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Detailed magnetic survey at Dahshour archeological sites Southwest Cairo, Egypt

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Abstract Dahshour area has recently shown a great potential of archeological findings. This was remarkable from the latest discovery of the causeway and the mortuary temple of the Pyramid of Amenemhat III using geophysical data. The main objective of the present work is to locate the buried archeological remains in the area of Dahshour, Southwest Cairo using magnetic survey for shallow investigations. Land magnetic data is acquired using proton magnetometer (two sensors) with a sensor separation of 0.8 m; i.e. gradiometer survey. The study area is located nearby the two known pyramids of Dahshour. The field data is processed and analyzed using Oasis Montaj Geosoft™ software.

The processed data is presented in order to delineate the hidden artifacts causing the magnetic anomalies. The results indicated a distribution of the buried archeological features within the study area. These archeological features are detected according to the magnetic contrast between the magnetic archeological sources (such as mud bricks, basalt and granite) and the surroundings; mainly sandy soil. The delineated archeological features at Dahshour are probably dated back to the old kingdom having a depth reach up to 3.0 m. Consequently it is highly recommended to carry out excavation to precisely classify them and high light their nature and value.

1. Historical background

Egypt has many unexplored archeological sites. The archeologists know where to search, but they like to know more where to dig. Two archeological sites are selected in the southern part of Dahshour area for the application of the detailed magnetic measurements (Fig. 1). The Dahshour region is a part of the Memphis necropolis (cemetery), the capital of the old kingdom, extends from Abu Roah in the north to Meidum in the south. King Senefru from 4th Dynasty (old kingdom) has built two pyramids at Dahshour area using limestone blocks; the red pyramid in the north and the pent pyramid in the south. The kings Amenemhat III and Senusert III of middle kingdom had built their pyramids from mud bricks. Definitely the surveys are carried out at a tomb, natively called "Mastaba" and an archeological hill, natively called "Tell Athery" which belonged to princes and princesses of the old kingdom.

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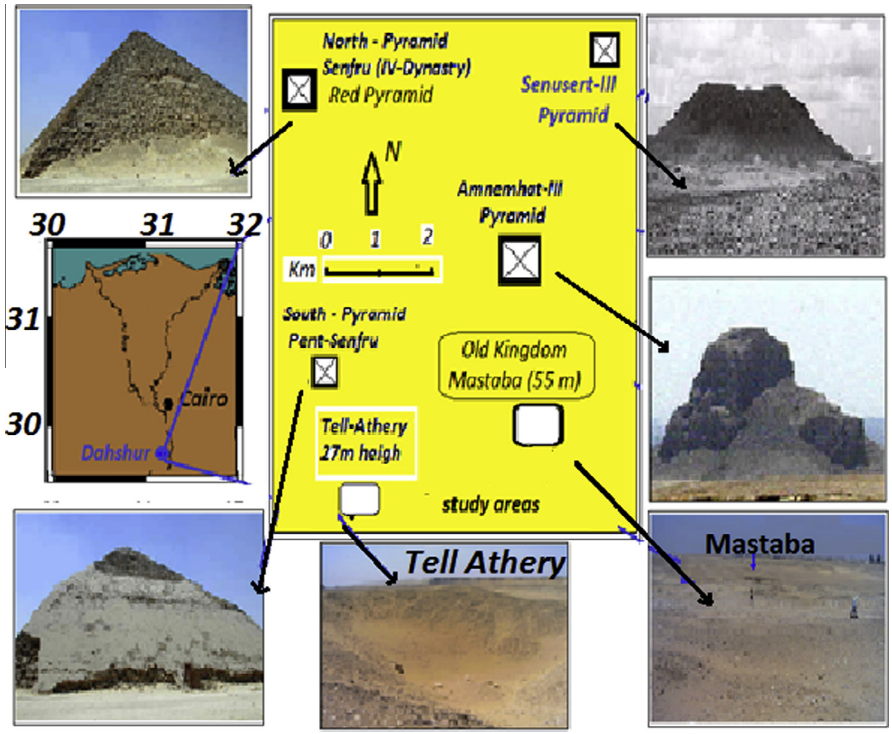

Fig. 1 Archeological remains at Dahshur area, showing the locations of Mastaba and Tell Athery (old kingdom) considered in this work.

There are many kinds and structures of Egyptian archeological features and soils. During pre-dynastic period, most of the houses and tombs were made from mud bricks. In the old kingdom or period of pyramids, ancient Egyptians have used huge blocks of limestone to build their pyramids. In the middle kingdom, the capital of ancient Egyptian changed to Fayoum region and the Kings had built their pyramids from mud bricks at Hawara, Lahun, Lisht and Dahshour areas while, the new kingdom and late periods erected funerary temples, statues and tombs to Gods that were made from different sorts of materials (mud bricks, granite, basalt, bronze and gold) see Fig. 2.

