Geophysical study of subsurface structures of the area surrounding the new port of Jarjob in El-Negila-Marsa Matruh using magnetic data

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ABSTRACT
The purpose of the current paper is to investigate the subsurface geological active structures, through the analysis of the magnetic data, to conduct a scientific evaluation of the infrastructure of the area surrounding the new port of Jarjob that located on the northern coast about 60 km from the city of Marsa Matruh towards the city of Salloum and sited in the vicinity of the proposed area.

The magnetic data comprise the RTP aeromagnetic map as well as the resulting map from the geomagnetic survey for the part that was chosen in the proposed area. Two Overhauser Magnetometers are used to make a detailed comprehensive land magnetic survey, while the aeromagnetic map is obtained with authorisation from the General Petroleum Company. The necessary reduction-filtering phases like the daily variation, regional gradient, and the time variation are applied to obtain the total intensity anomaly map. Resulting total land magnetic intensity map is then reduced to the north magnetic pole and followed by the application of filtering linear wavelength technique to RTP aeromagnetic map and RTP land magnetic map to isolated the shallower residual components using different grid intervals.

The obtained major tectonic trends of the study area show that the regional structures are controlled by the regional deeper structure taken NE-SW and E-W directions. The average calculated depth to the basement surface ranges from 2.6 to 3.2 km. So, the strength and solidity of the infrastructure of the port area, especially land magnetic survey area being studied that occupies a privileged place, which overlooks directly on the port coast and close to the main building, makes it a candidate for the establishment of industrial and economic projects and logistical services in the port.

1. Introduction
Matrouh governorate represents one of the most promising places in the northern coast of Egypt, especially Matrouh-El-Negila area for new and future sustainable development projects (Figure 1).

The study area is situated between latitudes 31° 23′ 40″ & 31° 29′ 30″ N and Longitudes 26° 26′ 35″ & 26° 39′ 05″ E, far north-west extending along Matruh–El-Salloum road between mark 60–85 km of about 25 square kilometres with an aerial extension of about 20 Km (Figure 1). The new port of Jarjob is sited in the vicinity of the proposed area of study, where the largest part of which has been established. The purpose is to find the subsurface and tectonic structures through analysis of the magnetic and aeromagnetic data to neutralise the infrastructure of the area of interest and the factors affecting.

The magnetic method is considered one of the most important and broadly geophysical techniques used for exploring the Earth’s subsurface. It can solve a wide variety of subsurface exploration problems including the horizontal magnetic variations from Earth’s crust base to within the uppermost metre of soil. These variations cause disturbance in the Earth’s normal magnetic field readings that are traced and mapped by the magnetic method Hinze et al. (2013). The magnetic method records the variations in the earth magnetic field that caused by lateral differences in the magnetisation of the subsurface Hinze et al. (2013).

2. Geological setting
Geologically, the Mediterranean coastal zone is intensively studied by Hum (1925), Ball (1939), Shukri et al. (1956), Shata (1957), and El-Shazly (1964). The exposed rocks in the northwestern Mediterranean coastal zone are entirely of sedimentary origin that dated back to Late Tertiary and Quaternary ages; their stratigraphic sequence was given by Shata (1957) and Conoco (1989) (Figure 2). Tectonically, the northern Western Desert represents a part of the unstable belt of the tectonic framework of the Egyptian Territory (EGPC) (1984) and Said (1990).

The study area is not levelled in sense that some topographic highs Road, Camel tracks, wadis and
3. Data and methodology

The sources of the magnetic field data used in this work consist of the following:

3.1. Aeromagnetic data

The aeromagnetic map was beneficial as an important source of the magnetic data representing the study area with Scale of (1:5000) obtained with authorisation from the (G.P.C).

3.2. Land magnetic survey

The land magnetic survey was done at an area of about 25 square kilometres, using two Overhauser Magnetometers. The acquisition of the magnetic survey data was done to make a detailed comprehensive land magnetic survey. One of the magnetometers is fixed in the middle part of the area as a local reading base station, while the other is measuring the total intensity of the different points in a mesh-like configuration. Approximately of 400 m station spacing was done through 15 working days period. Three readings were taken at each surveyed location with a time separation of approximately 5-min between successive readings. Locations of higher scatter magnetic readings greater than 3nT from its means values were ignored as it assumed to be a source of magnetic anomalies and other sites were selected. A local base station was situated at the middle of the area to record the drift curve every 10-min interval during the acquisition.

