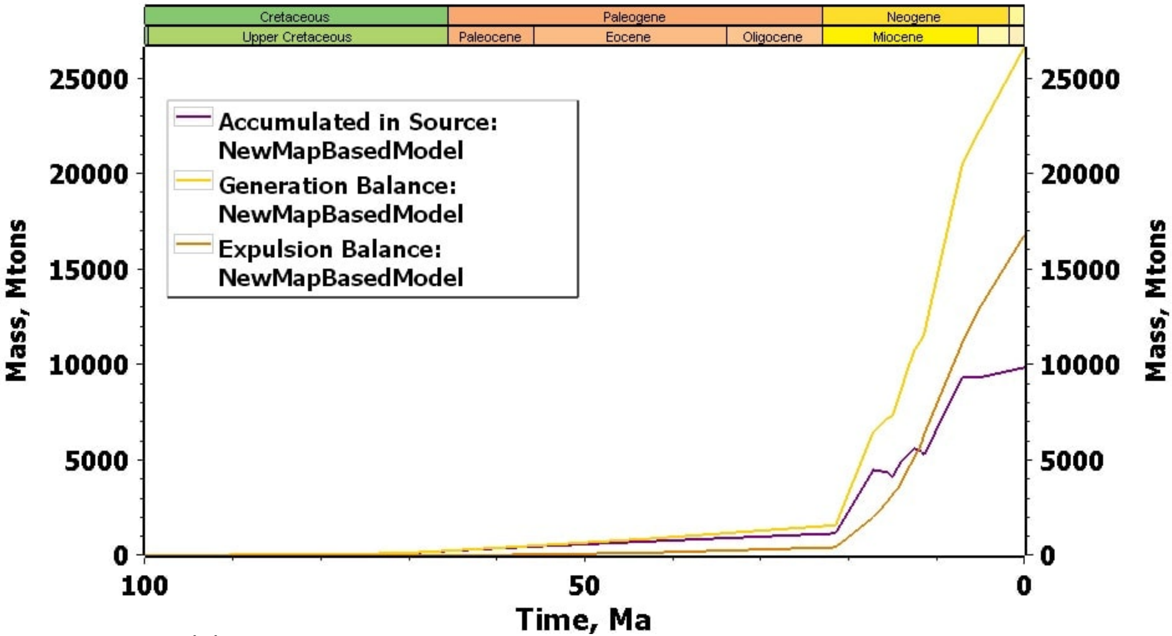

Figure 11. Overview of timing and total volumes of the generated, expelled and accumulated hydrocarbons over time for the entire digital model, eastern part of the Gulf of Suez, Egypt.

