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ORIGINAL PAPER

Discovery of an ancient pharaoh's temple on the Horus military road, Northern Sinai, Egypt

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Abstract Detailed geophysical measurements have been carried out in the northwestern part of the Sinai Peninsula. This area was mainly used by the ancient Egyptian army forces to support the trading and mining trips to Sinai and Asia. The geophysical field work aimed to discover new buried archeological remains using the efficient archeogeophysical detailed and nondestructive methods including total magnetic field, vertical magnetic gradient, and very-low-frequency electromagnetic measurements. Results of the field geophysical measurements have led to a discovery of a temple which is located on the Horus military road. This discovery has been verified by an excavation program, under the supervision of the Supreme Council of Egyptian Antiquities, where buried remains of a pharaoh's temple were detected and photographed. Some other sites were recommended for further excavation in the future.

Keywords Egypt · Sinai · Geophysics · Archeology · Magnetic · VLF-EM · VLF-R

Introduction

Archeological sites in Egypt cover some thousands of square kilometers, which form a unique situation in the world. These sites are partially excavated but most of them still need further exploration studies. Most, if not all, of the archeological digging efforts in Egypt are concentrated on the monumental sites in the River Nile valley region as it attracts the attention of foreign archeological expeditions.

After the war of 1973 between Egypt and Israel, the Supreme Council of Egyptian Antiquities (SCEA) has started a regular excavation program in the northern part of Sinai. At the same time, the Egyptian government planned to reclaim 400,000 ac in the northern Sinai, East of the Suez Canal. The governmental reclamation program was started by providing water through a system of artificial irrigation canals, resulting in the discovery of several buried archeological remains during the digging procedures. Consequently, most attention is paid to that region, where the reports of the SCEA have recorded about 25 archeological sites. All of these sites require detailed studies including both geophysical and excavation to locate and identify the buried archeological remains. For that, the present geophysical work aimed to explore one of these sites, which is called "Tell Heboua" (Fig. 1).

The region of the northern Sinai Peninsula served as the eastern gate of Egypt. It was mainly used, throughout Egyptian History, for military purposes. Most of the discovered sites are citadels, barracks, weapons storages, and stables. These were established to support the Egyptian expeditions to south Sinai for mining and to Asia for trading. One of the biggest citadels in this region is the Tjarou citadel, which means the dwelling of lions as first mentioned in the historical depiction of King Sit-I. Tjarou, recently called "Tell Heboua," is located in the northwestern part of the Sinai Peninsula (Fig. 1) and represents the starting point on the ancient military road of Horus which ends at Gaza in Palestine (Abd El-Maksoud 1987; Hoffmeier et al. 2003).

