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Using the HEM Technique and Its Relation to the Seismic Activity to Detect the Main Structural Setting and Rock Units at Abu-Dabbab Area, Egypt

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Authors' contributions

This work was carried out in collaboration between all authors. Author AAB designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors MT, AMA and KO managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Abu-Dabbab area is located in the western Red Sea coast at the Eastern Desert of Egypt. This area is characterized by the presence of different geological units and high seismic activity. It is one of the seismic source zones in Egypt. The purpose of this research is the detection of the structural setting and rock units by using the Helicopter Electromagnetic (HEM) technique and its relation to the seismic activity at Abu-Dabbab area. The spatial distribution of earthquakes recorded by the Egyptian National Seismic Network (ENSN) was used to study the seismic activity along the detected structures at the study area. The results of this work show that there is a resistivity variation over the study area. This variation may be due to the difference in the rock composition and its conductivities. In addition, the places of high resistivity values clearly show sites of faults. The sites of approximated values confirm the presence and expansion of the different rock units which are mixed in their electrical properties. The sites of the detected faults are identifying with the seismic activity of the area.

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Keywords: Abu-Dabbab area-Egypt; helicopter electromagnetic (HEM); seismic activity.

1. INTRODUCTION

Abu Dabbab area is located in the western bank of the Red Sea coast, to the north of Marsa-Alam city. It lies between latitudes 25.2º - 25. 5ºN and longitudes 34.5º - 34.65º E (Fig. 1). This area is a part of the Red Sea mountain range and has a rugged topography and complex tectonic setting. Abu-Dabbab area is characterized by a mild climate and clean environment in addition to its location on the Red Sea coast which makes it an attractive environment for tourism and various investments. Also, it contains many mineral resources (e.g. phosphate, feldspar, quartz, and gold). That is why it is very important to make the current study to detect the structural setting and its relation to earthquake activity at the study area. Abu-Dabbab area is characterized by high seismicity and considered as one of the most active seismic zones in Egypt.