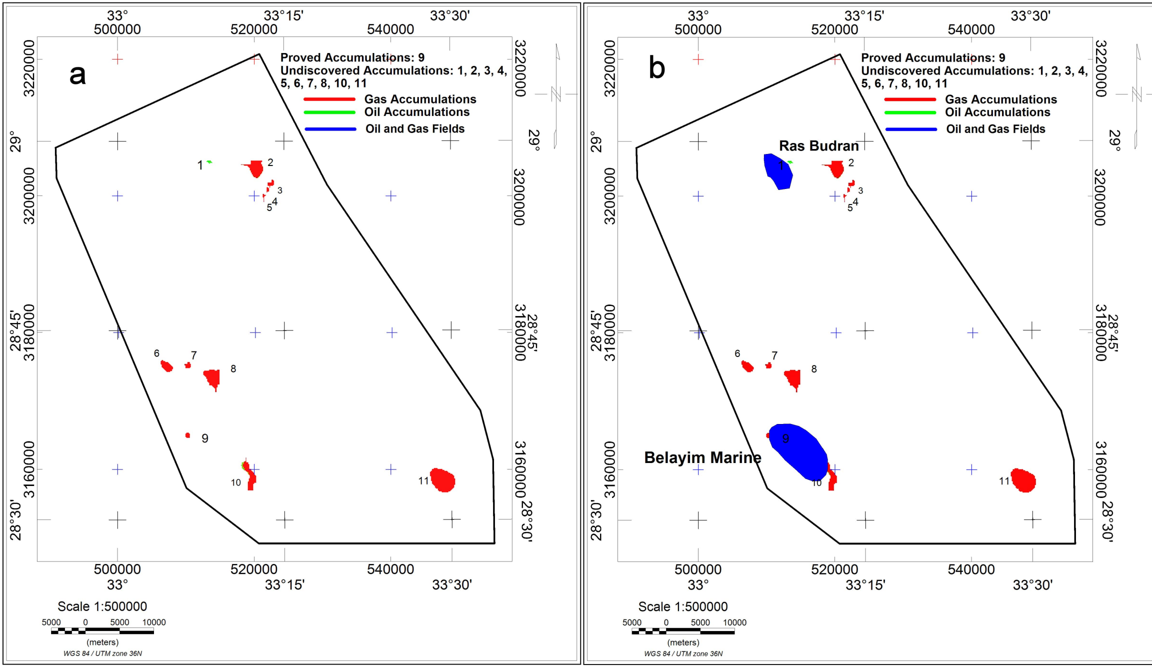

Figure 12. a) Proven and undiscovered modelled oil and gas accumulations map of the Nubia B reservoir, b) Contoured oil and gas fields are located on modelled accumulations map, eastern part of the Gulf of Suez, Egypt.

10. Forecast of Oil and Gas Accumulations Within Reservoir Rocks

10.1. Prerift Reservoirs

10.1.1. Nubia sand stone reservoirs.

The Paleozoic sandstone in the study area is represented in the Nubia sandstone formation which has a good porosity and permeability. This formation is considered as one of the major reservoirs in the Gulf of Suez. The Nubia sandstone (Cambrian-Lower Cretaceous) in the Gulf of Suez is characteristically mature and well-sorted sandstone. The Nubia sandstone yields oil in many fields along the Gulf of Suez. The hydrocarbon is produced from Ras Budran, Abu Rudeis, October and Belayim oil fields within the study area.

Nubia B Formation. Accumulations of oil and gas are modelled in the Nubia B formation using PetroMod software. The locations of the oil fields in the study area and places of modelled hydrocarbon accumulations are plotted together in a 2D view to compare the results of the modelled locations using PetroMod and the proven accumulations that have already been discovered and also, to predict undiscovered accumulations (Figure 12a, Figure 12b).

The modelled accumulations of oil and gas in the Nubia B reservoir show that the total mass of oil and total volume of gas accumulations is equal to 23.6 MMbbls and 31815.9 Mm^3 respectively.

The extraction of hydrocarbon from this reservoir has been proven in the Ras Budran field, and is consistent with modelling results. Some of the accumulations are modelled in the same locations of these oil and gas fields in the study area (Figure 12b). On the other hand, other accumulations of oil and gas are modelled in new locations, that haven't been discovered yet based on the results of PetroMod 3D modelling which indicates the probability of oil and gas existence in these locations.

The amount of oil accumulation in MMbbls and the volume of gas accumulations in m^3 for each accumulation within the study area are illustrated in the Table 2. The Nubia B reservoir contains 9 modelled oil and gas accumulations. Oil accumulations are modelled in green and gas accumulations are modelled in red, the type of each accumulation is illustrated as proven or undiscovered accumulations. The proven accumulations are considered as proven due to the adequate matching between their position and the locations of the contoured oil fields in the area, that already have