The field technique consists of setting up a systematic grid work station in which each reading was taken and then backed to the true value of the magnetic anomaly. The observed points were chosen along (N–S) lines as follows: Starting from an observed point in the area and well located in the map, a bearing was taken in a north direction by means of compass. A high wooden pole was adjusted at the starting point and another wooden pole was adjusted at a distribution of about 400 metres, along the established direction. Moving through these points, the following points were acquired along such lines. These points were marked on the ground and plotted on the map according to a certain scale. In this way, the N-S trend could be made. Starting from the chosen fixed point and selecting other fixed points northward or southward in which similar E-W traverses were made. The magnetic contour lines of equal values were then constructed from the reduced data of the magnetic survey (Figure 3). After that, the total

Figure 1. Matruh Governorate Map showing the location of the area of study.
magnetic intensity data were reduced to the pole technique using the equation of (Baranov 1975). Approximately of 43° magnetic inclination was used for the study area. An eastward shift on the magnetic anomalies is obtained on the comparison between the total land magnetic intensity map (Figure 3) and the RTP magnetic map (Figure 4) due to the removal of the inclination effect of the magnetic field for the area.

3.3. RTP land magnetic anomaly Map

Through careful analysis of the RTP land magnetic anomaly map for the surveyed area (Figure 4), it shows strong positive anomalies concentrated on three key areas. The boundaries of the first region start from the northeastern corner of the area and spreads to the south and west and consists of one closure irregular shape, a positive magnetic anomaly axis of high values and taking the direction of northeast-southwest. The second area of positive magnetic anomalies is placed in the west of the above-mentioned part of the area and consists of two closures of oval in shape, the size of anomalies ranges between 10 nT and 20 nT with high sharpness and gradient. By analysing the form and

Figure 2. Geologic map of Matruh area shows the main geological formations (after Conoco 1987).

Figure 3. Map of Total land magnetic intensity of the area of study.
nature of the anomalies found in this part, it indicates a zone of local faults that separate the (positive & negative) anomalies in the east and west. The last area is located in the southern part of the area that is characterised by irregular anomaly shapes ranged between 16 nT and 64 nT with high gradient.

The resulting strong positive magnetic anomalies may be due to the existence of the subsurface basic intrusions of high magnetic content. However, the negative magnetic anomalies are concentrated in the southeastern part of the region characterised by their irregular shapes and negative polarity, the size of the anomaly range between 0 nT and −50 nT with high gradient and high sharpness. These anomalies are taking north-south direction and can be interpreted as reflecting the change in the topography of the basement rock surface.

3.4. Aeromagnetic anomaly map

The analysis of the RTP aeromagnetic anomaly map of the area (Figure 5) shows that the highest values of the anomalies are found in the northwestern and southwestern parts for the lowest values are found in the north and northeastern part. Also, we note the presence of several local anomalies in the southeastern part of the study area. The closures of negative anomalies are concentrated in the northeastern and northern parts and the southeastern corner of the map. The contour values along these closures ranging between 0 nT and −140 nT. In the northeastern part of the area, two closures are characterised by ellipsoidal shape with high magnetic gradient. These anomalies are suggested to be resulted from a horst surrounded by two basins. To the west of the above-mentioned part, the anomaly is irregular with high sharpness and gradient, while the size of such anomalies ranges between 0 and 80 nT. These anomalies reveal a shallow sedimentary basin. The anomaly in the northwestern part of the area is irregular with positive polarity ranging in size between 100 and 320 nT. It has low sharpness and moderate gradient. This anomaly reflects uplifting of a basement block.

