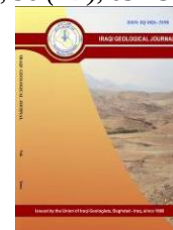




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Gravity Application to Obtain the Subsurface Structures of Mafid Region, North Nasser Lake, Egypt

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Abstract

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This study aims to define structures below the surface of the Mafid Area by using gravity data interpretation. Estimates were made for the contact density contrast and the gravity sources' depths. The source depths and contact locations were estimated using the Euler deconvolution method. Structures with shallow and deep seats were also assessed using power spectrum analysis. The structure at a shallow depth was between 0.032 km and 0.437 km. According to the Euler deconvolution method's outcomes, the basement may be below ground in the area's southernmost portion, and it has grown to between 200 and 300 meters in the area's northernmost portion. Multiple faults affect the region that most trends in the NW-SE, NNW-SSE, E-W, NE-SW, and NNE-SSW directions, according to the structural map that has been interpreted. Three-dimensional gravity modelling shows that the upper surface depth of crystalline rocks (Basement rocks) ranges from 170 to 374 m.

Keywords: Gravity; North Nasser lake; Power spectrum; Deconvolution; Egypt

1. Introduction

This study has shown that the Mafid area isn't as simple as shown on the geological map and has a more complicated pattern. The main pattern NW-SE trending faulting systems indicates that the Mafid area is characterized by the intersection of different fault patterns and is highly tectonically fractured, as can also be seen from the surface geological investigation. The tectonic stability of the Aswan area has been impacted by Nasser Lake, according to earlier geological and geophysical research, because some pre-existing faults have been reactivated by water seeping through exposed fissures and other tectonically vulnerable regions of the underwater land (Kamel and Elsirafe, 1993). The gravity data can be used for delineating the subsurface structures and defining the depth of basement rocks to locate the basins which can be referred to as the best locations for oil accumulation (Sultan et al., 2009; Araffa et al., 2014 and 2015; Abdelazeem et al., 2020). Microgravity observation has been carried out on a high-resolution grid in and around the Mafid region and gravity data qualitative and quantitative analysis has been carried out to identify shallow and deep-seated structures. This has been done by the Bouguer anomaly map interpretation as deduced from the gravity survey. To do this, spectral analysis was performed on the gravity data to identify deep sources and shallow sources. This paper is primarily concerned with the analysis and interpretation of gradient-based applications of Bouguer gravity data

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(filtering together with Euler deconvolution), furthermore, on surface and subsurface geology data that is available. It is important to link the seismicity with the underlying structures to identify the seismic sources. The objective of this research is to figure out the pattern of the Mafid region and its relation to the tectonic and seismological activities in the region by using microgravity.

2. The Reservoir Area's Surface Geology, Structural Setting and Seismicity

The geomorphological setting of the studied area is characterized by thick Nubian sandstone on the western part of the lake and a basement outcropping on the lake's eastern part. The Precambrian rocks are composed of igneous and metamorphic rocks (Fig. 1a). The Nubian Sandstone is flat-lying, relatively unreformed and gently dipping west, while it is between 250 and 400 meters thick beneath the reservoir's westernmost portion (Issawi, 1969; 1978; 1982). This area is a stable shelf of carbonate and clastic rocks that have accumulated atop the Arabian-Nubian Shield's crystallization, which is surrounded by shallow- and deep-water distorted unstable shelf sediment layers (Said, 1962; Youseff, 2003). It belongs to the Archican Nubian shelf under another modified categorization (Meshref, 1990).

The study area's geological layers are sedimentary rocks in shallow, deep, and near-shore waters from the late Cretaceous through the Tertiary and the Quaternary, as well as gravel deposits. These rocks are deposited over a granite basement from the late Precambrian period (Jerris, 2014). The Nubian Plain rises to a height of around 200 m above sea level (Issawi, 1969).

Faults cut through the plain of Nubia and the plateau of Sinn El-Kaddab, generally running eastern to western but also occasionally northern to southern and southwestern to northeastern (Fig. 1a). The faults' lengths of strike range from a few km to more than 200 km. In contrast to a continuous, uninterrupted fault trace, Numerous lengthier faults are divided and made up of several faults (Woodward-Clyde Consultants, 1985). In the studied area, two significant fault systems can be identified: Seiyal and Kalabsha faults are examples of the east-west fault trend. The system of north-south faults includes Kurkurthe, Gabel El-Barqa, Abu Dirwa, Khor el-Ramla, and Gazelle faults. Compared to faults that follow an east-west trend, the faults with a north-south trend are significantly more localized and run approximately parallel to Lake Nasser's main course (Issawi, 1978; 1982). There are no wells drilled in the study area that were measured by gravimetric measurements.