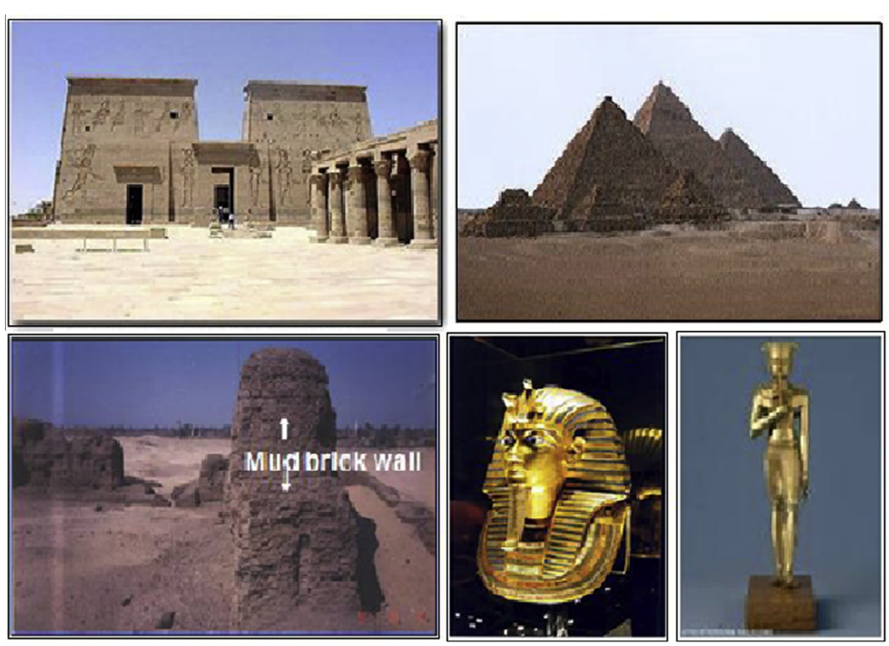

Fig. 2 The types of archeological features of ancient Egyptian from different historical periods.

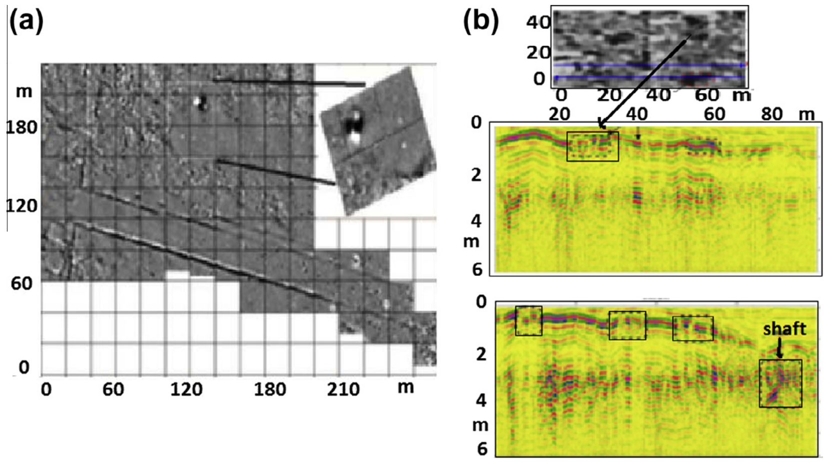

Fig. 3 (a) Vertical magnetic gradient image, showing cause way and funerary temple of Amenmhat III using the fluxgate magnetometer-FM36 (Abdellatif et al., 2010). (b) Magnetic image of site A shows the location of the GPR Profiles (P5 and P12) with GPR displays of profiles P5 and P12, (Awad, 2012).

The history of applying geomagnetism in archeology has begun in Europe during the fifties of the last century. Later on, it started in Egypt by Hussein (1983) who had measured land magnetic survey using proton magnetometer at Kom Oshim and Kiman Fares areas (Fayoum). During the nineties of the last century, the application of geophysics in Egypt began to use advanced magnetic instruments with real archeological discoveries (Abdellatif, 1998). Most of the Egyptian archeological features are made from mud bricks which contain some magnetic minerals (e.g. magnetite, hematite…etc., of high magnetic susceptibility), which are the reason for their high magnetization. So, they can be detected by sensitive magnetic instruments.

The problem of traditional and random archeological excavations, are time consuming and need effort and money. So that, the best way to explore the archeological remains is using passive geophysical tools (e.g. magnetic, electric and electromagnetic methods) without destroying or digging in the archeological sites.

