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Determining The Depth of Basement Surface and Subsurface Structures at Qarun Lake Through Magnetic Data

BY

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ABSTRACT

This study focuses on a specific region in the northeastern part of the Western Desert, located at northwestern Beni Suef, which includes the wadi Al Rayan area, the Gindi basin, the Kattaniya Inversion and the El Fayum depression. The main objective of this survey is to estimate the depth to the basement complex of the designated area. To achieve this goal, a comprehensive approach was adopted that includes collecting, interpreting and processing magnetic data. A detailed land magnetic survey integrated with existing aeromagnetic data. Both data of the aeromagnetic anomaly and land magnetic survey were processed and interpreted using various techniques to better understand the study area's tectonic setting. Several filters were applied during data analysis, including 2D power spectrum, Source Parameter Imaging (SPI), and Euler deconvolution techniques. The results of these analyses showed that the average calculated depth is between 200 and 700 meters for land magnetic data and between 900 and 10,500 meters for aeromagnetic data. Application of these filters revealed a series of large alternating highs and troughs trending in ENE-WSW, NE-SW and E-W directions. These major trends, along with other minor trends, have shaped the subsurface into numerous inclined fault blocks. Consequently, this brought about the creation of anticlinal and synclinal zones of varying depth and orientation.

Keywords: Land-magnetic-survey, Aeromagnetic, Euler-deconvolution and SPI.

INTRODUCTION

The area under investigation is situated within the Fayum region, which is bordered by the Nile Valley to the east. It is located southwest of Cairo, spanning latitudes 29° N to 30° N and longitudes 30° E to 31° 18' E, and covers approximately 700,000 km² (Fig. 1). This area has three main structural components: The El Fayum Depression, Lake Qarun and the Wadi Rayan Depression. The El Fayum Depression, a prominent basin in the limestone plateau of the Eocene epoch of Egypt's Western Desert, is situated in the northern side of the Western Desert. Lake Qarun is situated in the northern region of the El Fayum depression as a significant basin generated by the activity of two closely positioned strike-slip faults. The Wadi El-Rayan depression, the study area’s southwest portion, is cut by NW-SE faults. The Nile River flows at the eastern region, delineating a narrow North - South structural belt, which is accompanied by a more expansive cultivated area situated to the south of lake Qarun. The Nile depression on the eastern side is situated above a graben, characterized by two fault lines that are oriented from the northwest to the southeast. (Fig. 2).

The primary aim of this study was to integrate aeromagnetic and detailed magnetic-data to delineate and interpret the subsurface tectonic trends, structures and basement depths of the investigated area. To achieve this, the aeromagnetic map (scale 1:100,000 with a contour interval of 5 gammas) prepared by the General_Petroleum_Company in 1986 and a detailed land magnetic map were processed to reveal potential subsurface features. The results of these techniques are presented in various maps and help identify subsurface structures and basement depths.

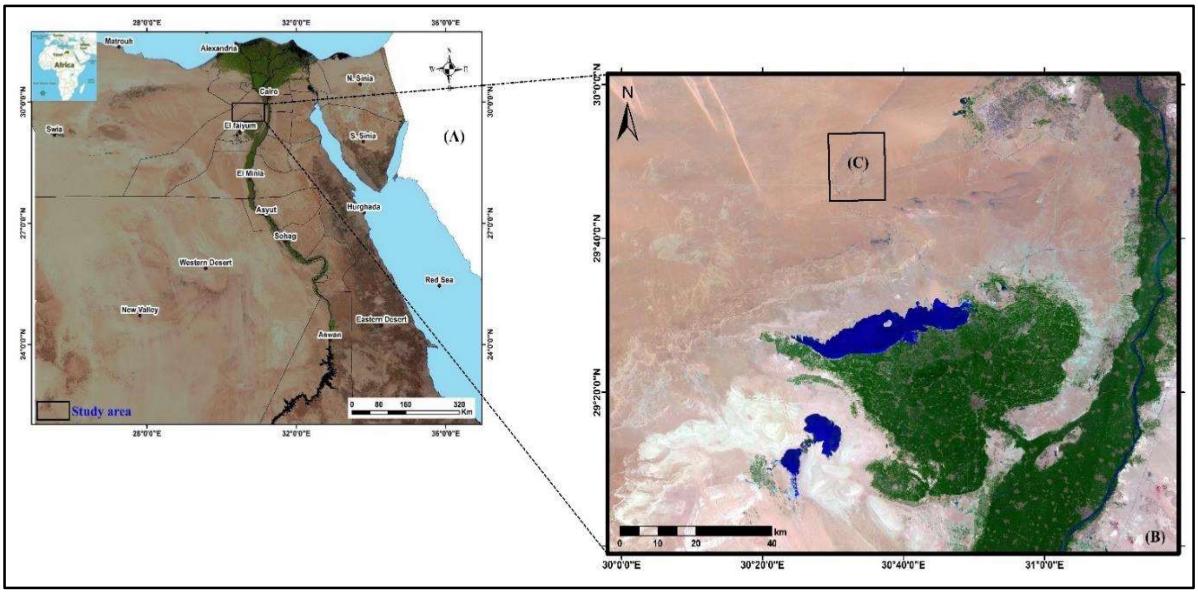

Fig. 1: a) The study area's location on a Landsat image of Egypt. b) Landsat image depicting the area covered by aeromagnetic data. c) The area covered by the land magnetic survey.