The most diagnostic features of the anomalies found in the middle part of the study area are positive anomalies lines extends across the entire area. The lengthened anomaly zones with steep gradient indicate significant subsurface faulting trending NE-SW. These anomalies can be clarified as the result of magnetic basaltic extrusions related to the NE-SW faulting trend. In the southeastern part of the area, the anomaly is irregular with different nature (positive and negative) it has high sharpness and high gradient. These anomalies are characterised by different nature and can be interpreted due to basement intrusion. In the area that lies west of the former area and extend to the western border of the surveyed area. The anomaly is irregular in shape with moderate gradient and positive polarities. These anomalies reflect uplifting in the basement complex.

3.5. Magnetic structures

The study of the structural anomaly trends of the study area as well as the regional magnetic trends
which is delineated in (Figure 6), indicating at least four essentials structural–morphological elements reflects the presence of dislocation in the basement surface that correlates well with the regional magnetic trends. These trends can be grouped in a system having different direction as follows:

3.5.1. Low magnetic anomaly trend (A/A)

This regional low magnetic trend occupies the northern part of the map area and take the NNE-SSW direction. Magnetic anomalies are distinguished along this axis by their negative polarity of high
gradient, elongated shape, and local areal extension. These magnetic anomalies reflect the presence of a major fault separating them from the positive regional anomalies and discarding of the fault is taking northeast.

3.5.2. II-High magnetic anomaly trend (B/B)

This trend follows the previously mentioned low trend (A-A) to the west. The anomalies along this axis of magnetic height are characterised by its high frequency, rectangular shape, low gradient and moderate local areal extension and trending E-W. The anomalies along this axis represent uplifting in the basement complex.

3.5.3. III-High magnetic anomaly trend (C/C)

This trend inhabits the central part of the area and extends from the eastern edge to the western border of the area. Such high magnetic trends are characterised by high elongation of contour lines and low gradient trend ENE-WSW. This high trend is separated from the next low trend by an intensive magnetic gradient expressed by a normal fault.

3.5.4. IV-Low magnetic anomaly trend (D/D)

This regional trend stretches to the southeastern part of the study area and oriented in the N80 E direction. It is separated from the regional high trend by a main normal fault trending NNE-SSW and throwing southward. This anomaly is due to the uplift of the basement surface.

4. Data interpretation

4.1. Qualitative interpretation of the Field Data

In this study, we used the 2-D filtering to the RTP aeromagnetic map and land magnetic map to the lineation deduced from the structural faulting in the basement rocks at different depths using (Oasis Montaj 2010). A frequency ranging between 0.070 cycle/unit data and 3.0 cycle unit data and cut off chosen at 3.0 kKm was suitable to apply for the depth in area being studied. Two categories of filters are used in this study, namely regional (Low-pass) and residual (high-pass). The low pass filter is used to pass long wavelength and rejects all wavelengths smaller than the cut-off wavelength while the high-pass filter highlights short wavelengths and eliminates wavelengths larger than the cut-off wavelengths. The filtering technique was applied to both the land magnetic map (Figure 4) and RTP aeromagnetic map (Figure 5).

The analysis of the high pass RTP aeromagnetic filter map with an effective wavelength at a depth of 3.0 Km (Figure 7) edification high frequency and short wavelength which are inferred as residual component placed in different parts of the area. Also, a large number of smaller anomalies are resulted from the filtering process. These anomalies distributed with varying trends. However, the major tectonic trend deduced from the residual magnetic filtered map (Figure 6) indicates that the local structures trends are controlled by the local shallow structures, which have ENE-WSW, N-S, and E-W. These trends occupy high magnetic anomalies.

Low-pass RTP aeromagnetic filtered anomaly map with an effective wavelength at a depth of 3.0 Km (Figure 8) displays that the well-defined trend of the RTP aeromagnetic map still persevere that reflects the deep extent of the subsurface structure causing these faults anomalies. The major tectonic trends are controlled by the regional deeper structures that take the NE-SW and E-W directions. These anomalies are structurally controlled by faults trends in NE-SW and E-W. We note the disappearance of faults that take the north-south direction, which was found in the high magnetic filtered map and indicate that the faults of the north-south direction extend to a shallow depth of less than faults with a north-easterly and east-west direction.