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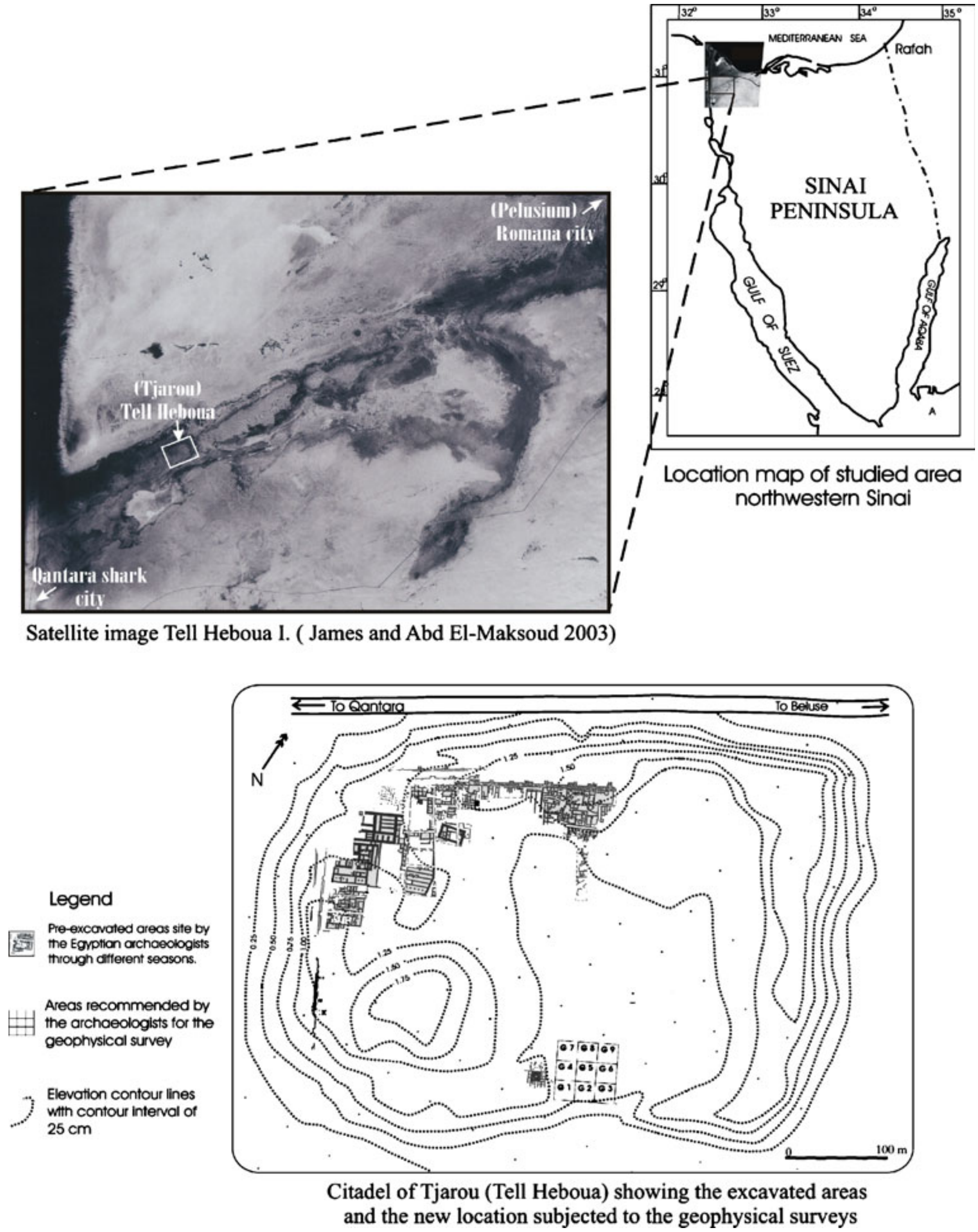
Fig. 1 Location map of the archeological site of Tell Heboua and the selected locations for the geophysical work



Geological and geoarcheological settings of Tell Heboua

Tell Heboua is a part of an old delta plain of the River Nile. The defunct Pelusiac branch (distributary) of the River Nile crossed the area to the north of the site. The branch was silted up in the course of history. Alluvial deposits of the delta plain, which is silted up by mud, can be recognized by a line of salt polygons or a slight difference in soil color due to difference in humidity (Sneh et al. 1975). Its elevation reaches about 1 to 2 m above sea level and it is bordered on the south by a dune ridge (Neev 1967).

Broad sand sheets with plant-stabilized dunes and scattered muddy sabkhas characterize the present geomorphology of the studied area. Holocene sedimentary facies are discontinuous, reflecting the coastal-deltaic setting of the area for much of the past 5,000 years. A discontinuous sand dune ridge passes through the studied area, running between the ancient Pelusium branch (recently, Romana city) and the new Qantara Shark city (i.e., NE to SW; Fig. 1). This ridge appears to be controlled by the Pelusium fault line and marks the shoreline of the ancient Mediterranean coast. After New Kingdom times, the shoreline moved northeast with the advance of the ancient Pelusiac branch of the River Nile delta. A sabkha of about 7 km in diameter is located south of the dune ridge where remains of an ancient lagoon in which dense, olive-gray clay with sparse shells were accumulated. The paleolagoon was filled with sediments delivered by local drainage or the Pelusiac distributaries, probably beginning prior to New Kingdom settlement in the area. Tell Heboua is located on the dune ridge along the ancient shoreline (Moshier and El-Kelani 2002).