GEOLOGICAL SETTING

Egypt's northern Western Desert features a wide stratigraphic column that provides a detailed overview of almost the entire sedimentary history from the Precambrian basement complex to more recent deposits. The stratigraphy of the area, which has been extensively studied by various researchers, shows that middle Eocene and Oligocene rocks form the primary sediments and thin towards the south and southwest. Pliocene and Quaternary sediments are also predominant. Eocene rocks, consisting mainly of limestone with some flints, dominate the southwestern part around the El Faiyum Depression. A thin layer of Oligocene rocks, positioned north of Lake Qarun, distinguishes the Miocene deposits from the Eocene formations in the northwest, consisting of cross-stratified sandstones, gravels, shales and limestones. In the eastern region, the Nile Valley features a slim layer of recent Pleistocene sediments, punctuated by localized outcrops of Pliocene deposits. Sand dunes, basalt flows, and late Oligocene to early Miocene strata are also present in some locations (Fig. 2). The structural situation of the northern-western desert, characterized by faulted terrain, has been thoroughly studied. The region is dominated by step-normal faults trending NE-SW, E-W, NW-SE, and N-S, with several faults exhibiting strike-slip motion. The oldest faults trend EW and ENE and are intersected by younger faults trending NW and NNW. These fault systems exhibit significant Vertical and Horizontal displacements (El-Awady et al., 2016).

Abu El-Ata (1990) identified three structural highs: Abu Roash high, El Sagha-high and El Faras –Faiyum-high. Ghazala(2001) studied the-subsurface structure of the El Faiyum area and identified shallow normal faults trending mainly N N E and E N E and deeper faults trending mainly NW and ENE. He also pointed out that some northwestern faults, which include strike-slip components, are still active and linked them to the 1992 Cairo significant earthquake. In addition, Ghazala identified four major tectonic zones in the El Faiyum area: the Nile-Valley Graben, the East Nile-Valley Uplift, the Ginidi Basin and the Kattaniya Uplift.

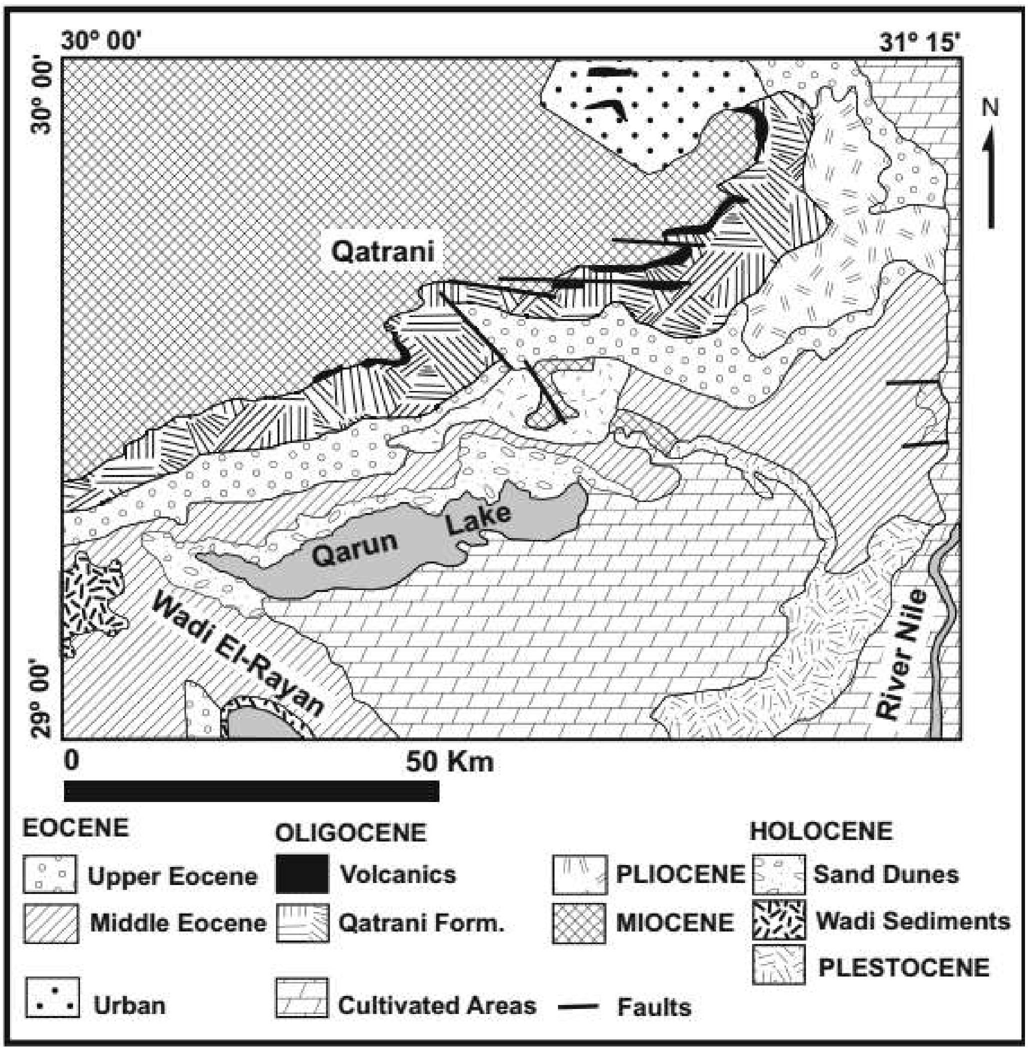

Fig. *2*: Geologic map of study area shows the main geological formations of the surface (after Kusky et al., 2011).

DATA AND METHODOLOGY

The magnetic field data utilized in this study is derived from the following sources:

Aeromagnetic data

The aeromagnetic map, acquired with authorization from the General Petroleum Company, serves as a significant source of magnetic data for the research area at a scale of 1:100,000 (Fig. 3).

