Identification of oil and gas bearing objects using geophysical data in the eastern part of the Gulf of Suez, Egypt

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Abstract. The airborne magnetic data is considered as one of the best methods to delineate the depth to basement layer. The airborne magnetic survey data obtained from the Egyptian Nuclear Materials Authority. Data is accurately processed, interpreted. Two-dimensional (2D) modeling was performed by GM-SYS, along one selected profile yielded from RTP map. In addition to that, three-dimensional (3D) Euler Deconvolution method was performed to delineate the depth to basement layer. Euler solutions were applied on RTP Grid by structural indexes 0, 1, 2, and 3 to select the best solution. The sedimentary succession of the study area is created using seismic data and well data. Petroleum system model was established to predict the locations of hydrocarbons within the study area. The results of PetroMod confirmed that the area is very promising for hydrocarbon aggregations, and also new hydrocarbon aggregations have been discovered.

1. Introduction
The Gulf of Suez is a rift basin oriented approximately north-northwest and south-southeast; it is approximately 400 km long and varies in width between 40 km and 80 km. The Red Sea splits into the Gulf of Suez and the Gulf of Aqaba, where the Gulf of Suez is considered as the western flank of the Red sea since the southern end of the Gulf of Suez meets the Red Sea [1]. The basin appears as a simple, narrow, elongated trough dominated by two almost symmetric shoulders. This extensional tectonic basin is approximately 60 to 80 km wide, contains a sedimentary prism about 3–5 km thick, ranging in age from Miocene to Holocene [2].

The tectono-stratigraphic history of the Gulf of Suez has created multiple reservoirs that lead to the hydrocarbon potentiality of the Gulf of Suez basin, in addition to existence of sufficient source rocks which are spatially distributed in the area [3]. The main objective of this research study is to determine the basement relief configuration of the study area using different techniques and understanding of the basin history of the study area, through building 3D depth-based structural model and then constructing petroleum system model to identify oil and gas aggregations.

2. Geologic features
Geologically, the area is covered by a variety of rock formation from Quaternary, Miocene, Paleocene, Cretaceous and Paleozoic Eras. It contains man made features such as several oil fields (Rudeis, Feiran and Belayim oil fields). The western side of the studied area is part of the Gulf of Suez. It is dominated by several mountains such as GabalZeit at the southern part of the area, which is formed of undeformed
alkali granitic rocks, GabalNazzazat (formed of siliciclastic- carbonate succession) and GabalEkmain the central part of the area. There are some Wadis within the area such as Wadi Abu Ratamat, WadiAbiad and WadiThaghada. The nearby eastern part of the Gulf of Suez is covered by Quaternary deposits (Figure 1) [4].

Figure 1. Surface Geological Map of the Middle Eastern part of the Gulf of Suez, Egypt [3].

3. Interactive 2D-magnetic modeling
GM-SYS Geosoft, (2007) software utilizes of interactive graphics to significantly rapid the interpretation processes. In GM-SYS, the techniques used to calculate magnetic model response are based on the methods of Talwani and Heirtzler [5], and utilizes of the algorithms described in Won and Bevis [6]. The results from GM-SYS have been analyzed and found correct by several organizations that use it for geophysical consulting work.
The 2D modeling was performed by GM-SYS, along one selected profile (Figure 2) yielded from RTP map. The profile extends more than 42 km in the NE-SW direction; this profile shows an adequate fit between the observed and calculated magnetic curves with RMS equal to 3.438%. The magnetic model proved the presence of a moderate sedimentary layer in the southwestern part of the profile, which has an average susceptibility value of 0.001 SI that decreases to the northeastern part because the depth to the basement decreases close to the Precambrian outcropped basement of Sinai.

![Figure 2. 2D inverted susceptibility layered-earth model and calculated geomagnetic response, eastern part of the Gulf of Suez, Egypt.](image)

4. 3D Euler Deconvolution

Recently, 3D Euler Deconvolution method has been widely used in the automatic interpretation of Magnetic and Gravity data. It has emerged as a powerful tool for direct determination of depth of the gravity and magnetic bodies. Also, it uses for determination the dykes and contacts with remarkable accuracy [7]. Usually the locations and depths of any sources \((x_0, y_0, z_0)\) can be determined by using the following equation (1):

\[
\frac{\partial f}{\partial x}(x-x_0) + \frac{\partial f}{\partial y}(y-y_0) + \frac{\partial f}{\partial z}(z-z_0) = SI (B-f),
\]

