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Shallow geophysical investigations at the Akhmim archaeological site, Suhag, Egypt

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Abstract: Ground penetrating radar, electromagnetic terrain conductivity, and electric tomography have proven to be effective tools if they are combined together to investigate archeological sites. We have conducted a geophysical survey at the Akhmim archaeological site, the main objective of our survey is to locate additional buried structures for further excavation. Geophysical data were acquired in the area using the GEM-300 multi-frequency terrain conductivity profiler, the SIR 2000 ground penetrating radar, and the Syscal R2 resistivity meter systems. The results of the integrated interpretation show a number of buried features and a strong linear zone about 1 m wide that coincides with the suspected trend of a buried wall. There appears to be two parallel ridges of strong reflections on either side, indicating two parallel walls extended East-West and a room is identified at the bottom left corner of the site. Moreover, the interpretation results of some selected GPR and dipole-dipole resistivity profiles adjacent to the open-air museum suggest the existence of a second statue of Ramses II to the right of the previously discovered statue which could still be buried in the sand.
Keywords: Archaeological prospecting, Akhmim, GPR, GEM, resistivity.

Introduction

In archaeology, geophysical methods such as resistivity and magnetic mapping are useful in the investigation of specific areas of archaeological interest. During the last decade, conventional geophysical methods have been integrated with high-resolution techniques such as ground penetrating radar, electrical tomography, and seismic refraction for archaeological prospecting (Tsokas et al., 1995; Tsokas et al., 1997). Archaeological investigations are some of the most aesthetic applications of near surface geophysics. Successfully integrated approaches include GPR, magnetics, conductivity mapping and/or geoelectric methods. Hesse et al. (1998) investigated the location of the Heptastadium in Alexandria, Egypt. Komatina and Timotijevic (1999) explored the Prevlaka Island, Montenegro, Yugoslavia. Cardarelli et al. (2000) conducted a geophysical survey on the vault of "Scarsella" of the S. Giovanni Baptistery, Italy, and El-Behiry (2000) used geophysical surveys to delineate buried tombs and identify their environmental status in Egypt. So far, GPR has shown efficiency for complete detection of archaeological remains characteristics (i.e., composition, geometry, and so on). However, GPR may fail to detect some archaeological objects due to unsuitable conditions, such as low relative dielectric contrast between the archaeological object and

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the surrounding soil, but, generally, GPR is a powerful non-destructive tool that discloses the objectives quickly and economically.

Resistivity methods have been widely used in archaeological investigations especially in detecting walls and hidden cavities. The interpretation of the data is usually made using the 2D approach, despite the 3D character of some investigated structures. The use of 3D modelling and 3D inversion techniques in archaeology is not common but has been described by some authors (Mauriello et al., 1998; Cosentino and Martorana, 2002). El-Quady et al (2005) and Sultan et al (2006) applied 3D inversion of resistivity data investigating archaeological sites in Egypt.

In this paper, ground penetrating radar, electromagnetic scanning, and electrical tomography methods have been used for archaeological prospecting in the area around the open air museum to locate additional buried structures for further excavation.The site was investigated using a pulse GEM 300 electromagnetic profiler. A SIR 2000 GPR system was used with a 200 MHz center frequency antenna. A survey wheel was attached to the antenna to control the interval between scans along the measured GPR profiles. A Syscal R2 system was used for geoelectrical measurements.

Archaeological background of the study area

Recently, the remains of a colossal seated statue of Ramses II have been discovered in a shanty area of the Upper Egyptian city of Akhmim adjacent to the open-air museum, The lower part of the limestone statue is seated on a throne, to the right and left of which are figures of two of the pharaoh's daughters and princess-queens, Merit-Amun and Bint-Anath, Akhmim, or Ekhmim, is a town in Upper Egypt on the east bank of the Nile 107 km by river south of Asyut and 6.5 km. from Suhag. The statue and the throne are carved from a single block and stand on a huge limestone base covered with carved hieroglyphic texts. The base also carries a register of captured enemies surmounting rings that bear the name of their home cities. Remains of colors are still visible. A colossal face, that matches the base of the statue showing the pharaoh wearing a false beard, has also been found. A splendid colossus of the Queen Merit-Amun has been found and is already displayed in the open-air museum. This splendid discovery not only attracts archaeologists but also visitors and the media as well. "It is really a very important discovery that reveals the largest seated limestone statue ever found of Pharaoh Ramses II" said the head of the Supreme Council of Antiquities (SCA). Early studies revealed that the statue might have stood in front of the entrance to the pylon of a great temple of Ramses II at Akhmim and that suggested the existence of a second statue on the other side of the Ramses II statue which could still be buried in the sand.