2. Previous geophysical tools

The Dahshour area is rich of archeological remains that belong to the old and middle kingdoms. Abdellatif et al. (2010) carried out near surface magnetic investigation at Dahshour area and has shown a great potential of archeological discovery such as the pyramid complex of Amenemhat III. It consists of funerary temple (mortuary), valley temple and causeway (Fig. 3a). Awad (2012) has correlated the vertical magnetic gradient measurements with the GPR data to explore any corridor, shaft and colonnade nearby of the study area (Fig. 3b).

3. Magnetic data acquisition and processing

3.1. Test site

Land magnetic survey was performed by using a proton magnetometer (G-856 AX, Geometrics, 2010, Fig. 4a). It can be used as normal magnetometer (one sensor) or as gradiometer (two sensors), it is characterized by light, high resolution 0.1 nT and storage (acquired 3600 stations). To examine the validity and sensitivity of the (G-856 AX) instrument before measuring on archeological sites at Dahshour, the land magnetic survey was carried out on the test site at Kom Oshim–Fayoum area by (Mekkawi et al., 2012). This test site was prepared by Lethy (2004); it was constructed from magnetic and nonmagnetic artificial objects buried at a depth of 1.0 m. Due to the small size of the test site the readings were measured at 0.5 m sampling interval; the total intensity magnetic field (nT) of either bottom sensor or top sensor, and the

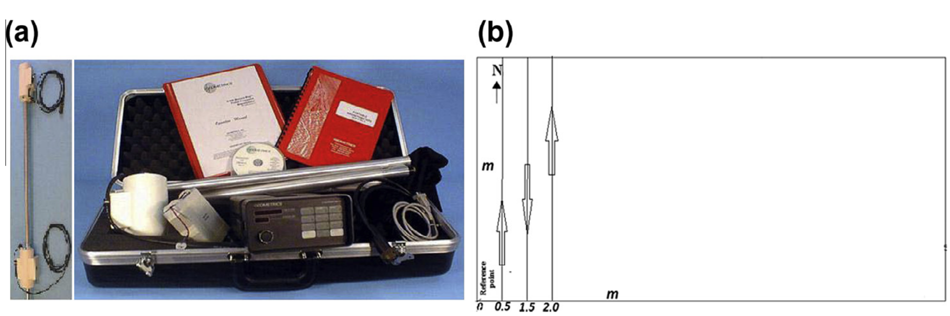

Fig. 4 (a) (G-856 AX) Proton magnetometer (Geometrics, 2010). (b) Layout of magnetic survey (Test Site) at Kom Ushem Fayoum.

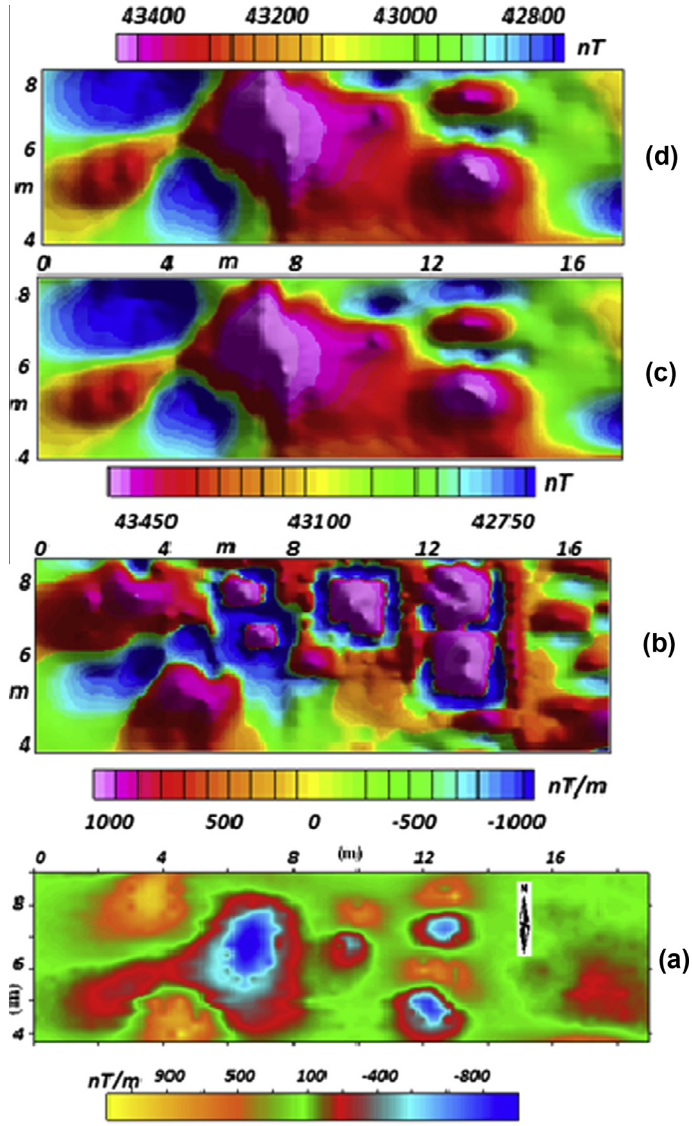

Fig. 5 (a) The vertical gradient (VG) of the total intensity measured over the test site by FM 36 fluxgate magnetometer (Lethy, 2004), (b) the VG measured by G-856 AX proton. Magnetometer with two sensors, (c) the total magnetic intensity measured by bottom sensor and (d) the total magnetic intensity measured by top sensor with height 0.8 m.

vertical gradient data (nT/m) are shown in (Fig. 5). The results are less suffering from the source ambiguity (Mekkawi et al., 2012), which enables us to remove the regional component to enhance shallow source anomalies.

