Subsurface structural characterization as deduced from potential field data—West Beni Suef, Western Desert, Egypt

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Received: 25 November 2020 / Accepted: 23 September 2022 / Published online: 19 October 2022
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Abstract
The goal of present study is determining subsurface structural elements by analyzing geomagnetic data sets aiming to examine their impacts on geological surface structures characterizing the western region in Beni-Suef Governorate, Western Desert, Egypt. A land-magnetic survey is conducted by two exceedingly sensitive proton magnetometers to measure the total intensity of geomagnetic field at the region under investigation. The measurements of regional gradients and time variation were applied to get the required reduction of daily variation. The regional expansions of subsurface structural units were obtained after applying the reduction to north magnetic pole (RTP) method to the corrected magnetic data acquired from land-magnetic survey along with Bouguer maps (1:100,000 scale and 1-mGal contouring interval). Regional-residual technique was applied depending on the power spectrum analysis. Moreover, the edge detection approach is conducted to depict the structures and subsurface hidden anomalies. Different handling processes were applied for acquired land magnetic datasets such as Euler deconvolution and trend analysis. The results of current study revealed that four significant structural forces across the N-S, NW–SE, NE-SW, and E-W directions affected the region. Estimating the basement depth was accomplished using a number of spectral analysis techniques. The values of estimated depths are used for creating a basement relief map. Moreover, the achieved results show that depths to the basement at the region under study vary between 2.3 and 4.7 km.

Keywords Magnetic survey · Gravity data · Depth of basement and subsurface structures

Introduction
The investigated region locates in western part from Beni-Suef Governorate, which found at the northeast part of the Western Desert. It is approximately 150 km faraway from Cairo in southwest direction. That region covers about 485 km² (lat. 29.06–29.25° N and long 30.81–31.03° E) as shown in Fig. 1A and B. Delimitating the structure and surface of basement in this area is exceptionally imperative since this range is promising for hydrocarbon exploration. One of foremost vital issues confronting the oil investigation companies is how to set the basement surface. In this consider, we attempted to decide the basement surface to dodge these problems during the penetrating of unused wells.

The most important geological applications of magnetic and gravity (M-a-G) overviews are to plot the auxiliary patterns for ensuing the lineations in M-a-G forms. Geophysical examinations such as M-a-G overviews above the sedimentary rocks show a few irregularities at shallow and profound profundities, which are regularly associated with rocks that covering the magnetic properties. This work proposed to investigate the area’s basic setup and structural system utilizing the M-a-G information. Distinctive handling strategies are connected on potential field information both M-a-G to reach the purpose of present study.

Geologic settings
The geologic map of the studied area is shown in Fig. 1C, and it shows different rock units from the Tertiary (Middle Eocene and Pliocene) and Quaternary eras. This map was modified after Said (1981) and Conoco (1987).
Tertiary rocks

Tertiary deposits are recognized from more seasoned to more youthful into the following: (1) Middle Eocene rocks are mostly composed of shallow marine limestone with *Nummulites gizehensis* that intercalated with shale and sandy shale related to Wadi Rayan formation. (2) Pliocene rocks, agreeing with Said (1971), the Pliocene silt of the Nile-Valley is separated into two parts: a lower marine grouping (marine deposits) and an upper fluvial non-marine deposits (late Pliocene age). The Pliocene sediments within the region beneath research are composed of undifferentiated clay, sand, and conglomerate.

Quaternary rocks

Concurring to Said (1981), the Quaternary deposits are recognized from more seasoned to more youthful into Pleistocene deposits and Holocene ones. The Nile Valley’s Pleistocene deposits include the Protonile (Early Pleistocene), the Prenile (Middle-Pleistocene), and the Neonile deposits. On the other hand, deposits of Holocene age contain an arrangement of non-consolidated sediments gathered beneath unsteady natural circumstances. They include the sand dunes and Nile Silt.

