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Inferring Depth to Basement using Airborne Magnetic Data at Qena and its Adjoining Eastern Part of the Western Desert of Egypt

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ABSTRACT

Airborne magnetic data set of Qena as well as the eastern margin of the Western Desert has been processed to estimate the depth of the basement, and accordingly the thickness of the sedimentary cover that could give some information about the groundwater potentiality in the area under consideration. Reduced to Pole Magnetic Map (RTP), Butterworth Low Pass Filter, and Butterworth High Pass Filter have been used to represent the aeromagnetic data. Depths of the basement were estimated by using both the source parameter imaging technique (SPI) and radial average power spectrum technique (RAPS). According to the results of the (RAPS) technique, the estimated average depths of deep and shallow magnetic sources are 2.331 km and 0.50 km respectively. On the other side, the (SPI) technique emphasized that the depth to reach crystalline basement rocks varies between -551 m to -2817 m. The southern and western portions of the target area are particularly distinguished by thick sedimentary cover. These portions may be areas with high potentialty of groundwater.

1. INTRODUCTION

Reynolds (1997) [1] stated that the magnetic method is an effective technique to determine the depth to reach magnetic source bodies (and consequently the thickness of the sedimentary cover) and detecting subsurface structures. The most beneficial parameters that could be obtained from the studies of potential field data (such as gravity and magnetic) is the depth to reach crystalline basement complex underneath the sedimentary cover. This depth determination is useful for resource exploration purposes. Kumar et al. (2006) and Abu El Ata et al. (2013) [2, 3] stated that the aeromagnetic data of high resolution are very important for the hydrologic and geologic mapping at different scales as well as for environmental investigations. The primary purpose of an aeromagnetic survey is to determine the subsurface geological setting based on differences in the earth's magnetic field that appear as anomalies resulting from the contrast in the magnetic susceptibility between the basement complex and the sedimentary cap rocks. Reynolds (1997) [1] stated that the magnetic characteristics of the sedimentary cap rocks are less than that of the crystalline basement rocks. The magnetic data has several applications and can provide extremely valuable subsurface information [1, 4, 5].

The area under investigation occupy both Qena and the eastern part of Western Desert of Egypt between latitudes 24° 15′ and 26° 45′ N and longitudes 29° 00′ and 33° 00′ E comprising an area of about 129000 Km2 (Figure 1). It represents a promising area for land reclamation and projects in the future that rely on groundwater for irrigation and domestic use. This work aims to deduce the depth of the basement rocks, and accordingly the vertical thickness of the sedimentary caps that could give some information on the potentiality of groundwater. This task has be achieved by applying and using the following avalable geological and geophysical data such as the geological map of Egypt (1:500.000) published by EGPC and Conoco (1987) [6] and the Western Atlas International established the Aeromagnetic data for EGPC (1989) [7] for oil and gas exploration.

2. GEOLOGICAL SETTING

Qena area in Egypt exhibits distinct geological features and structural settings. To the west, the sedimentary rocks are prominently exposed but the basement rocks are exposed in the eastern part (Figure 2), which are Pre-Cambrian in age, represented by metamorphic and igneous suite. These rocks are covered by sedimentary layers comprising Nubian and post-Nubian sediments. The sedimentary succession found in s such as Qena and intra-mountainous areas ranges in age from Paleozoic to Quaternary. The distribution of Paleozoic rocks is mainly influenced by the structural attitude during the pre-Cenomanian time. In the investigation area, sediments of Paleozoic age predominantly occur in the southern part of Egypt and crop out in the northern and western margins of Qena. The Nubian Sandstones play a vital role in the geological composition. The Nubian Sandstone thickness varies considerably, increasing towards the north, ranging from approximately 14 meters in the south to 403 meters thick due to the north [8].