According to the extensive historical record dating back to Pharaonic times, the High Dam in Aswan is situated in an area where earthquakes occur relatively infrequently (Kebeasy, 1990; WCC, 1985). However, after the filling began and before November 1981, there was a small amount of seismic activity near the reservoir (Kebeasy et al., 1982). Yet, no incidents are listed in instrumental collections within a 20-kilometers range of the Aswan region (Kebeasy and Gharib, 1991). Aswan's seismically active zone is the one that is nearest to Egypt's High Dam, which controls irrigation and energy. Due to the first local seismic network being present in the area, thorough studies regarding the area's seismic activity were conducted to ensure the High Dam's safety (Mohamed, 1997 and 2001).

Fig. 1b shows the distribution of seismicity in and near Aswan from 1982 to 2021, which is categorized by moment magnitude. On the Richter scale, the magnitude values are more than 0.1 and less than 5.9, and the depth of seismic events from less than 1 to greater than 30 km Fig. 1c.

The percentage of earthquakes for magnitudes less than 1; 1-2; 2-3; 3-4; 4-5 and 5-6 is 14.19, 52.04, 29.66, 3.56, 0.49, and 0.05 (Fig. 1b).

The percentage of earthquakes for the depth of seismic events less than 1; 1-5; 5-10; 10-30 and greater than 30 is 1.78, 32.67, 41.31, 27.05, and 0.09 (Fig. 1c). Most of the fault elements dissect the sedimentary rocks, according to this fact, there is a relation between the structures and seismicity.

The November 14, 1981 earthquake (Kalabsha earthquake), which occurred at a depth of 20 km along the Kalabsha fault and had a magnitude of 5.3, was the most significant instrumental earthquake to occur in the study region in the previous 38 years. As a result, extensive research has been done to

determine the source of Aswan's seismic activity (Simpson et al., 1990) found that just below Gabel Marawa, he only experienced the Kalabsha earthquake and its immediate aftershocks at depths of 15–30 km. The Aswan region's other seismic activity is all less than 12 km away. Based on (Hassib et al., 2010), a deep seismic activity follows a typical aftershock pattern and disappears over time, but shallow seismic occurrences are still triggered in the seismic belt around Aswan.

Most of the seismic activity in Aswan looks to be concentrated where the north-south fault system and the east-west trend intersect. Moreover, this intersection zone is a favorable location for the build-up of tension and the occurrence of earthquakes (Hussein et al., 2013). It was found that the lateral movement of the transverse fault trends along the EW fault patterns (Hassib, 1997; Hussein et al., 2013; Abou-Elenean, 2003).

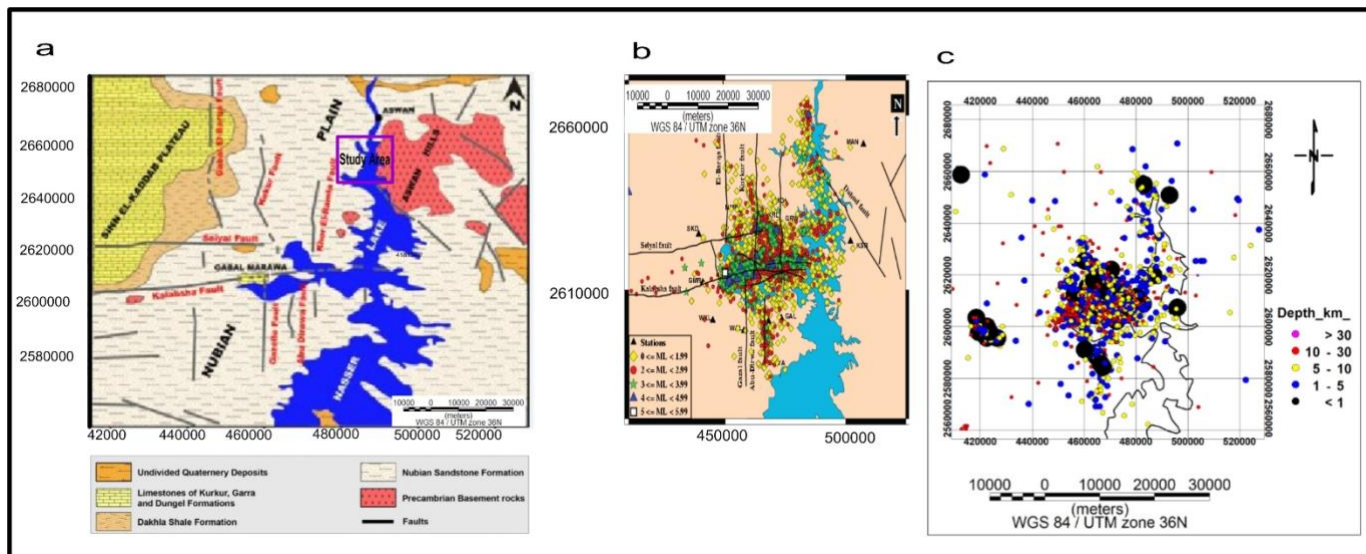


Fig.1. (a) The Aswan region's geology, geomorphology, and tectonic setting, modified after EGSM (1981); (b) Seismic of the Aswan from 1982 till 2021 after the Egyptian National Seismological Network (ENSN); (c) Depth of seismic events of the Aswan from 1982 till 2021 after the Egyptian National Seismological Network (ENSN)