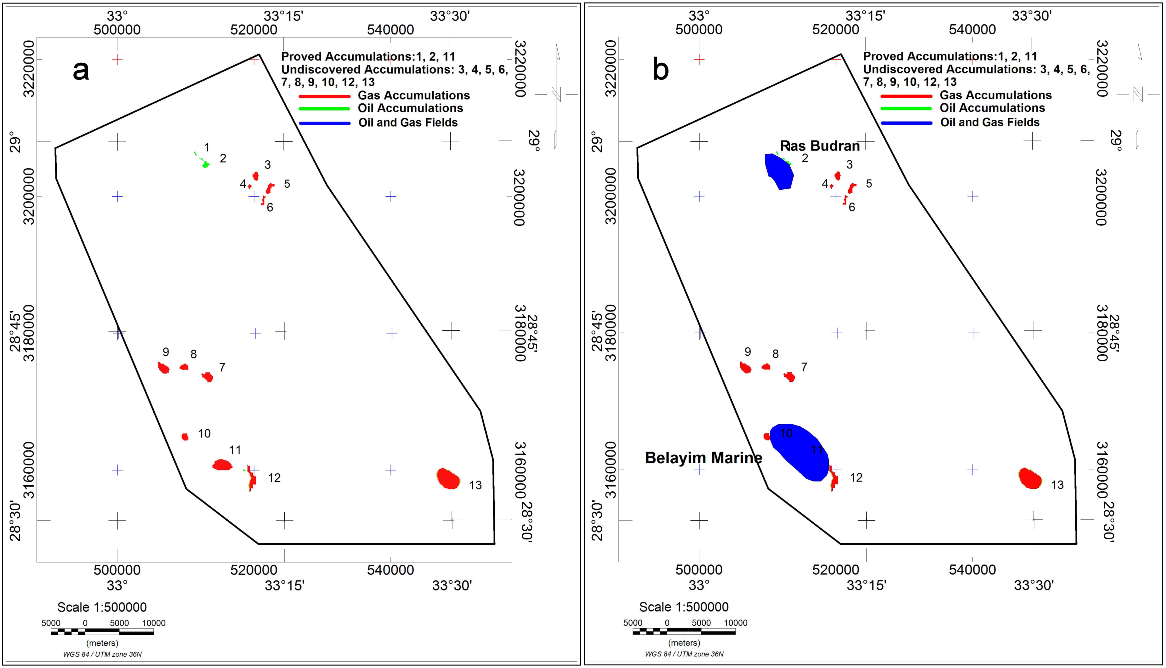

Figure 13. a) Proven and undiscovered modelled oil and gas accumulations map of the Nubia A-P3 reservoir, b) Contoured oil and gas fields are located on modelled accumulations map, eastern part of the Gulf of Suez, Egypt.

Table 2. The Amount of Oil Accumulations in MMbbls and the Volume of Gas Accumulations in Mm^3 for Each Accumulation in Nubia B Reservoir, Eastern Part of Gulf of Suez, Egypt

Accumulation No	Accumulated gas volume (Mm^3)	Accumulated oil mass (MMbbls)
1	103.18	4
2	3477.99	8.96
3	583.01	0.16
4	84.05	0.02
5	153.71	0.01
6	2956.6	–
7	305.17	–
8	1623.52	–
9	172.89	–
10	828.64	3.81
11	21527.14	6.64

oil and gas being extracted from them (Figure 12b).

Nubia A-P3 Formation. Accumulations of oil and gas are modelled in the Nubia A-P3 formation using PetroMod software (Figure 13a). The locations of the oil fields in the area under study and the locations of modelled hydrocarbon accumulations are plotted together in a 2D view to compare between the results of the modelled locations using PetroMod and the proven accumulations already have been discovered and also, to predict the undiscovered accumulations (Figure 13b). The modelled accumulations of oil and gas in Nubia A-P3 show that the total mass of oil and total volume of gas accumulations are equal to 49.85 MMbbls and 23,410.93 Mm^3 respectively. Oil accumulations are modelled in green and gas accumulations are modelled in red. The Nubia A-P3 reservoir contains 13 modelled oil and gas accumulations. The amount of oil accumulation in MMbbls and the volume of gas accumulations in Mm^3 for each accumulation within the study area are illustrated in Table 3.

Nubia A-P2 Formation. Accumulations of oil and gas are modelled in the Nubia A-P2 reservoir using PetroMod software (Figure 14a). The proven and undiscovered accumulations are discriminated according to the position of the contoured oil and gas field in the study area (Figure 14b). The modelled accumulations of oil and gas in Nubia A-P2 show that the total mass of oil and total volume of gas accumulations are equal to 235.13 MMbbls and 27,605.49 Mm^3 respectively. The Nubia A-P2 reservoir contains 15 modelled oil and gas accumulations. The amount of oil accumulation in