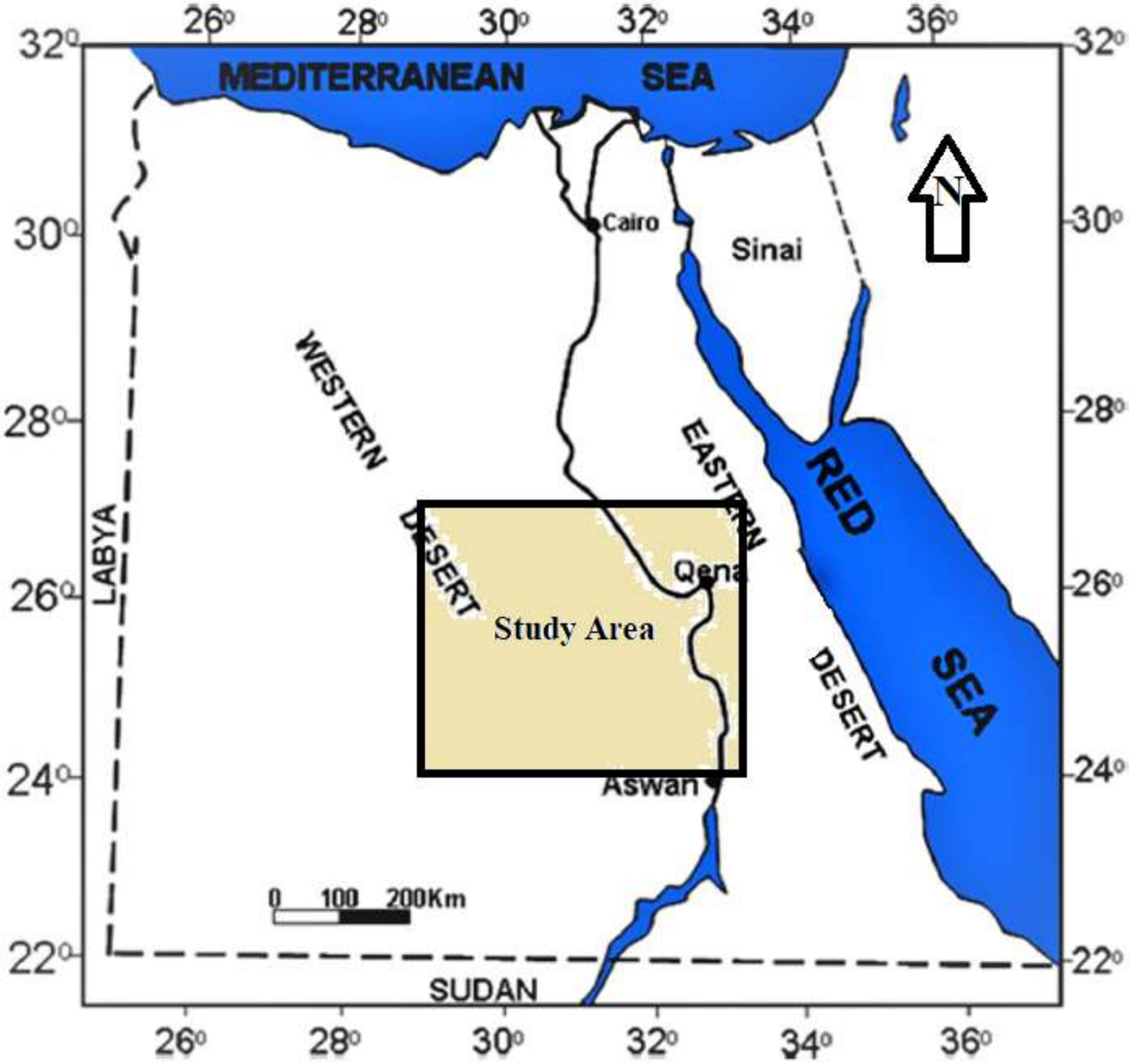

Figure 1: Location map of the studied area.

Two assemblages are distinguished in the Cretaceous period: the Lower Cretaceous formations which represent an important part of the Nubian Sandstone, and the Upper Cretaceous rocks interbedded with the Nubian Sandstone beds, mainly comprising shale, chalk, and limestone. Due to late Cretaceous-Tertiary Sea transgression, shallow marine and near-shore deposits submerged Qena [9]. This period also experienced intermittent erosion, leading to the removal of chalk and limestone from the . Subsequently, during the Tertiary and before the sea regression accompanied the close of the neo-Tethys, limestone and marly chalk ranging in age from Paleocene to Eocene epochs were accumulated.

The Quaternary deposits extensively cover Qena and are represented by coarse sands and conglomerates that were accumulated during a short pluvial time. This time also experienced hyper-arid phases when the silts of the Nile deposited [10].

The Qena area is a salient part of Egypt's stable shelf zone, which is subjected to mild folding and slight flexure affecting the structures of the region [11]. The limestone plateau in the studied area is significantly influenced by the Qena structures, which are characterized as anticline folds [12]. The fault systems bounding Qena depression particularly due to the west have an impact on these structures, which represent some of the oldest rock units of Egypt's stable shelf [13].

On the other hand, the Western Desert represents a vast platform with an elevation of 500 m above sea level. It is primarily composed of thick-layered sedimentary rocks that have been relatively unaffected by tectonic disturbances [11]. These rocks consist mainly of sandstones that slope and dip gradually toward the north, constituting the majority of surface and subsurface beds. Carbonate rocks are limited to hard limestone cover. Crystalline basement complex rocks are detected in the east of Bir Tarfawi [14].