3. Methodology

This study uses gravity data for delineating subsurface structures. Gravity measurements are obtained using CG-5 Autograv with a sensitivity of 0.01 mGal via 1665 gravity stations in space between stations 20–30 meters apart. It is observed that, most profile of gravity survey trending NE-SW to E-W. The spacing between the profiles approximately range between 100-300 meters (Fig.2a).

The gravity data measurements are reduced for various corrections, including topography, tide, latitude, and other corrections (Oasis Montaj, 2015).

3.1. Gravity Data Spectral Analysis and Filtering

The crust's depths of notable density contrasts, where the crustal structure is poorly understood, are revealed by the power spectral analysis (Fig. 2b and c).

The regional component can be separated from the residual component using a variety of techniques, such as low-pass and high-pass filters and Euler deconvolution. The energy (power) spectrum was utilised to apply the high-and low-pass filtering technique (Wingograd, 1978). The technique of high and low pass filtering (Figs. 3a and b) is used for gravity filtration at a wave number of 0.4201, which arises from the power spectrum curve.

Also, the Euler technique is used to estimate the different Euler solutions, which are superimposed gravity maps with zero structural index (SI). Moreover, the Euler deconvolution determine faults or contact at various depth levels, dissecting the examined area (Thompson, 1982). Based on information about the source geometry, the SI must be selected. SI, for instance, is equal to two for spheres, one for horizontal cylinders, zero for faults, and -ve one for contacts (Reid et al., 2003). In order to identify defects in the gravitational field (Reid et al., 1990 and 2003) and (Reid, 2003) proposed a structural index of zero. The best solution is shown at SI = 0 (Fig. 4b). The important trends of structural elements, which are determined by the high pass gravity map (Fig. 4a) and the Euler deconvolution of structural index equal to 0, are represented by rose diagrams (Fig. 4b).

3.2. Quantitative Analysis

Applying the quantitative analysis to the Bouguer gravity anomaly map in 2D and 3D uses the (Oasis Montaj Program, 2015). The method of 2D gravity modelling was used along four profiles (Fig.5a) via which the main gravity anomaly in the research area was cut P1-P1", P2-P2", p3-P3" and P4-P4" are the chosen profiles, as illustrated in Figs.5b, c, d and e. A direction from west to east is used for profiles (P1-P1", P2-P2", P3-P3"). From south to east is the direction in which the four-model is taken (Fig.5a). Modelling the mentioned cross-section has been done by finding the model that best fits the observed gravity variation along the profiles.

3D modelling has been carried out on a selected polygon in the studied region (Fig. 2a). A selection of the 3D polygon has been subjected to a significant gravity anomaly pattern, where the E-W trending anomaly intersects the N-S one. I collect many samples from the Nubian sandstone and basement rocks in and around the study area and measured the density in the laboratory of NRIAG, where the average density of the Nubian sandstone is 2.2 gm/ cm³ and the basement rocks is 2.67 gm/ cm³.

This has been done through multiple iterations to obtain the minimum residual between modelled and observed gravity data along the selected polygon (Figs. 6a and b). Based upon a continuous density difference between 2.2 gm/ cm³ of the sediments and (2.67 gm/cm³) of the basement, the sedimentary basin's thickness is approximated. The observed map of 3D modeling is a part of the Bouguer anomaly map (Fig. 2a). 3-D view map and basement depth map is drawn based on the outcomes of 3D gravity modeling (Figs. 7a and b).

4. Results and Discussion

The Bouguer anomaly map (Fig. 2a) shows a complicated anomaly pattern. The most significant feature is a low gravity anomaly in the southern part of the studied region with an amplitude of about 2 mGal/ km. On the other hand, a high gravity gradient can be observed in the northern part with a gradient of up to 5 mGal/ km. The higher gradient suggests a shallow fault pattern. The complicated gravity pattern suggests the intersection of the NW-SE fault with the older E-W fault set. This explains the recent seismological activity that occurred in the Mafia region.

Figs. 2b and c, displays the findings of the spectrum analysis of the Aswan active region's Bouguer anomaly.

There are essentially three elements that make up the spectrum: an extremely steep section with small wavenumbers ($0 \text{ km}^{-1} \leq \text{wavenumber} \leq 1.23 \text{ km}^{-1}$) and a portion that is less abrupt at medium

wavenumbers ($1.23 \text{ km}^{-1} \leq \text{wavenumber} \leq 5.01 \text{ km}^{-1}$) Additionally, with high wavenumbers, a soft part ($5.01 \text{ km}^{-1} \leq \text{wavenumber} \leq 14.8 \text{ km}^{-1}$) was noticed.