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**Fig. 1** A location map. (A) Google-Earth image for north Egypt includes Beni-Suef basin boundaries. (B) Beni-Suef Concession map. The considered area is surrounded by the red rectangle. (C) Geologic map includes the region under study (modified after Conoco, 1987). (D) Structural settings in the North-East Africa and Eastern Mediterranean region [modified after Guiraud et al. (2005) and Bosworth et al. (2008)]. The paleo-coastline during early Cretaceous period is achieved by Wycisk (1994). Inserted map demonstrates the recharging of West Gondwana separation in Early Cretaceous age after Guiraud and Bellion (1995). The black and white arrows in the map indicate the movement directions of the Arabo-Nublian masses at the early stage of Barremian and Late Aptian age (Guiraud and Maurin, 1992).
Tectonics and structure

To supply an exact and persuading picture of the structural system of the considered area, we must begin with dissect the regional structural components that influenced Western Desert. According to Schlumberger (1984), the Western Desert is distinguished into four structural units from southern side to northern one as follows: miogeosyncline, hinge zone, unstable shelf, and craton and stable shelf. Meshref (1990) stated that six major geo-tectonic elements (cycles) are recognized within the Western Desert. These geo-tectonic elements are the Caledonian phase, the Variscan Hercynian phase, the Cimmerian-Tethyan period, the Sub Hercynian and Early phase of Syrian Arc, the main phase of Syrian Arc, and finally the Red Sea stage. The Beni-Suef Basin can be considered as a petroliferous fracture basin. Shehata et al. (2018) showed that upper and lower constituents of Kharita formation are shaped amid syn-rift stage of basin formation. Moreover, the studied basin is defined as a half-graben rift basin due to tensional forces that occurred in Central and North parts of Africa during expansion of South-Atlantic Ocean in the Early Cretaceous age as revealed by Bosworth et al. (2008), see Fig. 1D. This basin is one of features of intra-continental rift basins (Bosworth et al., 2008). Agreeing with Moustafa (2008), Jurassic and early stage of Cretaceous sediments had been stored in half-graben basins as the North African rifting basins. During Early Cretaceous time, continental rifting at North Africa part and Arabia was very dynamic (Guiraud & Bosworth 1999).

Potential field data

Gravity data

A Bouguer map with 1:100,000 scale and 1-mGal contouring interval is presented in Fig. 2. This map is constructed by the General Petroleum Company of Egypt in 1976. The map was digitized in a network arrange with 1-km intervals. The gridding of gravity information was tight sufficient for keeping the irregularity data contained, and the information was collected at a secure space.

The investigation of this map uncovers high and low gravity inconsistencies of different sizes, shapes, patterns, and expansions. The irregularities of gravity data that observed in the inspected region can be described as follows: the major zone that characterizing by high values for gravity inconsistency (amplitude ranges from −8 to −16 mGal with an E-W trend) is observed in the western side. The second zone, which runs from the northeast to south, is characterizing by halfway gravity irregularity with amplitude extends from −16 to −24 mGal and the NNE-SSW and N-S patterns. The third zone, which is found within the southeast, is stamped by a low gravity irregularity. The NE-SW trends with amplitude extending from −24 to −28 mGal. The gravitational field within the western and northern headings agrees with the Bouguer irregularity map (Fig. 2). This may indicate the boundary of crust-mantle is more and more profound within the southeastern than the western and northern.
**Magnetic data**

Two proton magnetometers were utilized in a north–south line of navigation to conduct an intensive arrive magnetic survey. One magnetometer was used as a diurnal correction base station, whereas the other was utilized to degree add up to magnetic concentrated over the investigated zone. Controlled by surface geologic features within the studied region, the distance between stations along the surveying profile was ranging between 500 and 700 m. The positions of the estimation locales were set up using Global Positioning System (GPS) with a precision of almost 1 m. In addition, a magnetic concentrated map with contouring interval (10 nT) has been built after applying the needed corrections.