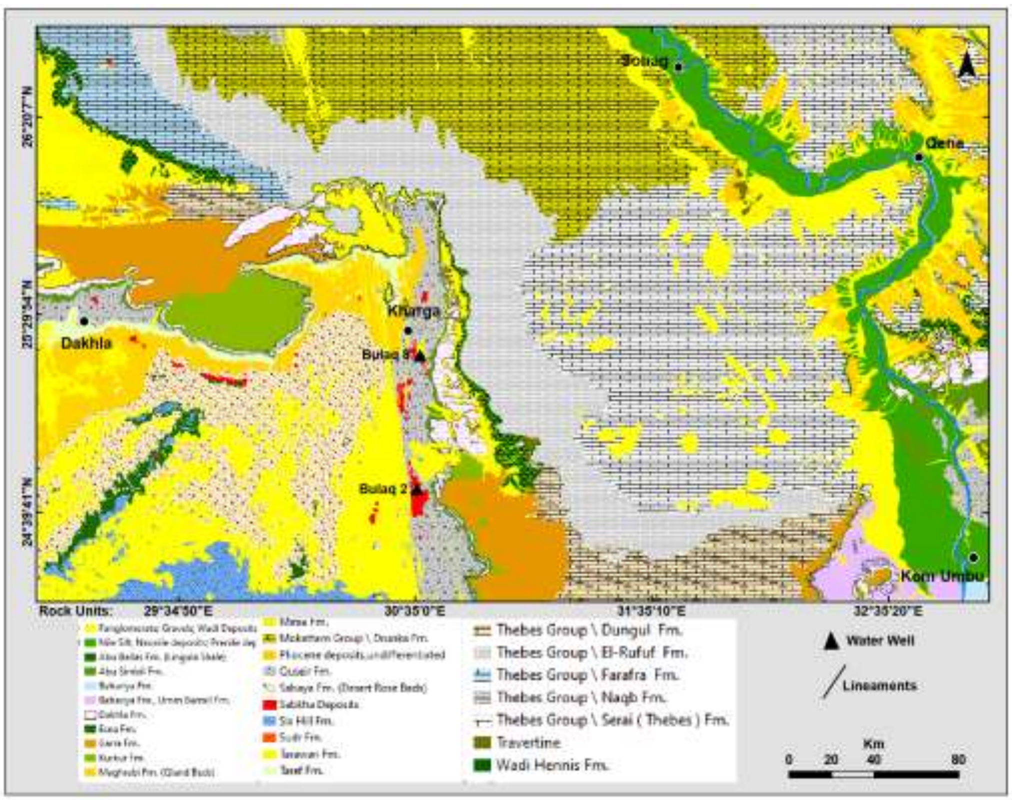

Figure 2: Simplified geologic map of the studied area (After Conoco, 1987).

The central areas of Egypt are covered by a large limestone plateau which elevated 450–550 m a.s.l. This plateau which ranges in age from Cenomanian to Paleocene is composed of sandstone, shale, and limestone with a gentle dipping toward the north and forming a resistant cap rock. Fluvial dissection has led to corrugated contours of the carbonate rocks with many spurs and isolated outcrops projecting into nearby areas. For example, the Abu Tartur plateau (known for its phosphate mines) is the largest one of these sub-plateaus situated in the northern margin of the target area. Structural studies in the southern part of Egypt revealed that the crystalline basement rocks represent a district of a regional fold zone (the Northern Zalingei fold belt of Schandelmeier et al., 1987 [15]). The fold axes and metamorphic foliations in this fold zone show regional trends that seem to be N-NNE-NE-ENE-oriented. The investigated area is distinguished by the occurrence of two big intra-cratonic basins (the Nile Valley and Dakhla basins). These basins are separated by basement uplifts. The N-S-oriented Kharga uplift separate between the two basins. Due to south, the deep intra-cratonic basins are isolated from the shallower basins of North Sudan by Oweinat–Bir Safsaf–Aswan uplift that strike E–W at the southern margin of the Dakhla basin and NE–SW at the southern rim of the upper Nile basin.

3. PREVIOUS GEOPHYSICAL STUDIES

Several geophysical studies were achieved on the southeastern desert by many authors that covers different parts of the study area [16, 17, 18, 19]. (Omran et al. 2001) [16] interpreted gravity data in the Nile valley area. He deduced the minimum values of the basement depths are detected in the southern part of the Nile valley area, where the basement depth decreases gradually until it crops out around Aswan, near Lake Nasser and around Tushka area.

(Abdel Zaher et al., 2009) [17] used the Bouguer anomaly map of scale 1:500,000 and the lithological logs of more than 120 deep wells distributed in the Southern part of Western Desert of Egypt to determine the thickness of the sedimentary cover containing the main sandstone water formation. Isopach maps were constructed and showed that the basement depth ranges between 0 and 1500 m (b. s. l.) and that and the maximum thickness of sandstone formations is recorded at west Oweinat, southwest of Aswan, Dakhla oasis and west of Qena town. These locations are characterized by the presence of huge amount of ground water as this formation is the main water aquifer in the study area.

The study area lies to the south of El-Dakhla Oasis in the central part of the western desert, Egypt has been studied by Bakheitet al., (2014) [18] using airborne magnetic data. The main purpose was the investigation of the subsurface structure and the estimation of the basement depth and consequently, the thickness of the sedimentary cover. The obtained results showed that the basement depth calculated from aeromagnetic data was achieved using different techniques showed that the depth values obtained vary from 400 to 1,700 m.

Beshr et al., (2021) [19] addressed the relationship between the geometry of the Qena Bend of the Egyptian Nile River and the structural setting of the underlying basement complex using remotely sensed and aeromagnetic data. The magnetic 2D forward modelling and 3D depth inversion suggest the basement consists of granitic rocks (0.02 – 0.033 cgs) and the positive anomaly below the bend probably attributes to a major uplift at a depth of 750 m.