The gravitational depth, as determined by the power spectral analysis of the Mafid area's Bouguer anomaly, is displayed in Fig. 2c. There are three different layers that can be distinguished: the near-surface layer depth is about 32 m, the intermediate-seated layer depth is about 92 m and the deep layer depth is about 437 m. The wave number obtained from the power spectrum ($0.4201/\text{km}$) was used for high and low pass filtering. Digital filtering is an optimum tool to enhance both shallow and deep gravity sources using the equation: $H = -S/4\pi$ Where H represents the depth and S represents the slope of the logarithmic (energy) spectrum, they are separated.

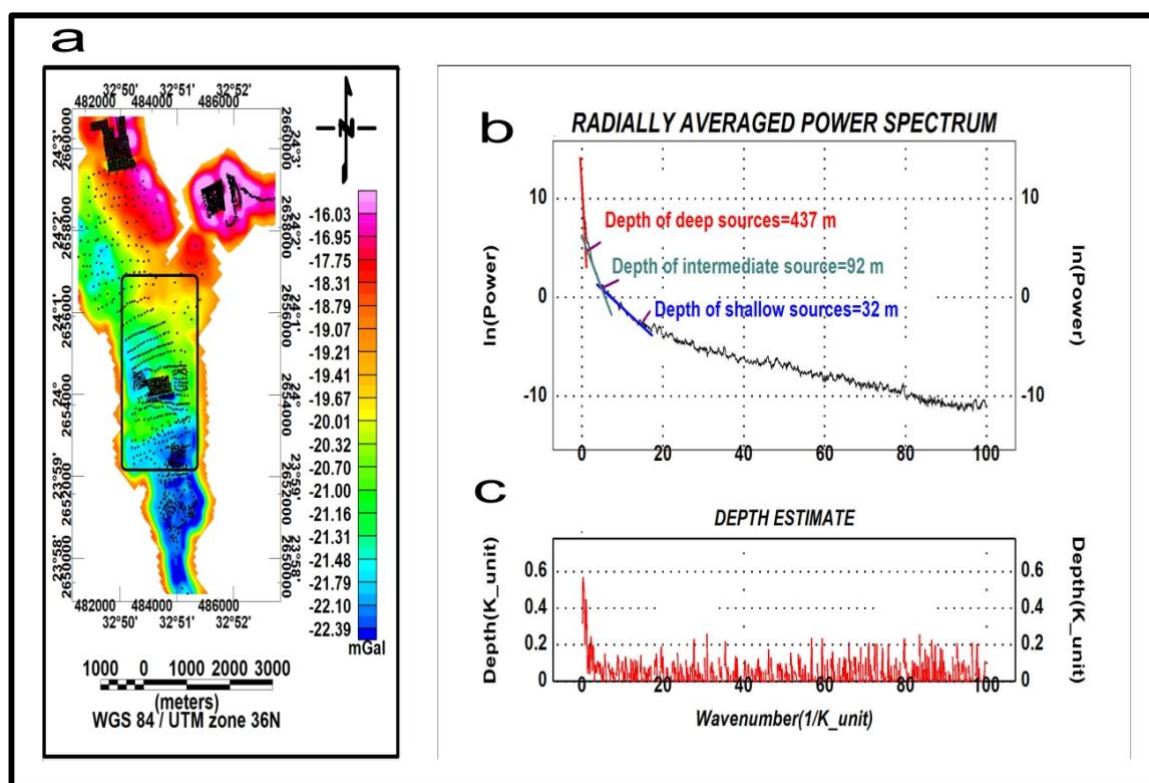


Fig. 2. (a) Bouguer anomaly map of the Mafid area (South Egypt); (b) Power spectrum curve of the Mafid area (South Egypt); (c) Depth of gravity using averages of the energy spectrum's slope of the Mafid area (South Egypt)

The map produced by the high-pass filter (Fig. 3a) reveals that the field of gravity anomalies has a value range of (-1.53 to 1.32 mGal) and most anomalies are considered to be trending in a NW-SE direction.

The map produced by the low-pass (Fig. 3b) reveals that the field of gravity anomalies has a value range of (-22.22 to -16.99 mGal) and most anomalies are observed to be trending north-south, east-west and northwest-southeast.

The denser basement rock's uplift is primarily responsible for the high gravity anomaly, while sedimentary basins are indicated by the lower gravity readings. High-pass filter shows the high-amplitude shallow sources fault pattern, while low-pass filter shows the faulting pattern has a deep-seated origin.