Geophysical measurements in Tell Heboua site

Most of the archeological prospecting activities in Egypt are concentrated in the recent River Nile Valley region (Hussain and Hassanain 1983) where the ancient Egyptians and noble families lived. Archeological sites of the northern Sinai region are very different from those in the Nile Valley. The ancient Egyptians have mostly used the building materials imported from the surrounding environment. However, the archeological remains of Tell Heboua are very unique since they were not built from stones or red bricks, but they used the clays that dominate immediately surrounding the Tell Heboua. This led to a small physical contrast between the buried features and the overburden sediments. The geophysical field work, which has been carried out in Tell Heboua area, comprised both the magnetic and the very-low-frequency electromagnetic (VLF-EM) methods. The data acquisition, processing, and interpretation are explained in the following paragraphs.

Magnetic method

The magnetic method has been widely used in many archeological sites both in Egypt and in the world as archeological remains, in most cases, produce a noticeable difference in their magnetic susceptibilities with that of the hosting medium.

The magnetic measurements, including the total magnetic field and its vertical gradient, have been conducted in the study area (using the Scintrex ENVI-GRAD geophysical system) with a resolution of 0.1 nT. A square area of 60×60 m was chosen in part of Tell Heboua and was divided into nine grids, denoted by G_1, G_2, …, G_9 on the lower part of Fig. 1, each 20×20 m in size. Measurements were recorded on a small regular mesh of 0.5×0.5 m where the station and line separation were 0.5 m. Attention was paid to eliminate the sources of noise in the magnetic data through different steps during and after the data acquisition. First, field clearance of the surface magnetic objects (from recent military activity) was done. Secondly, a base station was recorded regularly during the working day for reducing the diurnal magnetic fluctuations on the total magnetic field measurements. However, the vertical gradient measurements are not affected by diurnal variations, since the magnetic field is recorded simultaneously between two closely spaced sensors, compared with the depth to the causative body. Such effects on the two readings are essentially identical and, therefore, removed by differencing.

VLF-EM data

As a complementary method for the magnetic survey, VLF-EM surveys have been done over the grids (G_1 to G_9). The survey was applied at the same locations of the nine grids, but with a wider grid size of 1×1 m (i.e., station separation was 1 m and the profile separation was 1 m). In the modern VLF equipment, the receiver contains three perpendicular coils. Frequencies (or stations) covering the observer's location can be monitored using the VLF spectrum scanning features. The magnetic field at the receiver is determined in each of the coils, then resolved into horizontal and vertical components, further broken into in-phase (real) and quadrature (imaginary) components, and then the tilt and total field are computed.

The ENVI-VLF instrument, which has been used in the present work, allows the operator to measure the vertical in-phase of the secondary field in percent, the vertical quadrature components of induced secondary field in percent, the total field strength in nepers per meter, the apparent resistivity in ohm meter, and the tilt angle of the VLF signal from up to three different VLF transmitting stations. The unique three-coil sensor is omnidirectional; therefore, no special care was paid to leveling or orienting the sensor with respect to any of the transmitting stations. For the VLF resistivity measurements (VLF-R), two metal electrodes in the direction of the primary electric field component were used. Table 1 shows the three VLF transmitting stations, which could be detected clearly in the studied area by the VLF spectrum scanning option.

The VLF-EM data were not subjected to topographic corrections, since the area of investigation is flat. These data were plotted on five maps for every grid on each frequency. This could produce 135 maps for the whole nine grids of the three different frequencies. Of course, this huge amount of data cannot be represented in this article, but we will summarize the results of only one of the surveyed grids (G_7) as an example.

Table 1 The scanned frequencies used in the studied area

Frequency (kHz)	Station location	Power (kilo watt)	Expected penetration depth if ρ=35Ωm
23.4	Ramsloh, Germany	800	10.05 m
20.3	Tavalora, Italy	500	
18.3	Le Blanca, France	500	