**Total magnetic intensity map (TMI)**

The overall magnetic irregularities (Fig. 3A and B) can be assembled into diverse zones agreeing to their magnetic anomalies value. High positive magnetic irregularities concentrated within the northeastern parcel of the explored region which characterized by the occurrence of positive anomalous magnetic structure, their values range between 0 and 224 nT, and it takes semi-circular and stretched shapes. This high positive peculiarity is related to the thin sedimentary cover.

The second magnetic inconsistencies appeared as circular and prolonged shapes with N-S, NE-SW, and NW–SE trends. The halfway magnetic irregularities, which show up as a negative magnetic irregularity, concentrated within the middle parcel and expand from northwestern to southeastern portion, the northwestern portion and one spot in the northeastern portion of range beneath examination, most of them are negative magnetic anomalies which have esteem extending from 0 up to 238 nT. This middle magnetic anomalous structure is a middle recurrence and demonstrates on the middle sedimentary cover in this parcel of study region.

The third magnetic anomalies appeared as circular and stretched shapes with slant N-S, NE-SW, and NW–SE directions. The low magnetic irregularities, which show up as negative magnetic inconsistency, concentrated within the southern and southwestern parts; this magnetic irregularity contains a negative value ranging from −238 to 538 nT. This low magnetic irregularity could be a high recurrence that shows on the thick sedimentary covering layer in this part of the study area.

**Reduction to the pole (RTP)**

To decrease extremity impacts, a lessening to north magnetic pole (RTP) strategy is ordinarily connected to add up to escalated magnetic information (Blakely and Simpson, 1995). The crests and slopes of magnetic inconsistencies are adjusted straightforwardly over their sources employing a filtering procedure.

In the present investigation, the Geosoft-Oasis-Montaj (2007) software was applied for diminishing the recorded magnetic data to the magnetic pole (RTP). The information that was inputted to the software program was as follows: inclination value in degree (42.969°), declination value in degree (4.139°), the intensity of geomagnetic field (43,082γ), and the instrument sensor elevation (1 m).

**Fast-Fourier transform (FFT)**

FFT technique is applied to both M-a-G data sets for the estimation of energy spectrum curves and also to determine residual and regional sources. Radially averaged power spectrum approach was applied for computing depths of volcanic intrusions, basement complex depths, and subsurface geologic structures (Lee, 1960 and Bhattacharyya, 1966).

**Gravity data results**

FFT strategy is utilized to build 2D power spectrum and also to perform assist-filtering processes. Figure 3C indicates two straight fragments relating to regional and residual components within power spectrum curves. Besides, the wave-numbers indicate deep sources extending from 0.017 to 0.094 cycles/km (mean depth to their tops is almost 4.75 km), whereas shallow sources have wave-numbers extending from 0.094 to 0.36 cycles/km (average depth to their tops is approximately 1.50 km). The noisy zone of range features is a recurrence more prominent than 0.36 cycles/km.

**Magnetic data results**

Power spectrum graphs (Fig. 3D) indicate two straight fragments related to regional and residual components. In addition, the analysis of the regional constituents with smaller wave-number (smaller than 0.011 cycle/km) indicates that the depth of deep objects is about 4.9 km. Moreover, the higher wave-numbers indicate near-surface sources with about 1.16 km depth.

**Regional-residual separation**

**Regional separation**

The low-pass filter improves the regional gravity map, which is exceptionally comparative to the Bouguer map; the regional N-S and NE-SW gravity inconsistencies show a slightly gravity gradient and increment laterally from the southeast to the west portion (Fig. 4A). We noticed that, there is a remarkable correlation between...
the regional magnetic map after using the low-pass filter and the initial RTP map with an impressive improvement and smoothing in the N-S regional low magnetic intensities trend and the high magnetic inconsistency trend NE-SW possessing the northeastern portion of studied region (Fig. 4B). Moreover, the elongated regional magnetic low peculiarity at the southern portion was improved. Besides, the map uncovers a diminish within the number of neighborhood inconsistencies and also a discharge in their magnetic gradients.