3.2. Archeological sites

The detailed land magnetic surveys were carried out along two elected sites in the southern part of Dahshour area (Fig. 1). The total magnetic field and vertical gradient data were acquired and processed using Oasis Montaj™ (Geosoft software, 2009), some traditional filters and recent techniques, such as analytical signal and de-stripping were applied in order to enhance the magnetic data:

Total magnetic field:

$$F = \sqrt{H^2 + Z^2} = \sqrt{X^2 + Y^2 + Z^2} \quad (1)$$

Vertical magnetic gradient : $$VG(r) = \frac{\partial f}{\partial r} = \frac{F_{bot} - F_{top}}{\Delta r} \quad (2)$$

Analytical signal :

$$AS(x,\ y,\ z) = \sqrt{\left(\frac{\partial F}{\partial x}\right)^2 + \left(\frac{\partial F}{\partial y}\right)^2 + \left(\frac{\partial F}{\partial z}\right)^2}$$

De-stripping is the correction for the personal errors occurring during the measurements that accumulate from one profile to another (Stripping), provided that the misalignment remains constant along the profile (Arafa-Hamed, 2004). In order to remove these errors Eq. (4) is used, by subtracting a mean value (Z_M) from each profile data as follows:

$$Z_{corr} = Z_{row} - Z_M(x) \quad (4)$$

where Z_{raw} is the measured magnetic data along the profile. $Z_M(x)$ is introducing in Eq. (4) in order to overcome the

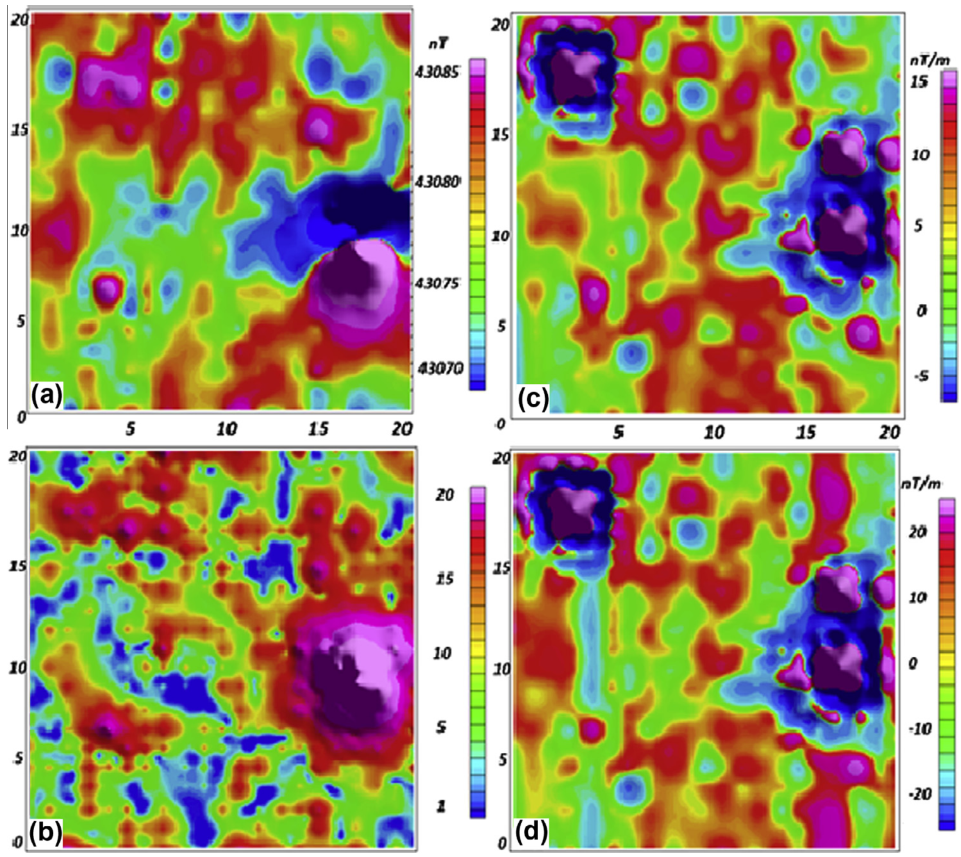

Fig. 6 (a) The total magnetic intensity (bottom sensor) at the top of Mastaba, (b) analytical signal of the total intensity, (c) vertical gradient (VG) of the total intensity and (d) de-stripping of the vertical gradient.