4. MATERIALS AND METHODS

The Western Atlas International established the Aeromagnetic data for EGPC (1989) [7] for oil and gas exploration. Also we used the geological map of Egypt, (1:500.000), by EGPC and Conoco (1987) [6]. In addition we used the available drilled wells that reached the basement at the study site (Bulaq 2 and Bulaq 8) as well as the available geological and geophysical information.

The aeromagnetic map has been digitized by using Geosoft Oasis Montaj software (GOM) V. 8.4 (2015) [20]. Aeromagnetic data is being filtered using Butterworth filter operators to improve the signal characters of the available data [21]. The RTP technique is a valuable method used to eliminate the influence of magnetic inclination on magnetic data. By transforming inclined magnetic data to a hypothetical vertical field, RTP eliminated anomaly asymmetry that caused by inclination and enables precise localization of anomalies immediately above their causative sources. Butterworth high-pass filters have been used to focus on detail on maps, with taking a risk to improve noise [22]. Butterworth low pass filter is used to remove local variations and noise to improve regional magnetic anomalies. By using the (GOM) software, the (SPI) and the (RAPS) techniques were all very effective in estimating the depth to reach the basement.

The Spectrum analysis technique that has been utilized to determine the depth of magnetic anomalies was discussed by many authors [23]. The radial average power spectrum technique was set for quantitative studies of magnetic anomalies. The slopes of the linear portions of the spectrum coincide to separate depth groups and provide the parameters used to design many of the enormous filters. Kivior and Byod, (1998) and Spector and Grant, (1970) [24, 25] initiated a depth profiling method to calculate the power spectrum of magnetic grids for depth estimation as follows:

$$h \text{ (depth)} = -\text{slope}/4\pi \qquad (1)$$

The (SPI) method is rapid and simple to delineate the depth to reach the magnetic sources. Similar to the Euler deconvolution technique, SPI has an accurate result. The SPI technique gives a wide range of points of solution that are both obvious and simple to use. (Thurston and Smith, 1997) [26] stated that the results of SPI are easily interpreted. SPI method has several advantages compared with other techniques such as the calculation does not take a long time, and noise errors could be minimized by sorting the data prior to the depth calculation.

5. RESULTS AND DISCUSSIONS

5.1. Reduced to the pole magnetic (RTP) map

The RTP magnetic map (Figure 3) obtained from the target area demonstrates a distinct shift in the locations of magnetic anomalies toward the north because of the minimizing of magnetic field inclination. Moreover, the RTP transformation leads to an intension in the anomalies number, while their aerial extension decreases, and their vertical relieves increase. This enhancement in magnetic gradients results in higher resolution, enhancing the identification of structural and lithological features.

Based on magnetic characteristics, frequencies, and amplitudes of the anomalies, the RTP magnetic map can be subdivided into two distinct zones. The first one is distinguished by comparatively high magnetic amplitudes and colored in red, is predominantly observed in the western, southern, and some eastern rims of the studied area. The anomalies in this zone exhibit elongated and semi-circular shapes, NW-NE, NE-SW, and N-S-oriented. The second zone is characterized by somewhat intermediate to low magnetic amplitudes and colored in light green and blue, occurs in the southwestern and northeastern margins of the studied area. The anomalies in this zone exhibit elongated shapes, trending in the NW-SE, NE-SW, and NS directions.

The application of the (RTP) technique on the corrected total magnetic field intensity data has significantly improved the interpretation and resolution of magnetic anomalies in the present work. The (RTP) magnetic map has revealed important geological information and provided insights into the structures of the subsurface and lithological variations.