Land magnetic survey

A land magnetic survey was conducted at the research site. The magnetic anomaly map was produced after applying corrections for daily variation and latitude. Data for the magnetic survey were collected using two Overhauser magnetometers to perform a detailed land magnetic survey. One magnetometer was installed at the central point of the area to serve as a local base station, while the other measured the total-magnetic-intensity (TMI) at different points in a grid pattern. A total of 259 stations were spaced approximately 150 meters apart, and data collection occurred over 10 working days. At each station, three measurements were taken, with a time interval of approximately 5 minutes between successive readings. Sites with magnetic scatter values exceeding 5 nT from the mean were excluded, as they were considered sources of magnetic_anomalies, and alternative sites were selected. The local base station recorded the drift curve every 10 minutes during data acquisition. Magnetic contour lines were then constructed from the reduced survey data. The total-magnetic-intensity (TMI) data were further processed using the reduction-to-the-pole (RTP) technique, following the equation by Baranov (1975). A magnetic tilt of approximately 43 degrees was implemented in the study area. The northeastward displacement of the magnetic anomalies was ascertained through a comparative analysis of the total-land-magnetic-intensity map (Fig. 4A) Utilizing the RTP magnetic map.

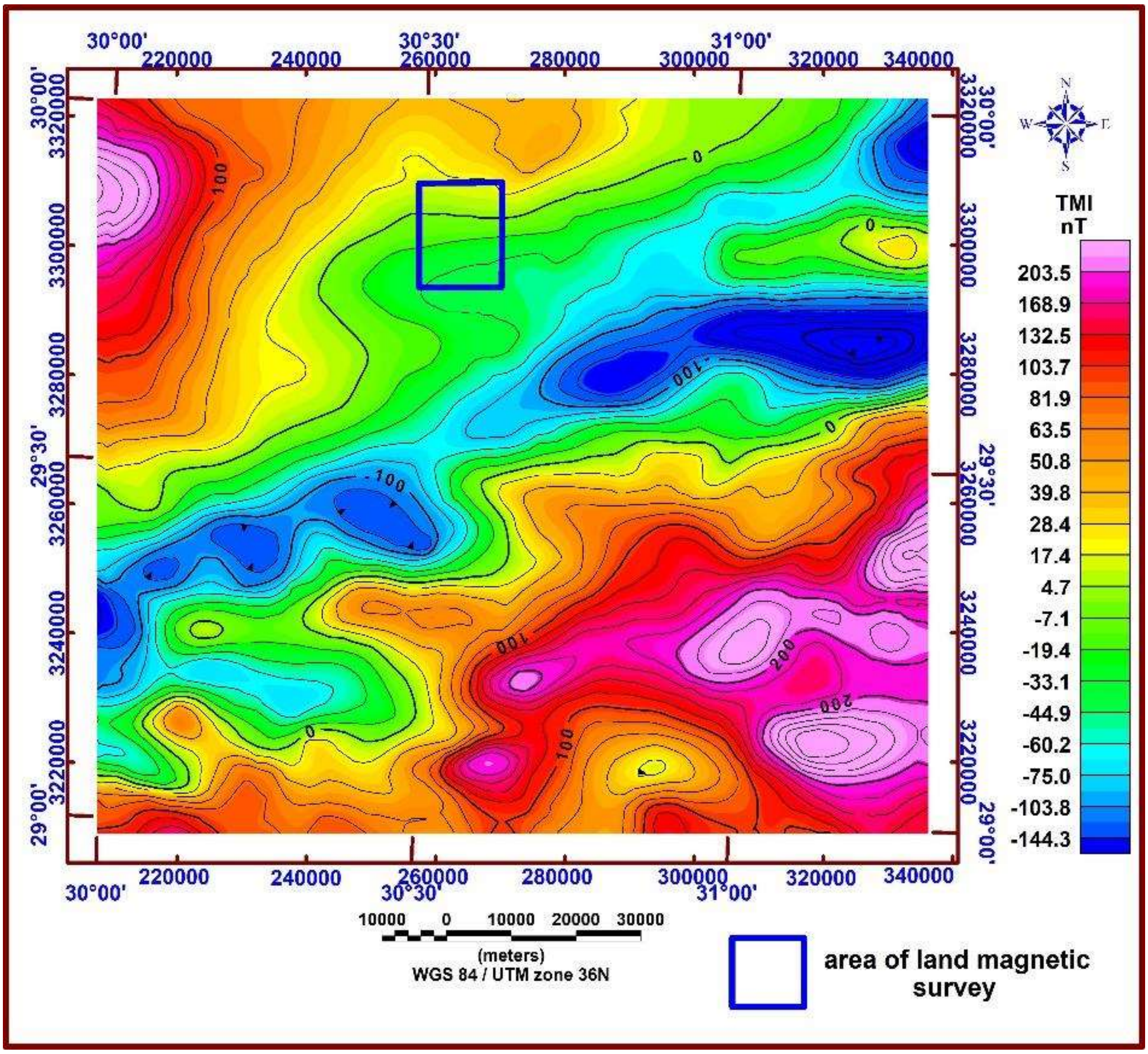

Fig. 3: Total aeromagnetic intensity (TMI) map of the area of study.