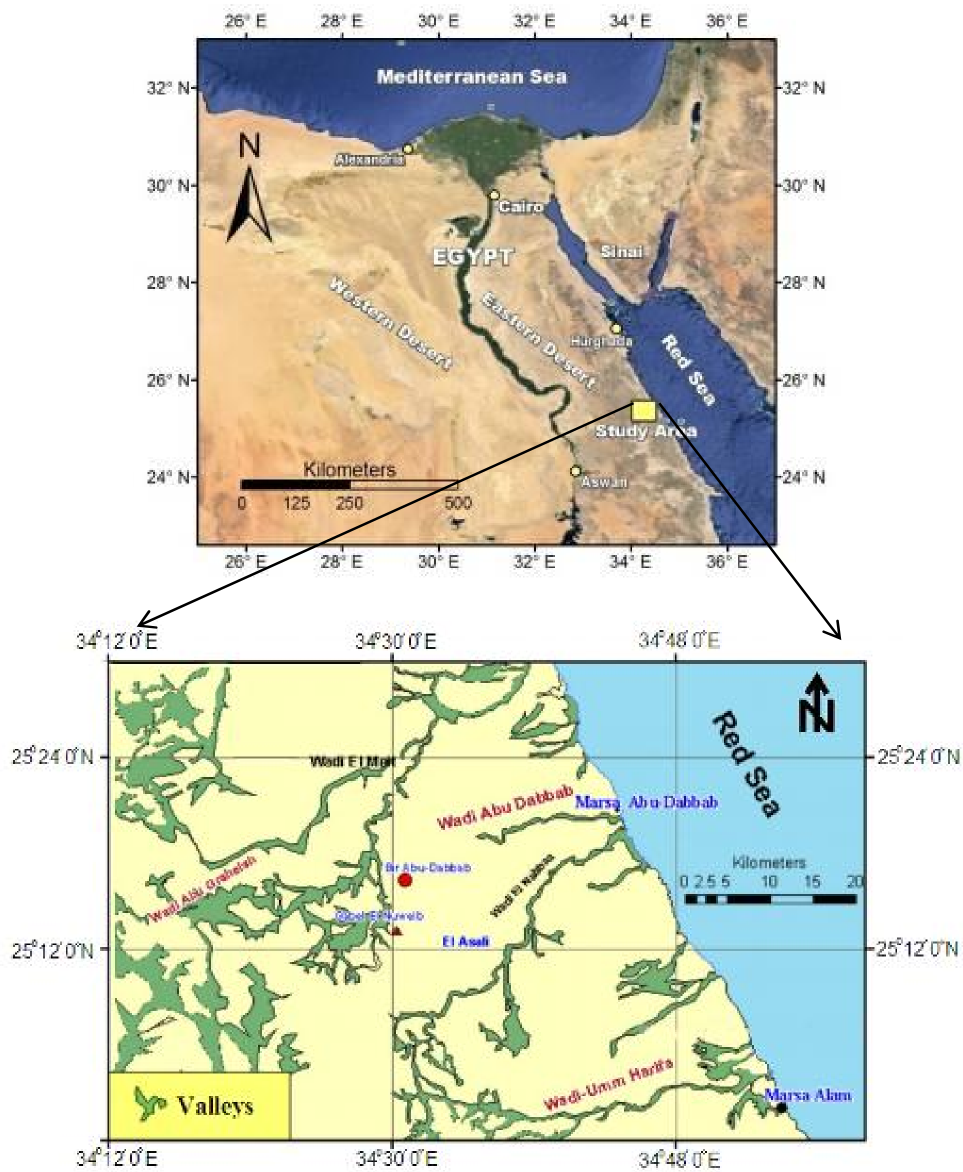

Fig. 1. Site map of the study area

Airborne ElectroMagnetic (AEM) technique is used in the current paper. In this technique, it is Helicopter that measured the data; so we will call it HEM (Helicopter ElectroMagnetic). The HEM is one of the most operational tools used to identify the rock units and structures at a certain area. So, in this research HEM is used as the key geophysical method. HEM in frequency domain is applied to uncover the conductivity anomalies located in Abu-Dabbab area. Due to the high level of seismicity of the study area, this study is strengthened by using earthquake data recorded by the Egyptian National Seismic Network (ENSN). This data has been correlated with the places of structures and multiple geological units in the vicinity of Abu-Dabbab area.

2. GEOLOGIC AND TECTONIC SETTINGS

Abu-Dabbab area is covered by Precambrian basement rocks mainly composed of meta-sediments which are the oldest rocks in the area (Fig. 2). Widespread acidic igneous rocks include large-scale of ultra basic to basic intrusions in the form of flow, dykes masses and other shapes that were introduced in the sediments before their metamorphism [1]. The derivatives of ultra basic intrusions are represented in the area by the serpentine rocks that were considered as a sector of the Pan-African belt. Some of these serpentine bodies are relatively mass of significant size and form many of the peaks in the area [2].

Structurally, Abu-Dabbab area is related essentially to the tectonic setting of the middle of the Egyptian Eastern Desert. According to the structural setting that is demonstrated by the geological map of the Egyptian Geological Survey and Mining Authority [3] shown in (Fig. 2), the local trends of major, minor faults and lineation are predominated by two directions. The azimuth frequency diagram of surface lineaments around Abu-Dabbab area [4] shows that the minor trend has a NNW–SSE direction with azimuth 155º parallel to the Red Sea coastal line and the major trend is ENE–WSW with azimuth 60º perpendicular to the former (Fig. 3).