Analysis of the high pass land magnetic filtered map with cut-off at a depth of 3.0 Km (Figure 9) clearly shows that the area is structurally controlled by tectonics of major axis in NE-SW and N-S directions. Also, most of the steep gradients have alternative positive and negative anomalies. There is a group of local anomalies of different polarities of high gradient, high frequency, and moderate amplitude, which is discontinuous of the surface structure of the study area.

Through the analysis of the low-pass land magnetic filtering map (Figure 10), it displays well-defined trends of anomalies in the RTP and magnetic maps that reflect the deep extension of the subsurface structures causing these faults anomalies. Moreover, the main fault trend of high-scale anomalies (NE-SW) reflecting the different stress that affects the deep subsurface. However, some smooth regional anomalies that appear not be related to a subsurface structure are most a result of regional variation in the magnetisation of magnetic susceptibility of the rock at high depth.

4.2. Quantitative interpretation of the field data

Quantitative interpretation of the geophysical magnetic data includes mainly the application of different technique to delineate some analytical parameters for the anomaly sources such as depth, width etc. Computation of the depth to the anomaly sources play an important role in such interpretation, like determining the density contrast and magnetic susceptibility. Three techniques are used to estimate the depth of the causative bodies. These techniques are:
4.2.1. Two-dimensional radially averaged power spectrum

The spectral analysis technique was explained by several authors (Solovyev 1962; Bhattacharya 1966; Spector and Grant 1970; Garcia and Ness 1994, and Maurizio et al. 1998). It was used to calculate the average depth levels to the magnetic sources. It gives general information about the area regarding the hidden structures that have a geographic extension.

The resulted diagram of the radially averaged power spectrum from aeromagnetic map (Figure 11) shows the estimated average depth levels to the deep...
and shallow depth segments in the proposed area. The 2-D power spectrum diagram of the aeromagnetic data shows that the deeper sources have an average depth about 2.5 km and the shallow or near surface source is of about 0.60 km.

4.2.2. 3-D Analytical signal method

This method was used to determine the depth of the magnetic anomaly of RTP aeromagnetic map. To calculate the analytical signal, the vertical and horizontal derivatives were calculated using frequency domain
FFT technique (Blakely 1995). Then, the analytical signal was calculated using equation of (Blakely 1995).

The analysis of the analytical signal of the RTP aeromagnetic map (Figure 12) shows that the higher values of the amplitude of the analytical signal are located above the central and south eastern and northwestern parts of the area. It is worth noting that the three boundaries with the highest topography represent the locations of tectonic faults in the area that take NE-SW and NW-SE directions.

The map of the analytical signal of the RTP land magnetic map (Figure 13) shows that the high values are concentrated in the middle and the northwest corner and that the boundaries of these areas express the path of the existing faults that take the N-E and N-W directions.

Seven magnetic profiles were carefully selected from the RTP antiferromagnetic map, in addition to the other six profiles represented by the RTP land magnetic map to calculate the depths to the top of

![Figure 11. Power spectrum of the aeromagnetic data.](image1)

![Figure 12. Analytical Signal of the RTP aeromagnetic map showing the profiles from M1 to M7 which were used to estimate the depths.](image2)
the geologic boundaries of faults from the analytic signal using the proposed method, as shown in (Figure 12 and Figure 13). We can conclude from applying this method to RTP aeromagnetic map, that the basement surface depth was ranging between 2.41 km and 2.94 km in Table (1). The maximum depth 2.94 is located in the central part of the area, forming the basement of low structure extending N20E direction. On the other hand, the minimum depth values 2.41 Km at the northwestern part of the area of a high basement structure. By examining the depth results estimated from the analytic signal of the land magnetic map, we noted that the depth to the basement surface ranging between (2.3 and 2.71 Km) in Table (2). The maximum depth is located in the northeastern part of the area reflecting a basement low structure extending NE-SW direction. Also, through the results, we will note that the minimum values of depth are located in the southwestern part forming the basement high structure extending in NE-SW direction.