**Residual separation**

The residual gravity map portrays a complicated gravity design with numerous nearby gravity irregularities of shifted amplitudes and introductions (Fig. 4C), where number of gravity features and their trend increase by increasing the height of extension. The residual gravity map’s major patterns are N-S, NW–SE, and NE-SW trends. From the high-pass filtered residual magnetic map, it is obvious that, there is an increment of nearby magnetic inconsistencies with distinctive polarities (Fig. 4D). The residual magnetic map with high-pass filter clearly appears an increment within the number of neighborhood magnetic inconsistencies with different polarity (Fig. 4D). These irregularities have changing shapes, expansions, orientation, and a noteworthy gradient that increment as the stature of the continuation increments. Two regions or zones of residual inconsistencies were observed. The first one is recognizable by
the occurrence of positive peculiarity values increasing from 135 nT, see Fig. 4D. The most patterns of these peculiarities are N-S, NE-SW, and NW–SE. The second one characterized by occurrences of negative inconsistencies esteem extending from 0 to −194 nT, clearly appeared in Fig. 4D. The major patterns of these peculiarities are N-S, NE-SW, and NW–SE.

**Edge detection methods**

**First vertical-derivative map**

The vertical subsidiary strategy is broadly utilized to progress the shallow geologic source in RTP magnetic data. Vertical subsidiary maps emphasize gradients at the borders of shallow geomagnetic sources. As a result, they are used for discovering boundaries of the magnetic body and to distinguish sources at shallow profundities (Dobrin and Savit, 1990). The RTP magnetic information was utilized for creating the first vertical subordinate map (Fig. 5A). Zero contour lines at this map clearly depict the most magnetic sources and give a wonderful figure with respect to the conveyance of magnetic inconsistencies. The zero contour lines may indicate the presence of faults. The major course of the magnetic sources is north–south, with some amplifying to the northeast and northwest.

**Horizontal-derivatives map**

Horizontal-derivatives for both the (X) and (Y) directions have been computed from the total geomagnetic field for data grids. The first horizontal-derivatives (FHD) is the root of sum squares of horizontal (X) and (Y) first derivatives. These derivatives are

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Fig. 4 Regional anomaly maps. (A) is created from gravity datasets while (B) is created from acquired magnetic datasets for the investigated region. Residual anomaly maps. (C) is obtained from the gravity datasets while (D) is constructed from magnetic datasets for the area under investigation.
capable of distinguishing the vertical boundary between subsurface rock units. Blakely (1996) reported that a FHD maximum or highest value indicates the fault structure’s appearance.

The first horizontal-derivatives map (Fig. 5B) shows boundaries and edges between different rock units. This map is produced from RTP magnetic data. Inspection of this map shows high anomalies in some places, representing positions of edges and boundaries. The most conspicuous FHD anomalies are high elongate positive anomalies that distribute in the whole map. The distinguished anomalous features are generally characterized by fairly high reliefs and low-amplitude values. The prolongation of the observed anomalies and their gradients that distinct between high and low areas reveals that the area is structurally controlled with major faults in N-S and NE-SW directions.

**Tilt derivative**

Tilt derivative (TDR) method is utilized in enhancing features and contributory object border recognition at the potential field pictures. TDR technique was first introduced by Miller and Singh (1994) and Verduzco et al. (2004) and later it was modified by some others researchers such as Salem et al. (2007 and 2008) and Fairhead et al. (2008). This filter is described as:

\[
TDR = \tan^{-1}(\frac{VDR}{THDR})
\]

where (VDR) is vertical-derivative and (THDR) is total horizontal-derivatives.