The first traces of discovery were made early in 1991, when the Akhmim city council decided to build a post office 50 meters from the open-air museum. A pre-construction archaeological inspection revealed the base of a statue inscribed with the names and titles of Ramses II and surrounded by mud brick walls. Also, unearthed votive remains had been set up in the temple, statues of individuals who may have worked there, and royal crowns carved in granite.

However, a large modern cemetery which surrounds the open air museum on the northern side (Figure 1) obstructed any further exploration and excavations were put on hold. The site was backfilled with sand and the statue base was packed with debris for protection. To resume the excavations, the cemetery was transferred to a site in New Suhag. The relocation of the cemetery continues alongside the archaeological excavation. One result of the discoveries at Akhmim was that unlicensed modern tomb robbers had already found their way onto the site. It was actually the illegal excavators exploring a tomb in the modern necropolis who stumbled upon a huge head of Ramses II. The head was 2.60 meters in diameter and was wearing a head-dress of royal names.

Excavations resumed in January 2003, led by the chief inspector at the Giza Plateau, who was assigned to oversee the excavations in Akhmim. He had two main goals: the first was to determine the size of the statue and the second was to explore its connection with the temple. The archaeologists determined that it was divided into two main levels with the top stratum containing Islamic features and a Coptic layer below.

Data acquisition, processing and interpretation

The study area was divided into three parts, A and B represent the area to the south of the open air museum and C represents the streets surrounding the museum (see Figure 1). Grids A and B are the extension of some previously excavated mudbrick walls which are located at a depth of 0.5 meter with a thickness of 1.5 m. The present study will concentrates on shallow geophysical tools of investigation.

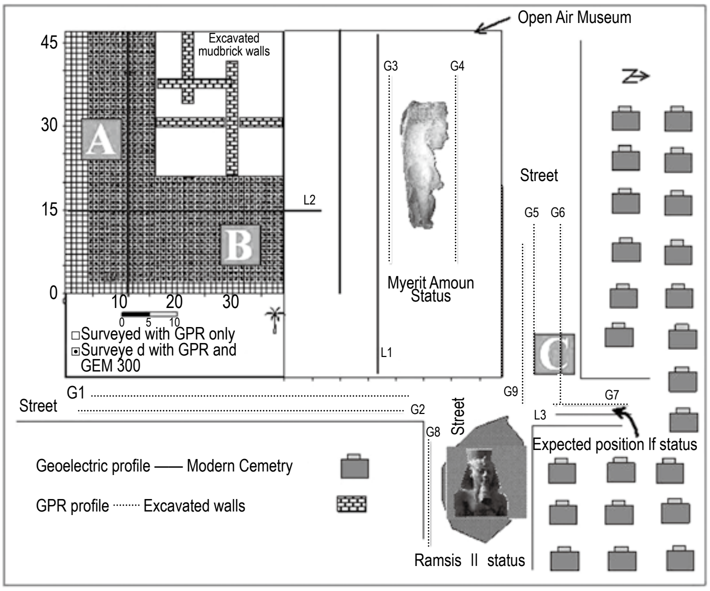

Fig.1 Schematic diagram showing the study area at Akhmim, Suhag, Egypt. A, B, and C represent the survey grids.

Electromagnetic terrain conductivity

The EM survey was performed using a GEM-300 multi-frequency electromagnetic profiler from Geophysical Survey Systems, Inc. The GEM-300 is a handheld electromagnetic induction-type instrument that measures in-phase and quadrature-phase terrain conductivity without electrodes or direct soil contact. The GEM sensor contains a transmitter and receiver coil separated by about 167.5 cm, along with a third "bucking coil" that removes the primary field from the receiver coil. All coils are molded into a single board with fixed geometry.