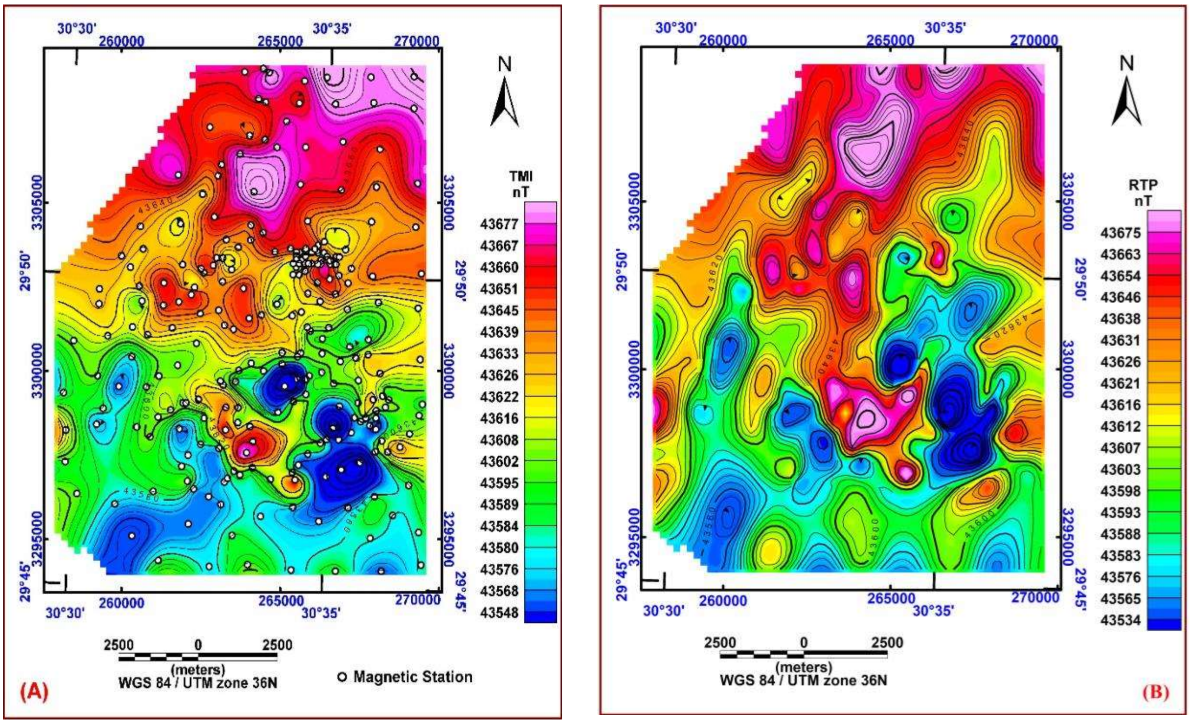

Fig. 4: Shows the Total land magnetic intensity (TMI) map
(A) and the Reduced to the Pole (RTP) map (B) of the area of study.

QUALITATIVE INTERPRETATION OF THE MAGNETIC DATA

The qualitative analysis of the magnetic data in this study is focused on determining the geological properties of subsurface structures. Additionally, magnetic anomalies are described, analyzed, and their effects clarified, particularly in terms of symmetry, strikes, extensions, gradients, and filtering techniques. The qualitative analysis presented in this research is founded upon a systematic approach to interpreting magnetic data, which involves the following methodological steps:

- Description and structural specification of the RTP's aeromagnetic map and the RTP's magnetic map. In this step, the size and shape of anomalies resulting from subsurface anomalous masses and their structural trends can be visualized.
- Filter techniques were employed on both the Reduced-to-Pole (RTP) aeromagnetic map and the associated magnetic map, using two types of specific areas for local and regional anomalies to remove unwanted noise, improve the directional features and find the contact or fault trace on the map.
- The_aeromagnetic_anomaly_data and detailed land_magnetic_survey_data were subjected to various processing and interpretation methodologies employed to enhance the understanding of the tectonic framework of the_study_area and estimate the depth to the subsurface.

RTP land magnetic anomaly Map

The Reduction to the Pole (RTP) technique is widely employed in various applications to remove distortions that affect the shape and size of magnetic anomalies due to the Earth's low magnetic field inclination. This method is beneficial when magnetization is primarily induced or residual magnetization is minimal, as it shifts anomaly peaks to align more closely with their source centers, simplifying the interpretation of the_RTP_map. This adjustment also facilitates a clearer correlation between the magnetic map and the area's geologic map (Al Kadasi, 2015).

The RTP map helps correct the spatial displacement of polarized magnetic sources using the magnetic field characteristics at this site (i.e., declination = 4.828°, inclination = 44.610°, and IGRF total intensity value = 43,855 nT). Figure 4B illustrates the_RTP_map of the_study_area, which is distinguished by the findings of circular to oval and linear anomalies. The majority of these anomalies trend in the northeast-southwest and northwest-southeast directions. In the central and northern areas of the study location, intense magnetic anomalies with high magnitudes have been recorded, indicating shallow bedrock. In contrast, the northeastern and southern regions present weak anomalies with lower magnitudes and smaller sizes.

Aeromagnetic anomaly Map

The analysis of the RTP map related to aeromagnetic anomalies in the region (Fig. 5) indicates that the most significant anomaly values are found in the southwestern and eastern areas, whereas the northern and western sections exhibit lower anomaly values. The contour measurements for these lower anomalies vary between -130 nT and -88 nT, suggesting the existence of a deep sedimentary basin. The most notable irregularity in the region has a non-standard shape and features polarity values that extend from 50 to 250 nT. This irregularity exhibits diminished sharpness and a moderate color transition, indicating the elevation of an underlying block. These anomalies display different traits and are probably linked to intrusions in the basement layer. The primary alignment of the anomalies is primarily along the NE-SW, ENE-WSW, and N-S axes.