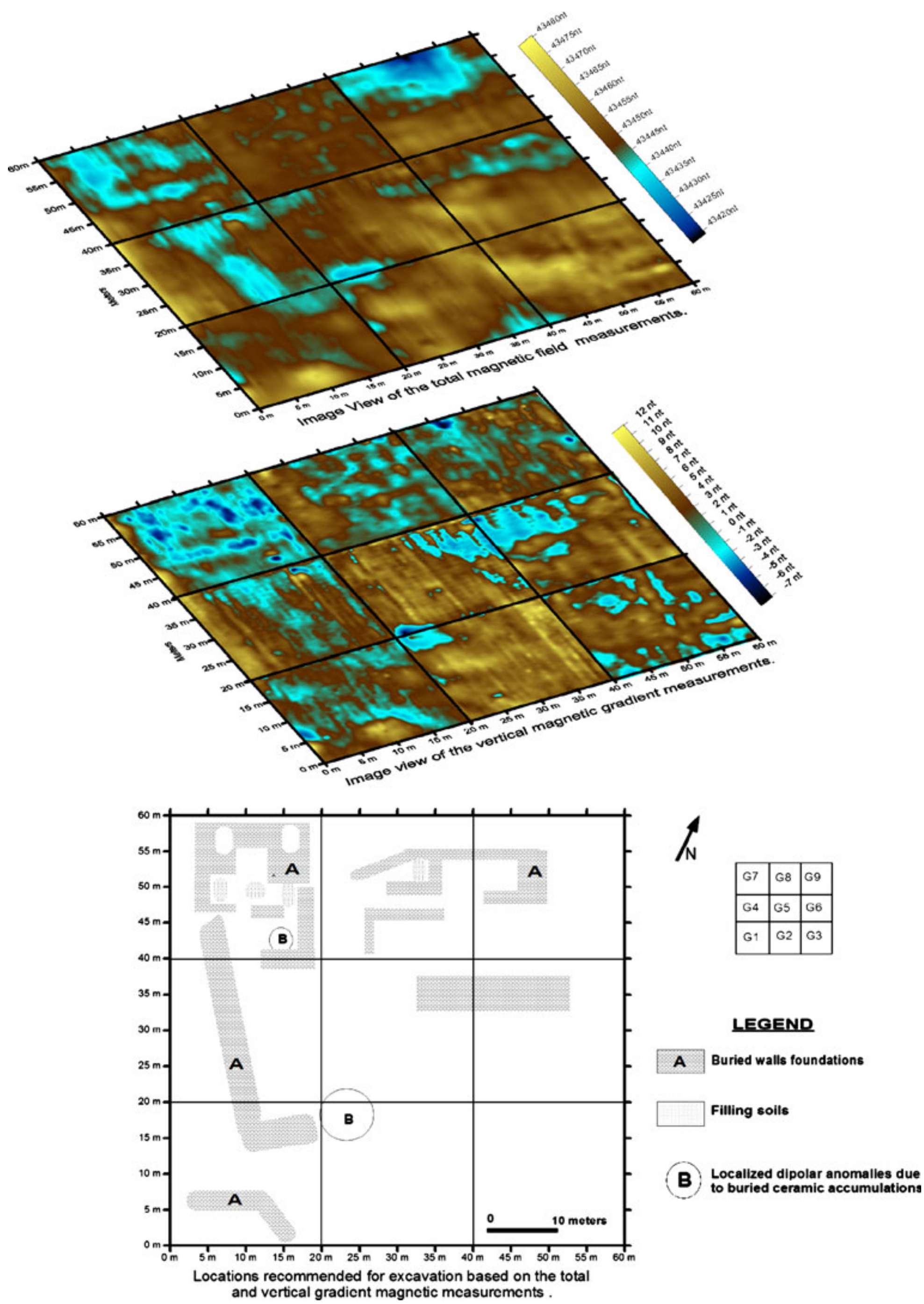
Results and discussion

Magnetic results

The magnetic results are displayed in Fig. 2 in the form of a mosaic of the total magnetic and vertical gradient maps of all nine grids. An interpreted base map (the lower part of Fig. 2) was also constructed showing the expected buried archeological features depending on their magnetic characteristics. These features are highly recommended for excavation programs.

Two different types of magnetic anomalies have been detected; the first is represented by low total magnetic closures with regular geometrical shapes: circular, squares, or rectangular. These shapes are accompanied, at their northern edges, by a sharp increase of the total field values, which reaches as high as 34 nT. This type of anomaly is classified as type A. The second anomaly type was

Fig. 2 Image view of the corrected total magnetic, vertical magnetic gradient measurements, and the recommended locations to start the excavations