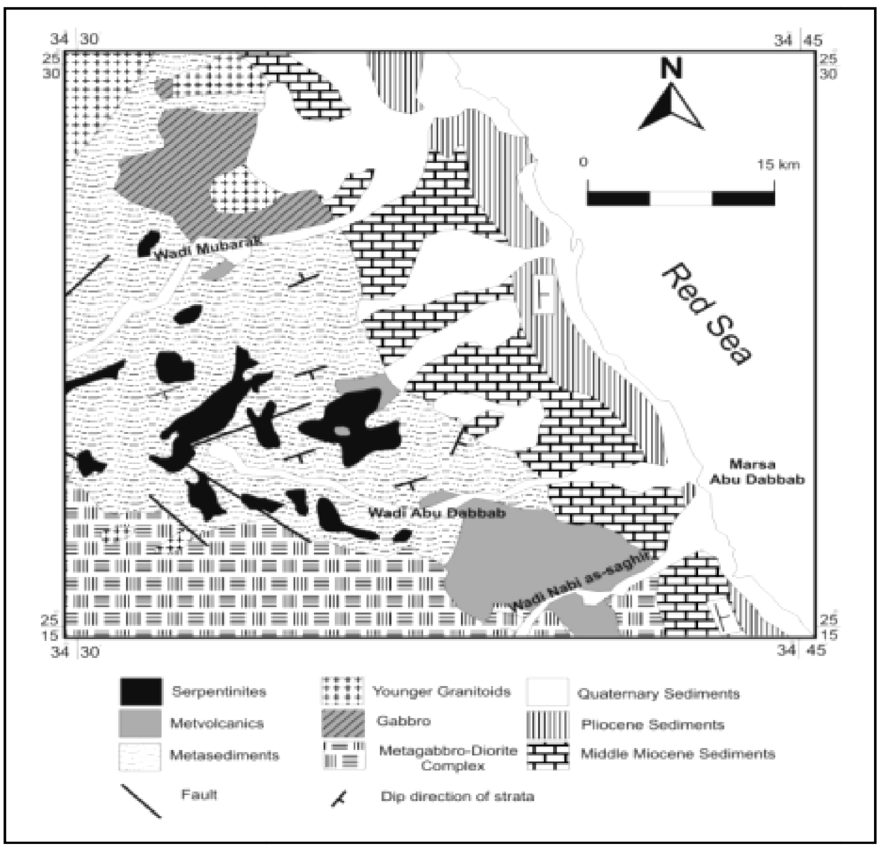

Fig. 2. Geological map in and around Abu-Dabbab site [3]

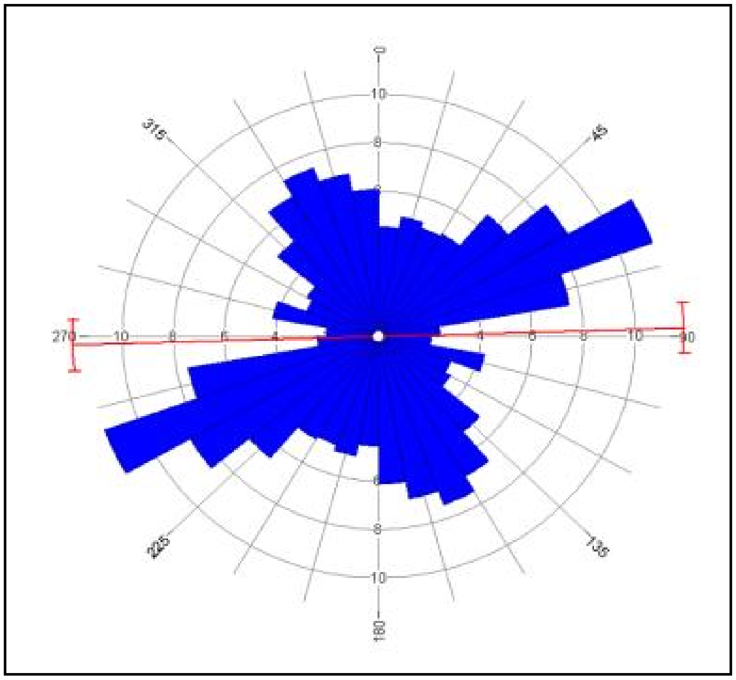

Fig. 3. Azimuth frequency diagram of surface lineaments close to Abu-Dabbab site [4]

Volcano Sedimentary Sequence is completely folded and faulted, suggesting that this process belongs to the first deformation phases of the regional tectonic evolution [3]. The E-W trending shear zones affecting also rocks of the intrusive complex belong probably to successive phases of deformation that may be associated with thrust faulting of the intrusive complex plutonites over volcano-sedimentary rocks.

3. SEISMICITY OF THE AREA

Abu-Dabbab area is the most active seismic zone in the Egyptian Eastern Desert in which seismic activity is recorded daily. Since the outset of the 20th century, earthquake swarms, accompanied by sounds of distinct rumbling similar to the sound of a distant quarry blast, have been detected at Abu-Dabbab area [5]. The sound is heard by Bedouins for several generations. The name ‘‘Abu-Dabbab’’ itself is meaningful since it means ‘‘earthquake sounds’’ in Arabic.

Many authors studied the seismicity of Abu-Dabbab area [6,7,8,9,10,11,12,13,14,15,16,17]. The area has been hit by two significant earthquakes on 12 November 1955 and 2 July 1984 with magnitudes 5.6 and 5.2, respectively [6,13]. The spatial distribution of earthquake foci, (Fig. 4) that was recorded by the Egyptian National Seismic Network (ENSN), shows that the earthquakes in Abu-Dabbab region are extremely tightly clustered in a planar shape and tends to align in the ENE–WSW direction marking a zone of activity transverse to the Red Sea trend. The recorded seismic activity from Abu-Dabbab region by the ENSN ranges from (10 – 15 events/day) to more than 60 events/day, and sometimes reached 100 events/day during swarms [13,17].