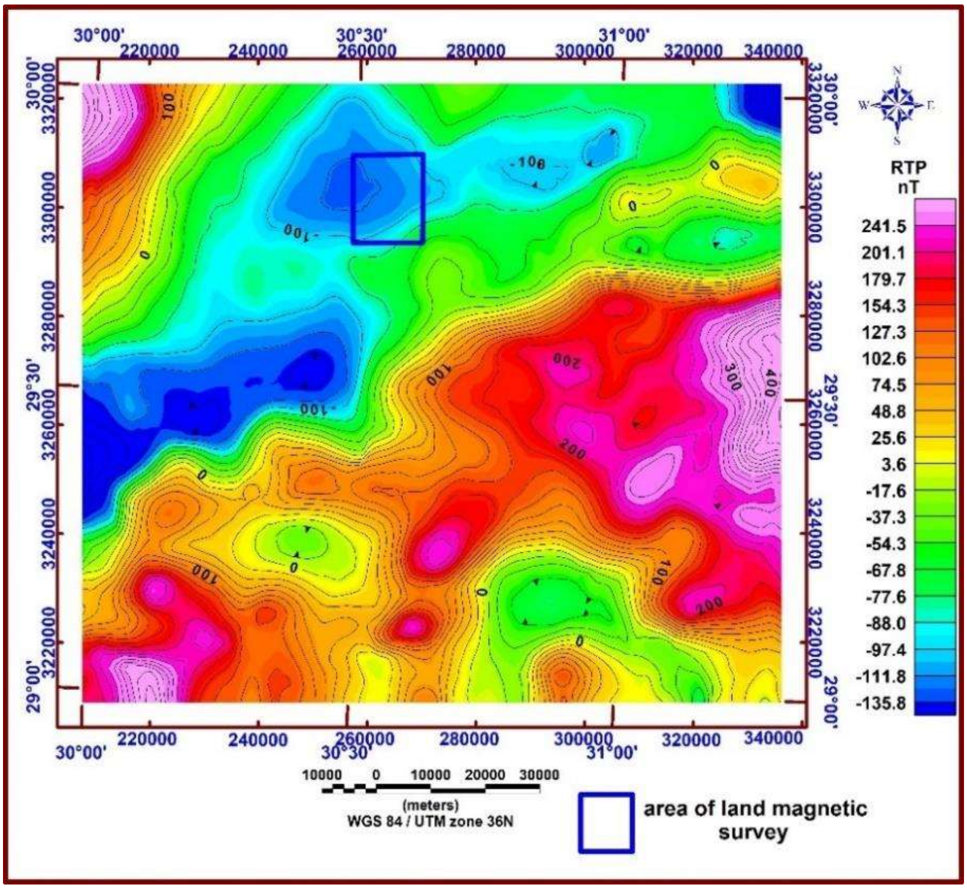

Fig. 5: RTP aeromagnetic anomaly map of the area of study.

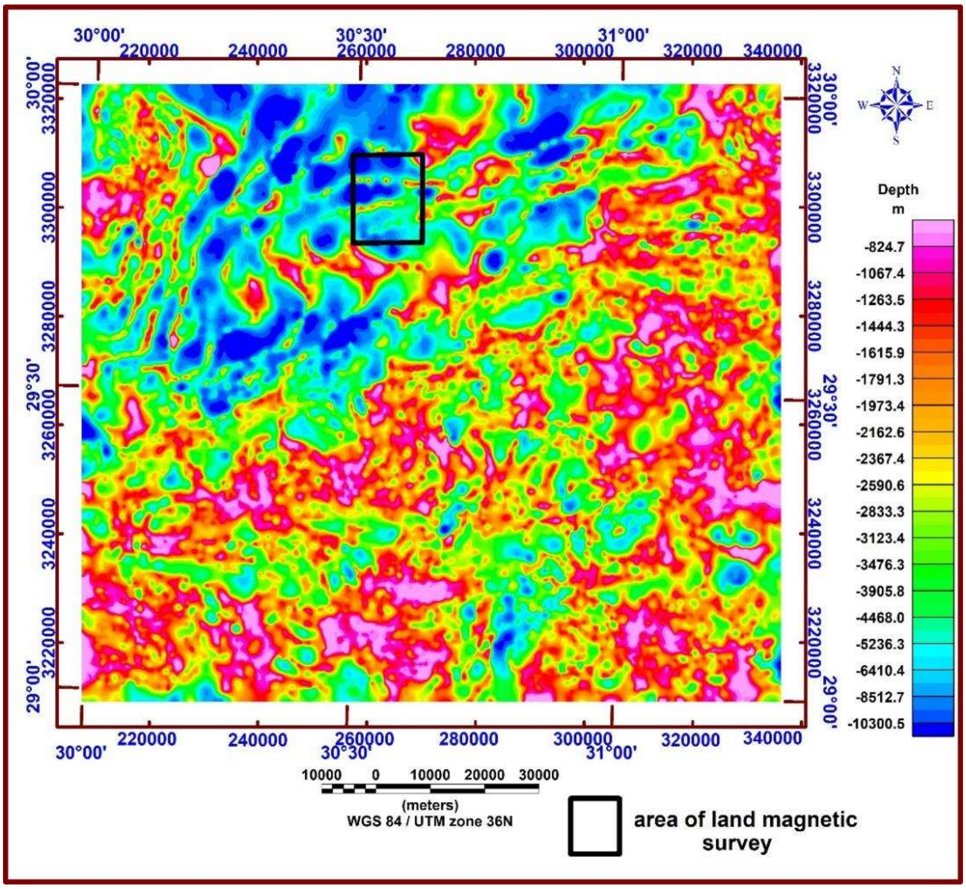

Fig. 6: Map of the depth to sources estimated by source parameter imaging technique for the aeromagnetic RTP of the study area.