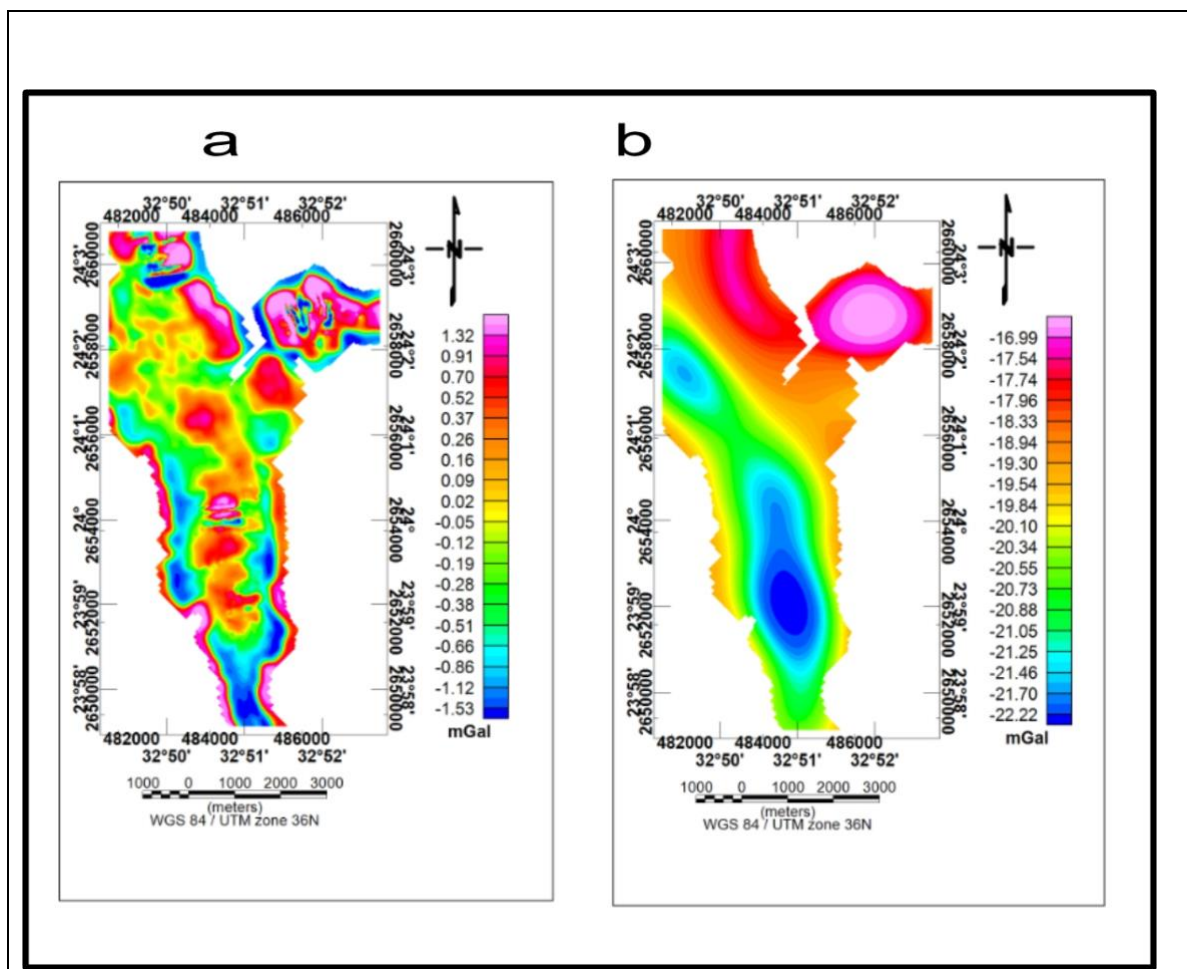


Fig. 3. (a) Gravity residual anomal (High pass) of the Mafid area (South Egypt); **(b)** Gravity regional anomal (Low pass) of the Mafid area (South Egypt)

It was determined from the residual Bouguer anomaly map which structural patterns were prevalent in the area under study. Various rock types' estimated faults and/or contacts with varying directions and lengths are shown by the map's lineaments that have been detected.

As illustrated in (Fig. 4a), clockwise from the north, these lineaments underwent measurement, statistical analysis, and a rose diagram presentation, one of the Rock Ware Utilities Package's components.

A total of 8 faults were found to pass across the area under study. These faults are numbered in (Fig. 4a) and follow several trends, including NW-SE, NNW-SSE and NE-SW.

A fault's trend at SI = 0 (Fig. 4b) is remarkably identical to the trend of faults shown in the residual gravity anomaly map that is divided by faults (Fig. 4a).

The best solution is provided by structural index (0) and the Euler map displays depth ranges of less than 40 meters to more than 450 meters (Fig. 4b). The trends of the fault elements are represented by rose diagrams, and the major trend is northwest-southeast (Fig. 4a and b).