[17] studied the crustal deformation model at Abu-Dabbab area using GPS and earthquakes’ data. They reported that most of earthquakes, that occurred in Abu-Dabbab area, are microearthquakes of local magnitudes less than 2.0. They also mentioned that the seismicity at Abu-Dabbab is concentrated at focal depth from 2 to 17 km, indicating that the seismicity is likely located in the upper continental crust and the ductile rocks that could be found beneath this depth.

The focal mechanism solutions at Abu-Dabbab area show different fault styles. Normal faulting with a strike-slip component characterizes some events (i.e. 2 July 1984 earthquake). Reverse faulting with a strike-slip component is characteristic in all events during the August 2004 swarm [8]. [13] located micro-earthquake seismicity in the area and estimated the focal mechanism solutions for 17 events. They found that the left lateral strike-slip motion is the common mechanism for all events and that all fault trends are evidently caused by surface faults (Fig. 5). Some of these faults are parallel to the Red Sea direction, while the others take a direction transverse to the Red Sea trend. They also used the earthquake focal mechanisms to study the regional stress field around Abu-Dabbab area. Their investigation showed that the maximum compressive stress (σ1) is perturbed from the regional NW–SE direction to E–W and ENE–WSW orientation.

The characteristics of the seismic activity at Abu-Dabbab area (extremely tight clustering with a relatively high level of seismic activity, different style of source mechanisms, and local stress field) suggest that the seismicity of the area is related to local sources rather than regional tectonics [8]. [13] suggested that the present-day seismicity and deformation at Abu-Dabbab area is originated by local stress and is likely related to the magmatic intrusion into the upper crust triggered by regional tectonics.

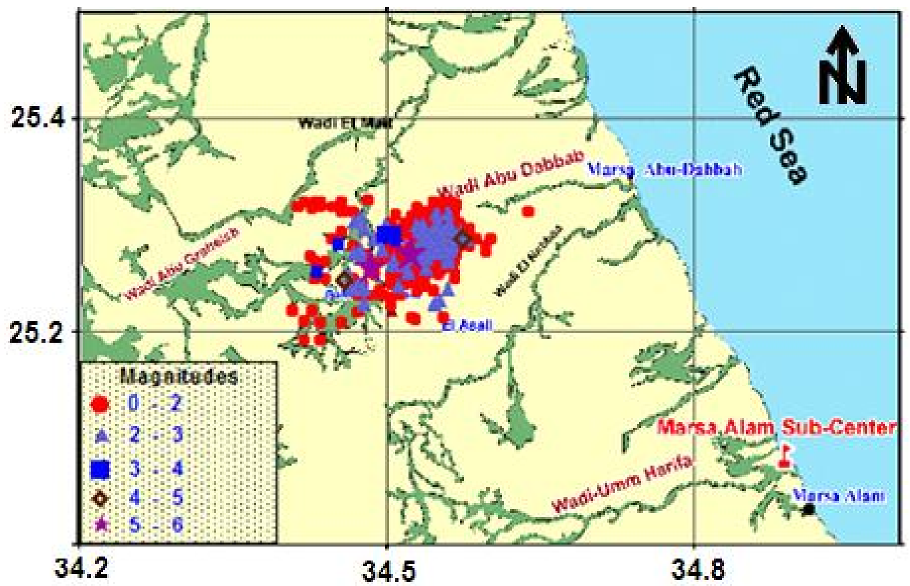

Fig. 4. Seismicity map of Abu-Dabbab site in the period from 1900 to 2012 [17]