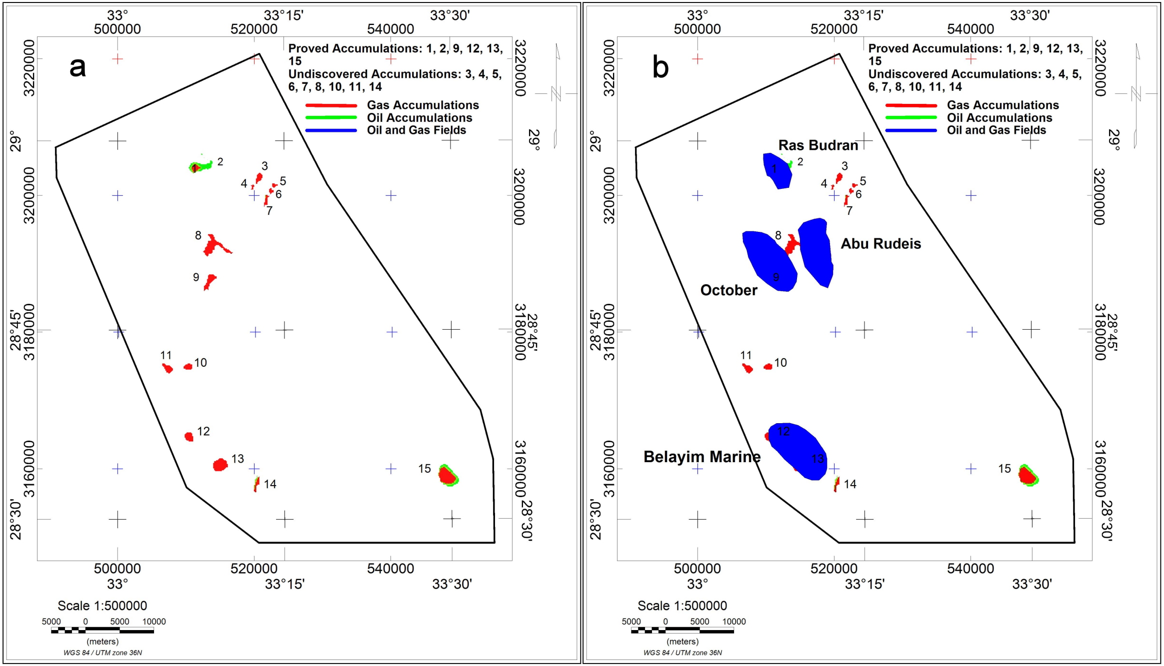

Figure 14. a) Proven and undiscovered modelled oil and gas accumulations map of the Nubia A-P2 reservoir, b) Contoured oil and gas fields are located on modelled accumulations map, eastern part of the Gulf of Suez, Egypt.

Table 3. The Amount of Oil Accumulations in MMbbls and the Volume of Gas Accumulations in Mm^3 for Each Accumulation in the Nubia A-P3 Reservoir, Eastern Part of Gulf of Suez, Egypt

Accumulation No	Accumulated gas volume (Mm^3)	Accumulated oil mass (MMbbls)
1	9.81	0.43
2	296.97	12.19
3	429.93	0.83
4	77.69	0.04
5	1192.59	0.69
6	407.26	0.13
7	302.21	–
8	977.34	–
9	3797.	–
10	968.38	–
11	1202.11	2.85
12	212.42	0.7
13	13537.22	31.99

MMbbls and the volume of gas accumulations in Mm^3 for each accumulation within the study area are illustrated in Table 4.

Nubia A-P1 Formation. According to the results of the PetroMod simulation the Nubia A-P1 reservoir contains 13 generated accumulations of oil and gas. The proven and undiscovered accumulations (Figure 15a) are discriminated according to the locations of the contoured oil and gas field in the study area (Figure 15b). The total mass of oil and total volume of gas accumulations are equal to 141.61 MMbbls and 11,175.14 Mm^3 respectively. The amount of oil accumulation in MMbbls and the volume of gas accumulations in Mm^3 for each accumulation within the study area are illustrated in Table 5.

10.2. Synrift Reservoirs

The Miocene sandstones are the most important reservoir units in the Gulf of Suez; dolomitised reef limestones also have reservoir potential in the Miocene units. These facies were deposited during rotational faulting, as the early Miocene uplifted horsts along the Gulf of Suez margins shed alluvial sands into marine basins. The active faulting provided a topographic