The GEM-300 was used to record multiple frequency (low, medium, and high) electromagnetic induction data. The effective depth of exploration is determined by the operating frequency of the primary electromagnetic signal. In effect, the lower EM frequencies penetrate deeper than the higher frequencies. Therefore, measuring the earth response to multiple frequencies (a low of 325 and 725 Hz, a medium of 1675 and 3825 Hz, and a high of 8775 and 19975 Hz) is equivalent to measuring the earth's responses from multiple depths (deep, intermediate, and shallow). This choice was based on the excavated mudbrick wall depth. The electrical conductivity measured by the GEM-300 represents the measured differences in the conductivity of soils that are a product of their composition and formation. When soils have been moved around in an archaeological site by its occupants, conductivity contrasts can be created which a GEM-300 might record.

Two main grids were surveyed: grids A (12×46) m^2 and B (23×19) m^2 were recorded in a parallel zigzag line starting from east to west. The line spacing was 1 m, the station interval (separation between the data collection points) along each line was also 1 m. All data were simultaneously recorded to memory within the GEM system and subsequently downloaded to a PC and processed. The Surfer for Windows software was used to create image plots of EM values. Grids A and B are combined to make one single map for the entire area for each frequency range.

The resultant plots, shown in Figure 2) correspond to the sections of frequencies 325 Hz, 1675 Hz, and 19975 Hz, respectively. The contour parameters were chosen to enhance subtle conductivity variations within the survey area because the difference in conductivity between manmade targets and natural buried features was quite small. Using this approach, we located a number of potential targets that were subsequently related to the buried archaeological objects.

Figure 2 shows several prominent anomalies, trending north-south and east-west and coinciding with the trend of the buried wall. These anomalies are detected in all frequency ranges because the mud brick wall extended from about. 0.5 m to 2 m below the ground surface. These anomalies suggest the extension of the mud brick walls which may constitute a regular pattern. Also, a large wide anomaly is identified with dimensions of 2×3 m^2 and located at a distance from 15 to 17 m north and from 2 to 5 m west. This feature may reflect a room and is marked by R as shown in Figure (7).

GPR survey

Forty six radar profiles have been measured over the study area. The area around the temple was subdivided into grids A, B, and C during the survey (Figure1) as follows:

1. In grid A (17×45 m^2), 18 profiles of 45 m length were measured in zigzag mode and trended east to west for the odd profile numbers and west to east for the even profile numbers.

2. In grid B (22×20 m^2), 22 profiles 20 m long were measured in zigzag mode and trended east to west for the odd profile numbers and west to east for the even profile numbers.

The data were collected along 1 m spaced traverses with recording each trace every 10 cm. These common-offset single-fold profiles covered the entire area.

3. In grid C, the profiles were measured in the street outside the temple and their lengths are not

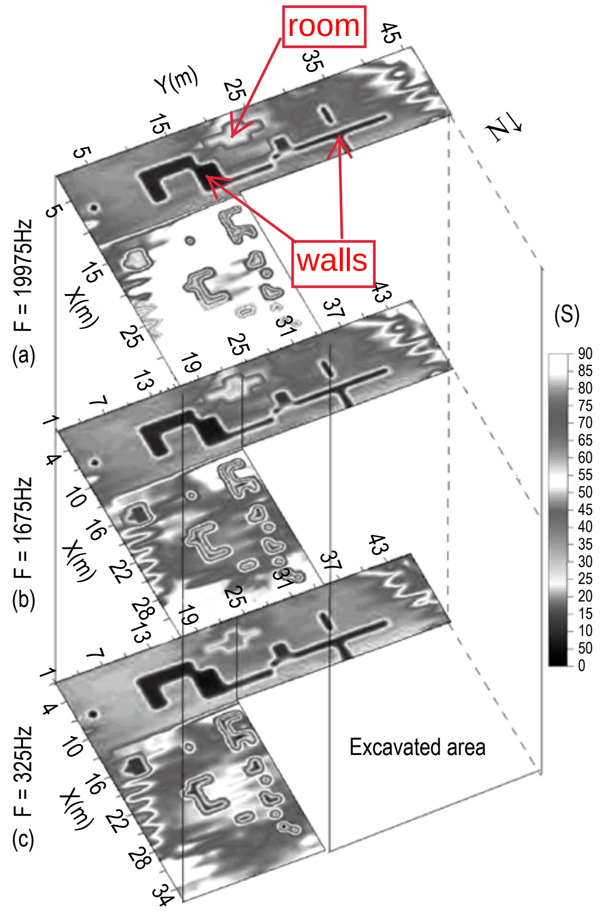

Fig. 2 Interpretation of GEM-300 data.
(a) high frequency range of 19975, (b) medium frequency range of 1675 Hz, and (c) low frequency range of 325 Hz.

constant because of the houses and modern cemetery which interferes with measuring long and regularly separated profiles.