QUANTITATIVE INTERPRETATION OF THE FIELD DATA

The quantitative analysis of geophysical magnetic data primarily utilizes a range of techniques to identify analytical parameters of the anomaly sources, including their depth and width, etc. Determining the depth of the anomaly sources is crucial for this interpretation.

Source Parameter Imaging (SPI):

SPI technique was implemented through an enhancement of Geosoft (2014) referred to as SPI.GX, which facilitated the generation of depth estimations. This method initiates with SPI.GX calculating both the tilt derivative (A) and the wavenumber (K), followed by identifying the peak wavenumber values, referred to as K-max, as determined by the Blakely test. These peak values are then employed to derive the depth solutions, which are subsequently recorded in a database. According to the SPI analysis, the aeromagnetic RTP map reveals a depth range from a minimum of -820 meters to a maximum of -10,310 meters (Fig. 6), while the land magnetic RTP map indicates a depth range between -180 meters and -670 meters (Fig. 7).

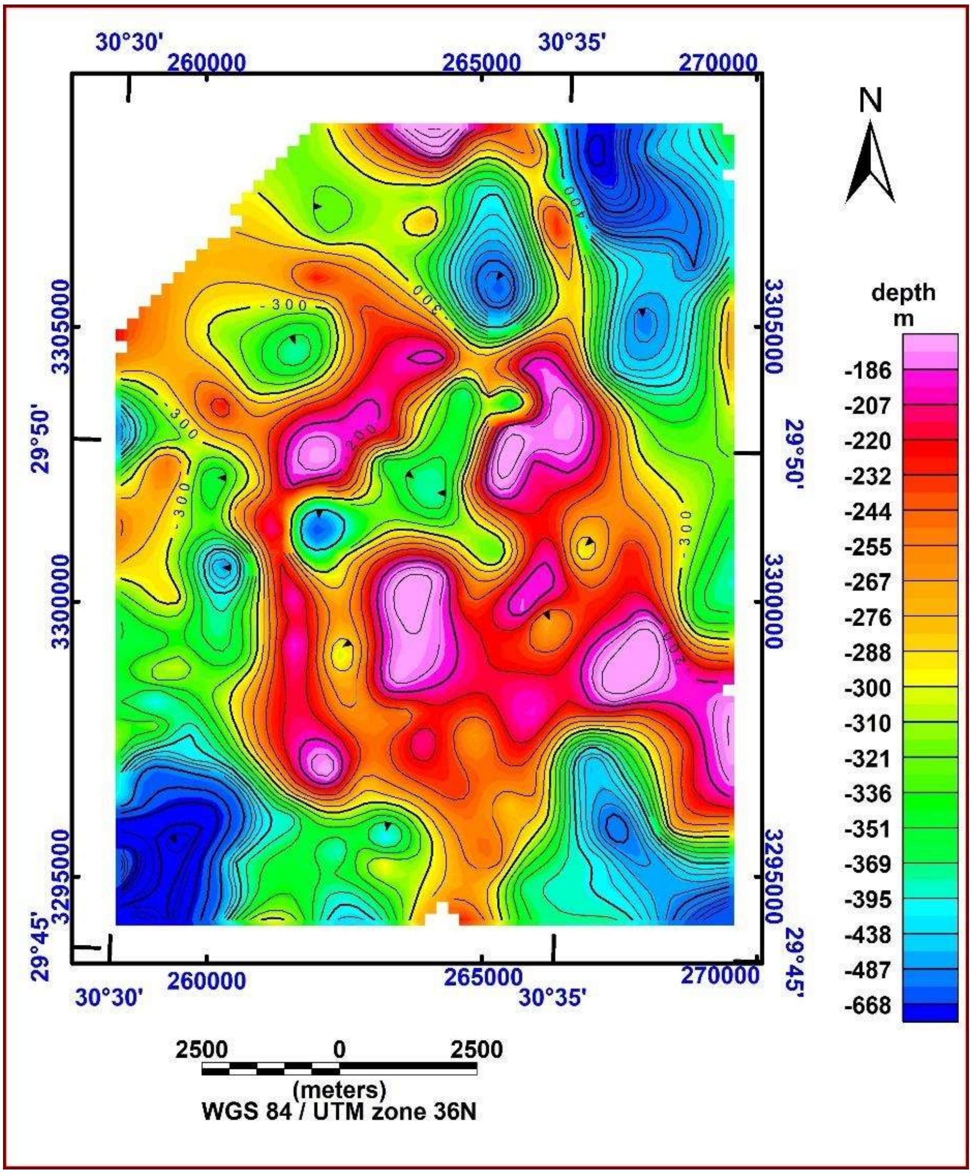

Fig. 7: Map of the depth to sources estimated by source parameter imaging technique for the land magnetic RTP of the study area.

Power spectrum

The basement depth was also estimated using the power spectrum technique, following the methodologies outlined by Macleod et al. (1993) and Roest et al. (1992). The power spectrum analysis of the aeromagnetic data indicates that the deep sources are located at a depth of approximately 10,566 meters, while the shallow sources are at a depth of 960 meters (Fig. 8). In contrast, the power spectrum analysis of the land magnetic data suggests that the deep sources are at a depth of around 650 meters, with shallow sources at 200 meters (Fig. 9). These depth estimates generally align with those derived using the SPI method.