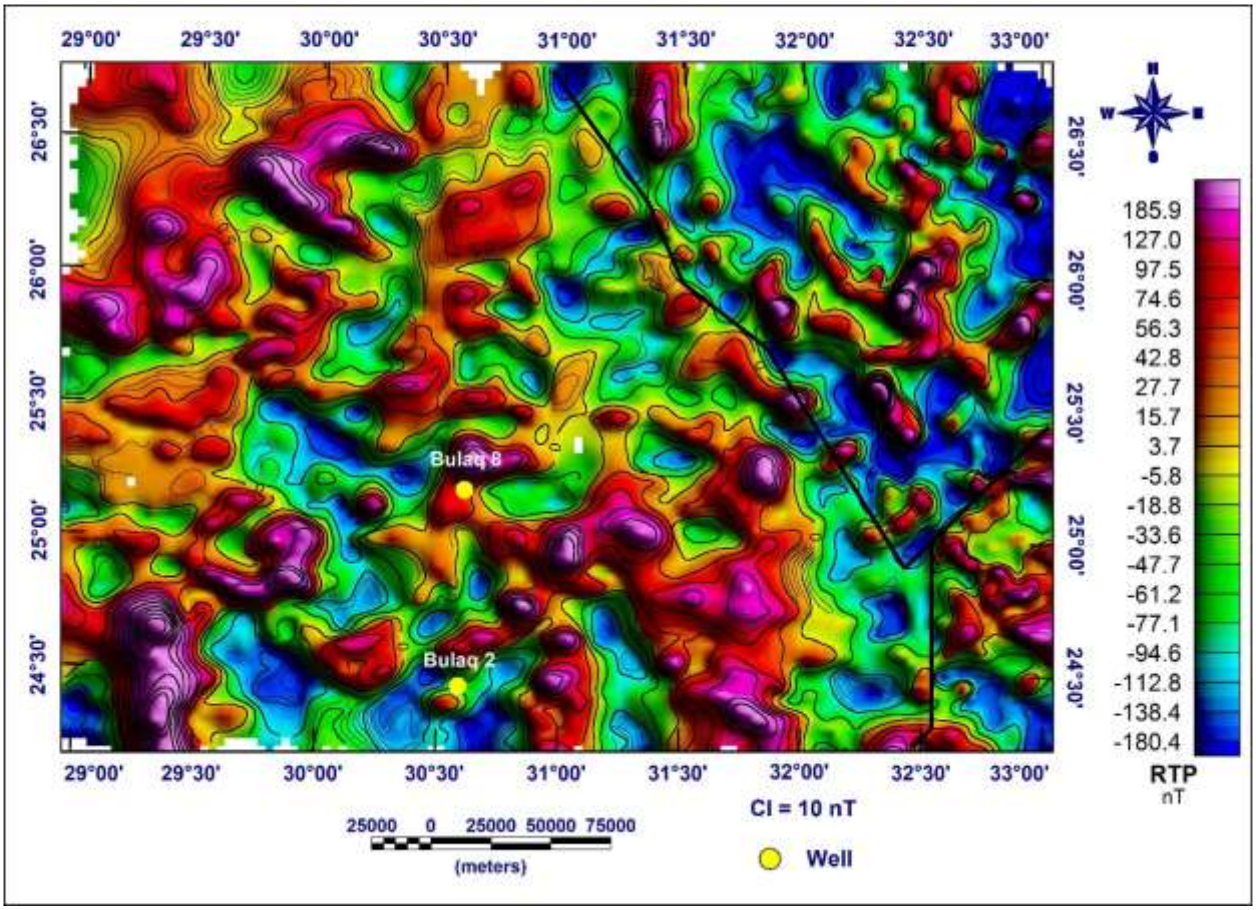

Figure 3: Reduced to the pole (RTP) magnetic map of the study area.

5.2. Butterworth Filter

The Butterworth filter is a versatile filtering technique used to apply high and low-pass filters on data, allow control over the filter roll-off with keeping the central wave number fixed. In the present study, the Butterworth filter has been applied to magnetic data, resulting in two distinct output maps: the regional and residual magnetic anomaly maps.

5.2.1. The regional (Butterworth Low Pass) magnetic map

Butterworth Low Pass filter applied on RTP magnetic map with Geosoft Oasis Montaje (2015) [16] to remove the influences of local magnetic field and its noise. The regional (Butterworth low pass) map (Figure 4) clearly shows positive anomalies due to high magnetic susceptibilities with sub-circular and oval shapes at the northwestern, southern, and eastern rims of the studied area, which colored with violent and red. These anomalies have short wavelengths and higher frequencies. It indicates that the causative bodies buried at shallow depths represent the uplifted margins of the studied area.

The negative anomalies at the southern, central, and northeastern margins which represented in blue, pale blue and green colors are due to low magnetic susceptibilities with long wavelengths and lower frequencies. These anomalies indicate that the causative bodies are deep seated. They represent the subsided parts or basins in the studied area.