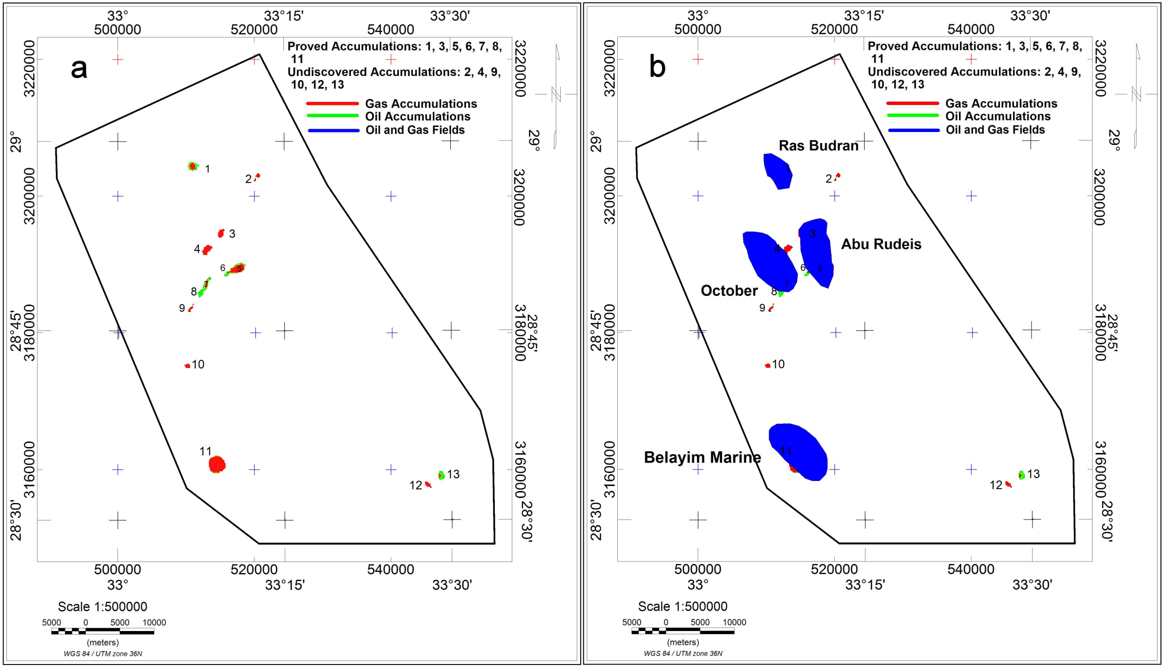

Figure 15. a) Proven and undiscovered modelled oil and gas accumulations map of the Nubia A-P1 reservoir, b) Contoured oil and gas fields are located on modelled accumulations map, eastern part of the Gulf of Suez, Egypt.

Table 4. The Amount of Oil Accumulations in MMbbls and the Volume of Gas Accumulations in Mm^3 for Each Accumulation in the Nubia A-P2 Reservoir, Eastern Part of Gulf of Suez, Egypt

Accumulation No	Accumulated gas volume (Mm^3)	Accumulated oil mass (MMbbls)
1	420.05	0.26
2	2555.27	104.87
3	631.16	0.3
4	76.53	0.04
5	583.66	0.55
6	478.4	0.5
7	618.56	0.61
8	3843.31	0.74
9	738.02	0.52
10	1124.04	–
11	2545.88	0.01
12	2777.45	0.02
13	1639.68	2.14
14	60.13	0.68
15	9513.35	123.89

relief, which was progressively submerged by a middle Miocene transgression, allowing the development of reefs on local highs [*Alsharhan,* 2003; *Coffield and Smale,* 1987; *Smale et al.,* 1988]. The synrift reservoirs have greater potential in the Gulf of Suez than the prerift ones.

10.2.1. Nukhul Formation.

According to the results of the PetroMod simulation the Nukhul reservoir contains 16 generated accumulations of oil and gas. The proven and undiscovered accumulations (Figure 16a) are discriminated according to the locations of the contoured oil and gas field in the study area (Figure 16b). The total mass of oil and total volume of gas accumulations are equal to 1951.72 MMbbls and 56,945.7 Mm^3, respectively. The amount of oil accumulation in MMbbls and the volume of gas accumulations in Mm^3 for each accumulation within the study area are illustrated in Table 6.

10.2.2. Rudeis Formation.

The Rudeis reservoirs are present over most of the study area and represent about 20% of production potential

Table 5. The Amount of Oil Accumulations in MMbbls and the Volume of Gas Accumulations in Mm^3 for Each Accumulation in the Nubia A-P1 Reservoir, Eastern Part of Gulf of Suez, Egypt

Accumulation No	Accumulated gas volume (Mm^3)	Accumulated oil mass (MMbbls)
1	1234.01	30.49
2	166.31	1.5
3	672.65	0.41
4	1001.08	3.53
5	523.78	0.18
6	321.58	20.25
7	107.82	0.03
8	476.55	29.92
9	168.54	0.07
10	407.29	–
11	5147.02	21.45
12	269.15	0.1
13	679.36	33.68