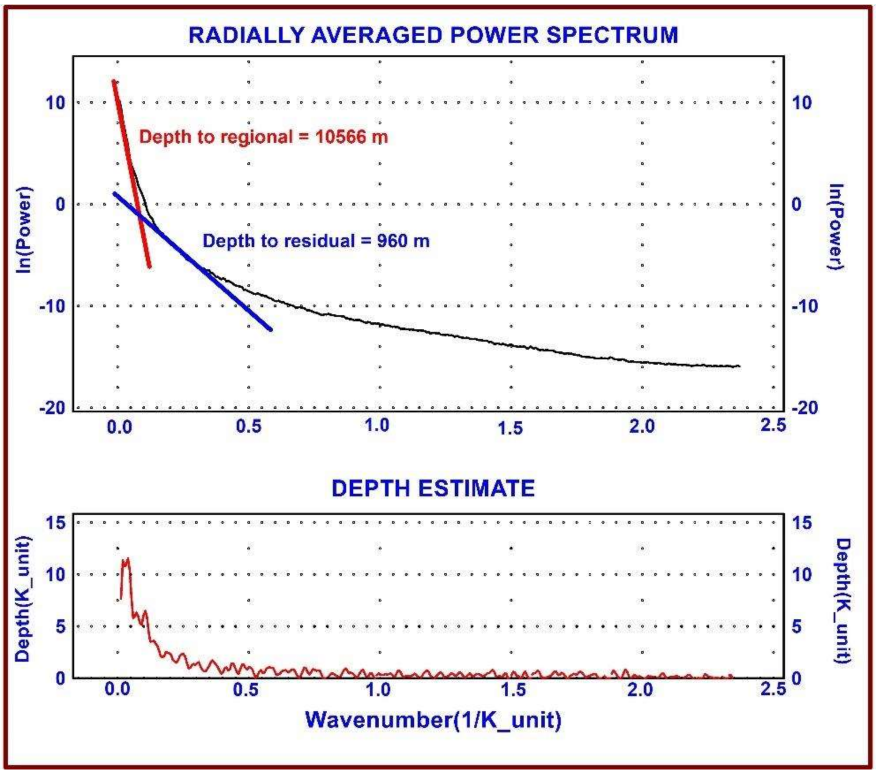

Fig. 8: Depths to deep and shallow sources as estimated from 2D radially average power spectrum of aeromagnetic RTP map.

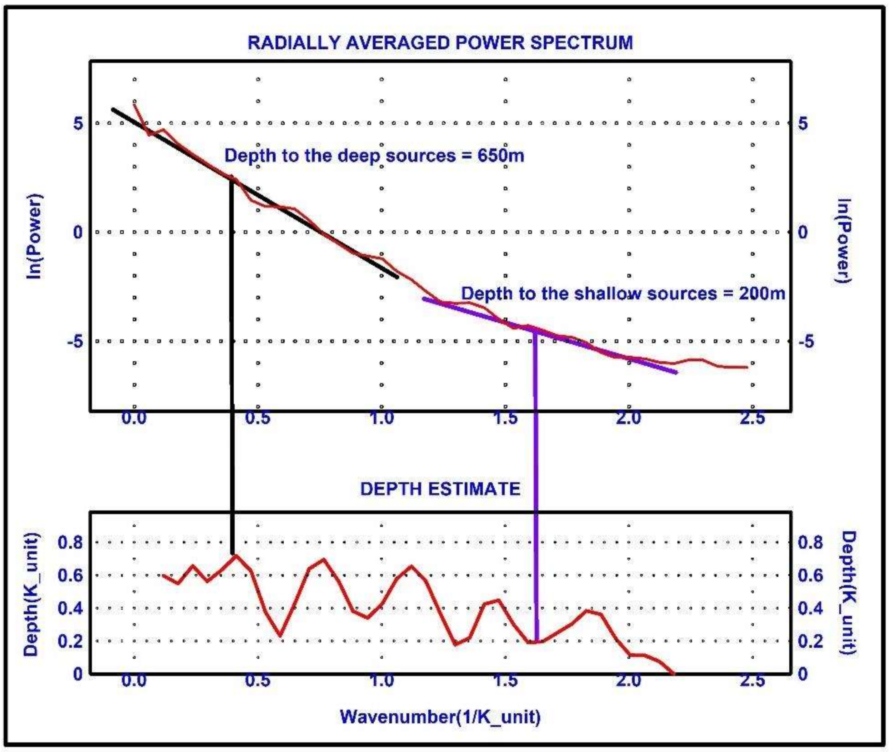

Fig. 9: Depths to deep and shallow sources as estimated from 2D radially average power spectrum of land magnetic RTP map.

The application of the 3D Euler deconvolution technique (ED)

This tool plays a crucial role in analyzing magnetic data to determine the depth of the interface between sedimentary and basement rocks. The precision of its outcomes is heavily impacted by elements like the structural index, sampling frequency, and the quality of the magnetic data. Additionally, a thorough grasp of the subsurface geological environment is crucial (Thompson, 1982; Reid et al,1990). Euler's homogeneity equation, which incorporates a base level for the background magnetic field, can be represented as follows:

$$(x - x_0)\frac{\partial T}{\partial x} + (y - y_0)\frac{\partial T}{\partial y} + (z - z_0)\frac{\partial T}{dz} = N(B - T)\ldots\ldots(1)$$

In this context, (T) represents the total magnetic field observed at the coordinates (x, y, z) with the source located at (x0, y0, z0). B represents the regional or background field, while N, termed the structural index, indicates the level of uniformity. The structural index measures how quickly the magnetic field diminishes and is closely linked to the shape of the magnetic source (Thompson, 1982). Equation (1), which contains four unknowns x0, y0, z0 and B can be solved through a least squares approach.