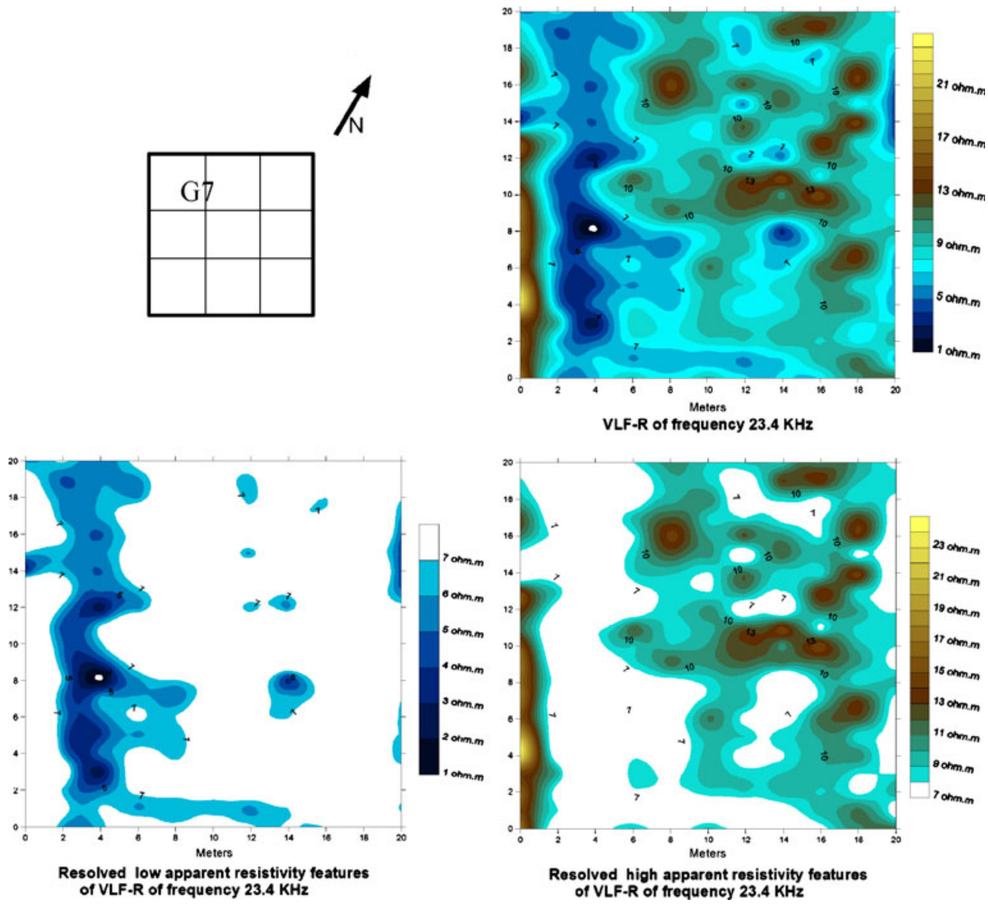


Fig. 3 The separation step of high and low apparent resistivity features, using frequency 23.4 kHz for grid G_7

represented by high total and vertical gradient magnetic values followed by sudden northern low values. This is a typical anomaly shape developed by a monopole magnetic source or a vertical dipole of a finite length located in the field of the northern midlatitudes (Breiner 1973). This type of anomaly can be produced by the presence of buried ceramic accumulations, small kilns and ovens of small scales, or any remains of higher magnetic susceptibility. This anomaly type is marked as type B in the lower part of Fig. 2.