An average near-surface velocity was determined from a common mid-point (CMP) survey conducted over profile No.7 using a bistatic antenna at 100 MHz frequency. We concluded that the average velocity is 0.121 m/nsec.

Data processing was conducted using the Reflex program (version 2.1.1). The data were processed with automatic gain control (AGC) to equalize all signals by applying a gain inversely proportional to the signal strength. To remove the low frequency induction component superimposed on the high frequency reflections, a running average filter was applied to each trace. Special types of temporal and spatial filtering (band pass frequency filter) were applied to suppress unwanted signals and enhance the dipping events (Annan, 1993).

The requirements of the archaeologists for an easy and more prospective way of viewing the subsurface to make a better interpretation which is the reason for making sectional plan views of the GPR profiles. Normally 3D block views are constructed from the parallel and closely spaced lines. Once the blocks are constructed, they may be viewed in a variety of ways, including as a solid block or as slices. Figure 3 shows a B-scan GPR profile measured in area A at x = 0. The figure shows some anomalous features at position coordinates 16 and 21 m.

Figure 4 shows a B-scan GPR profile measured in area B at x = 32 m. This profile also shows anomalous features located at position coordinates at 0 to 1 m, 4 to 6 m, 9 to 14 m, and at 17 m. These features may be interpreted as mud brick walls.

Time slicing is attempted to image the subsurface setup by providing a planimetric vision of the buried bodies (Goodman et al., 1995). Records in specific time windows were averaged over several pulse widths along the GPR sections. Selecting early or late time windows along the GPR time sections, shallow or deeper structures can be distinguished. Changing the width of the time slice (e.g., 5 or 10 ns) affects the clarity and resolution of the results. The gridded values were used to create time slice maps. Strong reflections, previously masked when comparing the individual radarograms, became clearly detectable. This energy comes from geometrical structures which are interpreted as concealed antiquities because the calculation of a slice is done by looking at a "slab" of data, rather than a wafer thin slice. This way, random noise will be suppressed and strong reflection sets will be enhanced. When looking at time slice maps, we can instantly see zones of weak and strong reflections, and the direction they trend. Generally, archaeological features will produce strong reflections.

Grids A and B are combined to plot one single time slice map for the entire area. The geometry of the time slice maps are shown in Figure 5. Figure 5 shows the pattern, by which the GPR profiles are arranged to conduct time slices image.

A summary of the structures shown in the time slices can be seen in the general interpretation map of (Figure 6). The most evident points are listed here as:

1. A strong linear zone about 1.5 m wide coinciding with the suspected trend of the buried wall labeled A. There appears to be two parallel ridges of strong reflection on either side of this wall, indicating two parallel walls extended north-south labeled B and C, and a room is identified at the left bottom corner of the site labeled R.

2. A strong linear zone trending East-West and marked by D, from where the wall was uncovered, coincides with the suspected trend of the previously discovered wall.

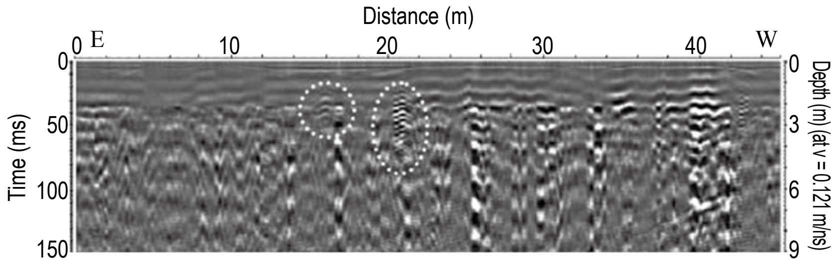

Fig.3 A B-scan GPR record measured along the profile at x= 0 m in Area A.