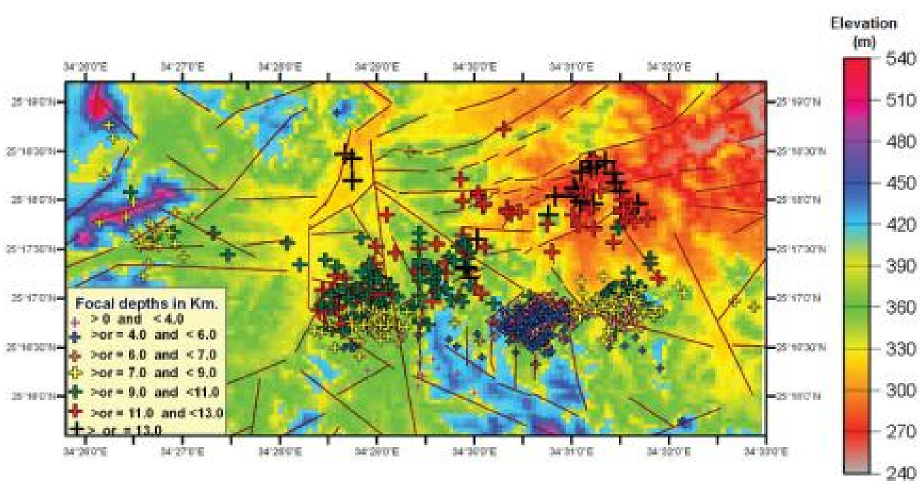

Fig. 5. Distribution of recorded seismicity by temporary network installed in Abu-Dabbab region [13]. Data plotted on a topographic map of the study site. The red lines show the surface faults compiled by the Egyptian Geological Survey in 1992

4. APPLIED GEOPHYSICAL METHOD (INSTRUMENTATION AND METHODOLOGY)

Both of Electrical and Electromagnetic (EM) methods illuminate the subsurface resistivity distribution. As in Direct Current (DC), electrical methods current is injected directly into the subsurface and they are limited to be applied on the ground. On the contrary, EM methods relied on the spread of EM fields, which make streams in the subsurface. Thus, the ground-based as well as airborne EM measurements are practicable. An effective practice of DC and EM methods in distinguishing subsurface resistivity structures needs an adequately high resistivity difference between the object and the nearby material.

Numerous transmitter and receiver coils are operated spontaneously by the HEM systems (Fig. 6). The sinusoidal current stream makes transmitter signals and the primary magnetic fields via the transmitter coils at distinct frequencies. The waver primary magnetic fields arouse eddy currents in the subsurface. The secondary magnetic fields are engendered by these currents, which depend on the conductivity circulation of the subsurface. The primary magnetic fields separate the secondary magnetic fields, which are measured by the receiver coils. They are measured at the receiver-coils centre and its measurement ratio is in parts per million. The primary fields have to be bounded because the secondary fields are very tiny compared with the primary fields. "The orientation of the transmitter coils is horizontal or vertical and the receiver coils are oriented in a maximum coupled position resulting in horizontal coplanar, vertical coplanar or vertical coaxial coil systems. Typically 4–6 frequencies are used on modern HEM systems" [18].

The vertical space from the TX-RX system to the target is wider compared with what is inside EM ground systems. That is why the quadrate anomalies and in-phase become rather tiny. The secondary-field value is mainly measured the primary magnetic field in parts-permillion (ppm). The researcher uses a survey type called Digital helicopter-borne electromagnetic (DIG-HEM).

Bucking coil is employed to overpower the primary magnetic field at the RX. This helps to detect the weak secondary field in the existence of a strong primary field. Numerous coil shapes have been used to let 9 combinations of TX and RX to be employed. "These will couple differently with different conductor geometries. Multiple frequencies give estimate of depth variation of conductivity" [19].

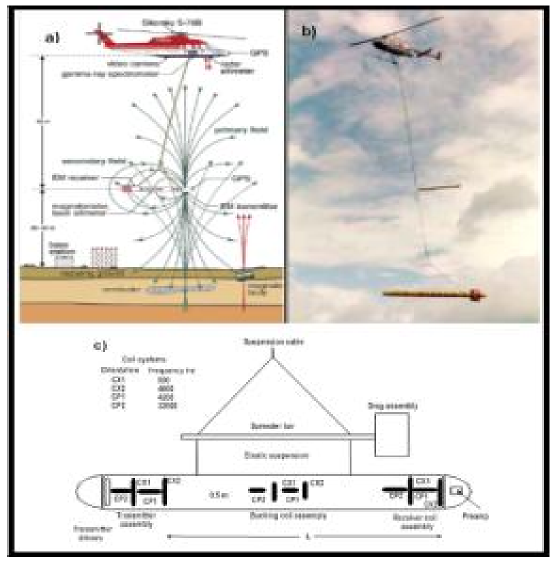

Fig. 6. (a) Bird Gama Rays (BGR) system: The minor bird altitude (30–40 m) overhead the ground. The helicopter is armed with difference video camera, a radar-altimeter, and GPS too; (*b*) General HEM system (*c*) the HEM system (the contents of the bird) [20]

The penetration depth relies on the covering depth, TX-RX space, and frequency. The difficulty of the measuring of weak secondary magnetic fields in the existence of the primary magnetic field is notable. The active conductors have minor quadrature feedback. Accordingly, frequency domain EM has the most difficult detection with the best targets in mineral exploration and structure mapping. Numerous frequencies is employed to estimate conductivity with depth variations. The measured data of ground (terrain) conductivity map or as primary field / secondary field as ppm are shown in 2D.