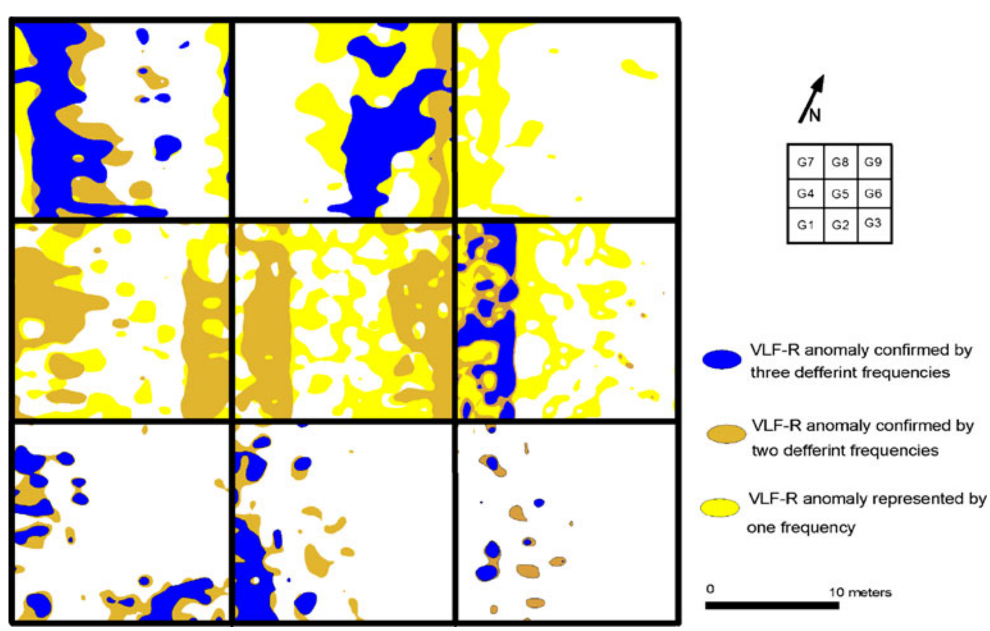


Fig. 4 Compiled resistivity anomaly from the measured VLF-R measurements

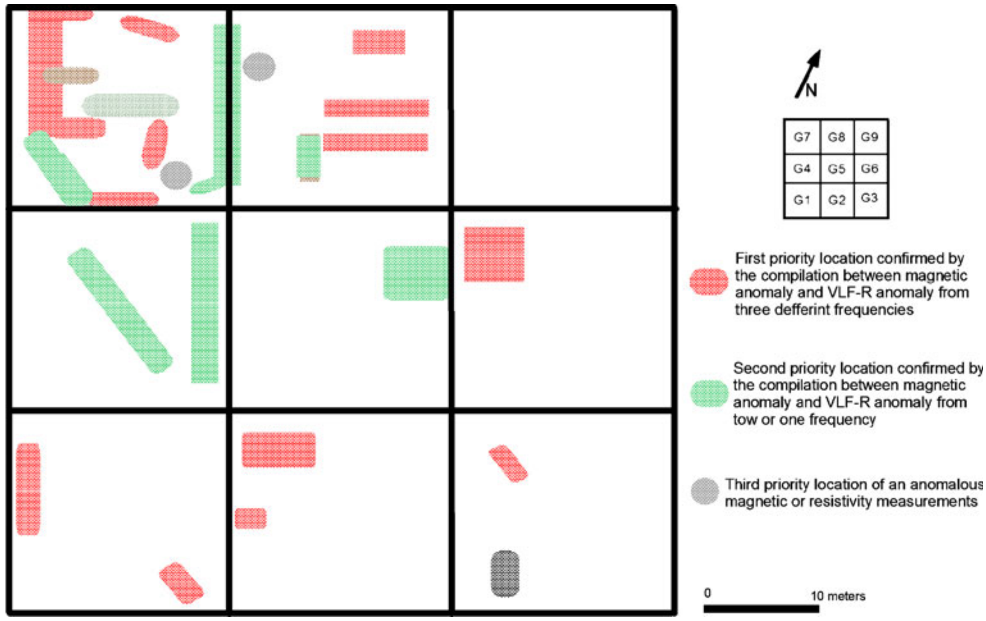


Fig. 5 Recommended locations for excavation based on the compilation of the VLF-R and vertical magnetic gradient anomalies

VLF-EM and VLF-R results

Almost all the VLF-EM interpretation techniques are biased toward mineral exploration where a great contrast in electrical conductivity exists between the conductive target and the nonconductive host rock (Vozoff 1971; Parry and Ward 1971; Olsson 1980; Poddar 1982). These models are rarely used in the case of archeological prospecting where there is a poor conductivity contrast between the buried remains and the host soil, especially if these remains were built from the same soil materials. This is why most of the archeological investigations using electromagnetic survey methods depend mainly on qualitative interpretation for locating the remains (Bruno and Warwick 1986).

From the large number of VLF-EM maps which have been constructed in the study area, no significant features could be detected from these maps except for the results of the VLF-R. This is due to two reasons; the first is the very small sampling interval of the measurements in comparison to the typical wavelengths of VLF-EM anomalies, this was reflected as a very smooth gradient with no distinguishable features that could be detected from the contour maps of the total field VLF, out of phase and in-phase components. The second is the absence of any highly conductive bodies, like copper or gold statues, as these sites were probably pillaged by thieves throughout history

On the other hand, clays retain moisture more than the surrounding coarser sediments of the overburden, which made it possible for VLF-R to detect some of the outlines of the buried clayey walls.