"zero-mean" value, instead of the simple arithmetic mean of a profile. The modified "zero-mean" $Z_{\mathrm{M}}(x)$ is calculated by:

$$Z_{\mathrm{M}}(x) = \frac{1}{N}\sum_{Y=0}^{Y-N} Z_{\mathrm{raw}}(x,\ y) \tag{5}$$

where N is the number of measuring points on a profile.

4. Results and discussion

4.1. The Mastaba (old kingdom)

The first site which is called Mastaba or tomb dates back to the old kingdom. Two zones of the Mastaba were surveyed; at the top (20×20 m) and at the bottom (15×20 m) using a station separation of 0.5 m. The results are represented in the Figs. 6 and 7, showing the total magnetic intensity, analytical signal, vertical gradient and de-stripping maps of the top and bottom of the Mastaba, The stripping effects are clear all in Fig. 7c; parallel to the direction of profiles. The de-stripping technique was applied in vertical gradient (Figs. 6d and 7d).

It is clear that the analytical signal maps (Figs. 6b and 7b) show that the high analytical signal anomaly could represent occurrence of shallow buried magnetic sources in the two zones of the Mastaba. Also, the vertical gradient in the Figs. 6d and 7d confirms the probable occurrences of archeological remains causing magnetic positive anomalies (white squares).

4.2. The archeological hill (Tell Athery)

The Tell Athery which means rising of land to several meters above ground is usually rich in archeological remains dating back to pharonic time. In this study, the detailed land magnetic survey was carried out along two parts of archeological hill (Tell Athery) in the southern Dahshour area (Fig. 1). Two parts on this hill were surveyed; the first part at the top (15×17 m) and the second at the bottom(25×25 m). The results total intensity, vertical gradient, analytical signal and de-stripping maps are shown in the Figs. 8 and 9. The close inspection of these maps reflects the proposed places of the hidden archeological remains traced with white squares that probably represent mud bricks (walls) and granite (sarcophagus).

4.3. Magnetic source locations and their estimated depths

Most of the archeological features have high magnetic contents, which reflect high magnetic anomalies. The most possible locations of the buried archeological features in the surveyed sites (Mastaba and Tell Athery) are in Fig. 10.

In this study, the depth estimation is obtained by using Salem and Ravat (2003) technique. They developed a method (AN-EUL), which is based on the combination of the analytic signal and the Euler deconvolution methods, to estimate the depth and geometry of the magnetic sources. This method of