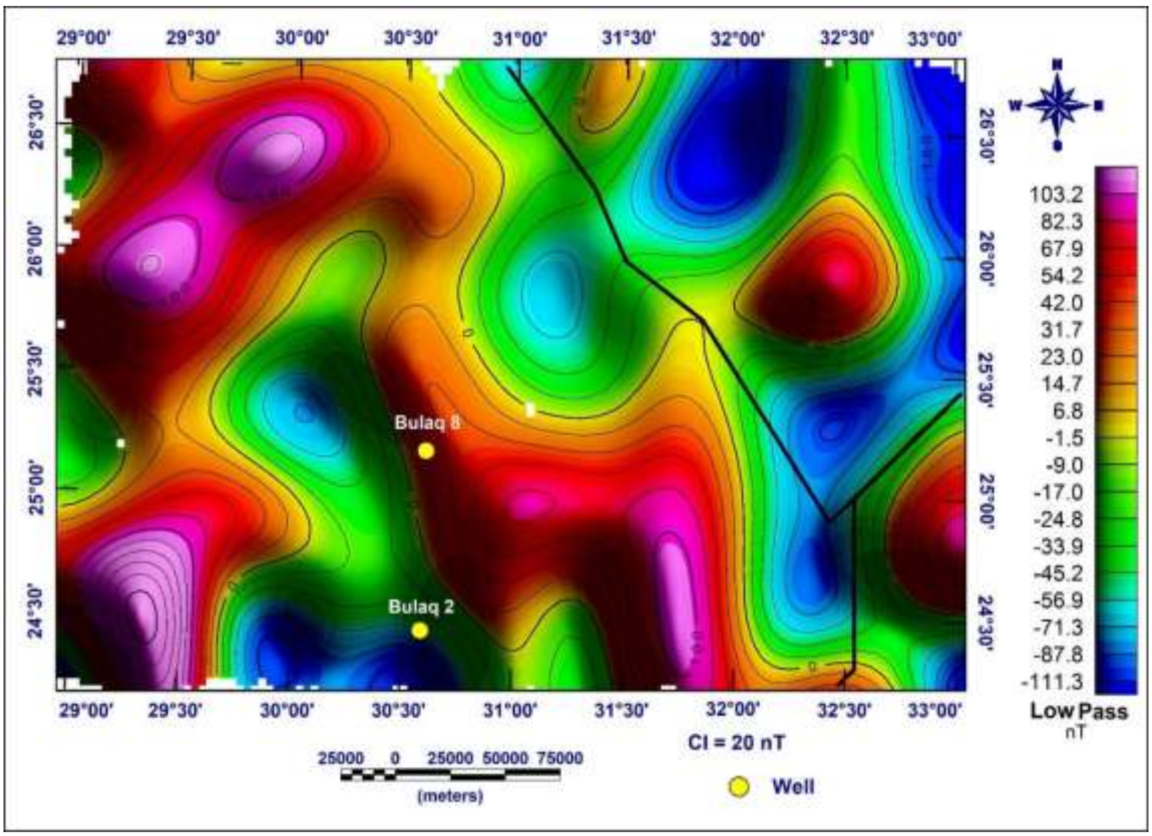

Figure 4: Butterworth Low Pass filtered (Regional) magnetic map.

5.2.2. The residual (Butterworth High Pass) magnetic map

Butterworth High Pass filter applied on (RTP) magnetic map with Geosoft Oasis Montaje (2015) [16] to improve the signal characteristics of available magnetic data and bring more details with the risk of noise increasing. The residual (Butterworth High Pass) map (Figure 5) clearly shows positive anomalies (red colored) and negative anomalies (green and blue colored), which have more details compared with those on the RTP map. The form of these anomalies is elongated and sub-circular. The anomalies are characterized by local variation because of the difference in their magnetic susceptibility, composition, and depths of their sources. The main trends in which the magnetic anomaly pattern arises are NW-SE, NE-SW, and N-S.

Although the filter was applied, there are still some influences of shallow basement rocks because these parts have been uplifted, and the structure of these parts may be extended to the surface with the same trends.