The HEM system runs at five frequencies between 56 Hz and 192 kHz. The receivers and transmitters of the horizontal coplanar coil system are nearly separated by 6.7 m. GPS detects the locations of the system and the helicopter. Radar altimeters and laser determine the altitudes of the HEM system and the helicopter, correspondingly. The minor ground clarity of the system is estimated 30–40 m. The sampling rate of 10Hz shows sampling spaces of nearly 4m at a flight speed of 140 km/h.

The Marquardt-Levenberg 1-D inversion technique is used to interpret the HEM data in terms of layered-earth resistivity models [21] & [22].

5. DATA PROCESSING AND INTERPRETATIONS

5.1 Data Processing of HEM (Frequency Domain)

The purpose of the data processing is to separate the field values from the measured data that are related to the subsurface material parameters and to lessen those rations in the data that are influenced by sources that do not belong to the subsurface. "HEM data processing requires a number of processing steps such as the conversion of measured voltages to relative secondary field values using calibration signals, standard and advanced drift corrections (zero-level drift correction/2D leveling), and other necessary data corrections" [23,24].

The external and internal calibration coils are used to standardize and calibrate the HEM system. These coils create specific signals in the HEM measured data. The external coils are employed for the calibration on ground to extract the transformation aspects. The calibration is tested by internal calibration coils many times throughout a survey flight, after phase and gain alteration at the start of every survey flight. The best adjustments of phase and gain perform are done over a ground with highly resistivity values or at elevated flight altitude (e.g. 350 m).

The detected signals at elevation altitude reveal low primary fields, joining chattel with the aircraft, or heat system drift. The function of these values is to change the HEM data regarding their zero-levels. The level of zero eradicates the long-term quasi-linear drift; this producer cannot successfully correct the varying air temperatures due to varying sensor elevations, which influence short-term differences, because there is no stable and standard calibration to zero-temperature correction. In order to eliminate the results of stripe patterns from residual zero-level and calibration errors, 2D filter techniques (micro-leveling) are essential to correct the line data.

The parameters of half-space are smoothed in its place, because the reliance of the secondary field on both the sensor altitude as well as resistivity of the subsurface is highly non-linear. The secondary field elements are matched with reference to the synthetic data of HEM. "It is derived from the leveled half-space parameters" [25].

The HEM data can be influenced by exterior sources (e.g. electrical cables or radio transmitters) or heavy-duty man-made conductors. Interpolation processes or suitable purifying can remove noise from the HEM data. The effects, which result from removal of buildings, electrical connections, and heavy magnetized sources, are a very sensitive step in processing. These effects are frequently not obviously distinguishable from that of natural sediments and rocks.

5.2 Resistivity Models Calculation

In many cases, the electromagnetic properties of the subsurface and the conductivity that dominates the HEM measurements are referred to by the three electric and magnetic material parameters: magnetic permeability, dielectric permittivity, and electrical conductivity. Permittivity and permeability, however, have only a slight affect at high and low frequencies, correspondingly. Accordingly, the conductivity or its inverse, the resistivity, is usually demonstrated to elucidate the HEM data.

Manual modeling barely processes the resistivity models. In airborne surveys, these resistivity models are commonly resulting from the secondary field data (in-phase and quadrature) using automatic inversion procedures as the enormous data values accessible. Thus, this study uses the techniques of the layered half-space, the homogeneous half-space, and the simple resistivity models.

Inversion of multi-layer (one-dimensional, 1-D) techniques puts the data of all frequencies into consideration, whereas the inversion of standardized half-space technique uses single frequency data. [26,27] hold a comparison between many methods accessible for calculating the corresponding centroid depth z_ [m] (meter in z direction), the apparent resistivity qa [Xm], and the HEM half-space parameters.

The presentation of the HEM results as apparent resistivity maps has been enabled by half-space parameters gained for numerous frequencies [28]. Moreover, there are many processes for the layered half-space inversion techniques of HEM data that are usually changed from progressed algorithms to ground-based EM data. [29] make a comparison of many 1-D inversion procedures. This comparison is handled in this study. Moreover the study employs the techniques that are designated by [22].