Table 1. Table (1) show the depths inferred through the quantitative analysis of the analytical signal of RTP aeromagnetic map Figure 12:

| Profile No. | Depth Results (Km) |
|-------------|---------------------|
| M1 – M1     | 2.41                |
| M2 – M2     | 2.73                |
| M3 – M3     | 2.94                |
| M4 – M4     | 2.63                |
| M5 – M5     | 2.68                |
| M6 – M6     | 2.46                |
| M7 – M7     | 2.53                |

Table 2. Table (2) show the depths inferred through the quantitative analysis of the analytical signal of RTP land magnetic map Figure 13:

| Profile No. | Depth Results (Km) |
|-------------|---------------------|
| A1 – A1     | 2.71                |
| A2 – A2     | 2.55                |
| A3 – A3     | 2.45                |
| A4 – A4     | 2.65                |
| A5 – A5     | 2.85                |
| A6 – A6     | 2.32                |

Close examination of the analytical signal, of the high RTP aeromagnetic filtered map and the low RTP aeromagnetic filtered map (Figure 14 and Figure 15) displays unrelated magnetic anomalies that vary in amplitude and frequency. These variations can be interpreted as different in structure and composition of the magnetic source of these anomalies. Also, we note that the shallow areas with a high topography in the local map is concentrated in the middle and extend from the north-east to the south-west and other areas are scattered in the north-east and south-west.

4.2.3. Euler deconvolution method

This tool is useful in interpretation of the potential magnetic data to know the depth to the contact surface between the sedimentary and basement rocks. It mainly depended on the structural index, sampling rate and level of the magnetic data. It also important to understand the subsurface geologic
setting (Thompson 1982; Reid et al. 1990). It is a semi-automatic technique, that does not affect by the presence of remanence and the source of magnetisation (Ravat 1996). In this technique, we use both of the horizontal and vertical gradients to compute the location and depth of the anomaly sources (Keating 1998). The interpretation of magnetic data is mainly passed out on the RTP aeromagnetic map and RTP land magnetic map by applying the Euler deconvolution method using (Geosoft Program, 1993).

Through the results inferred from the application of this method, we find that the depth to the detected faulting pictures of the subsurface structures as shown in (Figure 16) ranging from (2.0 to 2.5 km) with mean depth of 2.2 km. While the depth of the subsurface shown by land magnetic map (Figure 17) ranging between (2.0 and 1.5 km) with a mean depth 1.85 km. Solutions at different depths are shown in (Figure 18). The plots of the first solution show the dyke picture at depths ranging (2.0 and 1.7 km) with mean depth 1.75 Km, this result derived from the RTP aeromagnetic map (Figure 19). However, the land magnetic map (Figure 20) shows the depth to the surface range between (2.0 and 1.8 km) with a mean depth of 1.9 km. Also, through the results of applying Euler solution to RTP aeromagnetic and land magnetic map for faults and dykes (Figure 18, and 19), we can observe that the linear normal clustering deduced from the geological map was trending in the NW and NE direction that means the surface normal faults (in the geological map) have a vertical extension extent to 2.00 km in depth.

### 4.3.2. Euler deconvolution method along the magnetic profiles

This technique has an important role in maximising the role of magnetic data in order to calculate the location and depth to the magnetic anomaly causes and to delineate anomalies caused by isolated and multiple sources (El Dawi et al. 2004). Equation of Euler deconvolution method is stated that:

\[
(x - x_0) \frac{\partial T}{\partial x} + (y - y_0) \frac{\partial T}{\partial y} + (z - z_0) \frac{\partial T}{\partial z} = n(B - T)
\]

By applying the Euler’s expression to a line or a profile (2D source), the x-coordinate represents the amount of the distance along the profile while the y-coordinate put zero along the entire profile. The Equation will be written in this formula:

Where \((x_0, z_0)\) is the location of a 2D magnetic source that total field \(E\) is noticed at \((x, z)\). The total field has a regional value of \(G\) and \(n\) is the amount of fall-off rate of the magnetic field. \(N\) is referred to as the structural index and depends on the shape of the source (El Dawi et al. 2004).