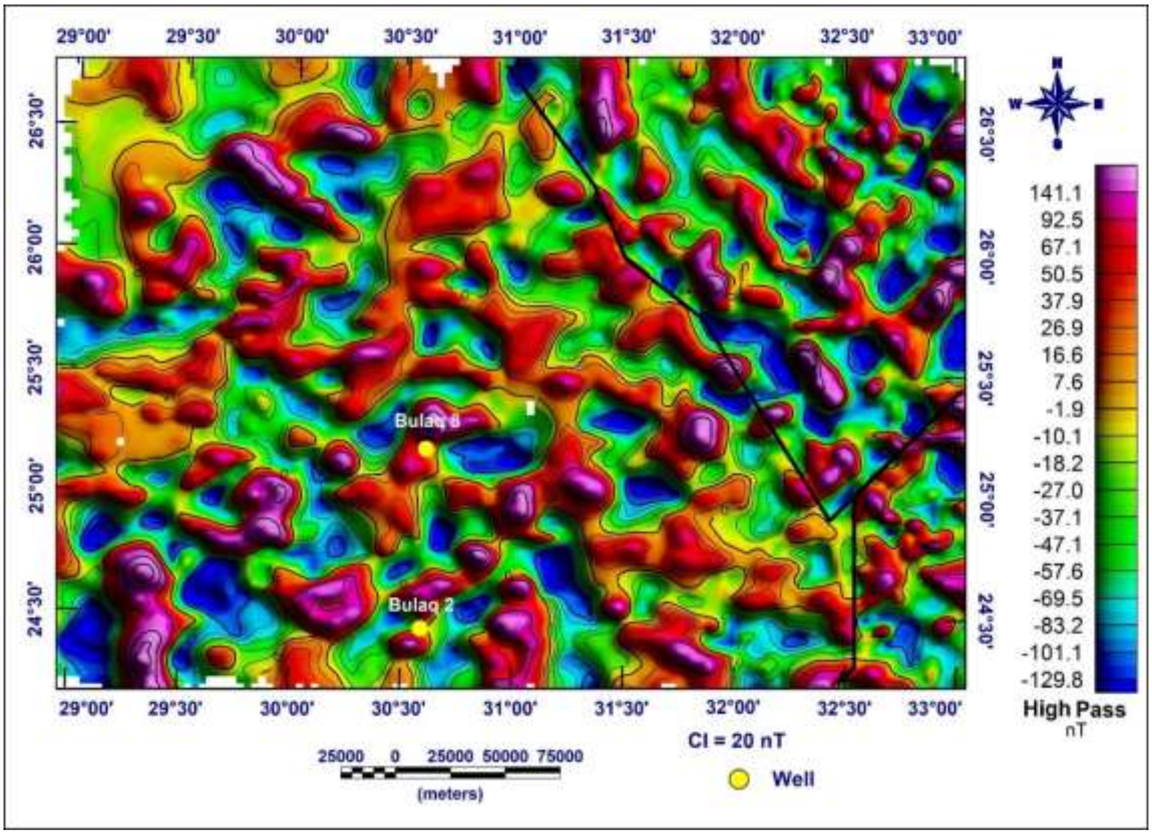

Figure 5: Butterworth High Pass filtered (Residual) magnetic map.

5.3. Depth to basement

5.3.1. The regional (Butterworth Low Pass) magnetic map

The application of the (RAPS) to reduce the Pole magnetic data allowed for the determination of average depths to subsurface geophysical sources. The resulting energy decay curve displayed linear segments with differentiated slopes attributed to contributions from both residual (shallow sources) and regional (deep sources) lithologic and/or structural features. Plotting the energy spectrum vs. frequency on a logarithmic scale revealed straight-line segments with decreasing slopes at higher frequencies, providing estimates of average depths to magnetic sources.

According to the power spectrum curve analysis (Figure 6), there zre two main average depth interfaces were identified at depths of 2.331 and 0.50 km below the measuring level. The average depths of deep and shallow sources were calculated using the slopes of the lines fitted to each frequency segment.

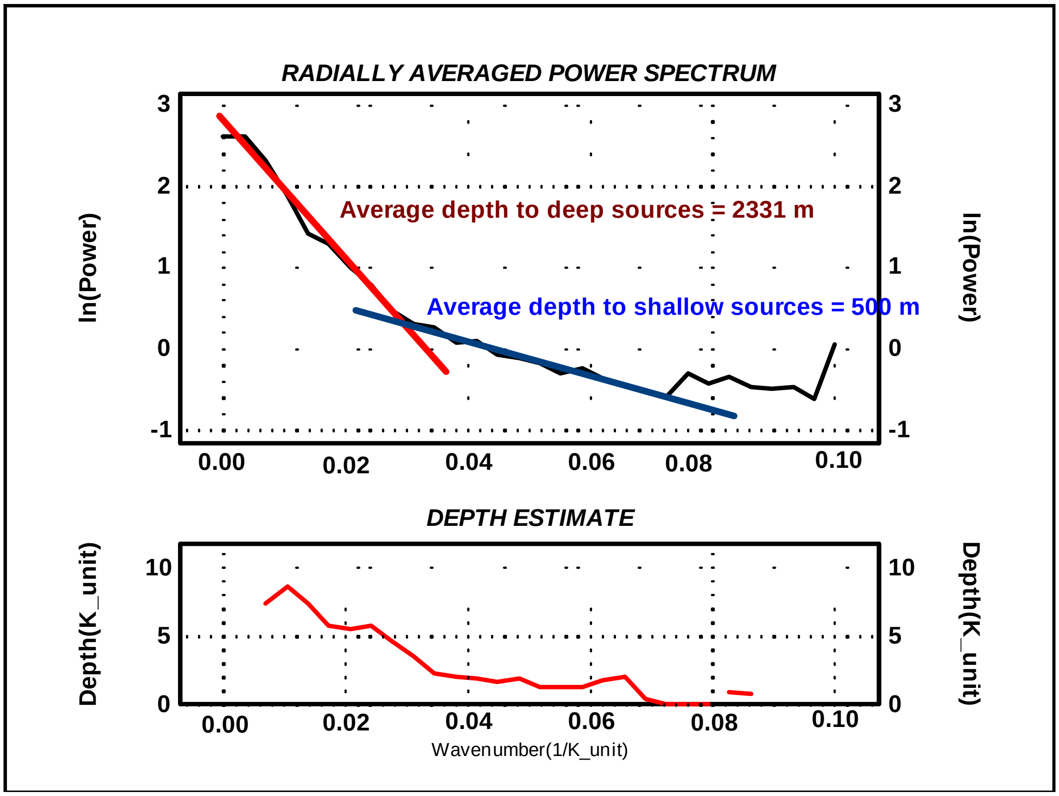

Figure 6: Radially Averaged Power Spectrum of the RTP magnetic data.

5.3.2 Source Parameter Imaging (SPI)

In practice, the method is used on gridded data by first estimating the direction at each grid point. The vertical gradient is computed in the wavelength domain, and the horizontal derivatives are computed in the direction perpendicular to the strike using the least-squares method. The results of the depth estimate from the SPI techniques are plotted in Figure 7. The depth of magnetic sources in the study area changes from -551 m to -2817 m in agreement with the resuts of the radial average power spectrum depthes. The shallow depths of magnetic sources are located in the eastern and extend to southwestern parts, while the depths of sources range from -551 m to -1509 m. meanwhile, the deep magnetic sources are located at depth ranges between -1509 and -2817 m and distributed in the southern and western parts of the study area. It is worth to mention that the depth to basement from the drilled wells of Bulaq 2 (-750 m) and Bulaq 8 (-800 m) matches very wth the depth to basement obtained from SPI map which are -698 m and -815 m, respectively.