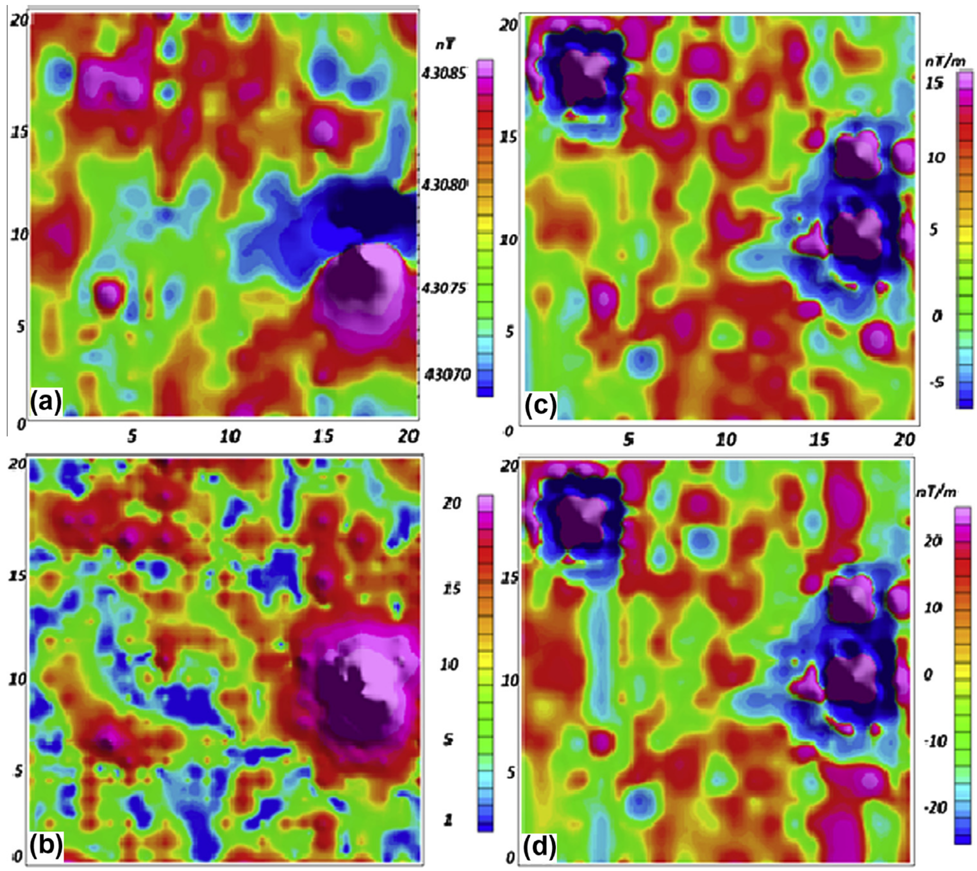

Fig. 7 (a) The total magnetic intensity (bottom sensor) at the bottom of Mastaba, (b) analytical signal of the total intensity, (c) vertical gradient (VG) of the total intensity and (d) de-stripping of the vertical gradient.

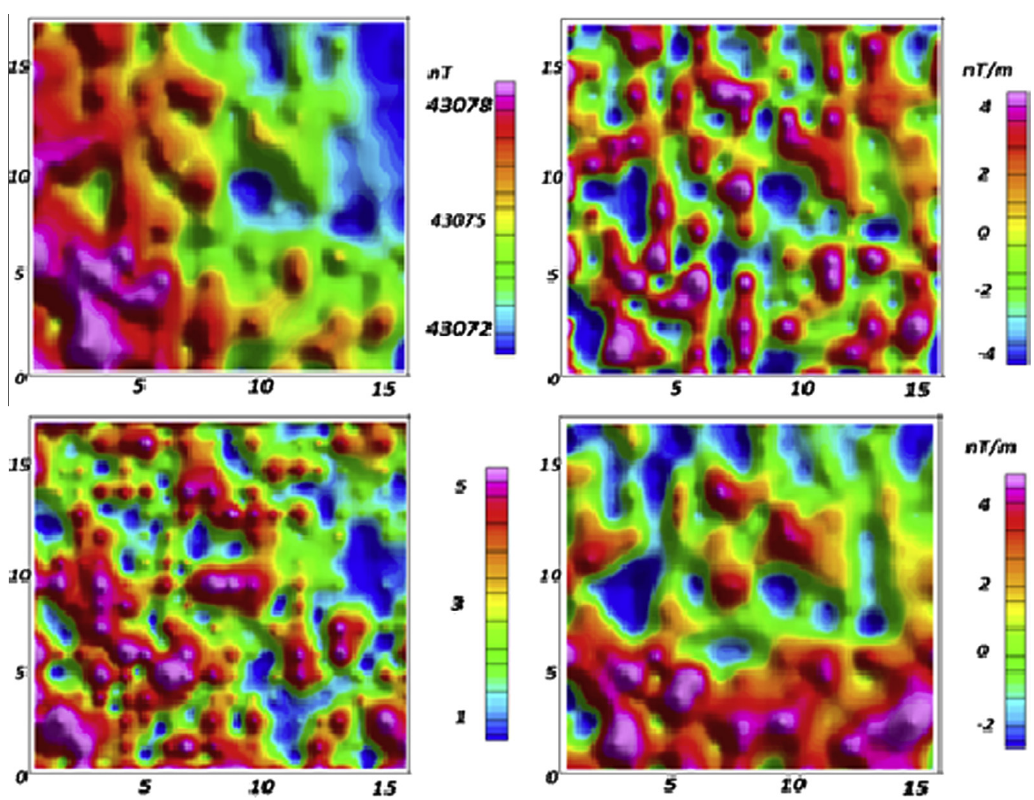

Fig. 8 (a) The total magnetic intensity (bottom sensor) at the top of Tell Athery, (b) analytical signal of the total intensity, (c) vertical gradient (VG) of the total intensity and (d) de-stripping of the vertical gradient.