The results of the grid G_7 VLF-R will be presented as an example (Fig. 3). A trial has been made to overlay the VLF-R

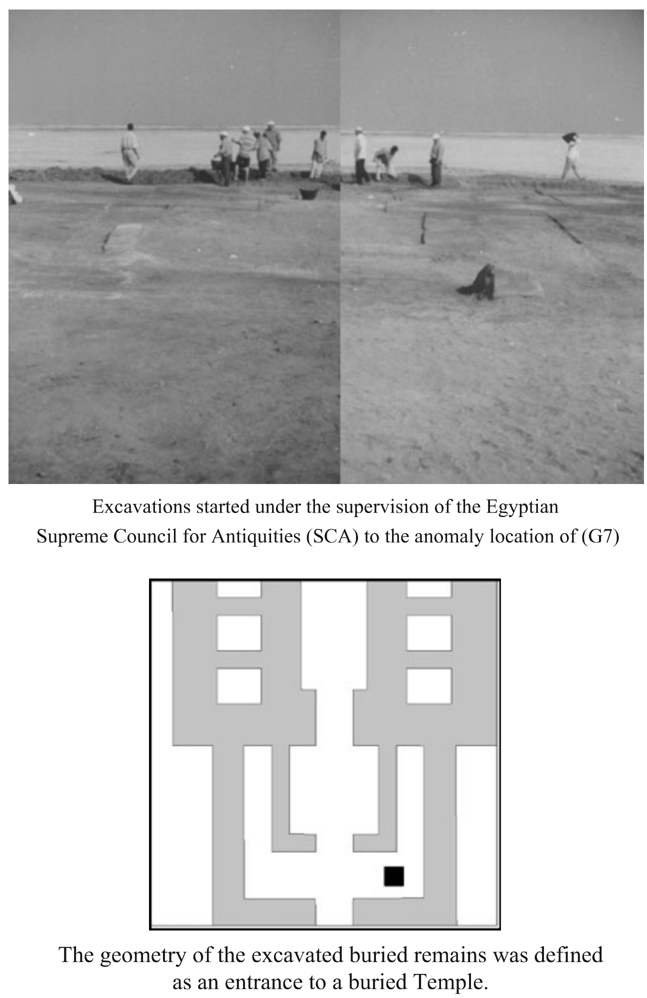


Fig. 6 Discovered buried temple and its geometry

maps of the three frequencies used for the nine grids to construct a composite map (Fig. 4). Three priorities are indicated on this map: the first priority exists where anomalies from the three frequencies are matched, the second is when two frequencies are matched, and the third priority where anomalies from only one frequency are detected.

VLF-R versus magnetic results

The comparison of the VLF-R maps (Fig. 4) with the total magnetic and the vertical gradient maps (Fig. 2) produced a map containing recommended sites for archeological excavation (Fig. 5). This map led to the following observations:

1. Regular elongated closures of low apparent resistivity values coincided with low magnetic gradient anomalies striking NW–SE with more or less similar geometry.
2. Irregular shapes with no specific orientations of high resistivity values are accompanied by features of relatively high magnetic gradient.
3. Localized anomalies of very low magnetic gradient values are not obvious in any of the resistivity maps of the three different frequencies used. This may confirm the presence of a very small, near-surface magnetized body as shown in Fig. 2 which is denoted by circle (B).
4. Features of high apparent resistivity with no corresponding magnetic anomalies might be produced by highly compacted sediments or a limestone floor.

Conclusion

The detection of buried remains with a very small magnetic susceptibility contrast is mainly dependent on the regular geometry of the anomalies rather than the value of the magnetic measurements. The VLF-EM maps were not useful for the small scale of archeological features, while the VLF-R could be effective in delineating the buried clayey walls (which were made of unfired or "adobe" blocks).

Based on the geophysical results, a limited excavation program has been done by the SCEA in order to verify these results. The excavation program has been started over the recommended location of grid G_7. Figure 6 shows the discovered remains and the outline geometry of the buried features. The small deep black square in Fig. 6 is due to a basaltic column base, which was the source of the dipolar anomaly in magnetic data.

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