The Euler Deconvolution method's results revealed that the basement could be seen on the surface (40 m above the surface) in the north and has gotten deeper in the center, which is between 200 and 300 m deep.

The High Dam area is the part of Aswan that is most folded. This might be caused by shallow intruded bodies. NNW and NW directions are where the majority of contact solutions are trending, roughly coinciding with the Red Sea's main trend. In a few locations, it is found that solutions have a NE-SW trend. This trend has something to do with the Red Sea rifting's transformed faults (Said, 1990).

According to 2D gravity modelling (Fig. 5b, c, d and e), the basement depth ranges from 22 meters to 697 meters.

Three-dimensional (3D) modelling is applied to Bouguer data using GMSYS-3D, which estimates the crystalline's depth basement rocks. The calculated and observed maps are correlated (Figs. 6a and b) and the error rate is relatively low (Fig. 6c).

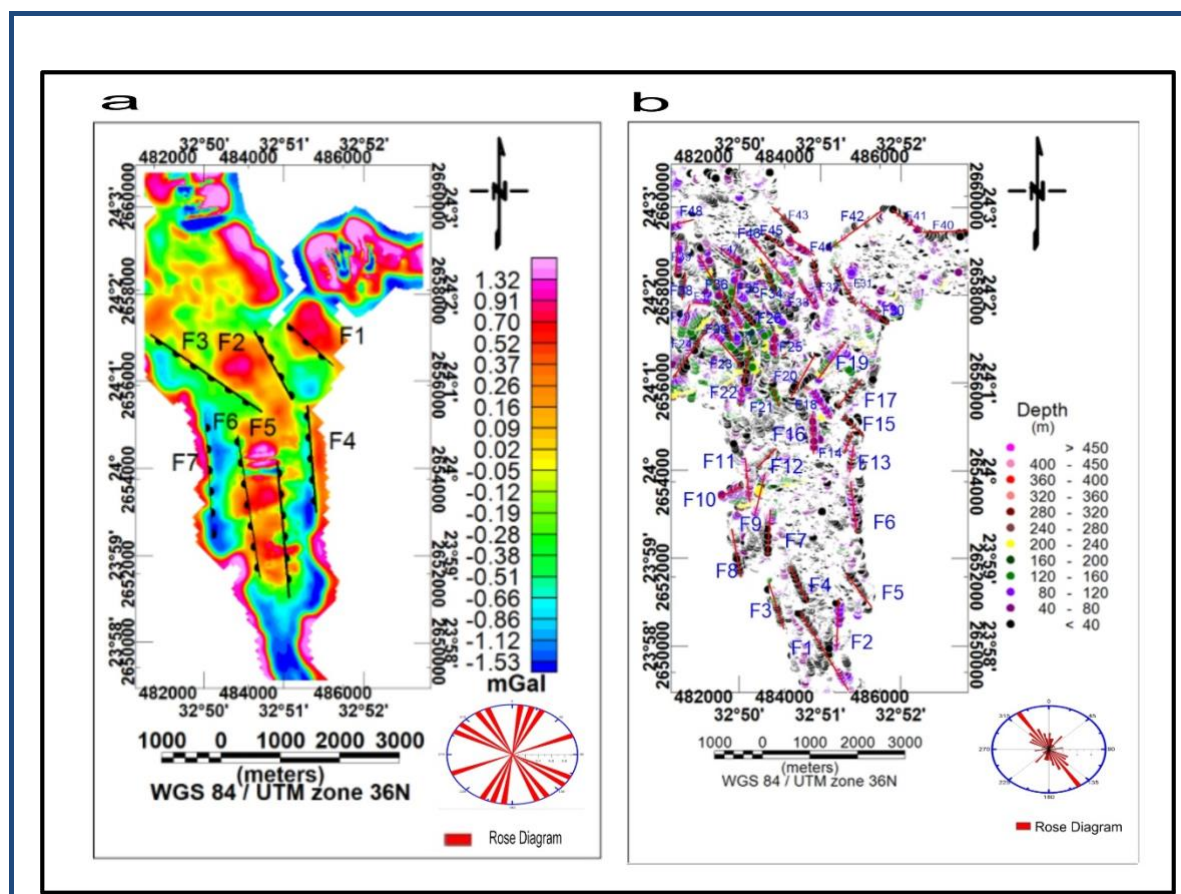


Fig.4. (a) and (b) the Mafid area's fault elements from highpass and Euler solutions with structural index zero and significant trend faults dividing the Mafid region, respectively

The basement depth map is drawn based on the results of 3D modelling (Fig. 7b), which shows the upper surface of crystalline rocks (basement), and has a value between 170 and 374 m. The central and southern areas of the examined area have basement depths that are deep, with values that are deeper than 295 m underneath the surface, indicating a sedimentary layer that is thick. However, they gradually decrease in the NE, NW, SE, E, and SW directions of the area, with values of more than 260 m below the surface.