where \(f\) is the observed field at location \((x, y, z)\) and \(B\) is the base level of the field [regional value at the point \((x, y, z)\)] and SI is the structural index or degree of homogeneity [7]. The equation (1) is solved for the source position by least-squares inversion of a moving window of data points. To obtain an accurate estimation of the source location, the field data used must adequately sample the anomalies present in the data. In this research, the 3D Euler Deconvolution technique was applied to determine the locations and depths of the faults in the study area. The obtained solutions of the interpretations of 3D Euler Deconvolution of magnetic data are shown in Figure 3. Euler solutions were applied on RTP Grid by structural indexes 0, 1, 2, and 3 to select the best solution. Structural index zero “SI = 0” indicates to Contact/Step (Figure 3a), structural index one “SI = 1” indicates to Sill/Dyke (Figure 3b), structural index two “SI = 2” indicates to Cylinder/Pipe (Figure 3c) and structural index three “SI = 3” indicates to Sphere/Barrel/Ordnance (Figure 3d). The structural index SI = 0 gives better solutions than the structural indices 1, 2, and 3, because the data is concentrated in the study area. The results of the Euler solution with structure index SI=0 are located on the RTP map as shown in Figure 4.
Figure 3. 3D Euler Deconvolution method. a) Euler Solutions of Structural Index = 0, b) Euler Solutions of Structural Index = 1, c) Euler Solutions of Structural Index = 2 and d) Euler Solutions of Structural Index = 3.
5. Model building and Identification of oil and gas bearing objects

3-D modeling involves reconstructing the history of petroleum systems at reservoir to basin scales and includes the ability to display that information in 1D, 2D and 3D space and through time. The models can be constructed as time-stratigraphic intervals, or delineated based on common formations or facies. Numerous variables are integrated and analyzed by the 3-D petroleum systems modeling software. These data and interpretations greatly augment the assessment of undiscovered oil and gas resources by showing the history of petroleum systems across provinces, and by analyzing the relative effects on these systems of vertical and lateral changes in lithology, heat flow, hydrodynamics, PVT behavior, and other processes [8].

The use of 3-D petroleum systems modeling can also enhance the assessment process by providing another level of support for conclusions from the assessments. Examples of this support include exclusion of areas and petroleum systems from assessment because source rocks are immature or overmature for petroleum generation, including these formations and areas because the modeling shows migration of petroleum from mature areas, and timing onset of petroleum generation relative to trap formation [8].

In this research the seismic sections and well data in the study area were collected from different published sources [9, 10, 11]. The geologic cross section for the southeastern part of the study area [12]. The locations of these lines were accurately tracked from the location map of the area. These data were collected and used to produce a depth-structure map for each formation in the area under study. Finally, a 3D depth model was created (Figure, 5).
Figure 5. 3D depth-based structure model, eastern part of Gulf of Suez, Egypt.

The results show that the Gulf of Suez has multi-reservoir character. Oil and gas aggregations 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 aggregations of oil and gas in these reservoirs show that the total mass of oil and total volume of gas aggregations is equal to 23.6 MMbbls and 31815.9 Mm$^3$ in Nubia B reservoir, 49.85 MMbbls and 23410.93 Mm$^3$ in Nubia A-P3 reservoir, 235.13 MMbbls and 27605.9 Mm$^3$ in Nubia A-P2 reservoir, and 141.61 MMbbls and 11175.14 Mm$^3$ in Nubia A-P1 reservoir.

Synrift Reservoirs include Nukhul, Rudeis and Belayim formations. The modelled aggregations of oil and gas in these reservoirs show that the total mass of oil and total volume of gas aggregations is equal to 1951.72 MMbbls and 56945.7 Mm$^3$ in Nukhul reservoir, 2449.77 MMbbls and 315649.55 Mm$^3$ in Rudeis reservoir, and, 454.98 MMbbls and 2708.9 Mm$^3$ in Belayim reservoir.

Oil and gas extraction from these reservoirs has been proven in the oil fields of the study area. Oil and gas aggregations are modelled at these oil and gas fields, while other accetions are being modelled on new sites, which have not yet been discovered. Based on the results of the PetroMod 3D modeling, there is a potential for oil and gas in these locations. These sites need more detailed verification of the presence of hydrocarbons. In the south-eastern part of the region, no activity was carried out, and according to the results of PetroMod, there is a possibility of hydrocarbons in various reservoirs.

6. Conclusion
One of the most important tasks in the oil and gas industry is to minimize the risk of exploration by obtaining sufficient information on the types and amount of hydrocarbons in the subsurface before starting drilling. A 3D model of the study area was created using seismic data and well data using the Petrel program. The petroleum system modeling was done using the PetroMod program to identify promising oil and gas objects in the eastern part of the Gulf of Suez. PetroMod results show that there are undetected aggregations generated in different locations within the study area. These sites need more detailed verification of the presence of hydrocarbons. In the south-eastern part of the region, no activity has been carried out, and according to the results of PetroMod, there is a possibility of hydrocarbons in different reservoirs.

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