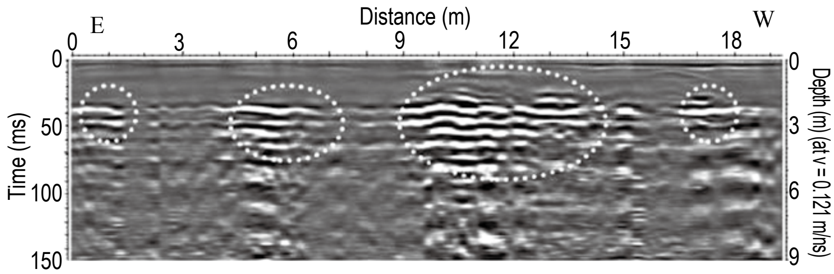

Fig.4 A B-scan GPR record measured along the profile at x = 32 m in Area B.

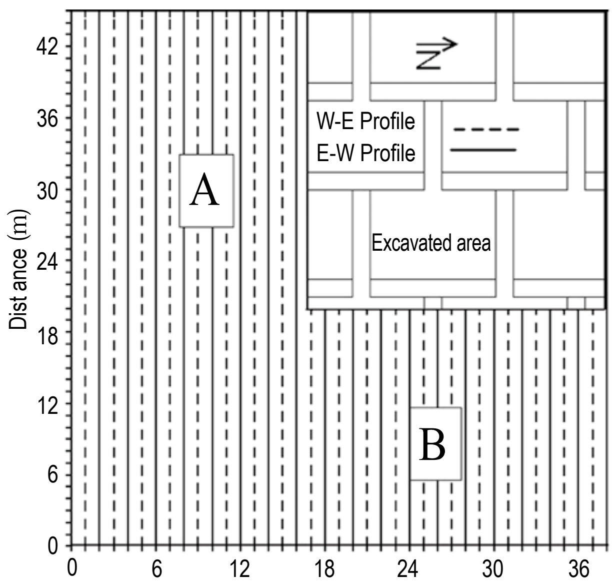

Fig.5 Geometrical pattern of GPR profiles used for constructing time slice maps.

3. A broad strip of strong reflection in the western margin of the site is assumed to be a wall formed from mud bricks (marked by E). However, this also appears to show some cultural contents, as long and linear features which show diffraction hyperbolae in the 2D GPR sections. Figure (7) Shows the inferred archaeological features deduced from GPR time slice.

Generally, archaeological features will produce strong reflections which will show a short vertical period, e.g. An object may be seen in the slice at 1m depth, yet the pattern may be changed or completely gone in the 2 m slice. Conversely, geological reflections will tend to be pervasive throughout the whole depth range of slices, as will a zone of weak reflection strength due to signal absorption by a wet zone. The shallowest and deepest slices will be noisy due to direct GPR waves and poor signal strength respectively.

Moreover, the inspection of randomly distributed profiles surveyed around the open air museum (Area C). Figure 8 shows one of the most important profiles (G7), which is at the right side of the discovered status of Ramsis II. A clearly hyperbolic arc is present at a horizontal distance ranging from 22 to 26 m which may be due to the presence of an anomalous archaeological feature. The depth of this feature is about 1.5 m. From the previous historical backgrounds, this feature may suggest the presence of the second statue, which could still be buried in the sand.

Geoelectric survey

The geoelectric survey was acquired using the IRIS-Instruments Syscal-R2 system (IRIS, 1998) configured with a dipole-dipole array. Four profiles have been measured with the dipole array with spacing "a" of one meter and factor "n" varying from 1 to 7 for shallow depth investigation (Loke, 1997). The factor "n" is the ratio of the distance between the first current and potential electrodes (C1-P1) to the distance between the two current electrodes (C1-C2) dipole spacing. The locations of the geoelectric profiles are shown in Figure (1). The dipole-dipole resistivity data were inverted using RES2DINV (Loke, 1998), which uses a non-linear least squares optimization technique for the inversion subroutine (Loke and Barker, 1996) to produce the inverted or model resistivity section.