5. Conclusions

According to obtained results, the following conclusion can be displayed:

The Bouguer anomaly map shows a complicated anomaly pattern with an amplitude up to 2 mGal and 5 mGal in the northern and southern parts of the studied region. The pattern suggests the intersection of the NW-SE fault with the older E-W fault set. This explains the recent seismological activity accrued in the Mafia region.

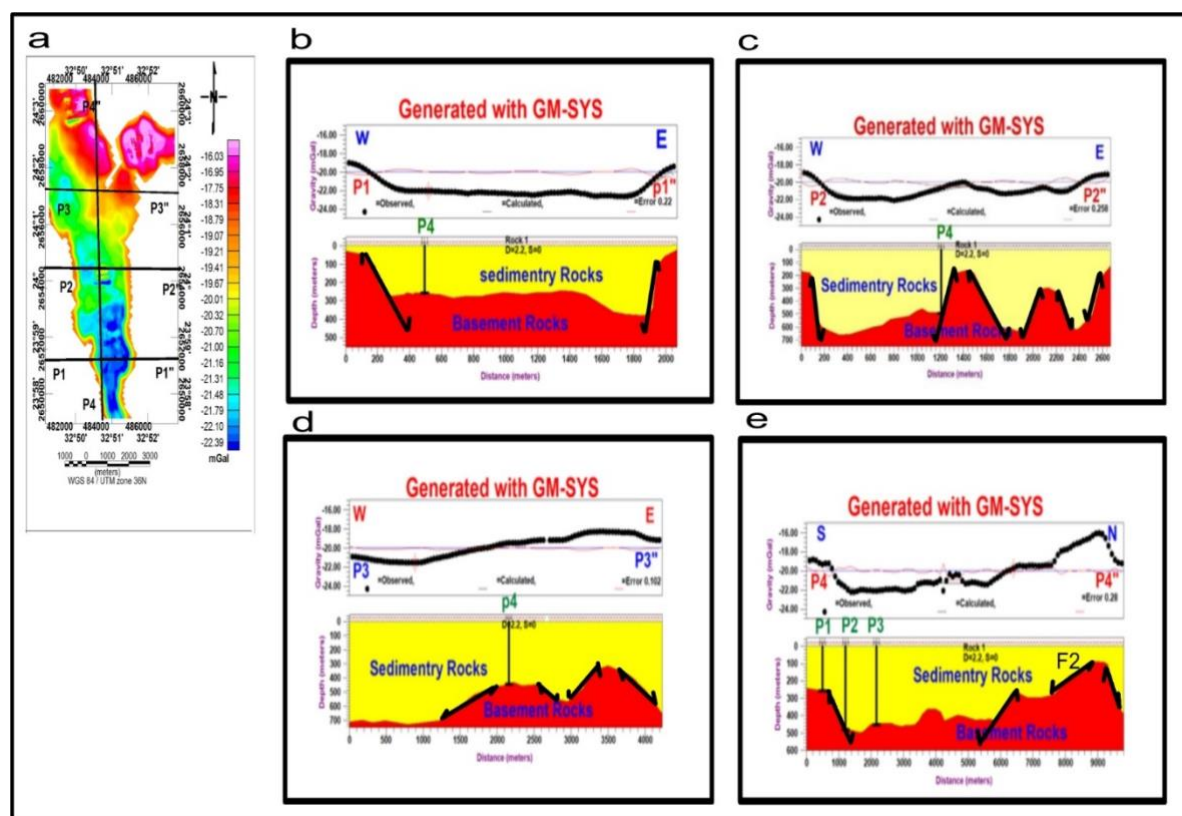


Fig.5. (a) Gravity profiles locations of the Mafid area and the 2D Gravity modelling along profiles **(b, c, d and e)**; P1-P1'', P2-P2'', p3-P3'' and P4-P4'', respectively

The Bouguer anomaly map's spectral analysis indicates the near-surface layer depth is about 32 m, the intermediate-seated layer depth is about 92 m and the deep layer depth is about 437 m. To enhance both shallow and deep gravity anomaly, digital filtering has been used on the Bouguer anomaly map.

The High-pass map displays many small-scale features with general NW-SE, N-S, and E-W trends and the low-pass map shows general north-south, east-west and northwest-southeast trends. The high-pass filter shows the high-amplitude shallow recent fault pattern, while the low-pass filter shows the faulting pattern has a deep-seated origin.

The Euler Deconvolution method's results revealed that the area's basement could be seen on the surface (40 m above the surface) in the north and has gotten deeper in the centre, which is between 200 and 300 m deep.