The magnitude of TDR ranges from \(-\pi/2\) to \(+\pi/2\) (in radian) or from \(-90^\circ\) to \(90^\circ\) (in degrees) whatever the magnitude values of the vertical-derivative or the absolute values of the total horizontal component (Salem et al., 2008).

Estimating basement depth

Two techniques are used for estimating the depth of causal bodies using magnetic data. These two techniques are Euler deconvolution technique and spectral depth analysis.

3D Euler deconvolution method

The depth and outline of basic geomagnetic or gravity-hidden bodies could be evaluated by Euler’s calculation for consistent capacities in 2D (Thompson, 1982) and 3D (Reid et al., 1990). This technique depends mainly on the hypothesis that localized structures’ abnormal magnetic areas can be considered as homogeneous parameters or functions for the source coordinate. The strategy runs specifically on the information and gives a numerical value without a plan of action to any
geologic limitations. The Euler-derived elucidation needs information about the geometry of the geomagnetic source and the vector of magnetization (Barbosa et al., 2000). The Euler deconvolution handling schedule of the Oasis Montaj™ can be the semiautomatic area and depth assurance computer program bundle for the M-a-G information (Hus, 2002).

Magnetic results

Magnetic thick step or fault model solution for the near-surface basic sources (Fig. 7A) and the deep-seated basic sources (Fig. 7B) are developed on regional-residual magnetic information. This gives the solution of profundities and areas of the faults that influence on diverse basement rocks at huge profundities by applying the basic record result ($SI = 0$). Near-surface basic sources’ profundities that were gotten run between $<250$ and $>1500$ m. This arrangement takes patterns in the N-S, NE-SW, and NW–SE bearings. The profundities of a deep-surface basic sources that were gotten reach to 3500 m. This solution takes patterns in N-S, NW–SE, NE-SW, NNW-SSE, and NNE-SSW bearings.

Gravity results

The arrangement of gravity inconsistency with a structure file ($SI = 0$) is represented in (Fig. 8) for the study region. Moreover, depth determination depending on 3D Euler deconvolution approach was utilized for a quick estimation of geologic contacts at distinctive levels. The entire contacts arrangement profundities map uncovers the subsurface contacts profundities reach to 3200 km with three major trending, the NE-SW, E-W, and NW–SE trends.

Determination of spectral depth

The calculation of profundities to buried or hidden rocks is one of the foremost common outcomes of the M-a-G information. The profundities of an individual M-a-G anomaly are calculated from widths and slopes of the inconsistency. The measurable procedure was used to deliver precise expectations of the basement depth beneath a sedimentary basin (Hahn et al. 1976 and Udensi et al., 2001). Spector (1968) and Spector and Give (1970) concocted a depth assurance procedure that compares the 2D power spectrum obtained from the magnetic information to corresponding spectral created from a hypothetical model.

Application of spectral analysis techniques using gravity data

The two-dimensional spectral investigation (Spector and Grant, 1970) has been connected to Bouguer gravity information. Twenty profiles covering nearly the Bouguer map (Fig. 2) are utilized for calculations of the profundities to surface of the basement. Figure 9A shows six illustrations...
for the spectral investigation calculation along profiles G1, G10, G12, G15, G17, and G20. All outcomes of the spectral investigation are organized in Table 1. Examination of these curves showed that basement surface profundities change from 2.5 km at the northwestern portion (profile G17 and G18) to almost 4.7 km at the most basin within the southeastern portion (profile G12).

Application of spectral analysis techniques using magnetic data

Twenty-six profiles were chosen and suffocate on the RTP map (Fig. 3B). They cover nearly the studied area, which is utilized to appraise profundities to the surface of basement utilizing the method.