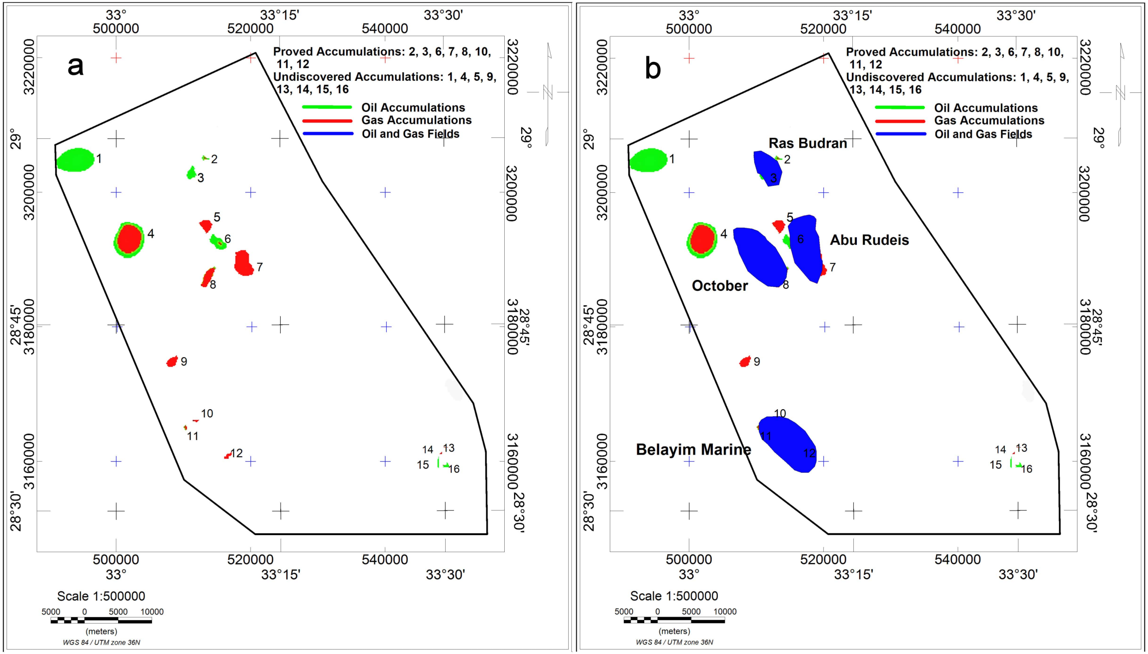

Figure 16. a) Proven and undiscovered modelled oil and gas accumulations map of the Nukhul reservoir, b) Contoured oil and gas fields are located on modelled accumulations map, eastern part of the Gulf of Suez, Egypt.

Table 6. The Amount of Oil Accumulations in MMbbls and the Volume of Gas Accumulations in Mm^3 for Each Accumulation in the Nukhul Reservoir, Eastern Part of Gulf of Suez, Egypt

Accumulation No	Accumulated gas volume (Mm^3)	Accumulated oil mass (MMbbls)
1	8713.58	520.94
2	602.98	38.49
3	2231.63	201.91
4	29906.5	862.01
5	1582.11	0.25
6	2690.8	243.4
7	4300.11	0.54
8	4431.65	44.14
9	1596.74	0.68
10	15.46	0.01
11	541.12	10.43
12	31	0.02
13	19.82	–
14	16.54	–
15	183.86	20.05
16	81.8	8.85