Line 1 (L1):

An east-west dipole-dipole

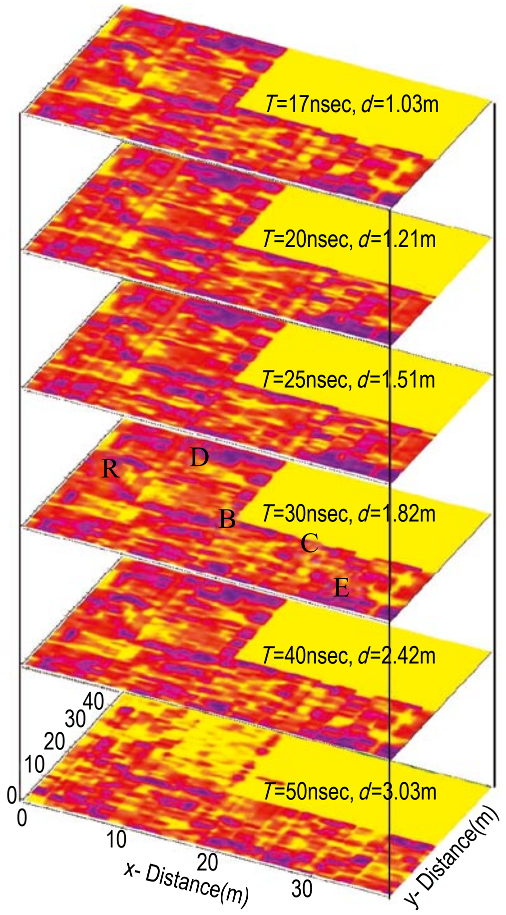

Fig. 6 Stacked horizontal time slices through the study area (1 m line spacing) over a time range from 17 ns to 50 ns.

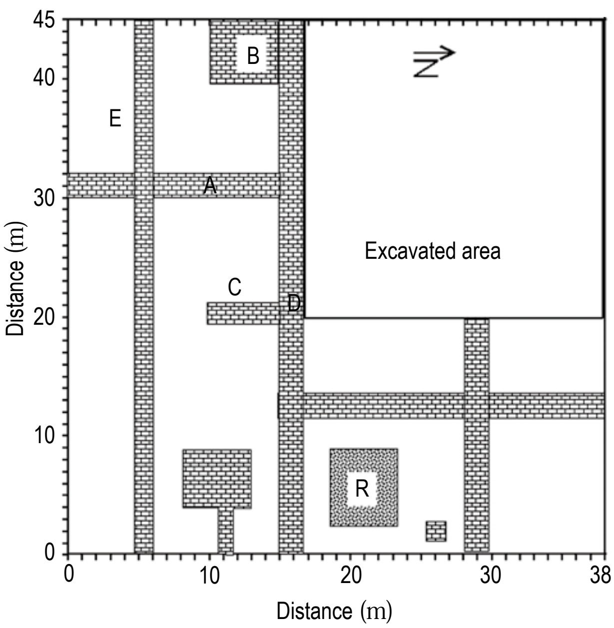

Fig. 7 Expected position of mud brick walls inferred from the GPR time slices.

resistivity profile L1 was collected along Line (1), The inverted model of profile L1 is shown in Figure 9. The inverted result presneted in the Figures 9 show a region of low resistivity extending from 0 to 10 m and from 33 to 48 m with apparent resistivity of less than 10 ohm-m close to the surface and extending to a depth of 1.5 m and representing the clay country rock. While, distances from 5 to 6 m and 30 to 33 m show apparent resistivity greater than 22 ohm-m extending to 1 m depth representing a mud brick wall which agrees with the previously discovered walls and electromagnetic interpretation. It should be mentioned here that the resistivity value of mud brick wall is higher than the resistivity of country rock, which is mainly non-compacted alluvium clay deposits and man-made ash debris. Given the fact that the lateral change in resistivity is due to conformable lateral changes of lithology along the line, the high resistivity values suggest the presence of walls. Further, the area of elevated resistivity is also coincident with an area of muted GPR reflections. At the base of the section there is a zone of high resistivity values ranging from 17 to 25 ohm-m which may represent the ground floor of the temple suggested by the historical background.

Line 2 (L2):

Adopting the same processing steps, inspection of Figure 10 shows low resistivity at horizontal distances from 10 to 15 m and from 45 to 48 m. Apparent resistivity ranges from 5 to 10 ohm-m and extends to 2 m depth represents clay, while moderate resistivity zones extend from 0 to 8 m and from 25 to 28 m with apparent resistivity of about 24 ohm-m close to the surface and extending to 1 m depth representing mud brick. As shown earlier, the high resistivity values suggest the presence of walls.