This technique was applied to three profiles carefully selected from the land magnetic map (Figure 20) and the depths of fault structures were calculated by analysing the analytical signal of these profiles and building the equations of both Atchuta et al. (1981), Nabighian’s (1972, 1984), Roest et al. (1992), and Hus, S. (2002).

Through careful analysis of the results of Euler solution along profiles (A-A1, B-B1, and C-C1) figures (21, 22, and 23), we can see that the models

![Figure 14. Analytical Signal of the high pass RTP aeromagnetic filtered map.](image)
exhibit numbers of peaks expresses the depth to the basement intrusions. These magnetic peaks show the location of the shallow magnetic structures of highest magnetisation. The depth to the top of the faults across these peaks ranging from (0.40 to 0.60 km) with respect to profile (A-A1) and the depth ranging from (0.50 to 0.70 km) along the profile (B-B1). As for the profile (C-C1) the depth

Figure 15. Analytical Signal of the low pass RTP aeromagnetic filtered map.

Figure 16. Resulted Euler deconvolution from RTP aeromagnetic data using structural index = 0.
is between (0.30 to 0.70 Km). However, the average depths across these profiles in the deeper parts range from (2.6 to 3.2 km).

5. Results and discussion

The qualitative explanation of the magnetic data involves at first the translation of the implicated...
magnetic belts into structural deformation. Two low magnetic trends are mutually arranged with other two high magnetic trends express positive and negative structural belts. It is important here to point out that these four structural axes, which represent the regional faults in the area of study lie at great depths from the surface of the earth and therefore they do not affect the subsurface structure of the area and do not affect the industrial and economic projects associated with the new port.

The wave number-filtering technique performed on RTP aeromagnetic map and RTP land magnetic survey map using two types of filtering (low pass filter and high pass filter). By analysing the results
of applying this method, we can extract that the regional structures representing the basic subsurface structure extends to great depths as reflected in the results of the RTP aeromagnetic map as well as the ground map and can be explained on the durability and strength of the subsurface structure in the study area.

Two-dimensional Radially Averaged Power Spectrum technique was applied on RTP aeromagnetic map to deduce the basement surface depth. Moreover, 3-D analytical signal was also applied for the girded magnetic data and accordingly the accurate position and boundaries of the causative bodies were determined and mapped. The Euler deconvolution technique was also applied to the same previous magnetic data to determine the depth to the contact surface between the sedimentary rocks and basement rocks. All these methods of computation are used with great accuracy to overcome the error and present reliability of some observed anomalies.

Low-pass RTP aeromagnetic filtered anomaly maps with an effective wavelength at a depth of 3.0 Km (Figure 7) demonstrates the well-defined trend in the RTP aeromagnetic map that reflecting the deep extend.
of the subsurface structure causing these faults anomalies. This major tectonic trend shows that the regional structures are controlled by the regional deeper structures, which have NE-SW and E-W directions. We find that the local structure trends are controlled by the local shallow structures which have NE-SW, N-S, and E-W. These trends occupy the high magnetic anomalies. The low-pass RTP land magnetic filtered map demonstrates also the well-defined trends of anomalies in the RTP land magnetic map that reflects the deep extend of the subsurface structures causing these fault anomalies. Moreover, the main fault trend of high-scale anomalies is NE-SW. Structurally, the western desert of Egypt, including our interested areas, is characterised by NE-SW and NW-SE trending normal faults (Meshref 1990, 1995).

6. Conclusion

This paper is devoted to delineate the infrastructure of the area surrounding the new port of Jarjob which is located about 60 km from the city of Marsa Matruh, and to throw some lights on the major structural elements dissecting the considered area as well as the tectonic interferences standing behind them. To accomplish these targets, the magnetic field data of the investigated area in the form of RTP aeromagnetic map and RTP land magnetic survey map are utilised. We can extract that the strength and solidity of the infrastructure of the port area, especially land magnetic survey area being studied that occupies a privileged place, which overlooks directly on the port coast and close to the main building, makes it a candidate for the establishment of industrial and economic projects and logistical services in the port.

Disclosure statement

No potential conflict of interest was reported by the authors.

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