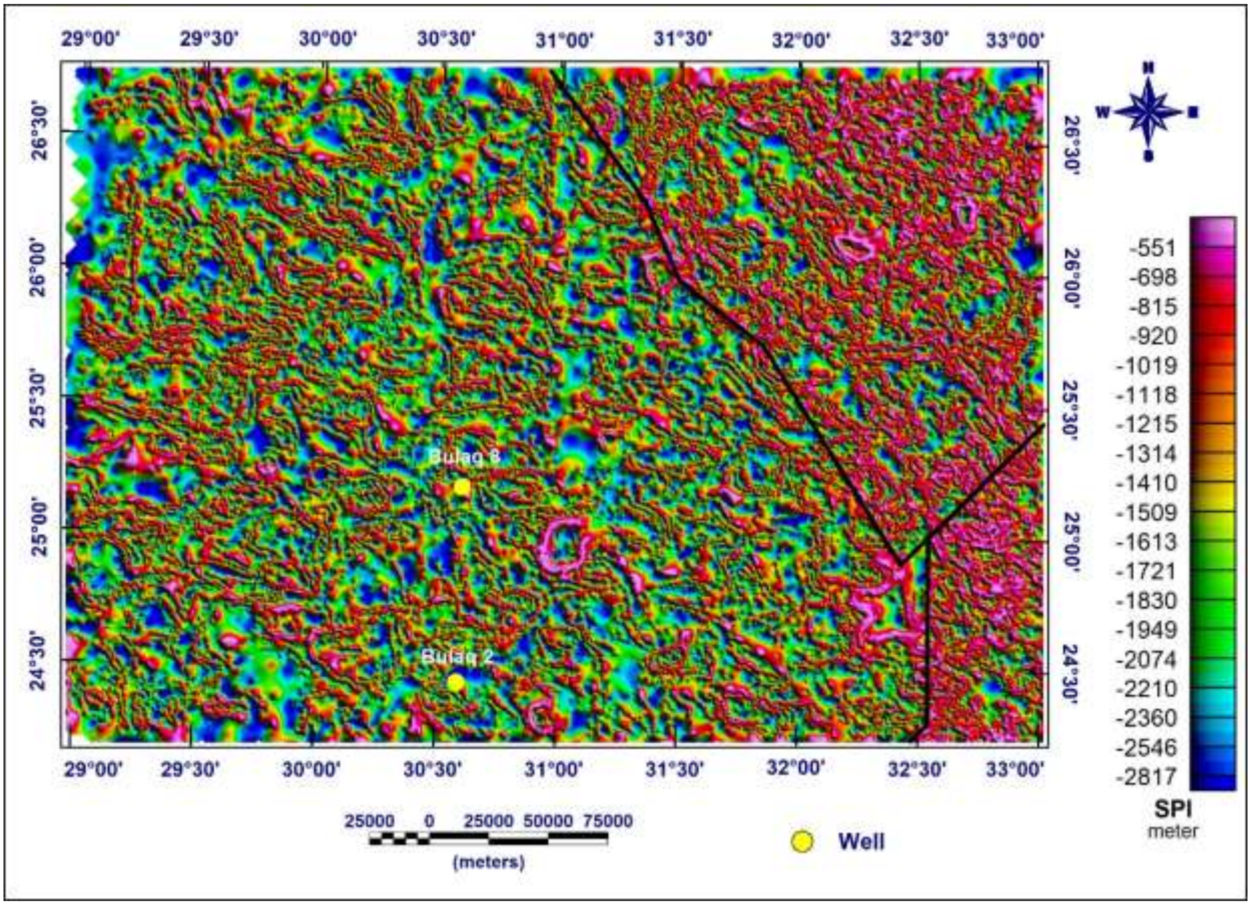

Figure7: Basement depth from Source Parameter Imaging (SPI) technique.

6. SUMMARY AND CONCLUSION

The scope of this work is to estimate the depth of the basement rocks at Qena and its adjoining eastern part of the Western Desert depending mainly on the explanations of the obtainable aeromagnetic data. The studied area represents Egypt's essential agricultural projects. Butterworth High pass filter has been applied on the RTP map to improve the signals of local anomalies. Also, Butterworth low pass filter was utilized to remove local magnetic field influences and noise. The depth of the basement obtained by the (RAPS) technique revealed that, there are two main average levels at 2.331and 0.50 km depths below the measuring level in addition to (SPI) technique ranges from from -551 m to -1509 m from the surface of the ground which matched very well with the results of the drilled wells at the site. The eastern and northeastern margins of the studied area displayed thin sedimentary cover and the northwestern, western, and southern parts displayed a thick sedimentary succession that may considered as areas of groundwater potentiality.

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