Line 3 (L3):

This line coincides with GPR profile G7. We see that there is a zone of very high resistivity values extended from 36 m to the end of the profile which attains resistivity values of about 600 ohm-m, which is coincides with the hyperbolic anomalous feature appear in the GPR profile G7. This suggests the presence of a huge limestone body buried within a zone of moderate resistivity ranging from 15 to 50 ohm-m which is mainly due to a sandy clay layer. There is a surface layer of low resistivity values less than 10 ohm-m which is mainly clay (Figure 11).

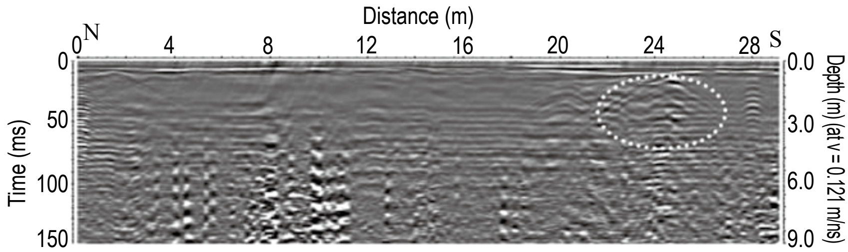

Fig. 8 2-D GPR profile (G7) measured in the vicinity of the museum.

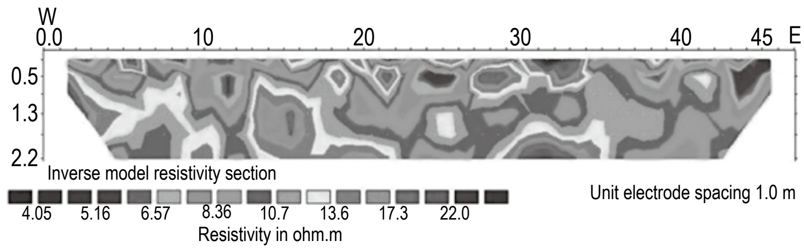

Fig. 9 Dipole-dipole resistivity section along survey line L1.
(a) Measured apparent resistivity, (b) Calculated apparent resistivity, and (c) Inverted model resistivity.

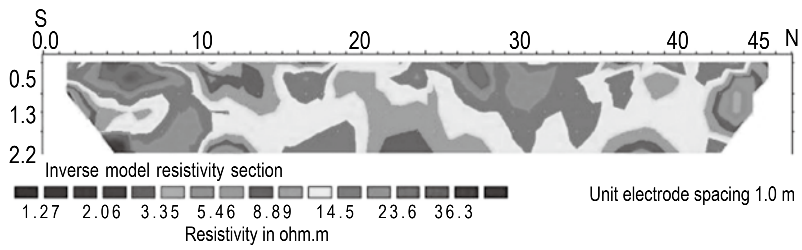

Fig. 10 Inverted model resistivity along survey line L2.

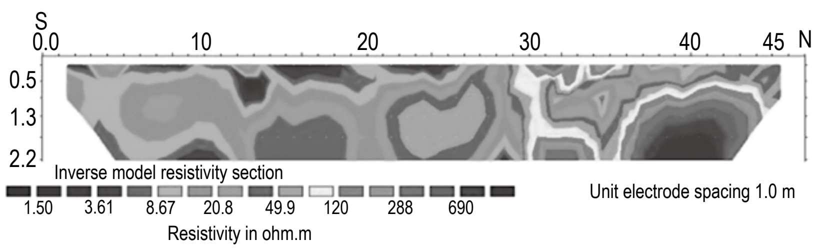

Fig. 11 Inverted model resistivity section along survey line L3.

Conclusions

The results of the geophysical survey in the vicinity of the Merit Amun temple demonstrate the usefulness of multiple geophysical techniques. In this case, EM and GPR measurements at archaeological sites close to the Merit Amun temple were done for further archaeological prospecting. A number of buried targets, including the foundations of brick walls, were detected which are the extension of previously discovered walls. However, the results also show that, in the absence of additional archaeological information from other sources, it may be difficult to identify the features producing an electrical anomaly and distinguish it from contrary materials with similar electrical properties. At this site, the combination of multiple geophysical techniques with other sources of information such as geological and historical data, test pits, and client feedback after excavation all helped. As a result, the expected location of the second buried statue is located refining the geophysical data interpretations. A subsequent site survey after removal of the modern cemetery is recommended because the presence of the modern cemetery constitutes an obstacle for further excavation and does not allow us the rare opportunity to examine the site as a whole.

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