Fig. 7 Basement depth as calculated by Euler deconvolution where (A) typical residual magnetic Euler solution map for fault (SI = 0), and (B) typical regional magnetic Euler solution map for fault (SI = 0)

Fig. 8 Depths to the basement rocks as estimated based on Euler deconvolution by typical gravity data with structure index (SI) = 0
of spectral analysis (Spector and Grant, 1970). Figure 9B shows a number of spectral investigation profiles that were calculated along some magnetic profiles (P2, P3, P12, P14, P17, and P25). The results of spectral examination strategy are organized in Table 2. This table shows the profundities to basement bedrock surface shifting from 2.30 km at profile P7 to approximately 4.44 km at profile P17.

Fig. 9  (A) Spectral analysis along profiles G1, G10, G12, G15, G17, and G20 as examples obtained depending on Spector and Grant (1970) technique. (B) Spectral analysis along profiles (P2, P3, P12, P14, P17, and P25) as cases of applying the Spector and Grant (1970) method. Basement depth as estimated from gravity datasets (C) and magnetic datasets (D) depending on Spector and Grant (1970). Rose diagrams demonstrate the evaluated structural trends at the study area as deduced from (E) regional magnetic Euler solution map, (F) residual magnetic Euler solution map, and (G) Bouguer gravity Euler solution map.
Basement depth maps

This map is developed from twenty gravity profiles as appeared in Table 1. The basement map (Fig. 9C) indicates that the sedimentary bowl thickness increments towards the southeastern and eastern parts whereas basement depth comes to 4.7 km. The basement surface’s shallow depth was shown within the northeastern and western parts, whereas the basement’s depth comes to 2.5 km. From this map, two major basins are noted; the first is found at the southern portion whereas the second is found at the eastern portion. The major patterns that show up on this map are NW–SE, E-S, and NE-SW directions.

On the other side, contour map of basement depth (Fig. 9D) is built from examination of twenty-six magnetic profiles as appeared in Table 2. The estimated values of depth suggest that the basement relief or surface is changing from shallow to deep in the direction of alleviation at the studied area. The depth to magnetic surface ranges from 2.301 to 3.201 km within the western and northern parts and 4.401 km within the southeastern. A closer perception demonstrates a common increasing in thickness at northwestern and southeastern areas. This common tendency of sedimentation processes indicates that the basin has more thickness at both the southwestern and northeastern parts. One of unmistakable sedimentary reservoirs is observed in northeastern and southwestern parts.

Structural trend analysis

Structural trend examination approaches have been broadly used to characterize basic issues in different areas of geology and geophysics. Agreeing to Hall (1964), there is a noteworthy relationship between the trend, pattern, and the intensity of M-a-G anomalies trends, which may be due to the presence and intensity of M-a-G differentiation in the body rocks included decides which faults show up on the M-a-G maps.

Application of structural trend analysis using magnetic data

Applications of Euler deconvolution on regional anomaly (Fig. 7B) and the residual irregularity maps (Fig. 7A) are built to decide the common basic patterns influencing the region under investigation. The azimuth and extent of every recognized lineament on the distinctive maps indicates to the fault lines and/or boundaries of shifting lengths and directions. Thus, the structure frameworks were significantly investigated and then plotted as rose diagrams, see Fig. 9E and F. These lineaments observed anticlockwise from south, and presented in Table 3. Examination of the regional rose chart (Fig. 9E) reveals five transcendent auxiliary patterns having variable force and lengths. These are the N-S, NNE, NNW, NW, and NE patterns, whereas examination of the leftover rose graph (Fig. 9F) shows three overwhelming

| Profile name | Depth of basement (km) |
|--------------|-----------------------|
| P1           | 3.2                   |
| P2           | 3.03                  |
| P3           | 2.43                  |
| P4           | 2.94                  |
| P5           | 3.15                  |
| P6           | 3.33                  |
| P7           | 2.30                  |
| P8           | 2.66                  |
| P9           | 2.57                  |
| P10          | 3.70                  |
| P11          | 3.84                  |
| P12          | 3.80                  |
| P13          | 4.00                  |
| P14          | 2.8                   |
| P15          | 4.00                  |
| P16          | 4.00                  |
| P17          | 4.44                  |
| P18          | 3.8                   |
| P19          | 3.48                  |
| P20          | 3.63                  |
| P21          | 3.48                  |
| P22          | 2.35                  |
| P23          | 3.81                  |
| P24          | 4.00                  |
| P25          | 3.12                  |
| P26          | 3.07                  |
auxiliary patterns with variable power and extents. These patterns are the N-S, NNW, and NNE that reflect the foremost predominant structural designs influencing the locale beneath examination as found from magnetic information investigation.