5.3 Data Interpretation of (HEM) (In Frequency Domain)

The location of Abu-Dabbab's data has been inverted by technique, which requires an initial model. This model comes from plotting apparent resistivity cross with values of depth. The primary multi-layer (resistivity–thickness) model uses sensitivities (Jacobian matrix) calculation. It has been adapted to the HEM data. While a particular threshold is obtained, the inversion process is paused. This threshold is referred to as the distinction fitting of the formed data to the collected HEM data. In other words, the inversion is paused when the increase of the fitting is less than 10%, for instance.

After the separation and processing of HEM data, the dissimilarities between the apparent electrical resistivity values show many rock units. This difference is attributed to the conductivities range of rock's components that HEM apparatus measures. Nearly twenty one faults is shown in the study location with extremely high resistivity values. The main long faults take N-S trend parallel to the Red Sea direction, while the other short faults take the direction of NE-SW and they cross, sometimes, the main long faults.

This study uses the analytical signal filtering to display of the high resistivity values and the sites of values change to represent the contact sites of the rock units in the study area (Fig. 7). The scattering in data with unclear parted outlines of rock units that shown in (Fig. 7), as an apparent resistivity map (7.2 KHz), may be caused by the difference of rock units' conductivities. The difference between rock units' resistivities becomes more lucid by reducing the frequency to (133 Hz) (Fig. 8).

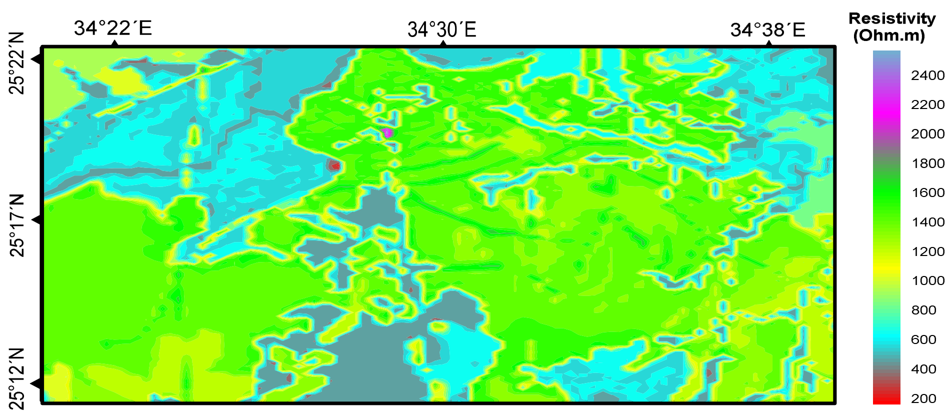

Fig. 7. Apparent resistivity map of the study site (at frequency 7.2 KHz)

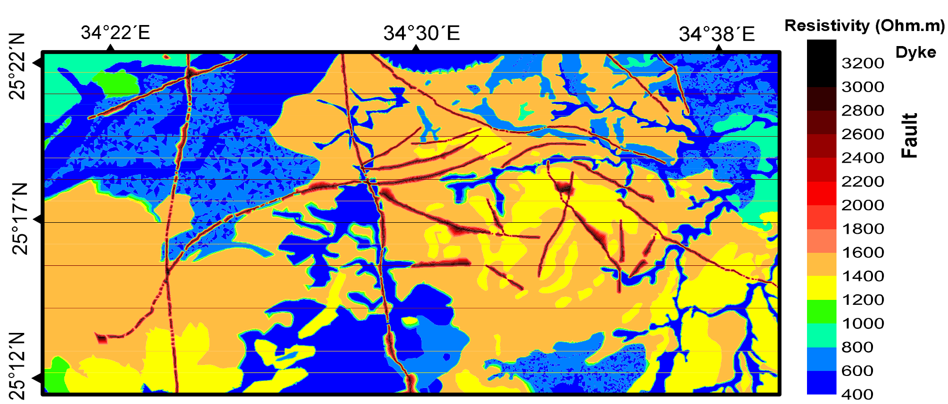

Fig. 8. Apparent resistivity map of the study site (at Frequency 133 Hz) and its classification of rock's units with respect to its resistivity data