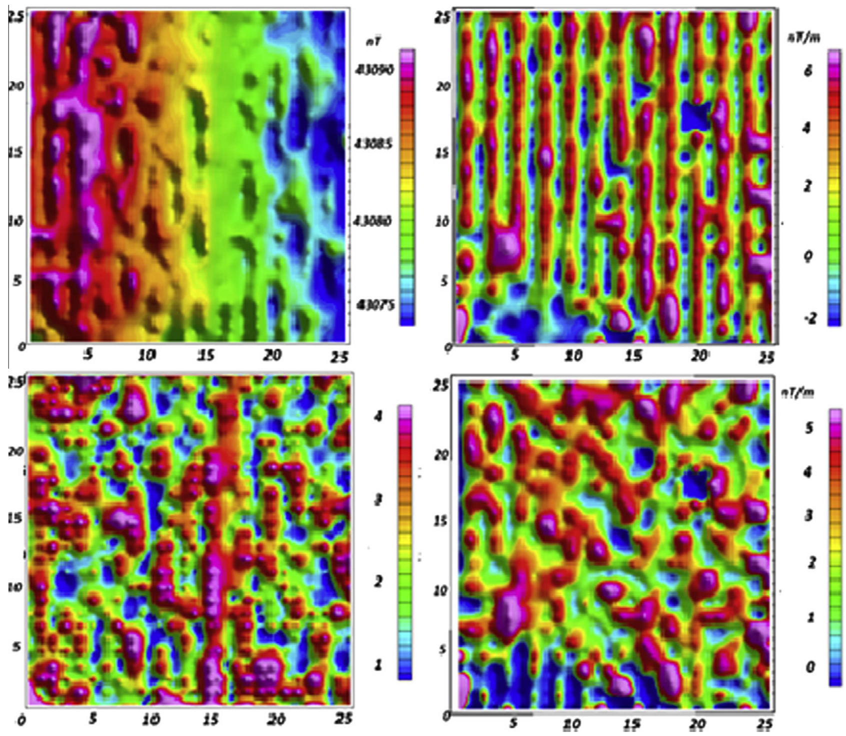

Fig. 9 (a) the total magnetic intensity (bottom sensor) at the bottom of Tell Athery, (b) analytical signal of the total intensity, (c) vertical gradient (VG) of the total intensity and (d) de-stripping of the vertical gradient.

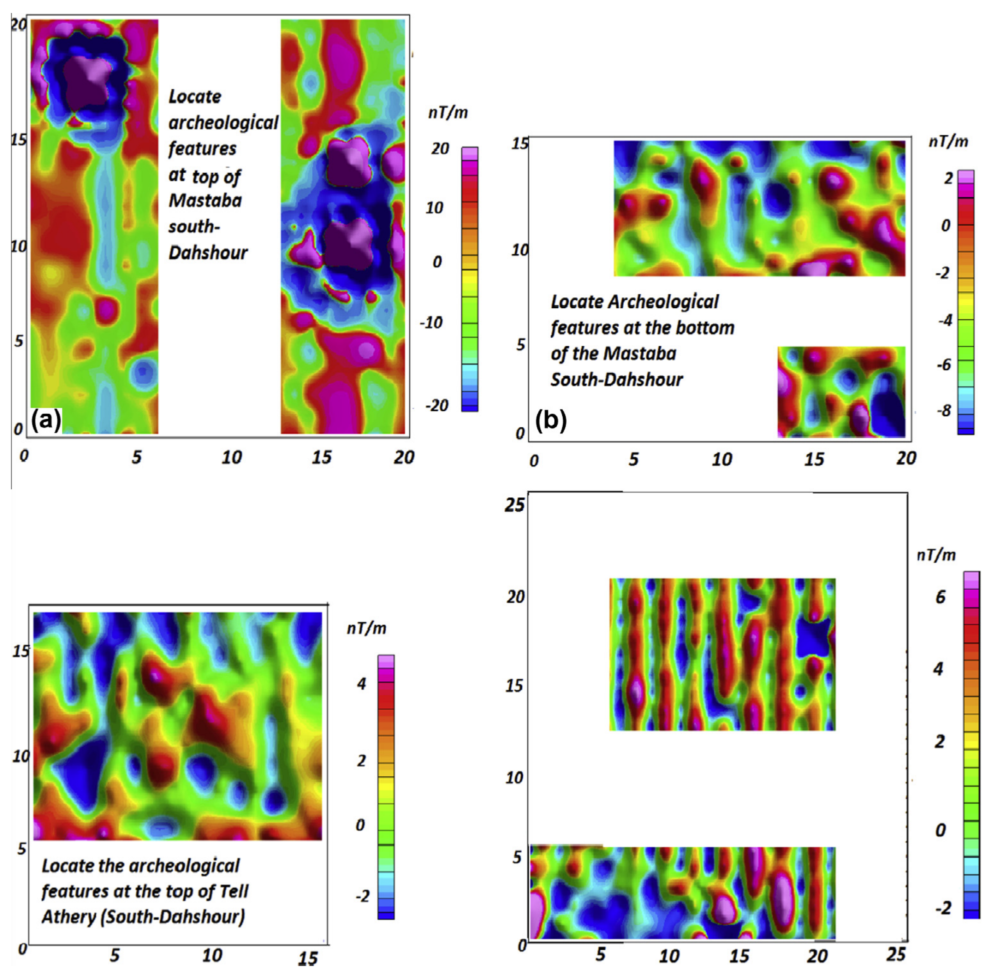

Fig. 10 Final interpretation of archeological remains at south-Dahshour area.