In this research, Euler solutions were obtained by applying a structural index (S. I) of 0 to both aeromagnetic and terrestrial magnetic datasets, highlighting magnetic contacts and faults The findings suggest that the magnetic source solutions are predominantly aligned with ENE–WSW and NE–SW orientations, with smaller clusters along the NW–SE direction (Fig. 10). In contrast, the land magnetic solutions predominantly align with the NE–SW trend. Alongside analyzing fault trends, the basement depth was determined through Euler depth estimation. The aeromagnetic data suggest basement depths ranging from surface level to over 6,000 meters, while the land magnetic data indicate depths ranging from surface level to over 600 meters (Fig. 11).

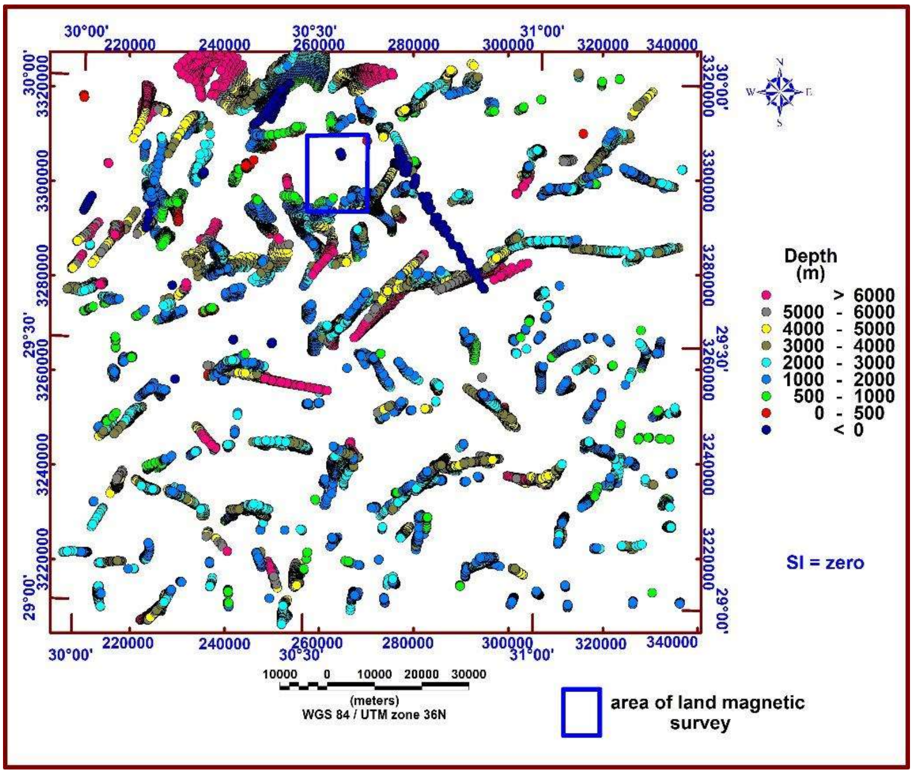

Fig. 10: Resulted Euler deconvolution from RTP aeromagnetic data using structural index=0.

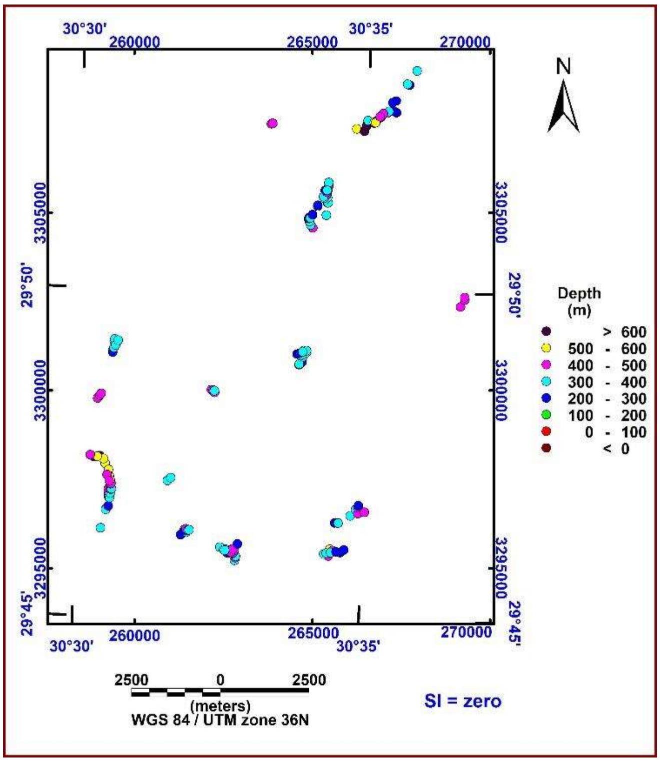

Fig. 11: Resulted Euler deconvolution from RTP land magnetic data using structural index=0.

CONCLUSION

This study aims to map the subsurface structures and ascertain the depth of the basement beneath Qarun Lake. To do this, we employed magnetic field data from the area, including RTP aeromagnetic and RTP land magnetic survey maps. Using techniques such as power spectrum analysis, SPI, and 3-D Euler Deconvolution, we uncovered the subsurface structural features. Tectonic trend analysis revealed that the dominant orientations are N-S, NW-SE, NE-SW, and NNW-SSE. Various filtering methods applied to the aeromagnetic and land magnetic data indicated an average depth of 960 meters for shallow sources and 10,560 meters for deep sources. Additionally, analysis of the land magnetic data estimated shallow sources at an average depth of 200 meters and deep sources at 700 meters.

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