2-D gravity profiles have been modeled to show that the source body is of different density contrast, depth, and width and the outcomes of a 2D gravity model are between 22 and 697 m and are consistent with the depth of basement rocks calculated using 3D gravity modelling and the depth estimated by Euler deconvolution.

The research area's southern and central regions have basement depths that are deep and reach values of greater than 295 m underneath the surface, which suggests a thick sedimentary covering. However, in the NW, NE, SE, SW, and E directions of the area, they gradually decrease, where they reach values of less than 260 m below the surface.

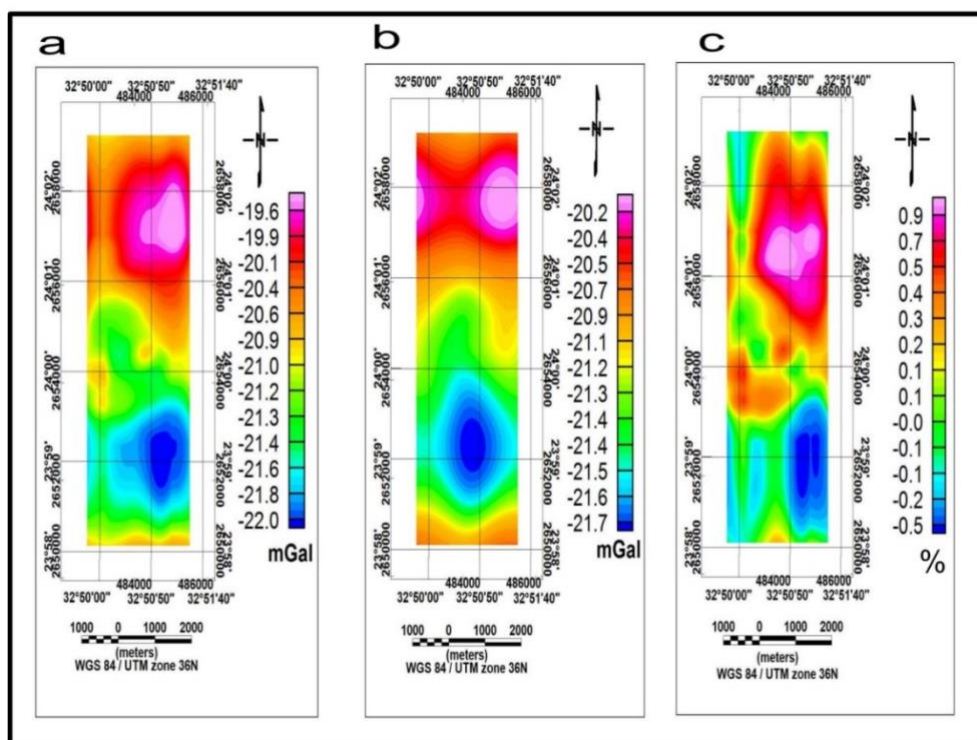


Fig. 6. (a) Observed gravity anomalies; (b) Calculated gravity anomalies; (c) Percentage of errors of the Mafid area

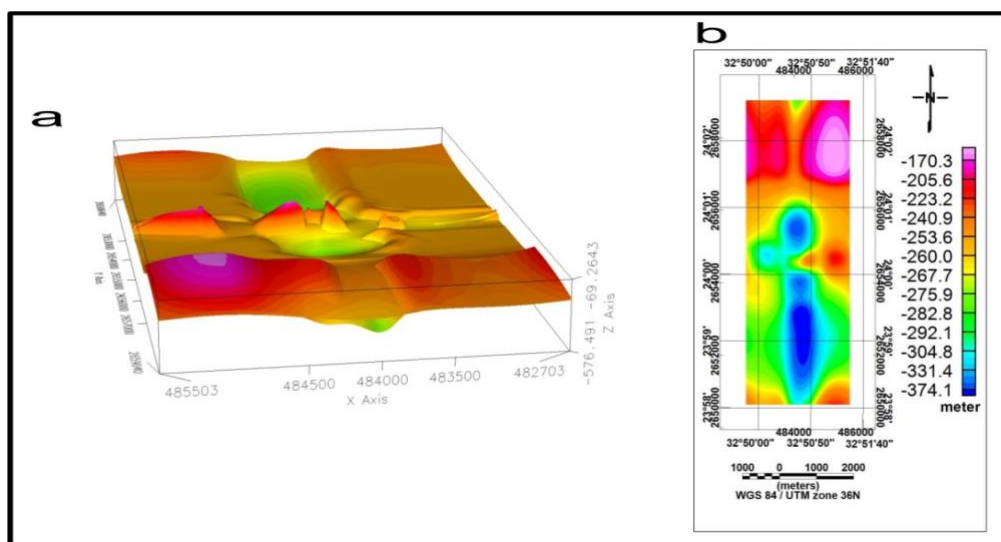


Fig. 7. 3-D view map (a) and Basement relief map (b) of the Mafid area

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