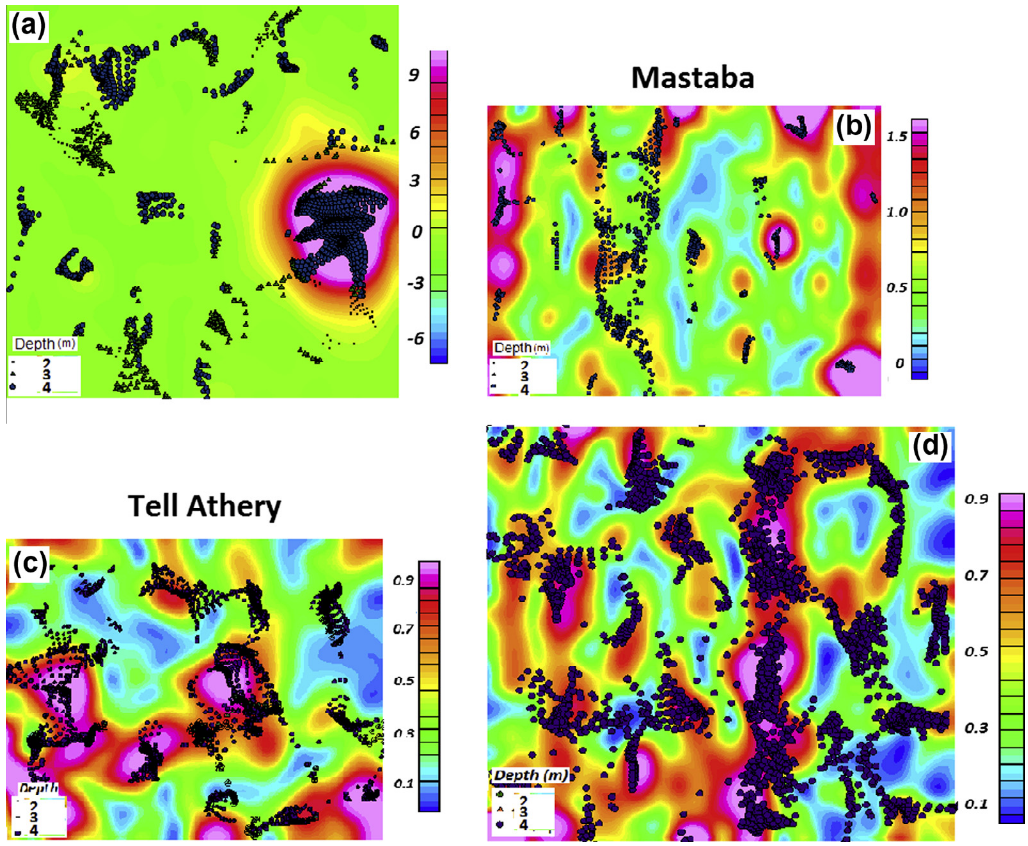

Fig. 11 Analytical signal based on An-Eul depth method of archeological remains using (a) top of Mastaba (b) bottom of Mastaba (c) top of Tell Athery and (d) bottom of Tell Athery.

Ardestani (2009) is used for the first time by taking the derivatives of Euler equation in the x and z directions, Eq. (6) (i.e., taking the observation point above the center of the source) we get:

$$z_0|\mathrm{AAS}_1|_{x=x_0,\,y=y_0} = (N+1)|\mathrm{AAS}_0|_{x=x_0,\,y=y_0} \tag{6}$$

where x, y are the coordinates of the measurement points and |AAS0| and |AAS1| are the amplitudes of the analytical signal of the anomaly and its first-order derivative, respectively. Eq. (6) implies that the depth of the magnetic source can be estimated through the AAS0 and AAS1 above the center of the source.

$$z_0 = (N+1)\left|\frac{\mathrm{AAS}_0}{\mathrm{AAS}_1}\right|_{x=x_0,\,y=y_0} \tag{7}$$

The Eq. (7) estimates the depth of a magnetic source (archeological remains) above its center (Fig. 11). The structural index ($N = 1$) for Mastaba and Tell Athery was used. The estimated depths for defined archeological features at Dahshour area are ranging from 2.0 to 4.0 m with an average depth of 3 m.

5. Conclusions

The application of vertical magnetic gradient at the southern Dahshour has successfully achieved the aim of the present study. The delineated archeological features are mostly belonging to the old kingdom which is characterized by buildings, tombs, and structures mainly of mud bricks and some granitic blocks. The measurement of the vertical magnetic gradient of the geomagnetic field gives more accurate results than the measurement of the total magnetic field, in particular, in the near-surface applications. The fluxgate gradiometer is highly recommended for shallow investigations (e.g. archeology, engineering…etc.) than the normal magnetometers. The tentative depth of the buried features is expected to be very shallow (~3 m). Successful delineation of archeological features at the area of Dahshour lead to more information about the duel behavior of the mud-brick features.

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