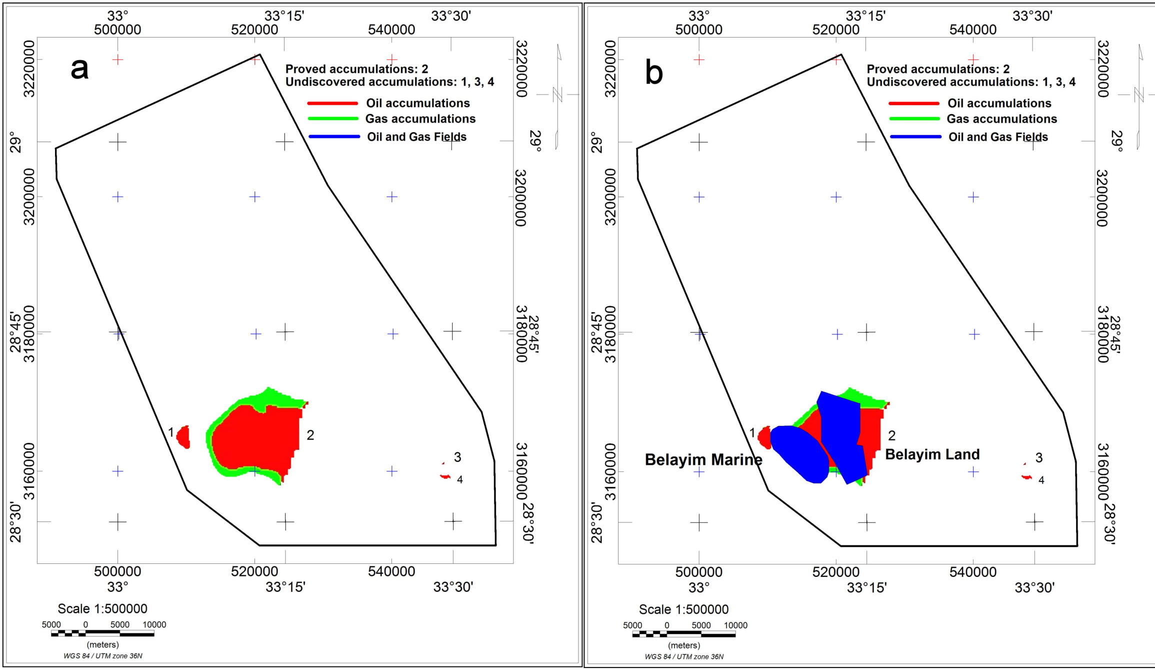

Figure 17. a) Proven and undiscovered modelled oil and gas accumulations map of the Rudeis reservoir, b) Contoured oil and gas fields are located on modelled accumulations map, eastern part of the Gulf of Suez, Egypt.

in the Gulf of Suez. The Rudeis sandstone has produced oil from fields such as, Belayim Marine, Belayim Land [*Alsharhan,* 2003].

According to the results of the PetroMod simulation the Rudeis reservoir contains 6 generated accumulations of oil and gas. The proven and undiscovered accumulations (Figure 17a) are discriminated according to the locations of the contoured oil and gas field in the study area (Figure 17b). The total mass of oil and total volume of gas accumulations are equal to 2449.77 MMbbls and 315,649.55 Mm^3, respectively. The amount of oil accumulation in MMbbls and the volume of gas accumulations in Mm^3 for each accumulation within the study area are illustrated in Table 7.

10.2.3. Belayim Formation.

The Belayim reservoir contains about 10.5% of the oil produced in the Gulf of Suez. The Belayim sandstones produce oil in the following fields: Belayim Land, Belayim Marine [*Alsharhan,* 2003].

In the Belayim reservoir, the producing of hydrocarbon from Belayim Land and Maine fields was proven, and that is demonstrated in the resultant modelled accumulations map produced using PetroMod software.

Table 7. The Amount of Oil Accumulations in MMbbls and the Volume of Gas Accumulations in Mm^3 for Each Accumulation in the Rudeis Reservoir, Eastern Part of Gulf of Suez, Egypt

Accumulation No	Accumulated gas volume (Mm^3)	Accumulated oil mass (MMbbls)
1	5876.62	2.92
2	309732.88	2446.85
3	0.35	–
4	39.7	–

The proven and undiscovered accumulations are illustrated in (Figure 18a). There is a good matching between the modelled accumulations and the proven ones in Belayim Land and Belayim Marine fields (Figure 18b). The total mass of oil and total volume of gas accumulations are equal to 454.98 MMbbls and 2708.97 Mm^3, respectively. The amount of oil accumulation in MMbbls and the volume of gas accumulations in Mm^3 for each accumulation within the area under study are illustrated in Table 8.

Table 8. The Amount of Oil Accumulations in MMbbls and the Volume of Gas Accumulations in Mm^3 for Each Accumulation in the Belayim Reservoir, Eastern Part of Gulf of Suez, Egypt

Accumulation No	Accumulated gas volume (Mm^3)	Accumulated oil mass (MMbbls)
1	–	1.32
2	1.67	1.52
3	485.14	136.54
4	162.2	20.43
5	0.9	1.89
6	202.03	47.34
7	0.5	1.41
8	1247	89.38
9	0.87	1.22
10	412.47	110.54
11	37.23	4.69
12	19.39	4.61
13	111.37	34.09
14	28.2	–