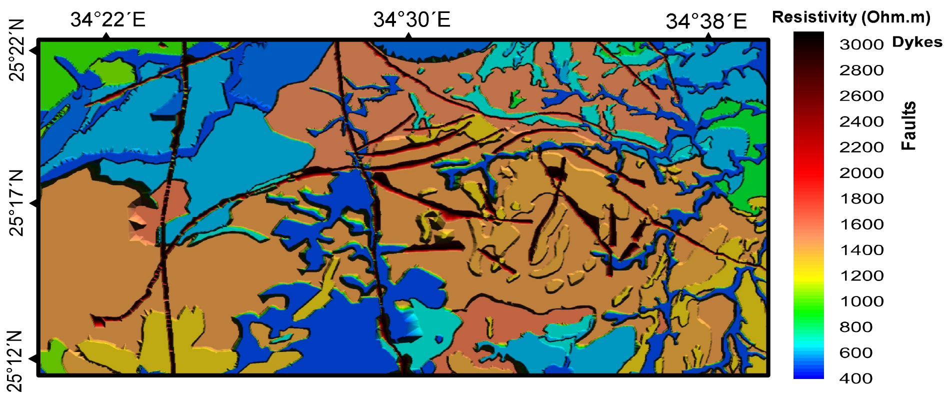

Fig. 9. 3-D apparent resistivity map of the study site (at Frequency 56 Hz) and its classification of rocks with respect to its resistivity data

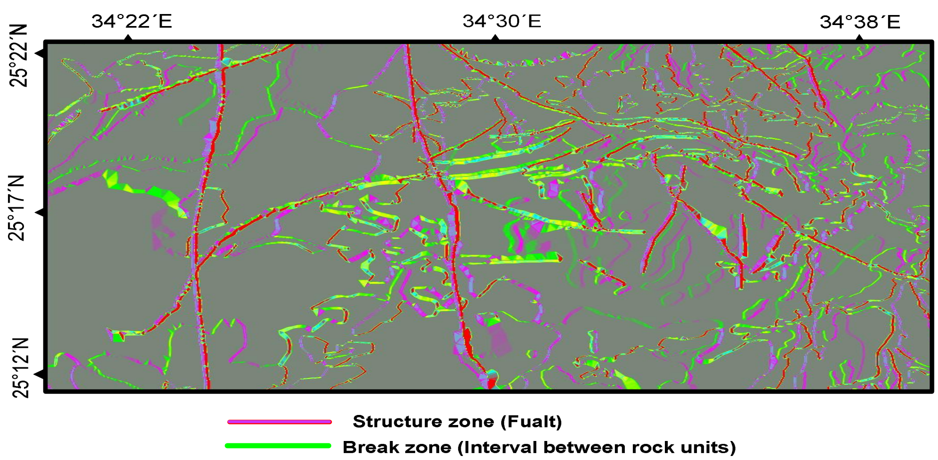

Fig. 10. Isolated map shows the main structure (faults) and the break/contacts between different rock units in the study site (by using smoothing analytical signal filtering method)

An obvious 3-D image to the rock's units and the structures among it under low frequency (56 Hz) is shown in (Fig. 9 above). The sites of closed values illustrate the presence and extension of the dissimilar rock's units that are mingled with its electrical characteristics; and the sites of high resistivity values obviously illustrate the places of faults at the location of the study. The places of the structures and the interval break zones between the rocks units can be located by using analytical signal filtering technique (Fig. 10 above).

6. DISCUSSION AND CONCLUSION

The main target of this paper is to detect the main structures in terms of faults and contact zones between the different rock units at Abu-Dabbab area in the Egyptian Eastern Desert. The Aero-Electromagnetic (AEM) survey was used as the main geophysical tool. The AEM survey has been done by Helicopter (HEM). With the aim of proving the consistency of the HEM technique to detect the structural setting of Abu-Dabbab area, we also used the recorded seismic activities at the area as an additional maintained geophysical device. This tool was used to allow us to evaluate the activity of the detected structures.

The HEM measured data have been numerically isolated and handled. The obvious difference between the apparent electrical resistivity values shows many rock units. This difference is attributed to the conductivities range of its constituents that are measured by the HEM instruments. Nearly 21 faults and dykes are shown in the study area with utmost high resistivity values. The main long faults take N-S trend parallel to the Red Sea direction, while the other short faults take the direction of NE-SW and cross in some places the main long faults. This result is in a good agreement with the earthquake activities and structural setting of the study area shown in (Fig. 5). This may prove that these detected structures represent the local stresses which are responsible for the seismic activities in Abu-Dabbab area.

Developments of both hardware and software tools will reduce the difficulties in measuring and processing HEM data in urban areas. Thus, it is most likely that HEM applications in populated areas will be more and more requested and applied in future.

The results show that the degree of similarity between the detected structures by the HEM technique and seismic activity in Abu-Dabbab area is relatively high.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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