**Application of structural trend analysis using gravity data**

Gravity anomaly map solution (Fig. 8) was analyzed and investigated in order to identify the main structural patterns that affected the considered region. The detected lineaments on Euler map present the fault lines and/or boundaries between different rocks of varying lengths and directions (Fig. 8). The measured lineaments (with anticlockwise direction starting from the south direction) are represented in Table 3. These fault systems are analyzed statistically and plotted as rose diagrams (Fig. 9G). The inspection of these graphs indicated four main structural patterns or trends that have variable strength and length. These patterns are the NE-SW, N-S, E-W, and NNW trends. In addition, some minor structural trends were extracted from the rose diagrams, for example, the NNE, ENE, WNW, and NW trends.

**Results and conclusions**

Analyzing and investigating both the M-a-G data sets and maps and also separating both of them into regional and residual sections helped in determining the subsurface structural patterns of the studied region. The directional filtering analysis, edge detection, and Euler deconvolution approach were used to refine and update the structural forms or patterns of geological components derived from M-a-G maps. The edge detection process for magnetic information clearly defines the structural structures’ limits. The investigated area represents a part from Western Desert that has gone through several structural stages over its history. The mega shear (N-S direction) in East Africa and Pelusium may be involved in the earliest structural events. The NE-SW Aqaba pattern and the NNW-SSE pattern also take trends in the considered region into account. Syrian Arc structures were bordered and consequently re-activated by the Mediterranean E-W structures that occurred due to collision of the African plate and European plate. The spectrum investigation of Bouguer gravity and RTP information reveals that the average estimated depth gauges for shallow and deep sources are 1.5 and 4.75 km, respectively, for gravity information, and 1.16 and 4.9 km, respectively, for magnetic information. The investigations done by Euler deconvolution showed clustering of source arrangements along faults that follow sharp M-a-G differences or contacts. Depths assessed by Euler deconvolution showed a solid relationship among M-a-G investigation. Depth of residual M-a-G sources is 3500 m and 3200 m, individually. Depth of residual magnetic sources was around 1500 m. The basement rocks’ depths were resolved utilizing the spectral investigation strategy along the M-a-G profiles covering the review region. The depth changes begin with only one spot and then move onto following one. It changes between 2.5 and 4.7 km from the gravity information, while for the magnetic information, the depth changes between 2.3 and 4.4 km.

The M-a-G maps’ primary patterns were decrypted and subjected to pattern evaluation technique, yielding five major patterns:

1) The N-S pattern mirroring the most overall faulting direction in the intriguing region as first order.
2) The NNW-SSE pattern was recorded as a significant pattern in the deep-seated magnetic and an auxiliary pattern in the shallow-situated M-a-G examination.
3) The NNE-SSW pattern is respectably significant in both M-a-G investigation maps.
4) The NE-SW pattern was recorded in the well-established M-a-G examination as an essential pattern.
5) The E-W pattern is strongly significant in the gravity examination map.
Acknowledgements Authors acknowledge the support of the National Research Institute of Astronomy and Geophysics. Authors are grateful to the General Petroleum Company of Egypt for providing the Bouguer map of the study area. Also, they are grateful to the Editor and anonymous referees for their comments and suggestions to improve this paper.

Funding Open access funding provided by The Science, Technology & Innovation Funding Authority (STDF) in cooperation with The Egyptian Knowledge Bank (EKB).

Declarations

Conflict of interest The authors declare no competing interests.

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