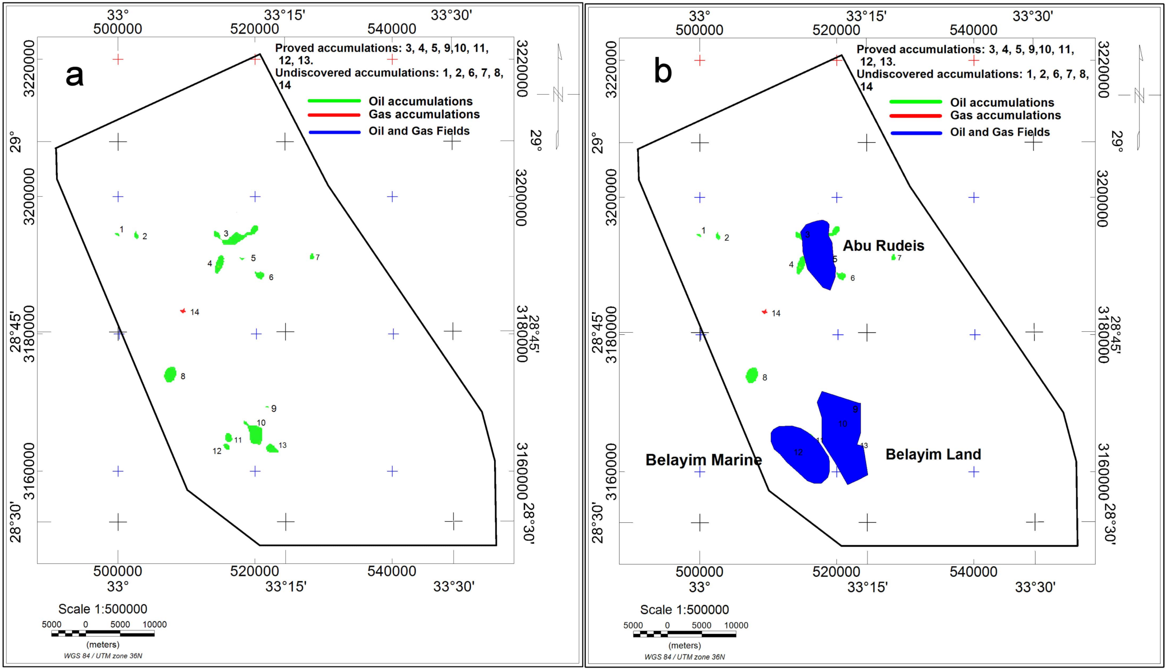

Figure 18. a) Proven and undiscovered modelled oil and gas accumulations map of the Belayim reservoir, b) Contoured oil and gas fields are located on modelled accumulations map, eastern part of the Gulf of Suez, Egypt.

11. Recommendations and Conclusion

1. The results of the PetroMod software showed that there are undiscovered modelled accumulations generated within the area under study. These locations need 2D and 3D seismic prospecting.

2. In the southeastern part of the area no activity was done and according to the result of the PetroMod simulation, there is the probability of the existence of hydrocarbon in different reservoirs.

3. Extending in the drilling of wells to east and west of the Belayim land field, we expect larger accumulations than those currently discovered.

4. The locations of the undiscovered accumulations in each reservoir need more detailed 2D and 3D seismic prospecting to ensure the presence of hydrocarbon in these places.

One of the most important tasks in the oil and gas industry is decreasing the risk of exploration through obtaining enough information about the types and volumes of hydrocarbons in a planned structure before starting drilling. A 3D model of the study area using Petrel software was generated using seismic and well data. Petroleum system modelling was performed using PetroMod software to identify the promising oil and gas bearing objects in the eastern part of the Gulf of Suez.

The resulting accumulations of the PetroMod software are generated and modelled in a 3D view. The results show that the Gulf of Suez has multi reservoir character. Oil and gas accumulations are modelled in seven reservoirs within the study area. Pre-rift reservoirs include Nubia B, Nubia A-P1, Nubia A-P2 and Nubia A-P3 formations.

The modelled accumulations of oil and gas in these reservoirs show that the total mass of oil and total volume of gas accumulations are equal to 23.6 MMbbls and 31,815.9 Mm^3 in the Nubia B reservoir, 49.85 MMbbls and 23,410.93 Mm^3 in the Nubia A-P3 reservoir, 235.13 MMbbls and 27,605.9 Mm^3 in the Nubia A-P2 reservoir, and 141.61 MMbbls and 11,175.14 Mm^3 in the Nubia A-P1 reservoir.

Synrift Reservoirs include the Nukhul, Rudeis and Belayim formations. The modelled accumulations of oil and gas in these reservoirs show that the total mass of oil and total volume of gas accumulations are equal to 1951.72 MMbbls and 56,945.7 Mm^3 in the Nukhul reservoir, 2449.77 MMbbls and 315,649.55 Mm^3 in the

Rudeis reservoir, and, 454.98 MMbbls and 2708.9 Mm^3 in the Belayim reservoir.

There is currently extraction of oil and gas from these reservoirs in the oil fields in the study area, where some of the accumulations of oil and gas are modelled in these locations. On the other hand, other accumulations of oil and gas are modelled in new locations, that is haven't been discovered yet based on the results of PetroMod 3D modelling, therefore there is the probability of oil and gas existence in these locations.

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Note: Five more references for technical reasons were omitted. See for details the basic version of the article (http://rjes.wdcb.ru/v19/2019ES000669.pdf.